SE
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Chair of Subsurface Engineering
Geotechnics and Underground Constructions
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ATHENS

22nd – 23rd March 2012

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Contracts for Underground Constructions – the Austrian Practice

Introduction

In the Austrian tunnelling construction contract the first main rules are

- **the ground belongs to the client and is his risk**
- **a unit price contract is used**

Please keep these principles in mind for the following explanations!

Contracting practices

Contractual regulations **in tunneling** have to be different from other sectors of the construction industry because the **construction material**, the ground, **is not known exactly** until we do the underground construction!

Contracting practices – risk sharing

- General risk sharing for underground constructions:
  - The **ground** belongs to the **client** and is **his risk**
  - **Means** and **methods** for **unchanged** ground conditions (compared to the prognosis) are the contractor's risk

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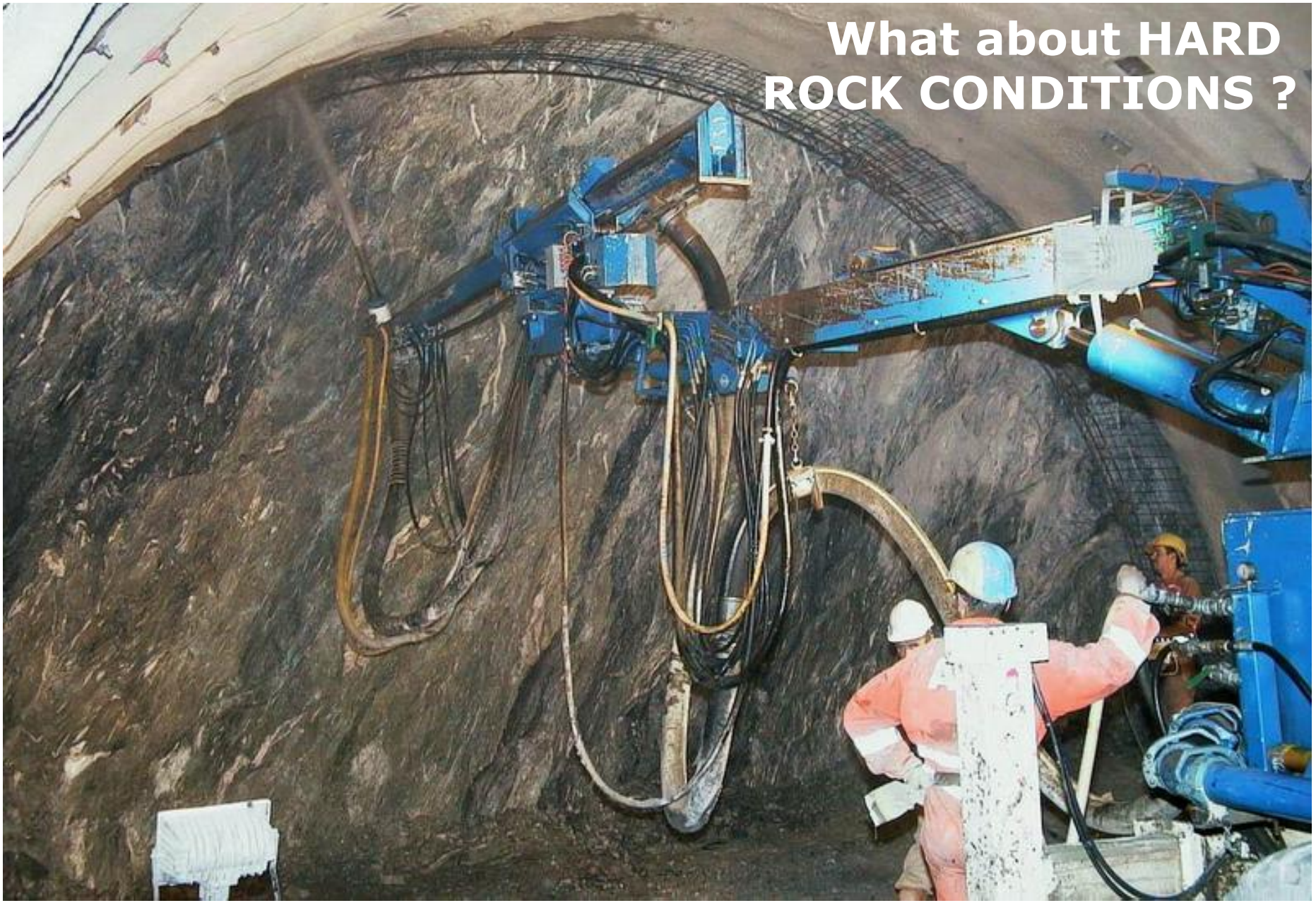

HARD ROCK CONDITIONS

- The typical sequence for conventional excavation is subdivided into top **heading – bench – invert**.
- The top half of the tunnel cross section is excavated first, the **bench follows simultaneously a few hundred meters behind**. A ramp is maintained on one half side of the cross- section to enable access to the top heading.
- The **invert** is prepared at quite **some distance to the bench** excavation.

What about SQUEEZING ROCK CONDITIONS?

SQUEEZING ROCK CONDITIONS

- As a reaction to failure of the shotcrete lining occuring during excavation due to large deformations **longitudinal slots** are left open in order to allow displacements without damaging the shotcrete.
- This approach is accompanied by a dense **rock bolting** to **increase the shear strength** of the rock mass and to reduce deformation of the tunnel.
- In the late nineties, **yielding elements** were developed, which have been integrated into the shotcrete lining.

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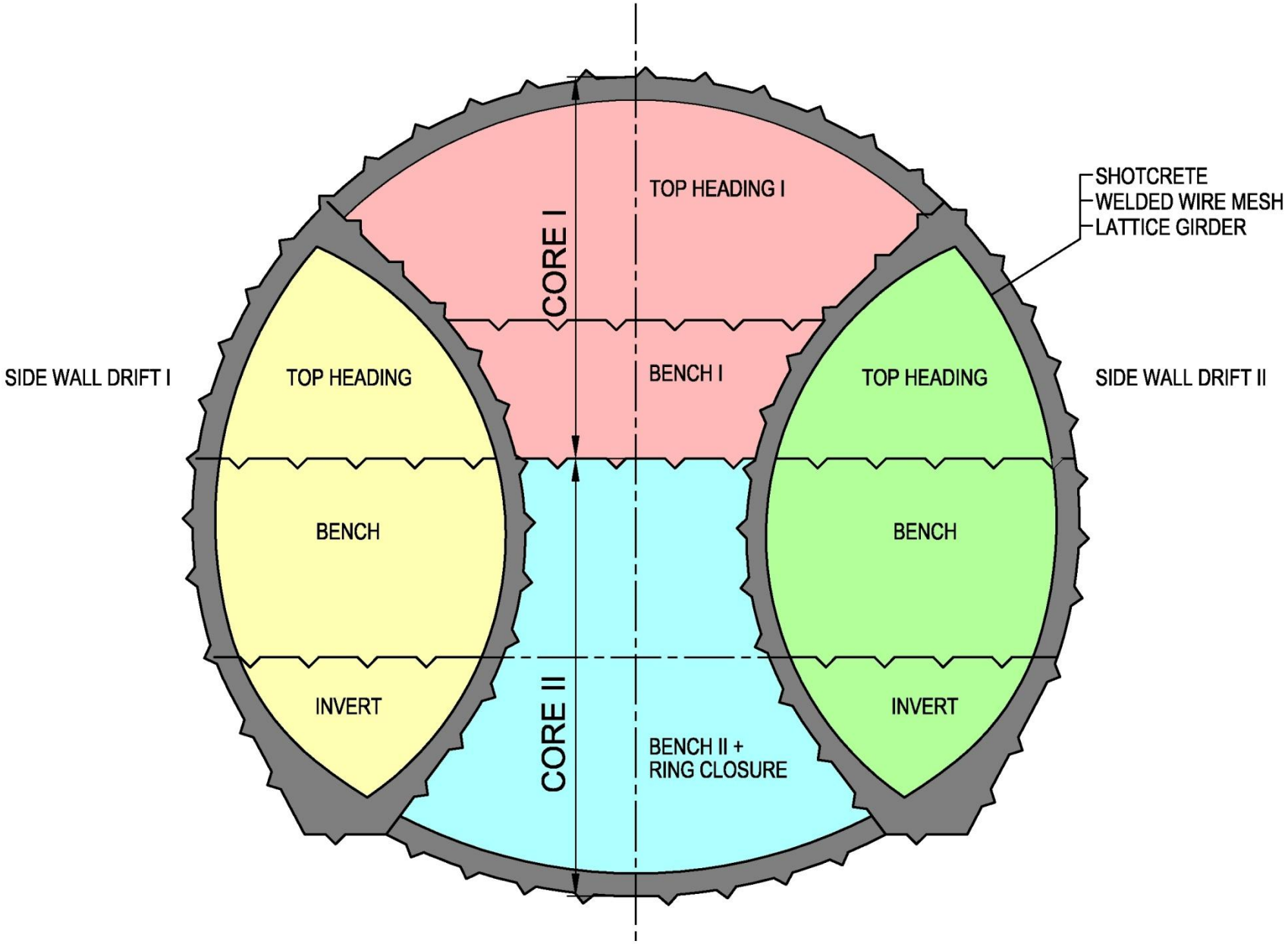

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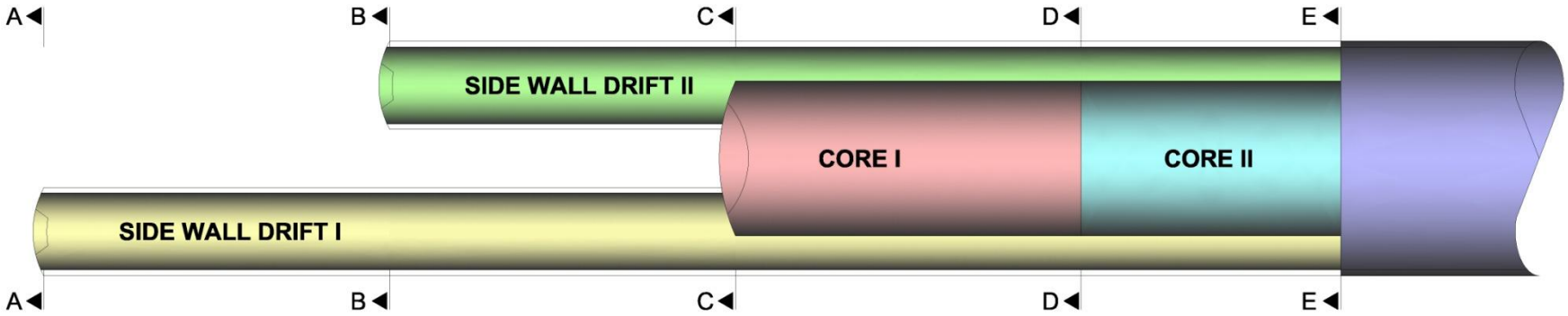
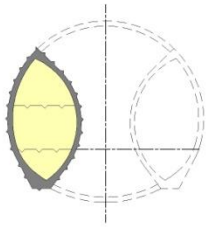
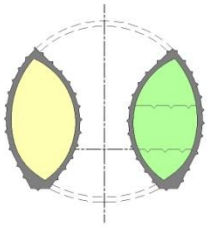


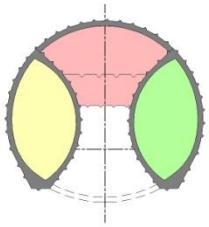
cross section A-A



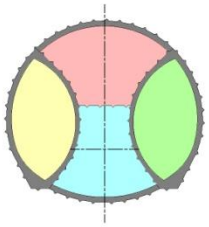
cross section B-B



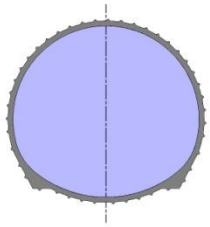
cross section C-C



cross section D-D



cross section E-E



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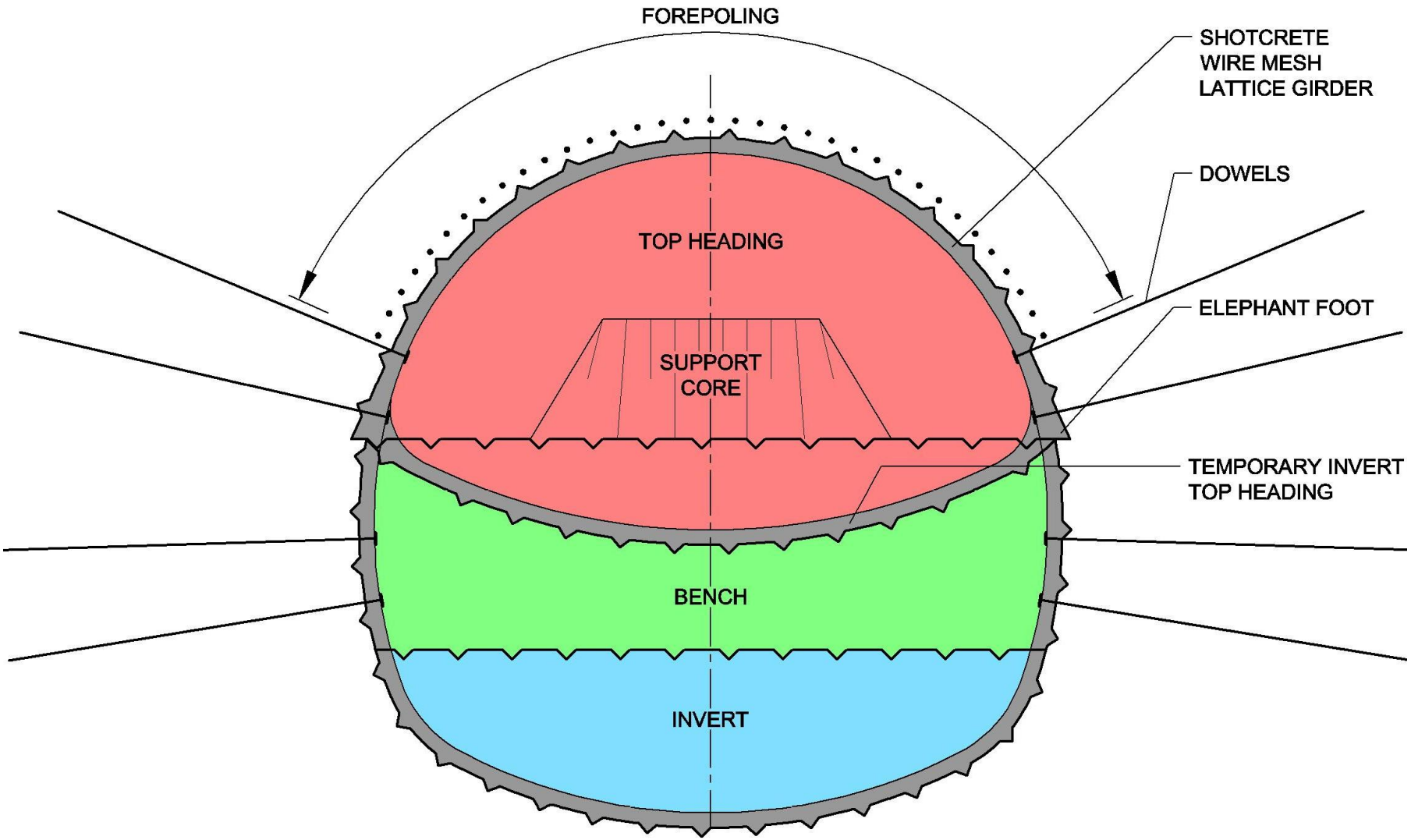

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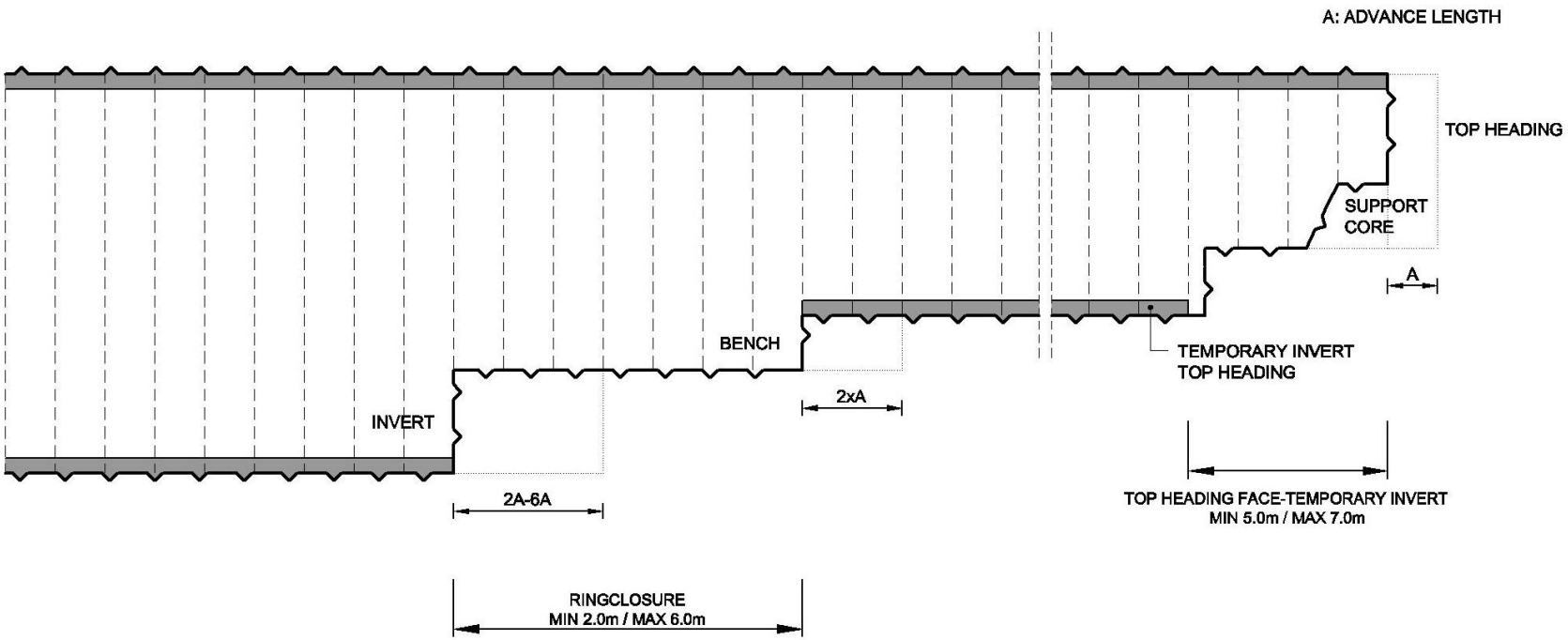

SOFT GROUND CONDITIONS

- Typically the length of **excavation rounds** in this example is **limited to 1.0 m** at a maximum and the **closure of the invert follows after 5.0 m**. The advance rate is restricted to **4.0 m in 24 hours** to limit deformations of the young shotcrete primary lining.

- To allow excavation of a typically double-track tunnel, the groundwater level is lowered by a system of external wells. The tunnel cross section is **excavated in small portions** when tunnelling in gravel which comprises flowing layers of soil.

- Massive **support of the excavation face** with shotcrete and face anchors or even ground treatment by grouting ahead of the face is occasionally required to provide safe tunnelling conditions.

ARE GROUND INVESTIGATIONS NEEDED?

YES,OF COURSE!

- The geological investigations are the **client's responsibility**.
- The description of the ground is required for the elaboration of a **geological model**
- The characteristic properties of the ground must be reported in the **geotechnical model**
- The investigations should be planned and supervised by **experienced geologists** in close cooperation with the **design engineer** and the **client**.
- The elaboration of the geotechnical model is the **responsibility** of the **geotechnical engineer**.

PRINCIPLES OF NATM TUNNELLING CONTRACTS

- The theoretical basis for NATM is to **conceive the ground around the tunnel not just as a load**, but as a load-bearing element of support. In combination with the **time-dependent development** of ground reactions as a result of tunnel excavation, the type and quantity of the support elements required is **systematically adjusted**.

- The ground reactions, taking the form of lining deformations and lining pressures, are **measured** and the stability of the excavation is confirmed by **frequent monitoring**.

- Depending on the project conditions (e.g. shallow soft ground tunnel, deep rock tunnel) and the results of the geotechnical measurements, the **requirements** for a specific support are **determined**.

Normative document:

ÖNORM B2203-1:
Underground works – Works contract
Part 1: Conventional Tunnelling

History

first issue: 1975
Revisions: 1983, 1994, **2001**

2001: Part 1 – conventional tunnelling
2005: Part 2 – continous tunnelling

Scope of ÖNORM B2203-1

1) **Rules of Procedure**
2) **Terms of Contract**

for the implementation of underground works using conventional tunnelling.

Does not apply to pipe jacking and tunnels constructed by open-cut methods.

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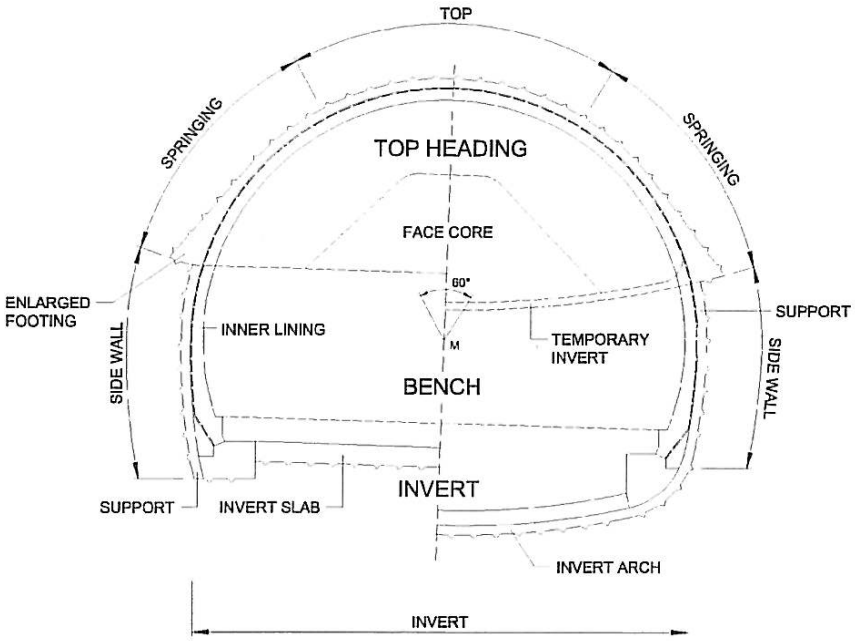
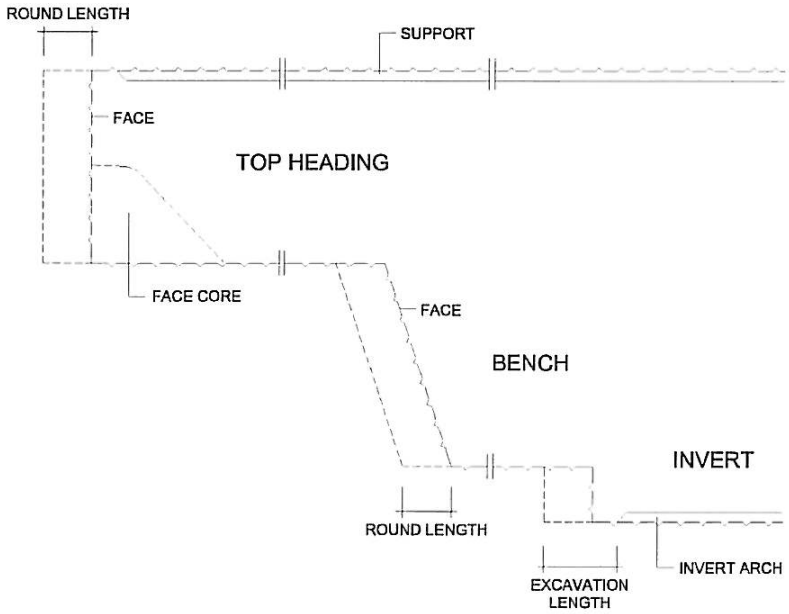
Cross Section



Longitudinal Section



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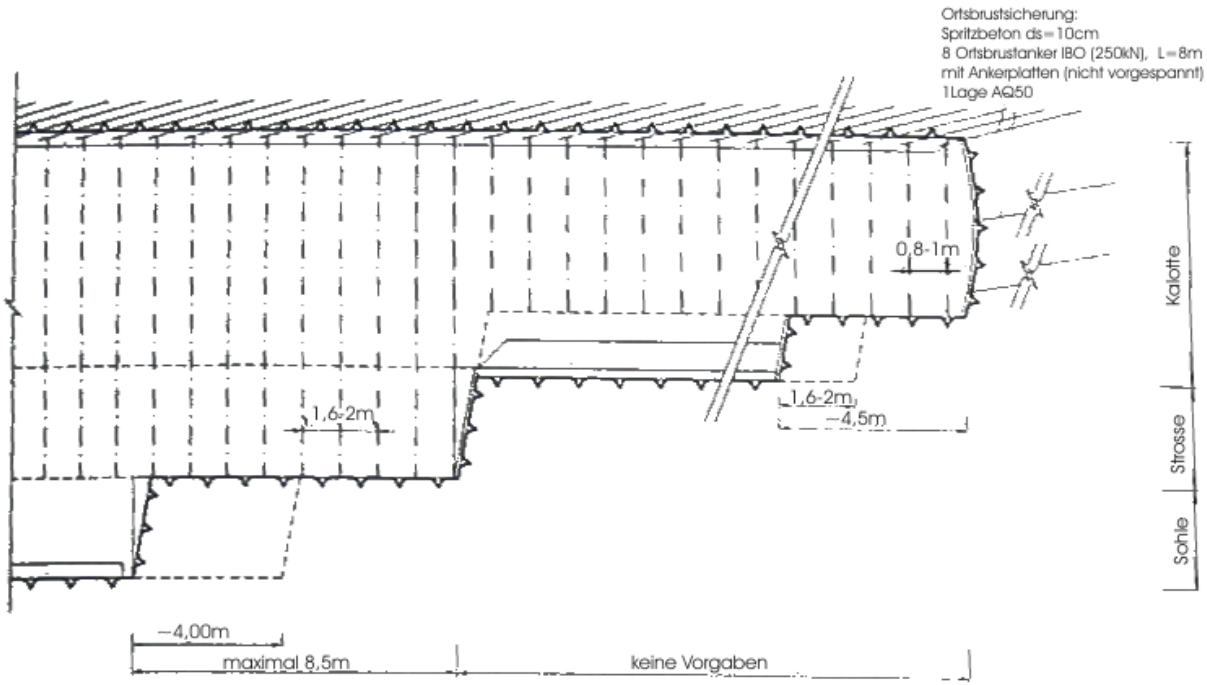
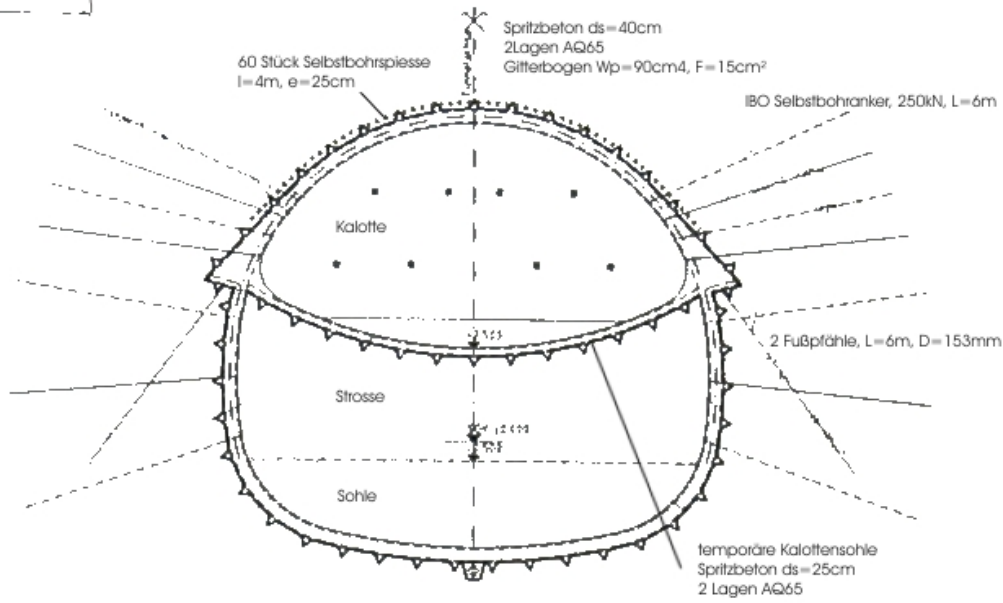




Classification system

The classification system considers **two major factors**, which are decisive for advance rate and cost:

- **Ground properties** and **ground behaviour** during excavation
- **Amount** and **type of supporting measures** on the advance rate

Guideline for the preparation of Tender Documents and Bids - Definition of Tunnelling Classes

The matrix shall comply with the following principles:

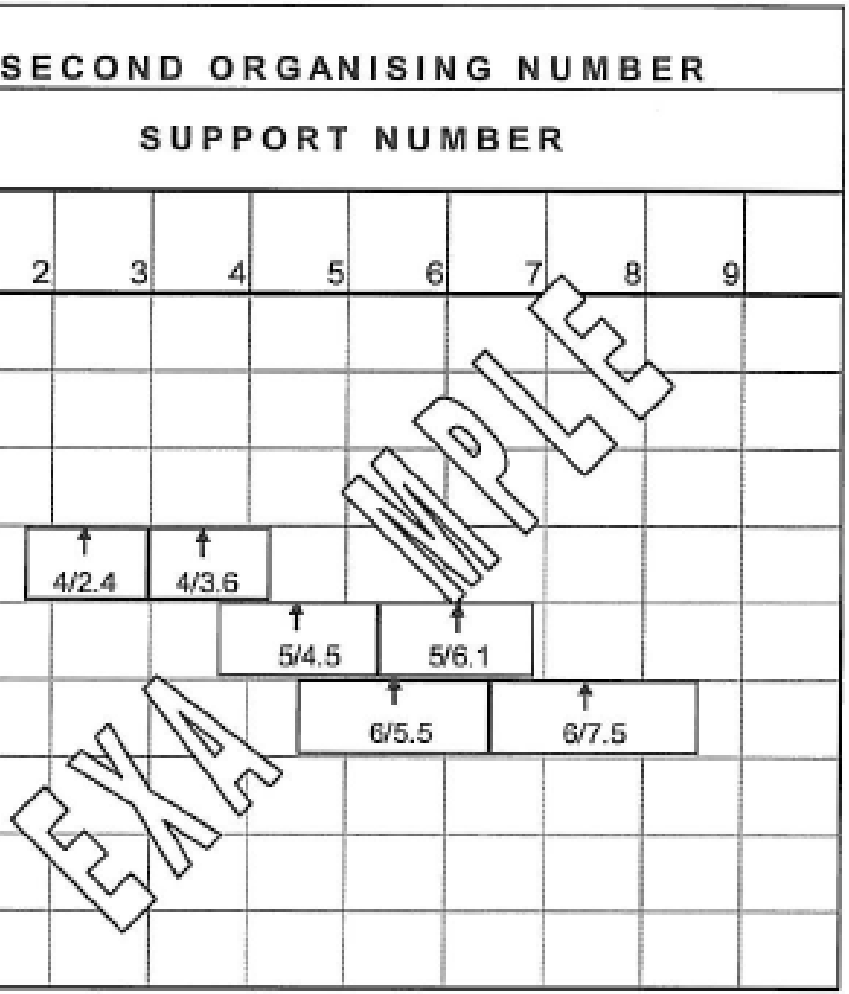
- **First Organising Number:** Subdivision of Top, Bench or Top-plus-Bench headings according to the **round-length range**
- Support and supplementary measures in the top, bench or top-plus-bench headings shall be rated with the **Support Factor** (calculated as **Second Organising Number**).
- The scope of the Second Organising Number shall be defined **within limits**.

Definition of Tunnelling Classes – Tunnelling Class Matrix for top, bench or top-plus-bench heading

Table 1 — Tunnelling Class Matrix for top, bench or top-plus-bench headings

FIRST ORGANISING NUMBER	ROUND LENGTH UP TO: TOP HEADING or TOP + BENCH HEADING	ROUND LENGTH UP TO: BENCH
1	No limit	Project-specific specification
2	4.0 m	
3	3.0 m	
4	2.2 m	
5	1.7 m	
6	1.3 m	
7	1.0 m	
8	0.8 m	
9	0.6 m	

SECOND ORGANISING NUMBER — SUPPORT NUMBER



Tunnelling classes
= excavation and support- classes

The Matrix is defined and filled as follows:

- round length (1. Organising Number)
- support factor (2. Organising Number)
  - rating factors for each support element (indirectly reflecting the time necessary for installation)
  - rating area
- result: single point => would lead to an infinite number of such „excavation points"
- support factors are delimited by a tolerance of +/- 0,35 to +/- 2,1, depending on the round length defining areas => excavation classes
- for each class the bidder supplies a unit price for excavation and a guaranteed advance rate (m/day)
- topheading, bench and invert separately

Special features of the classification of excavation

The **tunnelling classes** of top heading and bench are defined by **two characteristic values**.

One being the **round length**, the other being the **support factor (sf)**, which reflects the influence of supporting measures on the excavation rate.

$$sf = \frac{\sum sq \cdot rf}{ar}$$

rf … rating factor

sf … support factor

sq … support quantity

ar … rating area

Construction contract – Rating factors

Support and additional measures		Rating Factor per quantity unit	quantity unit
Anchors and Rockbolts	Swellex or equal	0,8	m
	SN Rockbolts	1,1	m
	Selfdrilling Rockbolts	1,7	m
	Grouted Tube Anchors	2,0	m
	Rockbolts tensioned	2,5	m
Faceanchors	Number of Anchors per Roundlength	8,0	PCS
	Placement of Anchorplates without Tensioning	1,7	PCS
	Placement of Anchorplates with Tensioning	5,0	PCS
Spiles	driven Spiles	0,5	m
	ungrouted Spiles	0,6	m
	grouted Spiles	0,9	m
	Selfdrilling Spiles	1,3	m
	Grouted Tube Spiles	1,6	m
Grouting more than 10 kg per m Anchor, Spile, Footpile		0,1	kg
Steel mesh	exterior (rock) side with Arch	1,0	m²
	interior (excavation) side with Arch	1,5	m²
	exterior (rock) side without Arch	2,0	m²
	Temporary invert ot Topheading	0,8	m²
	Additional Reinforcement, Face Mesh Reinforcement	2,0	m²
Arch and Dispatcher		2,0	m
Shotcrete	Topheading and Bench	20,0	m³
	temp. Invert of Topheading, Elephant Footing	12,0	m³
	Face	14,0	m³
	Filling of gaps and Overexcavation	14,0	m³
Deformationsslots	withoutStress Controller	3,5	m
	with Stress Controller	5,0	m
Forepolingboards		5,5	m²
Footpiles	Footpiles ∅ ≤ 38mm	4,5	m
	Footpiles ∅ ≥ 38mm	5,0	m
Sequences		22,0	PCS
Excavation Elephantfooting		50,0	m
Demolition temporary invert of Topheading whilst Benchexcavation		50,0	m

Definition of Tunnelling Classes
Scope of Second Organising Number

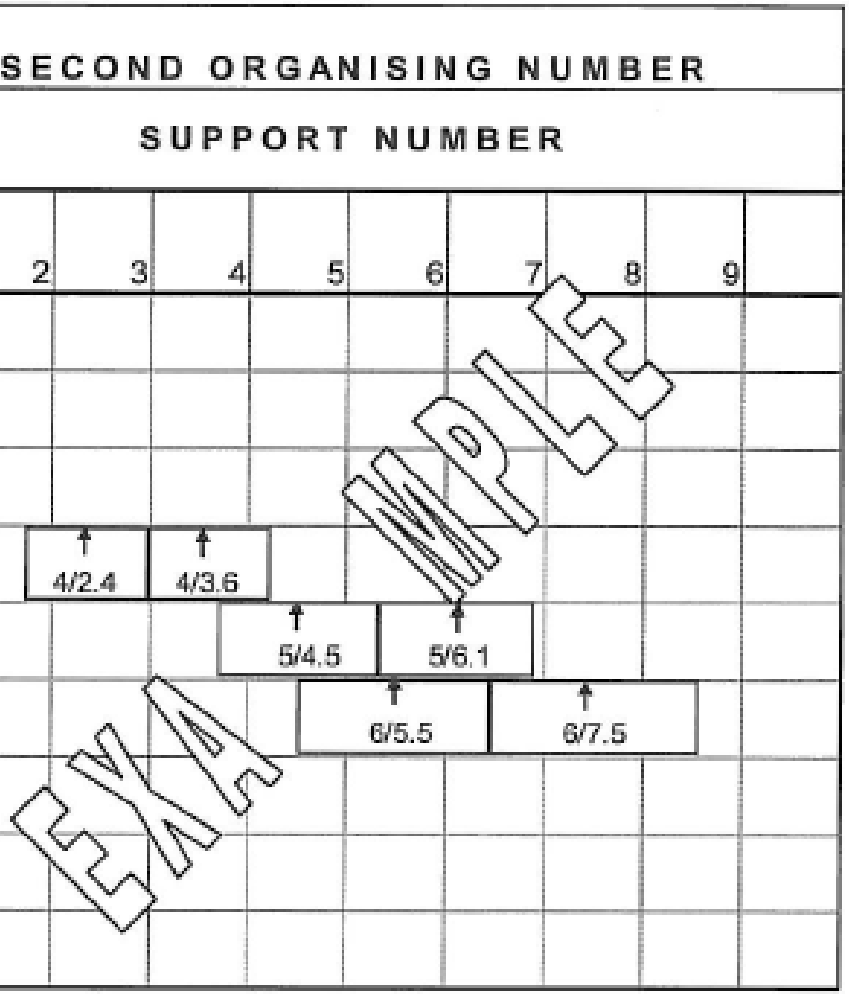
Round Length Topheading	Maximum scope for second ordinal number (Support Factor) Topheading		Round length bench maximum	Maximum scope for second ordinal number (Support Factor) Bench
no limit	+/- 0,35		no limit	+/- 0,45
4,0 m	+/- 0,35			
3,0 m	+/- 0,45		3,0 m	+/- 0,70
2,2 m	+/- 0,60			
1,7 m	+/- 0,80		2,0 m	+/- 1,20
1,3 m	+/- 1,00			
1,0 m	+/- 1,30		1,0 m	+/- 2,10
0,8 m	+/- 1,60			
0,6 m	+/- 2,10			

Definition of Tunnelling Classes – Tunnelling Class Matrix for top, bench or top-plus-bench heading

Table 1 — Tunnelling Class Matrix for top, bench or top-plus-bench headings

FIRST ORGANISING NUMBER	ROUND LENGTH UP TO: TOP HEADING or TOP + BENCH HEADING	ROUND LENGTH UP TO: BENCH
1	No limit	Project-specific specification
2	4.0 m	
3	3.0 m	
4	2.2 m	
5	1.7 m	
6	1.3 m	
7	1.0 m	
8	0.8 m	
9	0.6 m	

SECOND ORGANISING NUMBER — SUPPORT NUMBER



Example:

Topheading of a typical two lane highway tunnel

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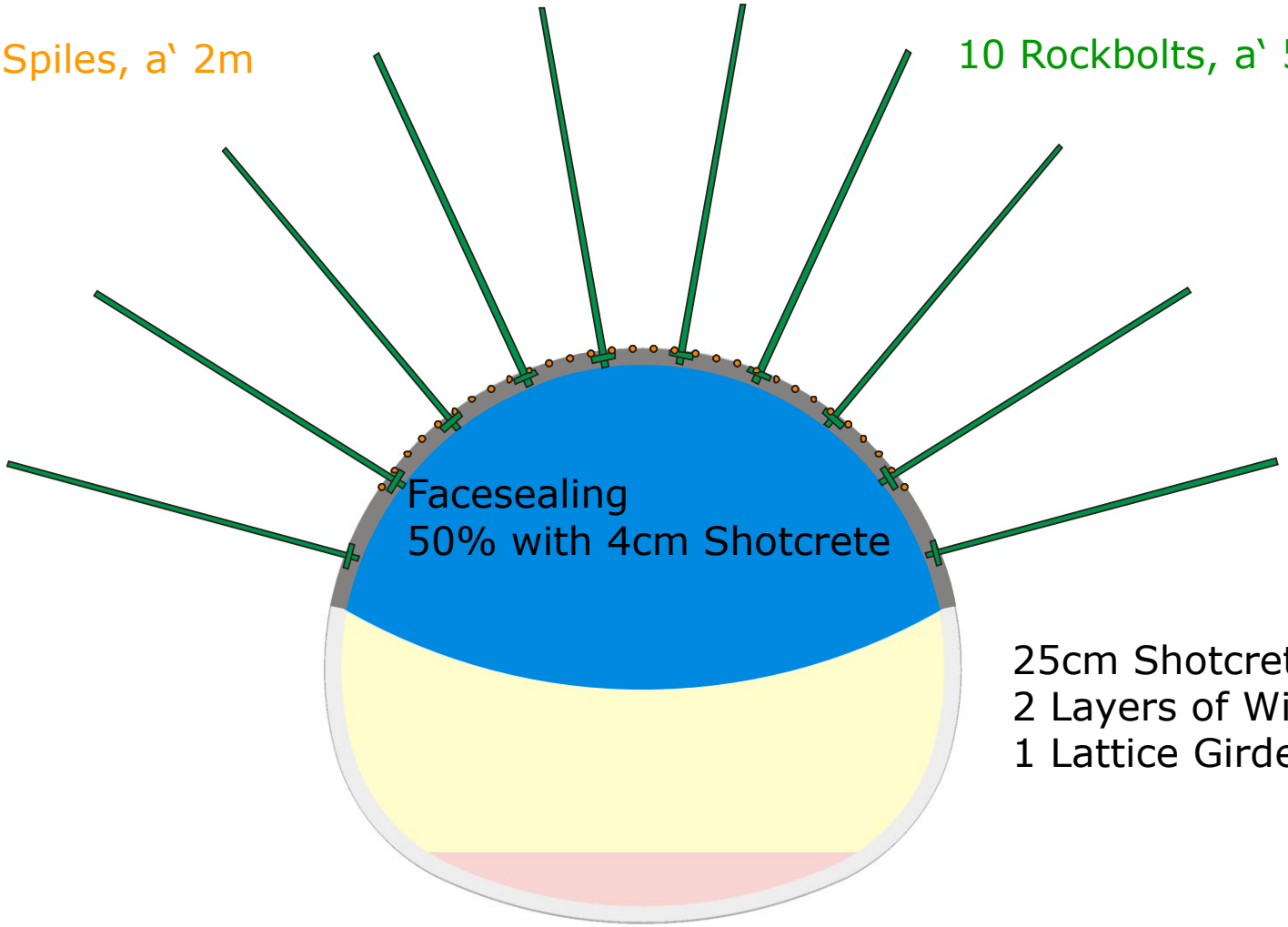

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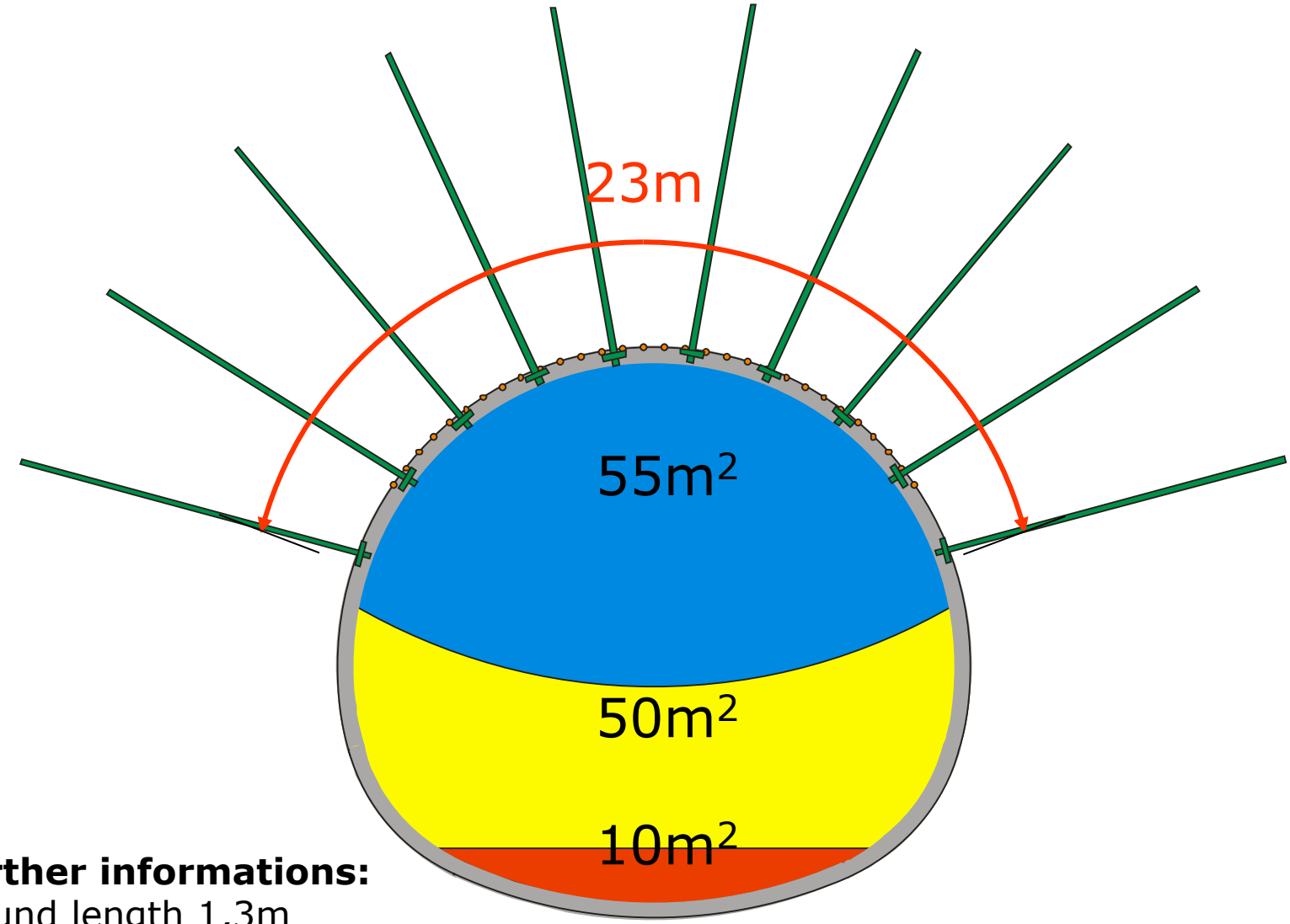


further informations:
Round length 1,3m

Example **Excavation Class**

- Round length
- Support and Reinforcement
  - list
  - quantity/linear meter tunnel
  - rating factors
  - sum
- Rating Area
- Determination for every design drawing
- Separate determination for each Topheading, Bench and Invert

Construction contract – Example

Support/Round length (RL)			Quantity/m Tunnel			Factor	Sum	
Shotcrete thickness (theo.)	0,25	m	23,0 × 0,25 × 1,0	5,75	m³	20,00	5,75 × 20,0	115,00

Support - Shotcrete	
Shotcrete thickness	0,25 m
Line 1a	23,00 m
Rating Factor (ÖNORM B2203-1)	20,00
Quantity/m Tunnel	5,75 m³
Sum	115,0

$$Quantity/lfm = 23{,}0 \times 0{,}25 \times 1{,}0 = 5{,}75$$

$$Sum = 5{,}75 \times 20 = 115$$

Construction contract – Example

Support/Round length (RL)			Quantity/m Tunnel			Factor	Sum	
Rockbolts Swellex (RL)	10,00	Pieces	(10 × 5,5)/1,3	42,31	m	0,80	42,31 ×0,8	33,85

Support - Rockbolts	
Rockbolts	10 Pieces
Bolt length	5,50 m
Round length	1,30 m
Rating Factor (ÖNORM B2203-1)	0,80
Quantity/m Tunnel	42,31 m
Sum	33,85

$$Quantity/lfm = \frac{(10 \times 5{,}5)}{1{,}3} = 42{,}31$$

$$Sum = 42{,}31 \times 0{,}8 = 33{,}85$$

Construction contract – Example

Support/Round length (RL)			Quantity/m Tunnel			Factor	Sum	
Shotcrete thickness (theo.)	0,25	m	23,0 × 0,25 × 1,0	5,75	m³	20,00	5,75 × 20,0	115,00
Facesupport (RL)	0,04	m	(0,04 × 55,0 × 0,5) / 1,3	0,85	m³	14,00	0,85 × 14,0	11,85
% of Face	0,50	Top-heading						-
Wire mesh CQS 6	2,00	Layers	1,0 × 23,0 × 1,0	23,00	m² (ext.+Arch)	1,00	23,0 × 1,0	23,00
			1,0 × 23,0 × 1,0	23,00	m² (int.+Arch)	1,50	23,0 × 1,5	34,50
Arch (RL)	1,00	Pieces/RL	(1,0 × 23,0)/1,3	17,69	m	2,00	17,69 × 2,0	35,38
Rockbolts Swellex (RL)	10,00	Pieces	(10 × 5,5)/1,3	42,31	m	0,80	42,31 ×0,8	33,85
Bolt length	5,50	m						-
Spiles grouted (Round length)	30,00	Pieces	(30 × 2)/1,3	46,15	m	0,90	46,15 × 0,9	41,54
Lentgh of Spiles	2,00	m						
Sum								**295,12**

Calculation Excavation Class				
Round length	1,30	1. Ordinal Number		**6,00**
Line 1a	23,00			
Topheading Area	55,00	2. Ordinal Number	295,15 / 55,00	**5,37**
Support	295,12			

Construction contract – Example
Excavation Class Matrix

- First Ordinal Group: Round Length
- Second Ordinal Group: Support Factor

FIRST ORDINAL NUMBER	Round length maximum: TOPHEADING or TOPHEADING + BENCH	Round length maximum: BENCH	SECOND ORDINAL NUMBER / SUPPORT FACTOR 1	2	3	4	5	6	7	8	9
1	no limit	is to be determined for each project									
2	4,0 m										
3	3,0 m										
4	2,2 m										
5	1,7 m										
6	1,3 m						6/5,37				
7	1,0 m						1,0	—	1,0		
8	0,8 m										
9	0,6 m										

Round Length Topheading	Maximum scope for second ordinal number (Support Factor) Topheading
no limit	+/- 0,35
4,0 m	+/- 0,35
3,0 m	+/- 0,45
2,2 m	+/- 0,60
1,7 m	+/- 0,80
1,3 m	+/- 1,00
1,0 m	+/- 1,30
0,8 m	+/- 1,60
0,6 m	+/- 2,10

Round length bench maximum	Maximum scope for second ordinal number (Support Factor) Bench
no limit	+/- 0,45
3,0 m	+/- 0,70
2,0 m	+/- 1,20
1,0 m	+/- 2,10

Construction contract - Excavation Class Matrix
Rock Tunnel, double track railway tunnel

Erste Ordnungszahl	Abschlagslänge bis Kalotte		Zweite Ordnungszahl: Stützmittelzahl 1 2 3 4 5 6 7 8 9 10 11 12 13 14
1	keine Vorgabe		
2	4,0m		
3	3,0m	0,90 – 1,80 1,20 – 2,10	F2 3/1,65
4	2,2m	0,80 – 2,00 1,94 – 3,14	F2 4/1,48 F2 4/2,54
5	1,7m	1,21 – 2,81 2,76 – 4,36	F2 5/2,01 F2 5/3,56
6	1,3m	2,54 – 4,54 3,85 – 5,85 5,56 – 7,56	F2 6/3,56 F2 6/4,85 F2 6/6,56
7	1,0m	4,34 – 6,94 6,41 – 9,01 8,74 – 11,34	F2 7/5,64 F2 7/7,71 F2 7/10,04
8	0,8m		
9	0,6m		

Construction time and time dependent costs

Construction contract

Generally the **time** required for excavation and support as well as the additional time required because of delays such as water hindrances is kept **variable**.

In his offer the **contractor** has to indicate **advance rates for each excavation class** and **rates for reductions** due to hindrances, all of which he has to guarantee.

The adjusted construction time is the **basis for the compensation** of all time dependent costs.

Construction time

Having available rock mass types the **tunnelling classes (excavation and support)** will be derived. The distribution of the tunnelling classes along the tunnel alignment is based on the geotechnical data **from the site investigations**.

For each tunnelling class the necessary **excavation time** can be calculated. This gives an excavation velocity in meter per month and shall be a contractual component.

The summation of the excavation time of all tunnelling classes gives the **total excavation time for the tunnel**.

Construction contract

Top-heading, 2lane, falling driving, soil				
EXCAVATION CLASS	Length	v_{VT}	Duration	VT-Duration
	m	lm/d	days	month
	a	b	c=a/b	d=c/28
L-DR 5/4,38	133,25	5,70	23,38	0,83
L-DR 5/5,70	43,00	5,20	8,27	0,30
L-DR 5/7,02	12,00	4,63	2,59	0,09
L-DR 5/8,61	19,00	4,23	4,49	0,16
L-DR 5/10,03	9,50	3,75	2,53	0,09
L-DR 6/6,48	62,50	4,53	13,80	0,49
L-DR 6/8,21	52,50	4,17	12,59	0,45
L-DR 6/9,94	83,25	3,77	22,08	0,79
L-DR 6/13,12	80,00	2,83	28,27	1,01
L-DR 7/8,90	29,00	3,63	7,99	0,29
L-DR 7/11,37	28,50	3,27	8,72	0,31
L-DR 7/13,96	15,00	2,90	5,17	0,18
L-DR 7/18,64	95,00	2,23	42,60	1,52
L-DR 7/20,88	20,00	2,10	9,52	0,34
Subtotal	682,5		192,00	6,86

Construction time

The **encountered** tunnelling class distribution will be different from the **assumed** distribution.

That means the **excavation time may be different** compared with the time based on the tunnelling class distribution as proposed in the **tender drawings**.

The **advantage of this model** is that both the contractor and the client shear the risk of additional costs which results from the deviations between the prognosis in the tender documents and the encountered geological conditions.

THEORETICAL construction time

Each individual **tunnelling class** requires a certain amount of time for excavation and installation of supporting measures, as defined.

The application of the assessed progress rates for the predicted tunnelling class distribution yields a **theoretical construction time** for the tunnelling works.

ACTUAL construction time

With the documentation of **actual rock classification** the initial theoretical construction time is adjusted and any difference will be used for re-definition of the target dates and for reimbursement of corresponding payment items.

Continuous monitoring of the progress with respect to the theoretical construction time allows to allocate the cause of delays.

ACTUAL construction time

Due to the actual tunnelling classes the **actual construction time** may be extended and reimbursement of corresponding **payment items will be adjusted**.

In the used model where **payment is time dependent** both the contractor and the client shear the risk of the actual underground conditions which may differ from the predicted geological assessments.

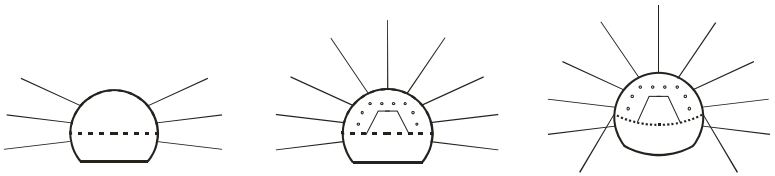
Recalculation of the **actual construction time** is based on the excavation progress rates (**excavation velocity**) **which are specified by the contractor as a contract component.**

Payment of additional construction time

The additional time dependent **costs have to be paid by the client only** if the reason for the longer construction time belongs to the owner's risks.

The inability of the contractor to perform under prescribed contractual conditions is **no reason for additional payment**.

Construction contract – Example – Excavation Period



Tender

	VKL 1	VKL 2	VKL 3	Summe
Tender (prognosis)	100m	100m	100m	300m
Bidder: Advance Rate	10 m/d	5 m/d	1 m/d	
Excavation Period	10 days	20 days	100 days	130 days

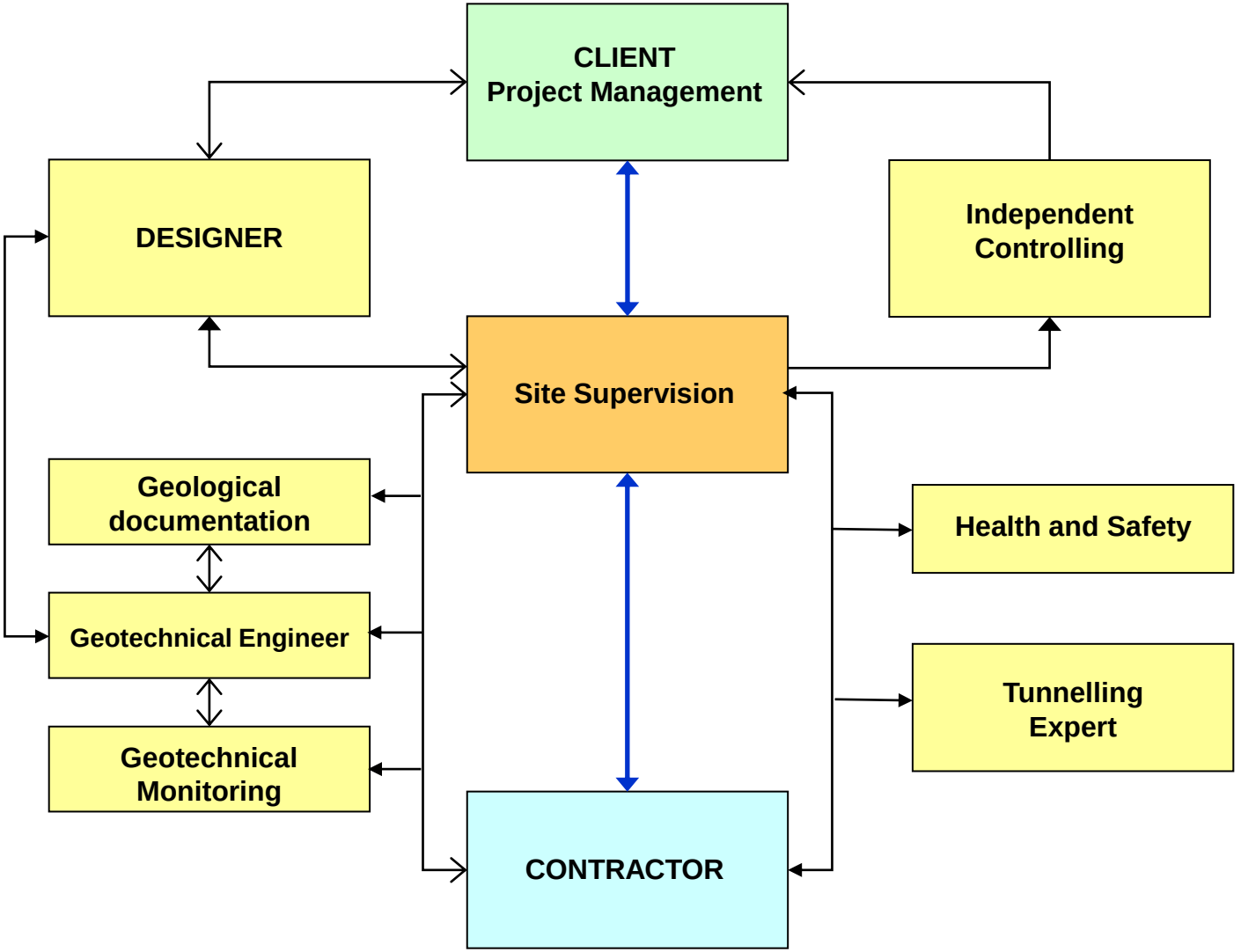
time dependent costs, total 1.300.000 € for 130 days = 10.000 €/d

Accounting

	VKL 1	VKL 2	VKL 3	Summe
actual length (Ist)	140 m	80 m	80 m	300m
Bidder: Advance Rate	10 m/d	5 m/d	1 m/d	
Excavation Period	14 days	16 days	80 days	110 days

time dependent costs, total 10.000 €/d for 110 days = 1.100.000 €

Organisation



Thanks for your attention!