From Palmström A.: RMi – a rock mass characterization system for rock engineering purposes.
PhD thesis, Oslo University, Norway, 1995, 400 p.

APPENDIX 7

COLLECTED DATA ON GROUND CONDITIONS AND ROCK SUPPORT IN CONSTRUCTED UNDERGROUND OPENINGS

> *"A good engineering design is a balanced design in which all the factors which interact, even those which cannot be quantified are taken into account. Therefore the responsibility of the design engineer is not to compute accurately but to judge soundly."*
> Evert Hoek and Pierre Londe (1974)

Collection of rock mass characteristics, field data on rock mass conditions and rock support has been carried out for the following underground excavations:

1. Gjövik Olympic mountain hall; Gjövik, Norway
2. Granfoss road tunnels; Oslo, Norway
3. Haukrei hydropower plant; Telemark, Norway
4. Vinstra hydropower plant; Gudbrandsdalen, Norway
5. Horga hydropower plant; Sigdal, Norway
6. Tromsö road tunnel; Tromsö, Norway
7. Nappstraumen road tunnel; Lofoten, Norway
8. Stetind road tunnel; Tysfjord, Norway
9. Njunis tunnel; Bardu, Norway
10. Sumbiar road tunnel; The Faroe Islands
11. Thingbæk chalk mines; Ålborg, Denmark

The information collected has been used to calculate the quality of the ground (given as the ground condition factor for discontinuous materials, or the competency factor for continuous materials) and the size ratio (tunnel size/block size). The calculations and data are presented in Section 2.

1 DESCRIPTION OF THE LOCATIONS

1.1 Gjövik Olympic mountain hall, Norway

This underground stadium has the following dimensions: span = 62 m, length = 91 m, total height = 24 m, wall height = 10 m. Orientation of the opening: N60^{o}E

<u>Description of the general ground conditions</u>:
Precambrian red and grey gneiss. It has a composition varying from granitic to quartzdioritic with about 30% quartz, 65% feldspar and a few percent of chlorite, mica and hornblende. The unconfined compression strength is in the range 63 - 94 MPa. The cavern is not intersected by any major weakness zone, except for a fault zone at the entrance of the main access tunnel.

The jointing is mostly irregular, usually three joint sets are found. The main joint set occurs along the foliation of the gneiss (strike/dip = N-E/50 SW), with joint spacing usually 0.2 - 0.5 m with and joint length mainly 2 - 5 m. The joints are smooth to rough and undulating. Most of the joints have

no filling, but in a few joints filling of clay, chlorite, silt/sand occurs; also calcite, epidote and quartz is found. Tectonism has resulted in an additional network of microjoints sometimes with clay coatings.
The average joint condition factor: jC = 3.0

The joint wall compressive strength obtained by means of Schmidt hammer readings, is between 50 and 100 MPa, i.e. the same as the strength of the rock.
Average block volume is Vb = 0.1 m^3.
The overburden is 20 - 50 m. The stresses measured (at a depth 40 m below surface) are:
horizontal stress = 3.5 MPa; vertical stress = 1 MPa, i.e. k = horizontal/vertical stress = 3.5

In general, the initial support consisted of 27 mm diameter and 4 m long expansion shell bolts in unstable blocks. For the permanent use, 6 m long and 25 mm diameter rebar rock bolts were installed in pattern 2.5 × 2.5 m in addition to 12 m long twin-strand cable bolts in 5 × 5 m pattern. All the permanent bolts are fully grouted. Initially, a 50 mm thick of fibre reinforced shotcrete was sprayed, followed by additional 50 mm after the cable bolts had been placed.

1.2 Granfoss road tunnels, Oslo

The four tunnels have all horse-shoe shape. The following locations have been inspected:
Lysaker N, span Wt = 10.7 m,
Ullern N, span Wt = 12 m,
Ullern S, span Wt = 9 m.

Description of the general ground conditions:
Ordovician sedimentary rocks consisting of bedded clayschists, claystones and limestones ("knollekalk"). The rocks were folded during the Caledonian orogenesis and therefore the orientation of the bedding varies. The layers consisting of schistose rocks have been most strongly folded. Assumed compressive strength: clay schist σ_c = 40 MPa, claystone and limestone σ_c = 40 MPa.

The tectonic activity during Permian time resulted in several small and large faults, mainly striking N-S. Several veins and dykes have been formed from volcanic activity in this period. Veins of maenaite and syenite can be several 10 m thick. The 0.5 - 3 m thick dolerite dykes are steep-dipping.

Two main joint sets occur in the tunnel. One is located along the bedding with strike N45^{o}E and dip of 70^{o}N. The other is steep with striking between East and South.
In the locations described the joint are mainly rough and planar to undulating. Most walls are fresh; they have seldom coating or filling. Generally there are mainly small, irregular joints with length 0.5 - 3 m. The degree of jointing (i.e. block size) vary in the various locations described. Some damage from the drill and blast excavation has been made in the tunnel periphery.

The overburden for tunnel varies between 10 and 50 m. Assumed k-value: $k = p_h / p_v = 2$.

The following input values have been used:

Lysaker N (chainage 400):

-Rocks: clay schists
-Average block volume: $Vb = 0.2 \ m^3$
-Average block shape factor: $\beta = 40$
-Average joint condition factor: $jC = 2.0$
-Main joint set -strike between tunnel and joint set: $\alpha_j = 20^o$
-dip between tunnel and joint set: $\beta_j = 90^o$

Roof support used: fibrecrete 100 mm, bolts spaced 1.5 m (length 3 m)

Ullern N (chainage 1320):

-Rocks: clay schists
-Average block volume: $Vb = 0.05 \ m^3$
-Average block shape factor: $\beta = 30$
-Average joint condition factor: $jC = 2.0$

Roof support used: fibrecrete 80 mm thick, rock bolts spaced 1.5 m (bolt length = 4 m)

Ullern N (chainage 1420):

-Rocks: limestone
-Average block volume: $Vb = 0.2 \ m^3$
-Average block shape factor: $\beta = 40$
-Average joint condition factor: $jC = 2.5$
-Main joint set: -average spacing: $Sa = 0.3$ m
-strike between tunnel and joint set: $\alpha_j = 70^o$
-dip between tunnel and joint set: $\beta_j = 80^o$

Roof support used: fibrecrete up to 100 mm thick, and rock bolts spaced 1.5 m (bolt length = 3 m)

Ullern N (chainage 1700):

-Rocks: limestone
-Average block volume: $Vb = 0.5 \ m^3$
-Average block shape factor: $\beta = 40$
-Average joint condition factor: $jC = 2.0$
-Main joint set: -average spacing: $Sa = 0.4$ m
-strike between tunnel and joint set: $\alpha_j = 70^o$
-dip between tunnel and joint set: $\beta_j = 80^o$

Roof support used: fibrecrete up to 100 mm thick, and rock bolts spaced 1.5 m (bolt length = 3 m)

Ullern S (chainage 1875):

-Rocks: limestone
-Average block volume: $Vb = 0.1 \ m^3$
-Average block shape factor: $\beta = 40$
-Average joint condition factor: $jC = 2.0$

Roof support used: fibrecrete up to 100 mm thick, and rock bolts spaced 1.5 m (bolt length = 3 m)

1.3 Haukrei hydropower plant, Telemark, Norway

The observation have been made in the headrace tunnel which has a horse-shoe shape with a cross section area: 12 m^2, the tunnel span is Wt = 3 m.

<u>Description of the ground conditions:</u>
Precambrian gneiss and granitic gneiss (strike/dip related to tunnel = 20-30°/70-80° to the right) with main joint set along foliations with spacing S = 0.5 - 2 m. Some random joints occur. The foliation joints are rough, undulating with fresh walls and a length of 1 - 5 m
Overburden at the locations described below: z = 50 m,
There are probably high horizontal stresses in this area; assumed $k = p_h / p_v = 4$

<u>Rock conditions at chainage 200:</u>

- -Rocks: grey gneiss, assumed compressive strength: σ_c = 130 MPa
- -Average block volume: Vb = 3 m^3
- -Block shape factor: β = 40
- -Average joint condition factor : jC = 3.5
- -Main joint set: -average spacing: Sa = 0.75 m
  - -strike between tunnel and joint set: α_j = 30°
  - -dip between tunnel and joint set: β_j = 70°

Roof support: no rock support, occasionally some scaling work.

<u>Rock conditions at chainage 110</u>:
A 10 m wide weakness zone was encountered at chainage 110. Its orientation related to the tunnel is (strike/dip = 45/90). It consists of a partly chloritized diabase (assumed σ_c = 100 MPa). The zone consists of several parts having somewhat different composition as described in the table below.

FEATURE		Adjacent rock on left side	**Thickness of individual parts of the zone between the adjacent rock masses (m)**							Adjacent rock on right side
			0.5 - 1	1 - 2	2	1 - 2	1 -2	0.4 - 0.5	0.5 -1	
Joint spacing (m),	set 1	0.5 - 2	0.01-0.05	0.1-0.5	0.05-0.2	0.02-0.1	0.01-0.05		0.2-0.3	0.5-2
	set 2					0.3-1		a zone		
Joint length (m),	set 1	1-5	0.1-0.5	0.5-3	0.3-3	0.3-2	0.1-1	mainly of	0.5-2	1-5
	set 2					0.01-0.1		chloritic		
Joint smoothness		rough	smooth	smooth	smooth	smooth	smooth	clay	rough	rough
waviness		undul.	undul.	undul.	undul.	undul.	undul.		planar	undul.
Joint alteration		fresh	-	-	-	-	-			
or coating			chlorite	chlorite	chlorite	chlorite	chlorite			
Random joints		a few							a few	a few
Block volume,	min	0.3 m^3	2 cm^3	10 dm^3	5 dm^3	1 dm^3	2 cm^3		0.02 m^3	0.3m^3
	max	3 m^3	50 cm^3	100 dm^3	50 dm^3	10 dm^3	100 cm^3		0.1 m^3	3 m^3
Block shape		flat	long	flat	flat	flat	long (rhomb.)		flat	flat
Rocks		granitic gneiss	slightly altered diabase with chlorite coating on most joint planes							granitic gneiss

From the data presented in table above the following average values have been applied for the various parameters:

- -Width of weakness zone: Tz = 10 m
- -Strike between tunnel and zone: α_z = 45°
- -Dip between tunnel and zone: β_z = 90°
- -Average joint condition factor: jC = 0.75
- -Average block volume: Vb = 0.02 m^3
- -Average block shape factor: β = 40

Roof support:

- -initial support: rock bolts and wire mesh;
- -permanent support: additional rock bolts spaced 1.5 m and fibrecrete 100 mm thick.

1.4 Vinstra hydropower plant, Norway

The horse-shoe headrace tunnel has a gradient 1:11 and cross section area is 35 m^2.
The span is Wt = 6.5 m.

Description of the ground conditions:
The actual location described at chainage 3250 is in a weakness zone in which a large slide occurred after the tunnel had been in operation for 4 years. The slide involved approximately 15 000 m^3. Slided material from the progressive slide was transported by the water stream in the tunnel almost down to the power house; a distance of 3 km. This is the reason why such large volume could be involved in the slide.

The weakness zone (fault) had been supported by 15 cm thick fibrecrete and rock bolts 2 x 2 m. The main reason for the slide was that clay seams were washed out during infilling of the tunnel system (the system had been emptied 3 times). This outwash was possible because fibrecrete was not applied in the lowest part of the tunnel walls.

To remedy the tunnel it was decided to excavate a 150 m long by-pass tunnel 40 m from the old tunnel in the area where the weakness zone was located. Also this tunnel had to cross the weakness zone.

The rocks in the weakness zone consist of tectonized, folded phyllite. The rocks are moderately weathered with assumed compressive strength, σ_c = 10 MPa
The weakness zone (with strike/dip = $70^o/20^0$) is 10 - 15 m thick with a transition zone of approximately 2.5 m on each side. The rock masses in the zone split up along thin clay-coated partings (length approx. 0.2 - 2 m) spaced 5 - 50 mm along foliation. Some short (0.3 - 2 m long) joints cut across the foliation. Laboratory tests showed that the clay-coatings contain swelling minerals.

The overburden at the site is approximately z = 250 m

The following other input values have been used:

-Average volume of blocks:	$Vb = 25 \times 150 \times 250$ mm = 0.001 m^3
-Assumed k-value:	$k = p_h / p_v = 2.5$
-Strike between tunnel and zone:	$\alpha_z = 70^o$
-Dip between tunnel and zone:	$\beta_z = 20^o$
-Average joint condition factor:	jC = 0.4
-Average block shape factor:	β = 100

Rock support used:
- initial support: fibrecrete after each round, approx. 80 - 100 mm thick and rock bolts spaced 2.5 m
- permanent support:[1] additional 50 - 80 mm thick fibrecrete, plus 1 m wide reinforced ribs of fibrecrete 200 mm thick spaced 2.5 m; the ribs are strengthened by rock bolts at approx. 1 m distance.

[1] This support may be considered equal to:
Initial fibrecrete 60 - 100 mm thick strengthened by cast in place concrete lining as permanent support. The reason why this solution was not chosen was that it would have taken longer time.

1.5 Horga hydropower plant, Buskerud, Norway

The observation were made in the headrace tunnel, which has horse-shoe shape with a cross section area 8 m^2
The span is Wt = 3 m

Description of the general ground conditions
Precambrian red, striped gneiss (σ_c = 100 MPa) with some thin schistose layers or zones. The main joint set occurs along the foliation, mainly consisting of smooth to rough and undulating joints.
Overburden: z = 50 - 200 m
Assumed k-value: k = 2 - 3

The following input values have been used:

Chainage 470:
The main joint set occurs as flat-dipping, short foliation joints spaced 0.2 - 0.5 m. Some other short (0.1 - 1 m long) joints (25/90) occur.

- -Average joint condition factor: jC = 2
- -Average block volume: Vb = 0.05 m^3
- -Average block shape factor: β = 40
- -Main joint set: -average spacing: Sa = 0.4 m
  - -strike between tunnel and joint set: $\alpha_j = 0^o$
  - -dip between tunnel and joint set: $\beta_j = 0^o$

Roof support: some spot bolting (average spacing estimated to 2.5 - 4 m)

Chainage 810:
Crushed weakness zone (strike/dip = 90/45), 4 m thick. The individual 0.3 - 2 m long joints in the main joint set along the zone are spaced 0.05 - 0.3 m, average 0.08 m. It is thin clay coating on a few joint walls.

- -Strike between tunnel and zone: $\alpha_z = 90^o$
- -Dip between tunnel and zone: $\beta_z = 45^o$
- -Average joint condition factor: jC = 0.5
- -Average block volume: Vb = 0.05 m^3
- -Average block shape factor: β = 40

Roof support:
- - initial support: fibrecrete 60 mm thick, rock bolts spaced 2 m,
- - additional permanent support: fibrecrete 60 mm thick, rock bolts spaced 2 m

Chainage 1485:
Foliation joints are the main joint set; in addition to many steep, irregular, small, planar joints.

- -Average joint condition factor: jC = 6
- -Average block volume: Vb = 0.1 m^3
- -Average block shape factor: β = 40

Roof support: rock bolts spaced 2.5 m

1.6 Tromsö road tunnel, Tromsö, Norway

The actual location is in a roundabout located in rock with the following dimensions:
Roundabout shape: horse-shoe
Roundabout span is: Wt = 13 - 20 m, its wall height: Hw = 8 m
The horse-shoe tunnels leading into it have cross section area 50 m^2
The tunnel span is: Wt = 9 m, wall height: Hw = 5 m

Description of the geological conditions:
Similar ground conditions occur in the tunnel and in the roundabout consisting of striped, folded gneiss with its main joint set along foliation. These flat dipping joints are smooth and undulating having length 1 - 3 m, occasionally up to 10 m.
Other joints occur mainly as random joints, which are smooth and planar; length 0.5- 5 m
Some 0.5 - 2 m wide joint zones occur with individual joints being smooth and planar; joint length 0.5- 1 m, sometimes up to 10 m.

The following other input values have been used
- Overburden: z = 20 m
- Assumed rock compressive strength: σ_c = 100 MPa
- Assumed k-value (p_h /p_v): k = 3
- Joint condition factor: jC= 1.5 - 2 (jR = 1.5 - 2, jA = 1, jL = 1)
- Average block volume: Vb = 3 m^3 (Vb_{max} = 10 m^3, Vb_{min} = 1 m^3)
- Block shape factor: β = 40

Rock support used:
- In tunnel (span 9 m): rock bolts spaced 3 m
- In roundabout (span 13 - 20 m): rock bolts spaced 1.5 m; fibrecrete 60 - 80 mm thick

1.7 Nappstraumen road tunnel, Lofoten, Norway

The cross section area of this horse-shoe shaped tunnel is 50 m^2, the span Wt = 10 m.

Description of the general ground conditions:
Precambrian gneisses varying between dark and light coloured types with assumed average compressive strength, assumed σ_c = 150 MPa. The main joint set occurs along the foliation, constituting rough - smooth, undulating walls, mainly with spacing 0.5 - 2 m. The joint walls are often stained. Often, several small (5 - 20 cm long) cracks occur; they are partly healed, rough and undulating.

Occasionally, up to 2 m wide zones occur consisting of more closely spaced joints spaced 5 - 20 cm. The joints are sometimes long. The following input values have been applied for the general ground conditions and rock support:
-Overburden: z = 30 - 50 m
-Assumed k-value (p_h /p_v): k = 3
-Average block volume: Vb = 5 m^3
-Average block shape factor: β = 35
-Average joint condition factor: jC = 2
-Average spacing of main joint set: Sa = 1 m
Roof support used: rock bolts spaced 2 m.

1.8 Stetind road tunnel, Nordland, Norway

Cross section area (horse-shoe): 50 m^2, span: Wt = 10 m

<u>Description of the ground conditions, chainage 15750</u>:
Caledonian granitic gneiss, coarse-grained, exhibiting few very rough and undulating joints. Heavy rock burst occurred during blasting. It is assumed that many of the joints which were observed during the inspection may have been developed from rock burst. Originally, the block size was probably in the range Vb = 5 - 30 m^3. After excavation and redistribution of stresses the block volumes are in the range: Vb = 0.5 - 3 m^3.

The high peak Stetind amounts to 1300 m above the tunnel at an inclination >30°. The vertical stress component is assumed to be equal to approximately 900 m overburden. The strongly anisotropic stresses are assumed with a value: k = 5
The following other input values have been applied:

- -Average joint condition factor: jC = 2.5
- -Average block size (before): Vb = 15 m^3
- -Average block shape factor: β = 40

Roof support used:

- initial support: rock bolts spaced 1.5 - 2 m, fibrecrete 60 mm thick.
- permanent support: some additional bolting; (the resulting bolt spacing is 1 - 1.5 m)

1.9 Njunis tunnel; Bardu, Norway

This access tunnel (horse-shoe) has gradient 1:7, cross section area: 10 - 12 m^2, and span: Wt = 3 m

<u>Description of the general ground conditions</u>:
Dark amphibolitic gneiss (meta-basalt), with foliation often parallel to the tunnel. Assumed compressive strength is σ_c = 200 MPa.
The main joint set which occurs along the foliation, has a joint spacing of 0.3 - 1 m. The joints are undulating, smooth - rough with length generally 5 - 20 m. Staining on joint wall is frequent.
Frequently, small (0.1 - 1 m) joints occur across foliation. They are strongly undulating, rough, often with calcite coatings.
The overburden is 200 m
Assumed k-value (p_h /p_v): k = 5

The following input values have been used from this tunnel:

<u>Chainage 6250</u>:

- -Average joint condition factor: jC = 3
- -Average block volume: Vb = 0.5 m^3
- -Average block shape factor: β = 40
- -Main joint set:
  - -average spacing: Sa = 0.4 m
  - -strike between tunnel and joint set: α_z = 45°
  - -dip between tunnel and joint set: β_z = 10°

Roof support: rock bolts spaced 3 m

<u>Chainage 6300</u>:

Here, a steep-dipping, crushed weakness zone, 6 m thick (strike/dip = $70^o/90^o$) was encountered. It consists of 1 - 10 mm thick clay-filled joints spaced 0.2 - 0.3 m along the zone. Additional, parallel small joints spaced 0.05 - 0.2 m and some short joints along the foliation (across the other joints) with spacing 0.1 - 0.3 m.

-Average joint condition factor: jC = 0.25
-Average block size: Vb = 0.005 m^3
-Average block shape factor: β = 40
-Strike between tunnel and zone: $\delta_z = 70^o$
-Dip between tunnel and zone: $\beta_z = 90^o$

Roof support:

- initial support: wire mesh and rock bolts spaced approx. 1.5 m.
- additional permanent support: fibrecrete 60 mm thick.

1.10 Sumbiar road tunnel, The Faroe Islands

Tunnel cross section (horse-shoe) area: 50 m^2, tunnel span Wt = 10 m

Description of the ground conditions:
Tertiary basalt, flat-layered, characterized by relatively thick layers intersected by thin layers of tuff. Assumed rock compressive strength: σ_c = 200 MPa. There are varying compositions of the basalt layers, also within each layer the rocks vary. All basalts in the locations described have a dense texture.

The degree of jointing is generally low to moderate. Most joints are smooth and undulating. There are sometimes joints with calcite coating. Generally, the block volume is 0.5 - 2 m^3 caused by a few meter long joints. Smaller blocks are mainly caused by shorter (dm long) strongly undulating joints.

The stability in the tunnel (i.e. in the roof) is mainly influenced by the flat-dipping joints.
The weakness zones are generally steep, often at right angles to the tunnel. There are often parallel joints with calcite coating in the adjacent rock masses.

Overburden: z = 100 - 300 m
Assumed k-value (p_h/p_v): k = 2

The following other input values are:

Chainage 650:

-Average joint condition factor: jC = 1.5
-Average block volume: Vb = 1 m^3
-Average block shape factor: β = 30
-Main joint set: -average spacing: Sa = 0.8 m
-strike between tunnel and joint set: $\alpha_j = 75^o$
-dip between tunnel and joint set: $\beta_j = 90^o$

Roof support: spot bolting

Chainage 1315:

-The joints in this location are mostly rough, short and discontinuous, therefore the joint condition factor is: jC = 7

-Average block volume: Vb = 0.025 cm^3

-Average shape factor: β = 35

Roof support: 50 mm thick shotcrete

Chainage 2100:

This i a 3 m thick crushed weakness zone consisting of rough, undulating joints with silt/sand coatings intersects the tunnel at strike/dip = $45^o/90^o$.

-Average joint condition factor: jC = 0.75

-Average block volume: Vb = 0.05 m^3

-Average block shape factor: β = 75

-Strike between tunnel and zone: $\alpha_z = 45^o$

-Dip between tunnel and zone: $\beta_z = 90^o$

Roof support: 50 mm thick shotcrete

Chainage 600:

Another crushed weakness zone, 1.5 m thick (65/90), with many clay-filled joints. Some water leakage occurs.

-Average joint condition factor: jC = 0.5

-Average block volume: Vb = 100 dm^3

-Average block shape factor: β = 40

-Strike between tunnel and zone: $\alpha_z = 65^o$

-Dip between tunnel and zone: $\beta_z = 90^o$

Roof support: rock bolts spaced 1.5 m, straps and wire mesh [2]

1.11 Thingbæk chalk mines, Ålborg, Denmark

The Thingbæk mines, which are located near Ålborg in Denmark, have not been in operation since 1920. The observations are from the old mine in the branch tunnel leading to the newly excavated (1992) connection tunnel between the old mine and the new mine where a museum has been established. The tunnel with a rectangular shape, has a span of Wt = 5 m, and a height Ht = 7 - 8 m

Description of the ground conditions:

The Jurassic - Tertiary rocks are flat-layered chalk with thin bands rich in flint. The compressive strength is measured as: σ_c = 1 - 2 MPa. The main joint set occurs along bedding planes generally spaced 1 - 2 m. The joints are rough, partly planar with length mainly in the range 3 - 15 m. In the rock blocks between the bedding joints there are short (0.1 - 0.3 m long) cross joints spaced 1 - 3 m. Average block volume is Vb = 2 - 50 m^3. The flat (top of the) roof at the actual location is shaped along one of the bedding weaknesses.

Some few large (> 10 m) steep-dipping joints cut the mine tunnel at 60 - 80^o. Many of the tunnels in the mine are located along these. The roof is often flat where it is developed along pervasive bedding joints.

---

[2] Rock bolt spaced 2 m and 60 mm shotcrete could also have been applied.

The following input values have been used:

- -The overburden: $z = 5 - 10$ m
- -Assumed k-value: $k = 1$
- -Joint condition factor: $jC = 3.0$
- -Average block volume: $Vb = 30\ m^3$
- -Block shape factor: $\beta = 45$
- -Main joint set, average spacing: $Sa = 1.5$ m
- -Strike between tunnel and joints: $\alpha_j = 45^o$
- -Dip between tunnel and joints: $\beta_j = 10^o$

Roof support used:

- Spot bolting (spacing approx. 3 m) to prevent loosening along bedding joints.
- Some time-dependent loosening of fragments was observed in the rock blocks are caused by the small cross joints and a probably slight overstressing of the rock material.
- Long-term deterioration of the rock in the tunnel surface requires the use of shotcrete. This has been applied in the mine museum which occupies a part of the mine. The museum is open to the public.

2 CALCULATION OF GROUND CHARACTERISTICS APPLIED IN THE ROCK SUPPORT TABLES

The rock mass characteristics described in the foregoing have been used to calculate the jointing parameter (JP), the RMi value, and the ground characteristics which have been applied to develop the support charts in Chapter 6.

The data from the various locations are inserted in the 'input part' of the tables presented in the following. The various ground parameters are calculated using equations presented in Chapters 4 and 6.

ROCK SUPPORT EXPERIENCE - CASES

		Project / tunnel:		Gjövik OL stadium	Granfoss road tunnels	
INPUT DATA		Location:		general conditions	Lysaker S, chain. 400	Ullern S, chain.1875
Rock(s):				red and grey gneiss	clay schist	claystone "knollekalk"
Rock deformability		(brittle = 1	"ductile" = 2)	1	2	1
Tunnel span (width) (m)			Wt	62.00	10.70	9.00
Tunnel wall height (m)			Hw	10.00	6.00	6.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)				7	4	4
Overburden (m)			z	40	20	30
Rock compressive strength (MPa)			σc	80.0	40.0	60.0
Assumed stress ratio (Ph /Pv)			k	3.5	2.0	2.0
Joint condition factor			jC	3.0	2.0	2.0
Blocks:	- Block volume (m3)		Vb	0.2	0.2	0.1
	- Block shape factor		β	35	40	40
Main joint set:	- Average spacing (m)		Sa			
	- Strike (related to tunnel)		α_j		20	
	- Dip (related to tunnel)		β_j		90	
For weakness zone:	- Indicate type of weakness zone					
	- Thickness of weakness zone (m)		Tz			
	- Strike (related to tunnel)		α_z			
	- Dip (related to tunnel)		β_z			
	- Rock Mass index in adjacent rocks		RMi_a			
Rock support used:	- bolt spacing (m) in		- roof	2 (l=4-6m) and 5(l=12m)	1.5	1.5
			- wall			
	- shotcrete (mm) (F = fibrecrete) in:		- roof	(F) 100	(F) 70	(F) 70
			- wall			
	- concrete lining					
		Remarks:				
CALCULATIONS	Scale effect compr. strength		f_σ	**0.633013651**	**0.644383724**	**0.674856168**
Jointing parameter			JP	0.214776	0.168424	0.134723
Rock Mass index			RMi	17.182109	6.736963	8.083371
Equivalent block diameter (m)			Db	0.49	0.45	0.36
Intersection between main joint set and tunnel		-roof			favourable	
		-wall			very unfavourable	
Intersection between weakness zone and tunnel		-roof				
		-wall				
Assumed vertical stress (MPa)			p_z	1.08	0.54	0.81
Assumed horizontal stress (MPa)			p_h	3.78	1.08	1.62
Tunnel shape factors (according to Hoek & Brown, 1980):			Factor A =	2.0	3.2	3.2
			Factor B =	5.0	2.3	2.3
Tangential stress (MPa) in:		- roof	$\sigma_{\theta r}$	6.48	2.92	4.37
		- wall	$\sigma_{\theta w}$	1.62	0.16	0.24
Continuity of ground in:		- roof	**CF**	continuous (particulate)	discontinuous	discontinuous
		- wall	**CF**	discontinuous	discontinuous	discontinuous
Characteristics in jointed (discontinuous) rock masses						
Approximate stress level (MPa)				3.78	1.08	1.62
Stress level coefficient			SL	1	1	1
Ground condition factor (RMi x SL) in:		-roof	**Gc**	**17.18**	**6.74**	**8.08**
(RMi x SL x wall factor) in:		-wall	**Gc**	**85.91**	**33.68**	**40.42**
Orientation factor for joints in:		-roof	Co	1.5	1.0	1.5
		-wall	Co	1.5	3.0	1.5
Size ratio [(Wt/Db) Co] in:		- roof	**Sr**	**4342494.9**	**23.8**	**868122.2**
Size ratio [(Ht/Db) Co] in:		- wall	**Sr**	**700402.4**	**40.0**	**578748.1**
Characteristics in weakness zone or fault				(No weakness zone)	(No weakness zone)	(No weakness zone)
Orientation factor (intersection zone - tunnel) in:		-roof	Co_z			
		-wall	Co_z			
Ground condition [SL x RMi(m)] in:		-roof	$\mathbf{Gc_z}$			
		-wall	$\mathbf{Gc_z}$			
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:		- roof	$\mathbf{Sr_z}$			
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:		- wall	$\mathbf{Sr_z}$			
Characteristics in continuous rock masses						
Competency factor in:		- roof	**Cg**	**2.65**		
		- wall	**Cg**			
Possible stress behaviour of massive rock in:		- roof		high stress level		
		- wall				
Possible behaviour of continuous, particulate rock masses:				light squeezing		

ROCK SUPPORT EXPERIENCE - CASES

	Project / tunnel:		Granfoss road tunnels, Ullern N		
INPUT DATA	Location:		chainage 1320	chainage 1420	chainage 1700
Rock(s):			clay schist	claystone "knollekalk"	claystone "knollekalk"
Rock deformability	(brittle = 1 "ductile" = 2)				
Tunnel span (width) (m)		Wt	12.00	12.00	12.00
Tunnel wall height (m)		Hw	6.00	6.00	6.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)			4	4	4
Overburden (m)		z	30	30	30
Rock compressive strength (MPa)		σc	40.0	60.0	60.0
Assumed stress ratio (Ph /Pv)		k	2.0	2.0	2.0
Joint condition factor		jC	2.0	2.5	2.0
Blocks:	- Block volume (m3)	Vb	0.05	0.2	0.3
	- Block shape factor	β	30	40	45
Main joint set:	- Average spacing (m)	Sa			
	- Strike (related to tunnel)	α_j		70	70
	- Dip (related to tunnel)	β_j		80	80
For weakness zone:	- Indicate type of weakness zone				
	- Thickness of weakness zone (m)	Tz			
	- Strike (related to tunnel)	α_z			
	- Dip (related to tunnel)	β_z			
	- Rock Mass index in adjacent rocks	RMi_a			
Rock support used:	- bolt spacing (m) in	- roof	1.5	1.5	1.5
		- wall			
	- shotcrete (mm) (F = fibrecrete) in:	- roof	(F) 80	(F) 70	(F) 70
		- wall			
	- concrete lining				
	Remarks:				
CALCULATIONS	Scale effect compr. strength	f_σ	**0.680175601**	**0.644383724**	**0.637126946**
Jointing parameter		JP	0.107765	0.192613	0.191922
Rock Mass index		RMi	4.310607	11.556791	11.515295
Equivalent block diameter (m)		Db	0.34	0.45	0.48
Intersection between main joint set and tunnel	-roof			favourable	favourable
	-wall			unfavourable	unfavourable
Intersection between weakness zone and tunnel	-roof				
	-wall				
Assumed vertical stress (MPa)		pz	0.81	0.81	0.81
Assumed horizontal stress (MPa)		ph	1.62	1.62	1.62
Tunnel shape factors (according to Hoek & Brown, 1980):		Factor A =	3.2	3.2	3.2
		Factor B =	2.3	2.3	2.3
Tangential stress (MPa) in:	- roof	$\sigma_{\theta r}$	4.37	4.37	4.37
	- wall	$\sigma_{\theta w}$	0.24	0.24	0.24
Continuity of ground in:	- roof	**CF**	discontinuous	discontinuous	discontinuous
	- wall	**CF**	discontinuous	discontinuous	discontinuous
Characteristics in jointed (discontinuous) rock masses					
Approximate stress level (MPa)			1.62	1.62	1.62
Stress level coefficient		SL	1	1	1
Ground condition factor (RMi x SL) in:	-roof	**Gc**	**4.31**	**11.56**	**11.52**
(RMi x SL x wall factor) in:	-wall	**Gc**	**21.55**	**57.78**	**57.58**
Orientation factor for joints in:	-roof	Co	1.5	1.0	1.0
	-wall	Co	1.5	2.0	2.0
Size ratio [(Wt/Db) Co] in:	- roof	**Sr**	**1203839.9**	**26.7**	**25.2**
Size ratio [(Ht/Db) Co] in:	- wall	**Sr**	**601920.0**	**26.7**	**25.2**
Characteristics in weakness zone or fault			(No weakness zone)	(No weakness zone)	(No weakness zone)
Orientation factor (intersection zone - tunnel) in:	-roof	Co_z			
	-wall	Co_z			
Ground condition [SL x RMi(m)] in:	-roof	Gc_z			
	-wall	Gc_z			
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:	- roof	Sr_z			
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:	- wall	Sr_z			
Characteristics in continuous rock masses					
Competency factor in:	- roof	**Cg**			
	- wall	**Cg**			
Possible stress behaviour of massive rock in:	- roof				
	- wall				
Possible behaviour of continuous, particulate rock masses:					

ROCK SUPPORT EXPERIENCE - CASES

			Project / tunnel:	**Headrace tunnel, Haukrei**		**Headrace, Vinstra**
INPUT DATA			**Location:**	chainage 200	chainage 110	chainage 3250
Rock(s):				gness	dolerite, slightly altered	phyllite, slightly altered
Rock deformability		(brittle = 1	"ductile" = 2)	1	1	
Tunnel span (width) (m)			Wt	3.00	3.00	6.50
Tunnel wall height (m)			Hw	4.00	4.00	5.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)				4	4	4
Overburden (m)			z	50	50.0	250.0
Rock compressive strength (MPa)			σ_c	120.0	100.0	10.0
Assumed stress ratio (Ph /Pv)			k	4.0	4.0	2.0
Joint condition factor			jC	3.5	0.8	0.4
Blocks:	- Block volume (m3)		Vb	2	0.02	0.001
	- Block shape factor		β	40	40	100
Main joint set:	- Average spacing (m)		Sa	1.0		
	- Strike (related to tunnel)		α_j	30		
	- Dip (related to tunnel)		β_j	70		
For weakness zone:	- Indicate type of weakness zone				crushed, chlorite-containing	crushed, clay containing
	- Thickness of weakness zone (m)		Tz		10.0	15.0
	- Strike (related to tunnel)		α_z		45	70
	- Dip (related to tunnel)		β_z		90	20
	- Rock Mass index in adjacent rocks		RMi_a		45.0000	5.0000
Rock support used:	- bolt spacing (m) in		- roof		1.5	2.0
			- wall			2.5
	- shotcrete (mm) (F = fibrecrete) in:		- roof		(F) 80	(F) 200 + ribs
			- wall			(F) 100 + ribs
	- concrete lining					(could have been used)
		Remarks:		no rock support		Initial support by fibrecrete
						and rock bolts
CALCULATIONS	Scale effect compr. strength		f_σ	**0.549280272**	**0.751284731**	**1.036536462**
Jointing parameter			JP	0.456835	0.037386	0.005872
Rock Mass index			RMi	54.820252	3.738630	0.058723
Equivalent block diameter (m)			Db	1.00	0.21	0.04
Intersection between main joint set and tunnel		-roof		favourable		
		-wall		unfavourable		
Intersection between weakness zone and tunnel		-roof			favourable	unfavourable
		-wall			unfavourable	fair
Assumed vertical stress (MPa)			p_z	1.35	1.35	6.75
Assumed horizontal stress (MPa)			p_h	5.40	5.40	13.50
Tunnel shape factors (according to Hoek & Brown, 1980):			Factor A =	3.2	3.2	3.2
			Factor B =	2.3	2.3	2.3
Tangential stress (MPa) in:		- roof	$\sigma_{\theta r}$	15.93	15.93	36.45
		- wall	$\sigma_{\theta w}$	-2.30	-2.30	2.03
Continuity of ground in:		- roof	**CF**	continuous (massive)	discontinuous	continuous (particulate
		- wall	**CF**	continuous (massive)	discontinuous	continuous (particulate
Characteristics in jointed (discontinuous) rock masses				(The ground is continuous)		(The ground is continuous)
Approximate stress level (MPa)				5.4	5.4	13.5
Stress level coefficient			SL	1	1	1.5
Ground condition factor (RMi x SL) in:		-roof	**Gc**	**54.82**	**3.74**	**0.09**
(RMi x SL x wall factor) in:		-wall	**Gc**	**274.10**	**18.69**	**0.44**
Orientation factor for joints in:		-roof	Co	1.0	1.5	1.5
		-wall	Co	2.0	1.5	1.5
Size ratio [(Wt/Db) Co] in:		- roof	**Sr**	**3.0**	**21.5**	**233.3**
Size ratio [(Ht/Db) Co] in:		- wall	**Sr**	**8.0**	**28.7**	**179.5**
Characteristics in weakness zone or fault				(No weakness zone)		
Orientation factor (intersection zone - tunnel) in:		-roof	Co_z		1.0	2.0
		-wall	Co_z		2.0	1.5
Ground condition [SL x RMi(m)] in:		-roof	$\mathbf{Gc_z}$		**4.7**	**0.1**
		-wall	$\mathbf{Gc_z}$		**23.4**	**0.6**
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:		- roof	$\mathbf{Sr_z}$		**14.36**	**311.10**
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:		- wall	$\mathbf{Sr_z}$		**38.30**	**179.48**
Characteristics in continuous rock masses						
Competency factor in:		- roof	**Cg**	**3.44**		**0.00**
		- wall	**Cg**	**tension**		**0.03**
Possible stress behaviour of massive rock in:		- roof		high stress level		
		- wall		lack of stresses		
Possible behaviour of continuous, particulate rock masses:						weakness zone

ROCK SUPPORT EXPERIENCE - CASES

		Project / tunnel:		Horga hydropwer plant, headrace tunnel		
INPUT DATA		Location:		chainage 810	chainage 470	chainage 1485
Rock(s):				striped gneiss	striped gneiss	striped gneiss
Rock deformability		(brittle = 1	"ductile" = 2)	1	1	1
Tunnel span (width) (m)			Wt	3.00	3.00	3.00
Tunnel wall height (m)			Hw	4.00	4.00	4.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)				4	4	4
Overburden (m)			z	100	100.0	100.0
Rock compressive strength (MPa)			σc	100.0	100.0	100.0
Assumed stress ratio (Ph /Pv)			k	3.0	3.0	3.0
Joint condition factor			jC	0.5	2.0	6.0
Blocks:	- Block volume (m3)		Vb	0.001	0.1	0.1
	- Block shape factor		β	50	40	40
Main joint set:	- Average spacing (m)		Sa		0.4	
	- Strike (related to tunnel)		α_j		60	60
	- Dip (related to tunnel)		β_j		10	10
For weakness zone:	- Indicate type of weakness zone			crushed, clay-coatings		
	- Thickness of weakness zone (m)		Tz	4.0		
	- Strike (related to tunnel)		α_z	90		
	- Dip (related to tunnel)		β_z	45		
	- Rock Mass index in adjacent rocks		RMi_a	30		
Rock support used:	- bolt spacing (m) in		- roof		3.0	3.0
			- wall	(F) 120		
	- shotcrete (mm) (F = fibrecrete) in:		- roof	(F) 50		
			- wall			
	- concrete lining					
		Remarks:				
CALCULATIONS	Scale effect compr. strength		f_σ	**0.945042337**	**0.659753955**	**0.674856168**
Jointing parameter			JP	0.007507	0.134723	0.270109
Rock Mass index			RMi	0.750689	13.472286	27.010933
Equivalent block diameter (m)			Db	0.07	0.40	0.36
Intersection between main joint set and tunnel		-roof			unfavourable	unfavourable
		-wall			favourable	favourable
Intersection between weakness zone and tunnel		-roof		fair		
		-wall		fair		
Assumed vertical stress (MPa)			pz	2.70	2.70	2.70
Assumed horizontal stress (MPa)			ph	8.10	8.10	8.10
Tunnel shape factors (according to Hoek & Brown, 1980):			Factor A =	3.2	3.2	3.2
			Factor B =	2.3	2.3	2.3
Tangential stress (MPa) in:		- roof	$\sigma_{\theta r}$	23.22	23.22	23.22
		- wall	$\sigma_{\theta w}$	-1.89	-1.89	-1.89
Continuity of ground in:		- roof	**CF**	discontinuous	discontinuous	discontinuous
		- wall	**CF**	discontinuous	discontinuous	discontinuous
Characteristics in jointed (discontinuous) rock masses						
Approximate stress level (MPa)				8.1	8.1	8.1
Stress level coefficient			SL	1	1	1
Ground condition factor (RMi x SL) in:		-roof	**Gc**	**0.75**	**13.47**	**27.01**
(RMi x SL x wall factor) in:		-wall	**Gc**	**3.75**	**67.36**	**135.05**
Orientation factor for joints in:		-roof	Co	1.5	2.0	2.0
		-wall	Co	1.5	1.0	1.0
Size ratio [(Wt/Db) Co] in:		- roof	**Sr**	**1558331.4**	**15.0**	**16.8**
Size ratio [(Ht/Db) Co] in:		- wall	**Sr**	**2077775.2**	**10.0**	**11.2**
Characteristics in weakness zone or fault					(No weakness zone)	(No weakness zone)
Orientation factor (intersection zone - tunnel) in:		-roof	Co_z	1.5		
		-wall	Co_z	1.5		
Ground condition [SL x RMi(m)] in:		-roof	Gc_z	**1.6**		
		-wall	Gc_z	**7.8**		
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:		- roof	Sr_z	**67.84**		
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:		- wall	Sr_z	**90.46**		
Characteristics in continuous rock masses						
Competency factor in:		- roof	**Cg**			
		- wall	**Cg**			
Possible stress behaviour of massive rock in:		- roof				
		- wall				
Possible behaviour of continuous, particulate rock masses:						

ROCK SUPPORT EXPERIENCE - CASES

		Project / tunnel:		**Tromsö road tunnel to Breivika**		**Nappstraumen road t.**
INPUT DATA		**Location:**		tunnel (average cond.)	roundabout in rock	typical rock conditions
Rock(s):				grey, striped gneiss	grey, striped gneiss	gneiss
Rock deformability	(brittle = 1	"ductile" = 2)				
Tunnel span (width) (m)			Wt	10.00	20.00	10.00
Tunnel wall height (m)			Hw	5.00	8.00	5.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)				4	4	4
Overburden (m)			z	30	30	40
Rock compressive strength (MPa)			σ_c	100.0	100.0	120.0
Assumed stress ratio (Ph /Pv)			k	3.0	3.0	3.0
Joint condition factor			jC	1.3	1.3	2.0
Blocks:	- Block volume (m3)		Vb	3	3	2
	- Block shape factor		β	40	40	35
Main joint set:	- Average spacing (m)		Sa			1.0
	- Strike (related to tunnel)		α_j			
	- Dip (related to tunnel)		β_j			
For weakness zone:	- Indicate type of weakness zone					
	- Thickness of weakness zone (m)		Tz			
	- Strike (related to tunnel)		α_z			
	- Dip (related to tunnel)		β_z			
	- Rock Mass index in adjacent rocks		RMi_a			
Rock support used:	- bolt spacing (m) in		- roof	2.5	2.0	2,5 - 3
			- wall			
	- shotcrete (mm) (F = fibrecrete) in:		- roof		(F) 50	
			- wall			
	- concrete lining					
		Remarks:				
CALCULATIONS	Scale effect compr. strength		f_σ	**0.537955459**	**0.537955459**	**0.549280272**
Jointing parameter			JP	0.329849	0.329849	0.353596
Rock Mass index			RMi	32.984854	32.984854	42.431572
Equivalent block diameter (m)			Db	1.11	1.11	1.00
Intersection between main joint set and tunnel		-roof				
		-wall				
Intersection between weakness zone and tunnel		-roof				
		-wall				
Assumed vertical stress (MPa)			p_z	0.81	0.81	1.08
Assumed horizontal stress (MPa)			p_h	2.43	2.43	3.24
Tunnel shape factors (according to Hoek & Brown, 1980):			Factor A =	3.2	3.2	3.2
			Factor B =	2.3	2.3	2.3
Tangential stress (MPa) in:		- roof	$\sigma_{\theta r}$	6.97	6.97	9.29
		- wall	$\sigma_{\theta w}$	-0.57	-0.57	-0.76
Continuity of ground in:		- roof	**CF**	discontinuous	discontinuous	discontinuous
		- wall	**CF**	continuous (massive)	discontinuous	discontinuous
Characteristics in jointed (discontinuous) rock masses						
Approximate stress level (MPa)				2.43	2.43	3.24
Stress level coefficient			SL	1	1	1
Ground condition factor (RMi x SL) in:		-roof	**Gc**	**32.98**	**32.98**	**42.43**
(RMi x SL x wall factor) in:		-wall	**Gc**	**164.92**	**164.92**	**212.16**
Orientation factor for joints in:		-roof	Co	1.5	1.5	1.5
		-wall	Co	1.5	1.5	1.5
Size ratio [(Wt/Db) Co] in:		- roof	**Sr**	**310465.9**	**620931.7**	**344550.0**
Size ratio [(Ht/Db) Co] in:		- wall	**Sr**	**155232.9**	**248372.7**	**172275.0**
Characteristics in weakness zone or fault				(No weakness zone)	(No weakness zone)	(No weakness zone)
Orientation factor (intersection zone - tunnel) in:		-roof	Co_z			
		-wall	Co_z			
Ground condition [SL x RMi(m)] in:		-roof	$\mathbf{Gc_z}$			
		-wall	$\mathbf{Gc_z}$			
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:		- roof	$\mathbf{Sr_z}$			
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:		- wall	$\mathbf{Sr_z}$			
Characteristics in continuous rock masses						
Competency factor in:		- roof	**Cg**			
		- wall	**Cg**	**tension**		
Possible stress behaviour of massive rock in:		- roof				
		- wall				
Possible behaviour of continuous, particulate rock masses:						

ROCK SUPPORT EXPERIENCE - CASES

		Project / tunnel:	**Stetind road tunnel**	**Njunis access tunnel**	
INPUT DATA		**Location:**	chainage 15750	chainage 6250	chainage 6300
Rock(s):			granitic gneis, coarse-grained	amphibolite	amphibolite
Rock deformability	(brittle = 1	"ductile" = 2)	1	1	1
Tunnel span (width) (m)		Wt	10.00	3.00	3.00
Tunnel wall height (m)		Hw	5.00	4.00	4.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)			4	4	4
Overburden (m)		z	900	200	200
Rock compressive strength (MPa)		σc	90.0	200.0	200.0
Assumed stress ratio (Ph /Pv)		k	3.0	5.0	5.0
Joint condition factor		jC	3.0	3.0	0.3
Blocks:	- Block volume (m3)	Vb	30	0.3	0.005
	- Block shape factor	β	40	40	40
Main joint set:	- Average spacing (m)	Sa		0.5	
	- Strike (related to tunnel)	α_j		45	
	- Dip (related to tunnel)	β_j		10	
For weakness zone:	- Indicate type of weakness zone				crushed, clay-containing
	- Thickness of weakness zone (m)	Tz			6.0
	- Strike (related to tunnel)	α_z			70
	- Dip (related to tunnel)	β_z			90
	- Rock Mass index in adjacent rocks	RMi_a			40.00
Rock support used:	- bolt spacing (m) in	- roof	1.5	spot bolting	1.5
		- wall	2,5 ?		
	- shotcrete (mm) (F = fibrecrete) in:	- roof	(F) 50 - 80		(F) 60
		- wall			
	- concrete lining				
	Remarks:				
CALCULATIONS	Scale effect compr. strength	f_σ	0.461409274	0.630957344	0.824020244
Jointing parameter		JP	0.951299	0.242264	0.009045
Rock Mass index		RMi	85.616877	48.452715	1.809018
Equivalent block diameter (m)		Db	2.39	0.50	0.13
Intersection between main joint set and tunnel	-roof			unfavourable	
	-wall			favourable	
Intersection between weakness zone and tunnel	-roof				favourable
	-wall				unfavourable
Assumed vertical stress (MPa)		p_z	24.30	5.40	5.40
Assumed horizontal stress (MPa)		p_h	72.90	27.00	27.00
Tunnel shape factors (according to Hoek & Brown, 1980):		Factor A =	3.2	3.2	3.2
		Factor B =	2.3	2.3	2.3
Tangential stress (MPa) in:	- roof	$\sigma_{\theta r}$	208.98	81.00	81.00
	- wall	$\sigma_{\theta w}$	-17.01	-14.58	-14.58
Continuity of ground in:	- roof	**CF**	continuous (massive)	discontinuous	discontinuous
	- wall	**CF**	continuous (massive)	discontinuous	discontinuous
Characteristics in jointed (discontinuous) rock masses			(The ground is continuous)		
Approximate stress level (MPa)				27	27
Stress level coefficient		SL		1.5	1.5
Ground condition factor (RMi x SL) in:	-roof	**Gc**		**72.68**	**2.71**
(RMi x SL x wall factor) in:	-wall	**Gc**		**363.40**	**13.57**
Orientation factor for joints in:	-roof	Co		2.0	1.5
	-wall	Co		1.0	1.5
Size ratio [(Wt/Db) Co] in:	- roof	**Sr**		**12.0**	**785403.6**
Size ratio [(Ht/Db) Co] in:	- wall	**Sr**		**8.0**	**1047204.9**
Characteristics in weakness zone or fault			(No weakness zone)	(No weakness zone)	
Orientation factor (intersection zone - tunnel) in:	-roof	Co_z			1.0
	-wall	Co_z			2.0
Ground condition [SL x RMi(m)] in:	-roof	$\mathbf{Gc_z}$			**4.2**
	-wall	$\mathbf{Gc_z}$			**21.1**
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:	- roof	$\mathbf{Sr_z}$			**22.80**
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:	- wall	$\mathbf{Sr_z}$			**60.79**
Characteristics in continuous rock masses					
Competency factor in:	- roof	**Cg**	**0.41**		
	- wall	**Cg**	**tension**		
Possible stress behaviour of massive rock in:	- roof		heavy rock burst		
	- wall		lack of stresses		
Possible behaviour of continuous, particulate rock masses:					

ROCK SUPPORT EXPERIENCE - CASES

	Project / tunnel:		**Sumbiar road tunnel, Suderey, the Faroe Islands**		
INPUT DATA	**Location:**		chainage 650	chainage 1315	chainage 2100
Rock(s):			basalt	basalt	basalt
Rock deformability	(brittle = 1 "ductile" = 2)		1	1	1
Tunnel span (width) (m)		Wt	10.00	10.00	10.00
Tunnel wall height (m)		Hw	5.00	5.00	5.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)			4	4	4
Overburden (m)		z	200	200	200
Rock compressive strength (MPa)		σc	200.0	200.0	200.0
Assumed stress ratio (Ph /Pv)		k	1.5	1.5	1.5
Joint condition factor		jC	1.5	7.0	0.8
Blocks:	- Block volume (m3)	Vb	1	0.025	0.05
	- Block shape factor	β	32	35	35
Main joint set:	- Average spacing (m)	Sa	0.8		
	- Strike (related to tunnel)	α_j	75		
	- Dip (related to tunnel)	β_j	90		
For weakness zone:	- Indicate type of weakness zone				
	- Thickness of weakness zone (m)	Tz			
	- Strike (related to tunnel)	α_z			
	- Dip (related to tunnel)	β_z			
	- Rock Mass index in adjacent rocks	RMi_a			
Rock support used:	- bolt spacing (m) in	- roof			
		- wall			
	- shotcrete (mm) (F = fibrecrete) in:	- roof		50.0	50.0
		- wall			50.0
	- concrete lining				
	Remarks:		spot bolting		
CALCULATIONS	Scale effect compr. strength	f_σ	**0.574349177**	**0.72713166**	**0.694298769**
Jointing parameter		JP	0.244949	0.209854	0.053539
Rock Mass index		RMi	48.989795	41.970764	10.707801
Equivalent block diameter (m)		Db	0.80	0.25	0.31
Intersection between main joint set and tunnel	-roof		favourable		
	-wall		unfavourable		
Intersection between weakness zone and tunnel	-roof				
	-wall				
Assumed vertical stress (MPa)		p_z	5.40	5.40	5.40
Assumed horizontal stress (MPa)		p_h	8.10	8.10	8.10
Tunnel shape factors (according to Hoek & Brown, 1980):		Factor A =	3.2	3.2	3.2
		Factor B =	2.3	2.3	2.3
Tangential stress (MPa) in:	- roof	$\sigma_{\theta r}$	20.52	20.52	20.52
	- wall	$\sigma_{\theta w}$	4.32	4.32	4.32
Continuity of ground in:	- roof	**CF**	discontinuous	discontinuous	discontinuous
	- wall	**CF**	discontinuous	discontinuous	discontinuous
Characteristics in jointed (discontinuous) rock masses					
Approximate stress level (MPa)			8.1	8.1	8.1
Stress level coefficient		SL	1	1	1
Ground condition factor (RMi x SL) in:	-roof	**Gc**	**48.99**	**41.97**	**10.71**
(RMi x SL x wall factor) in:	-wall	**Gc**	**244.95**	**209.85**	**53.54**
Orientation factor for joints in:	-roof	Co	1.0	1.5	1.5
	-wall	Co	2.0	1.5	1.5
Size ratio [(Wt/Db) Co] in:	- roof	**Sr**	**12.5**	**1400707.7**	**1111768.1**
Size ratio [(Ht/Db) Co] in:	- wall	**Sr**	**12.5**	**700353.9**	**555884.1**
Characteristics in weakness zone or fault			(No weakness zone)	(No weakness zone)	(No weakness zone)
Orientation factor (intersection zone - tunnel) in:	-roof	Co_z			
	-wall	Co_z			
Ground condition [SL x RMi(m)] in:	-roof	Gc_z			
	-wall	Gc_z			
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:	- roof	Sr_z			
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:	- wall	Sr_z			
Characteristics in continuous rock masses					
Competency factor in:	- roof	**Cg**			
	- wall	**Cg**			
Possible stress behaviour of massive rock in:	- roof				
	- wall				
Possible behaviour of continuous, particulate rock masses:					

ROCK SUPPORT EXPERIENCE - CASES

		Project / tunnel:		**Sumbiar road tunnel**		**Thingbæk chalk mine**
INPUT DATA		Location:		chainage 600		old mine
Rock(s):				basalt		chalk
Rock deformability	(brittle = 1	"ductile" = 2)		1		
Tunnel span (width) (m)			Wt	10.00		5.00
Tunnel wall height (m)			Hw	5.00		7.00
Tunnel shape (2=high horse-shoe, 4=horse-shoe, 6=circular, 8=square)				4		4
Overburden (m)			z	200		20
Rock compressive strength (MPa)			σ_c	200.0		2.0
Assumed stress ratio (Ph /Pv)			k	1.5		1.0
Joint condition factor			jC	0.5		3.0
Blocks:	- Block volume (m3)		Vb	0.1		20
	- Block shape factor		β	40		45
Main joint set:	- Average spacing (m)		Sa			1.5
	- Strike (related to tunnel)		α_j			45
	- Dip (related to tunnel)		β_j			10
For weakness zone:	- Indicate type of weakness zone			crushed, clay coatings		
	- Thickness of weakness zone (m)		Tz	1.5		
	- Strike (related to tunnel)		α_z	65		
	- Dip (related to tunnel)		β_z	90		
	- Rock Mass index in adjacent rocks		RMi_a	40.00		
Rock support used:	- bolt spacing (m) in		- roof	1.5		spot bolting
			- wall			
	- shotcrete (mm) (F = fibrecrete) in:		- roof			
			- wall			
	- concrete lining					
		Remarks:		straps and wire mesh in roof		some loosening of rock
						fragments in surface
CALCULATIONS	Scale effect compr. strength		f_σ	**0.674856168**		**0.506495684**
Jointing parameter			JP	0.053149		0.843364
Rock Mass index			RMi	10.629837		1.686729
Equivalent block diameter (m)			Db	0.36		1.50
Intersection between main joint set and tunnel		-roof				unfavourable
		-wall				favourable
Intersection between weakness zone and tunnel		-roof		favourable		
		-wall		unfavourable		
Assumed vertical stress (MPa)			p_z	5.40		0.54
Assumed horizontal stress (MPa)			p_h	8.10		0.54
Tunnel shape factors (according to Hoek & Brown, 1980):			Factor A =	3.2		3.2
			Factor B =	2.3		2.3
Tangential stress (MPa) in:		- roof	$\sigma_{\theta r}$	20.52		1.19
		- wall	$\sigma_{\theta w}$	4.32		0.70
Continuity of ground in:		- roof	**CF**	discontinuous		continuous (massive)
		- wall	**CF**	discontinuous		continuous (massive)
Characteristics in jointed (discontinuous) rock masses						(The ground is continuous)
Approximate stress level (MPa)				8.1		0.54
Stress level coefficient			SL	1		0.5
Ground condition factor (RMi x SL) in:		-roof	**Gc**	**10.63**		**0.84**
(RMi x SL x wall factor) in:		-wall	**Gc**	**53.15**		**4.22**
Orientation factor for joints in:		-roof	Co	1.5		2.0
		-wall	Co	1.5		1.0
Size ratio [(Wt/Db) Co] in:		- roof	**Sr**	**964580.2**		**6.7**
Size ratio [(Ht/Db) Co] in:		- wall	**Sr**	**482290.1**		**4.7**
Characteristics in weakness zone or fault						(No weakness zone)
Orientation factor (intersection zone - tunnel) in:		-roof	Co_z	1.0		
		-wall	Co_z	2.0		
Ground condition [SL x RMi(m)] in:		-roof	**Gc_z**	**18.1**		
		-wall	**Gc_z**	**90.3**		
Size ratio [(Tz/Db)Coz] or [(Wt/Db)Coz] in:		- roof	**Sr_z**	**4.20**		
Size ratio [(Tz/Db)Coz] or [(Ht/Db)Coz] in:		- wall	**Sr_z**	**8.40**		
Characteristics in continuous rock masses						
Competency factor in:		- roof	**Cg**			**1.42**
		- wall	**Cg**			**2.40**
Possible stress behaviour of massive rock in:		- roof				no info on rock deform.
		- wall				info on rock def. required
Possible behaviour of continuous, particulate rock masses:						