02 Rock mass classification and geoinvestigations

Il progetto e la costruzione di un tunnel parte dalla conoscenza delle condizioni del terreno attraversato dallo scavo.

L’elemento fondamentale e’ il rilievo geologico .

L’esecuzione di prove e sondaggi completa la conoscenza dell’ammasso roccioso .

L’esecuzione di sondaggi e’ importante soprattuto ai portali e nelle zone di cambio di geologia.

Qui si parla si roccia ... Il miglior sondaggio e’ il tunnel

POLITECNICO DI TORINO

Post Graduated Master Course

TUNNELLING AND TUNNEL BORING MACHINES

Managed by COREP

Subject of the lesson : GEOMECHANICAL CLASSIFICATIONS

Lecturer : Dr. GIORDANO RUSSO

Company / Affiliation : GEODATA

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Academic Year: 20011-12

The design methods of underground constructions can be basically divided in [7]:

- **“analytical” methods** $\rightarrow$ mainly based on stress/strain analysis around the cavity (for example: numerical methods);
- **“observational” methods** $\rightarrow$ mainly based on behaviour monitoring during excavation, as well as on the the analysis of ground/support interation (for example, in general terms the NATM);
- **“empirical” methods** $\rightarrow$ mainly based on previous experiences of tunneling (for example, the geomechanical classifications)

It is conceptually important to distinguish [46]:

Geomechanical classes or groups (G.G.) ↓	→ Constituted by rock masses with comparable geomechanical characteristics (intrinsic properties)
Behavior categories (C.C.) ↓	→ Describe the deformation response of the cavity upon excavation, corresponding to different combinations of geomechanical and in-situ stress conditions
Technical Classes (C.T.)	→ Are directly associated with the different project solution (i.e. with the typical sections of excavation and support)

Main Classification Systems

Method	Author	Year	G.G.	C.C.	C.T.
Rock loads (T)	Terzaghi	1946	(combined system)		indications
Stand-up time	Lauffer	1958÷1988		√	√
RQD system	Deere	1964	√		√
RSR system	Wickham	1972	√		√
RMR system	Bieniawski	1973÷1989	√		√
Lombardi	Lombardi	1974		√	
(R-P)	Rabcewicz-Pacher	1974	(combined system)		indications
Q system	Barton et al.	1974÷1999	√		√
Strength-size	Franklin	1975	√		√
RMi	Palmstrom	1995÷2000	√		√
GSI	Hoek et al.	1995÷2000	√		
Adeco-RS	Lunardi	1993		√	indications
Geodata	Russo et al.	1998 ÷2007		√	indications

RABCEWICZ-PACHER CLASSIFICATION (1974)

Main features

- Developed on the system base classification proposed by Lauffer[1] (1958) originating The New Austrian Tunnelling Method (NATM)
- n.6 rock classes are considered (fig.7), a qualitative description of the characteristics and the behaviour is associated to applicative procedures and support dimensioning
- For the mechanized excavation with TBM specific adaptation and development have been arranged, as proposed by the Austrian Norm (ONORM) 2203 (fig.8), furthermore modified in fig.9.

Note: 1 The classified method proposed by Lauffer will be shown in the " direct quantitative methods" section

- Classificazione di Rabcewicz.

. Classi di roccia	Descrizione del comportamento della roccia	Scavo				Misure di sicurezza e di sostegno	
		Sezione	Lunghezza volate	Metodo	Tempo di autosostegno	Intervento	Tempo di posa in opera
I Stabile	Roccia sana massiva. Lo scavo si autosostiene e le tensioni al contorno non superano la resistenza della roccia.	Sezione piena	Dipende dalle condizioni locali	Con esplosivo	Settimane in calotta, illimitato in parete	Ancoraggi locali + rete in calotta o calcestruzzo proiettato	Senza limiti, a scavo avvenuto in caso di rilasci locali
II Leggermente fratturata	Roccia stratificata e leggermente fratturata. Nella fase di decompressione le tensioni tangenziali in calotta superano la resistenza della roccia con conseguenti distacchi. Sono necessarie opere di sostegno sistematiche in calotta. Le pareti dello scavo si mantengono stabili salvo possibili distacchi locali.	Sezione piena	max 3 m	Con esplosivo	Giorni in calotta, settimane in parete	Ancoraggi sistematici in calotta + rete + calcestruzzo proiettato (anche in parete per bloccare rilasci locali)	Ultimazione a 40 m max dal fronte scavo
III *a* Fratturata III *b* Poco spingente	Roccia da fratturata a molto fratturata. Il limite di resistenza della roccia viene raggiunto in parete e superato in calotta. Sono necessarie opere di sostegno sistematiche e l'inserimento dell'arco rovescio per la possibilità di rottura del fondo dello scavo.	Sezione piena con volate brevi. Preferibilmente sezione parzializzata (calotta più 1 strozzo)	Max 1,5 m per scavo a sezione piena. Max 3 m per scavo a sezione parzializzata	Esplosivi con cautela localmente a macchina	Ore in calotta giorni in parete	Ancoraggi sistematici + rete + calcestruzzo proiettato in calotta e in parete. Arco rovescio	Inizio subito dopo lo scavo e completamento a 20 m max dal fronte scavo
IV Spingente	Roccia alterata, scistosa, fagliata. La resistenza della roccia viene superata su tutto il contorno dello scavo. Sono necessarie opere di sostegno sistematiche, l'inserimento dell'arco rovescio e la protezione del fronte dello scavo.	Sezione parzializzata (calotta con più di 1 strozzo)	da 1 m a 1,5 m in calotta	a macchina	Molto breve, in calotta, alcune ore in parete	Ancoraggi sistematici + rete + calcestruzzo proiettato + centine metalliche in calotta e in parete Arco rovescio e protezione del fronte dello scavo con calcestruzzo proiettato	Inizio subito dopo lo scavo parziale! Il getto dell'arco rovescio a breve scadenza in funzione delle condizioni locali (misure in sito)
V Molto spingente	Roccia molto alterata, completamente milonitizzata. L'apertura dello scavo provoca l'insorgere di forti pressioni in tutte le direzioni. L'anello di roccia intorno allo scavo è completamente plasticizzato e tende verso l'interno con sensibile riduzione della sezione.	È necessaria una suddivisione in diverse sezioni parziali in funzione anche della stabilità del fronte dello scavo	da 0,5 a 1,0 m in calotta	a macchina	Nessuno in calotta, fino a poche ore in parete e sul fronte	Ancoraggi sistematici + rete + calcestruzzo proiettato + centine metalliche in calotta e in parete! Arco rovescio e protezione del fronte dello scavo con calcestruzzo proiettato	Tutte le superfici devono essere sostenute non appena aperto lo scavo. La successione delle operazioni e l'inserimento dell'arco rovescio devono essere definiti in funzione delle condizioni locali (misure in sito)
VI Materiale sciolto	Questa classe comprende tutti i terreni sciolti, franosi, per i quali lo scavo non può essere affrontato con i metodi convenzionali.	Lo scavo si regola in funzione dei metodi di sostegno				Misure speciali quali congelamento, iniezioni di miscele chimiche ecc.	

Fig.7 [13]

"STAND-UP TIME" SYSTEM (Lauffer, 1958÷1988)

Basic features

- Based on the following concepts of (fig.10):

  → Active unsupported span (lw) = Minor dimension between (1) the distance from tunnel face and the first installed support and (2) the width of the tunnel.

  → Stand-up time (ts) = Time in which the tunnel, for an active unsupported span, can remain stable after the tunnel excavation.

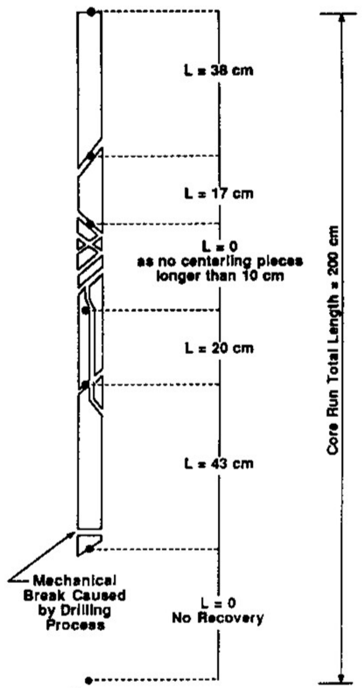
- 7 rock classes brought up to 9 in successive updating, are considered in the stand-up diagram.

RQD SYSTEM (Deere, 1964 and following)

Main features

- Based on the parameter Rock Quality Designation (RQD) defining 5 geomechanical classes (fig.15);
- Associated with these 5 classes, quantitative indications about necessary supports, are given, differing traditional and mechanized tunnelling with TBM (fig.16);
- As seen before (fig.6), Deere linked the index RQD to Terzaghi's classification.

RQD (%)	Rock Quality
<25	Very poor
25–50	Poor
50–75	Fair
75–90	Good
90–100	Excellent



$$RQD = \frac{\sum \text{Length of Core Pieces} > 10 \text{ cm (4 in.)}}{\underline{\text{Total}} \text{ Core Run Length}} \times 100\%$$

$$RQD = \frac{38 + 17 + 20 + 43}{200} \times 100\%$$

RQD = 59% (FAIR)

Procedure for measurement and calculation of rock quality designation. (After Deere, 1989.)

Fig.15 [8]

RMR SYSTEM (Bieniawski 1973, 1989)

Main features:

- Definition of a rock quality index RMR (Rock Mass Rating) derived from the sum of six geological-geomechanical and constructive parameters (fig.22):

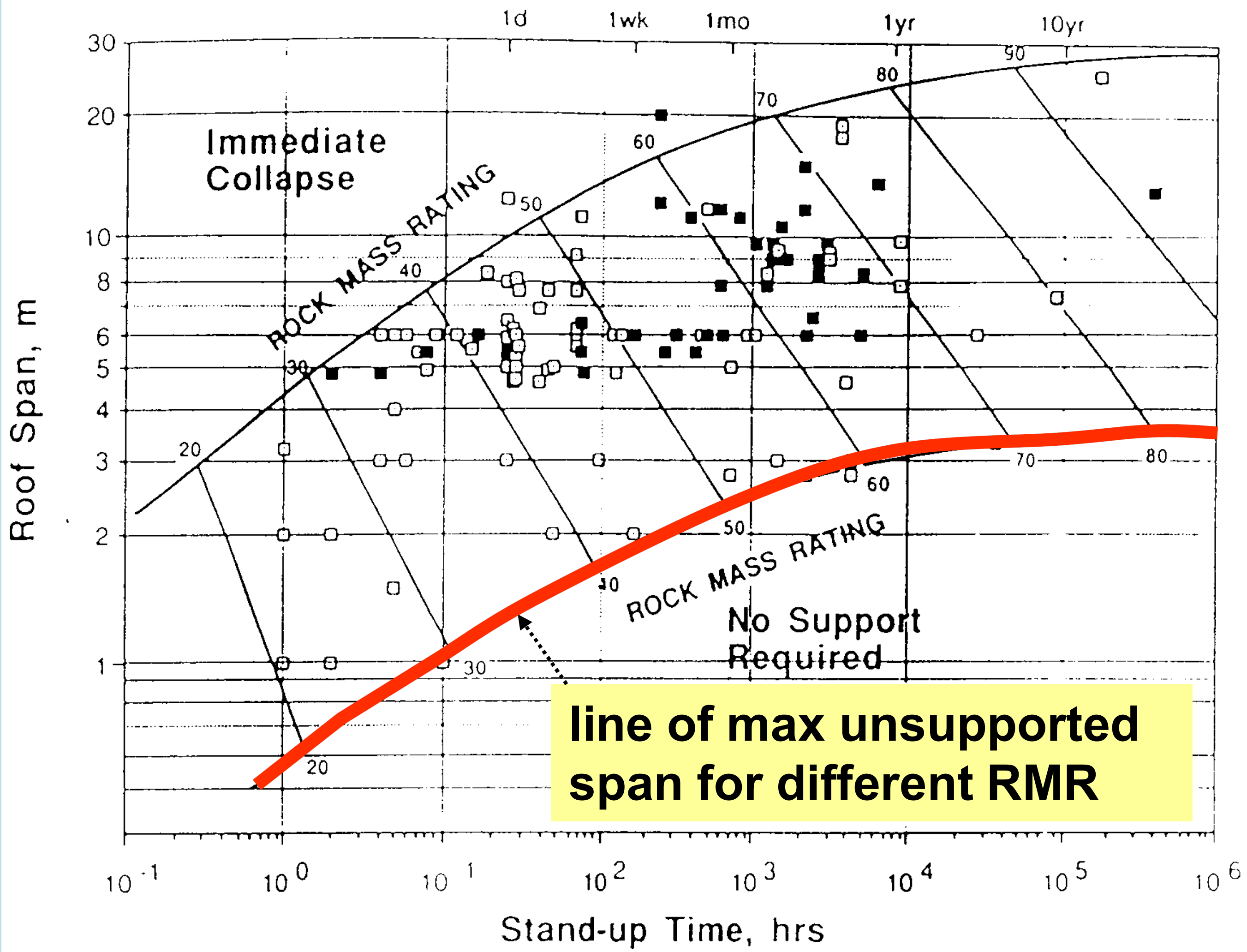
RMR=a+b+c+d+e+f

a	intact rock compressive strength
b	RQD
c	Spacing of discontinuities
d	Condition of discontinuities
e	Ground water
f	Adjustment for discontinuity orientation

Typical stand-up times for different roof spans of tunnel are proposed, according to the concepts proposed by Lauffer

Fig.29 [7]: traditional excavation→

Note: The points represent collapse limit conditions registered



III - RMR System (PRO→*C2b*)

Rock mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	Steel sets
I – Very good rock *RMR*: 81-100	Full face, 3 m advance	Generally no support required except spot bolting		
II – Good rock *RMR*: 61-80	Full face , 1-1.5 m advance. Complete support 20 m from face	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh	50 mm in crown where required	None
III – Fair rock *RMR*: 41-60	Top heading and bench 1.5-3 m advance in top heading. Commence support after each blast. Complete support 10 m from face	Systematic bolts 4 m long, spaced 1.5-2 m in crown and walls with wire mesh in crown	50-100 mm in crown and 30 mm in sides	None
IV – Poor rock *RMR*: 21-40	Top heading and bench 1.0-1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh	100-150 mm in crown and 100 mm in sides	Light to medium ribs spaced 1.5 m where required
V – Very poor rock *RMR*: < 20	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert	150-200 mm in crown, 150 mm in sides, and 50 mm on face	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close in-vert

Fig.31 [7]

Q-SYSTEM (Barton et al., 1974-1999)

Main features:

- Rock mass quality index Q (variable from 0.001 to 1000) obtained by the following equation:

$$Q = \frac{RQD}{J_n} * \frac{J_r}{J_a} * \frac{J_w}{SRF}$$

RQD	Rock Quality Designation
Jn	joint set number
Jr	joint roughness number
Ja	joint alteration number
Jw	joint water reduction factor
SRF	joint stress reduction factor

Fig.32 [20] : Q-System rating assessment table

1. Rock Quality Designation		RQD
A	Very poor	0 - 25
B	Poor	25 - 50
C	Fair	50 - 75
D	Good	75 - 90
E	Excellent	90 - 100

Note: i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q.
ii) RQD intervals of 5, *i.e.*, 100, 95, 90, *etc.*, are sufficiently accurate.

2. Joint Set Number		J_n
A	Massive, no or few joints	0.5 - 1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random, heavily jointed, "sugar cube", *etc.*	15
J	Crushed rock, earthlike	20

Note: i) For intersections, use ($3.0 \times J_n$)
ii) For portals, use $2.0 \times J_n$)

3. Joint Roughness Number		J_r
a) Rock-wall contact, and b) rock-wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
Note: i) Descriptions refer to small scale features and intermediate scale features, in that order.		
c) No rock-wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0

Note: i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3m.
ii) J_r = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength.

4. Joint Alteration Number		ϕ_r approx.	J_a
a) Rock-wall contact (no mineral fillings, only coatings)			
A	Tightly healed, hard, non-softening, impermeable filling, *i.e.*, quartz or epidote		0.75
B	Unaltered joint walls, surface staining only	25-35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, *etc.*	25-30°	2.0
D	Silty- or sandy-clay coatings, small clay fraction (non-softening)	20-25°	3.0
E	Softening or low friction clay mineral coatings, *i.e.*, kaolinite or mica. Also chlorite, talc, gypsum, graphite, *etc.*, and small quantities of swelling clays.	8-16°	4.0
b) Rock-wall contact before 10 cm shear (thin mineral fillings)			
F	Sandy particles, clay-free disintegrated rock, *etc.*	25-30°	4.0
G	Strongly over-consolidated non-softening clay mineral fillings (continuous, but <5mm thickness)	16-24°	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness)	12-16°	8.0
J	Swelling-clay fillings, *i.e.*, montmorillonite (continuous, but <5mm thickness). Value of J_a depends on percent of swelling clay-size particles, and access to water, *etc.*	6-12°	8-12
c) No rock-wall contact when sheared (thick mineral fillings)			
KLM	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition)	6-24°	6, 8, or 8-12
N	Zones or bands of silty- or sandy-clay, small clay fraction (non-softening)	-	5.0
OPR	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition)	6-24°	10, 13, or 13-20

5. Joint Water Reduction Factor		J_w
A	Dry excavations or minor inflow, *i.e.*, <5 l/min locally	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings	0.66
C	Large inflow or high pressure in competent rock with unfilled joints	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay	0.1-0.05

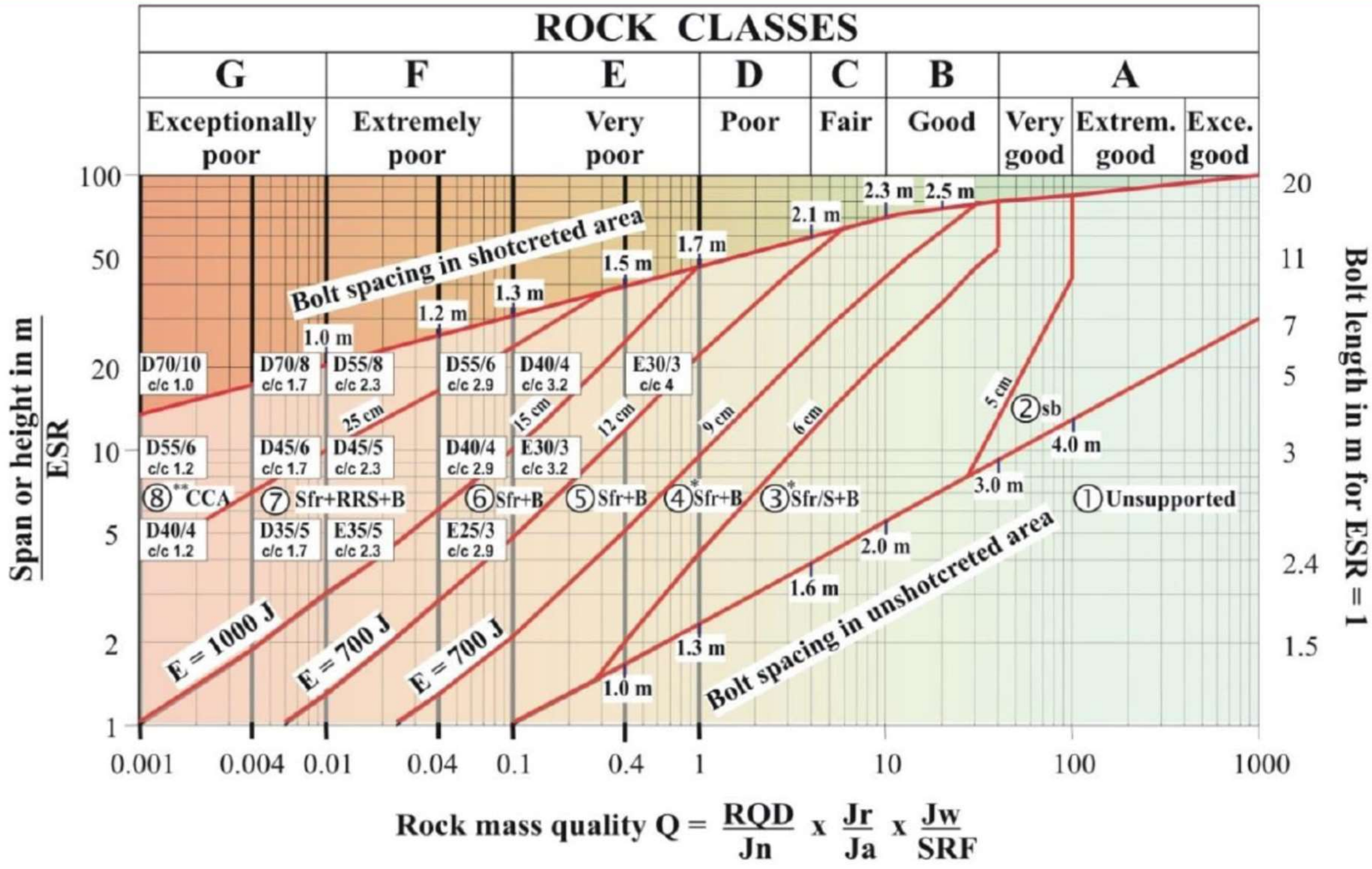
Note: i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed.
ii) Special problems caused by ice formation are not considered.

6. Stress Reduction Factor				SRF
a) Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated				
A	Multiple occurrences of weakness zones containing ***clay*** or chemically disintegrated rock, very loose surrounding rock (any depth)			10
B	Single weakness zones containing ***clay*** or chemically disintegrated rock (depth of excavation ≤ 50m)			5
C	Single weakness zones containing ***clay*** or chemically disintegrated rock (depth of excavation > 50m)			2.5
D	Multiple shear zones in competent rock (***clay-free***), loose surrounding rock (any depth)			7.5
E	Single shear zones in competent rock (***clay-free***) (depth of excavation ≤ 50m)			5.0
F	Single shear zones in competent rock (***clay-free***) (depth of excavation > 50m)			2.5
G	Loose, open joints, heavily jointed or "sugar cube", *etc.* (any depth)			5.0
Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.				
b) Competent rock, rock stress problems		σ_c/σ_1	σ_θ/σ_c	SRF
H	Low stress, near surface, open joints	>200	<0.01	2.5
J	Medium stress, favourable stress condition	200-10	0.01-0.3	1
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability.	10-5	0.3-0.4	0.5-2
L	Moderate slabbing after >1 hour in ***massive*** rock	5-3	0.5-0.65	5-50
M	Slabbing and rock burst after a few minutes in ***massive*** rock	3-2	0.65-1	50-200
N	Heavy rock burst (strain-burst) and immediate dynamic deformations in ***massive*** rock	<2	>1	200-400
Note: ii) For strongly anisotropic virgin stress field (if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, reduce σ_c to $0.75\sigma_c$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c to $0.5\sigma_c$, where σ_c = unconfined compression strength, σ_1 and σ_3 are the major and minor principal stresses, and σ_θ = maximum tangential stress (estimated from elastic theory). iii) Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases (see H).				
c) Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure			σ_θ/σ_c	SRF
O	Mild squeezing rock pressure		1-5	5-10
P	Heavy squeezing rock pressure		>5	10-20
Note: iv) Cases of squeezing rock may occur for depth $H > 350\ Q^{1/3}$ (Singh *et al.*, 1992). Rock mass compression strength can be estimated from $q \approx 0.7\ \gamma\ Q^{1/3}$(MPa) where γ = rock density in kN/m^3 (Singh, 1993).				
d) Swelling rock: chemical swelling activity depending on presence of water				
R	Mild swelling rock pressure			5-10
S	Heavy swelling rock pressure			10-15

Note: J_r and J_a classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance, τ (where $\tau \approx \sigma_n \tan^{-1}(J_r/J_a)$). Choose the most likely feature to allow failure to initiate.

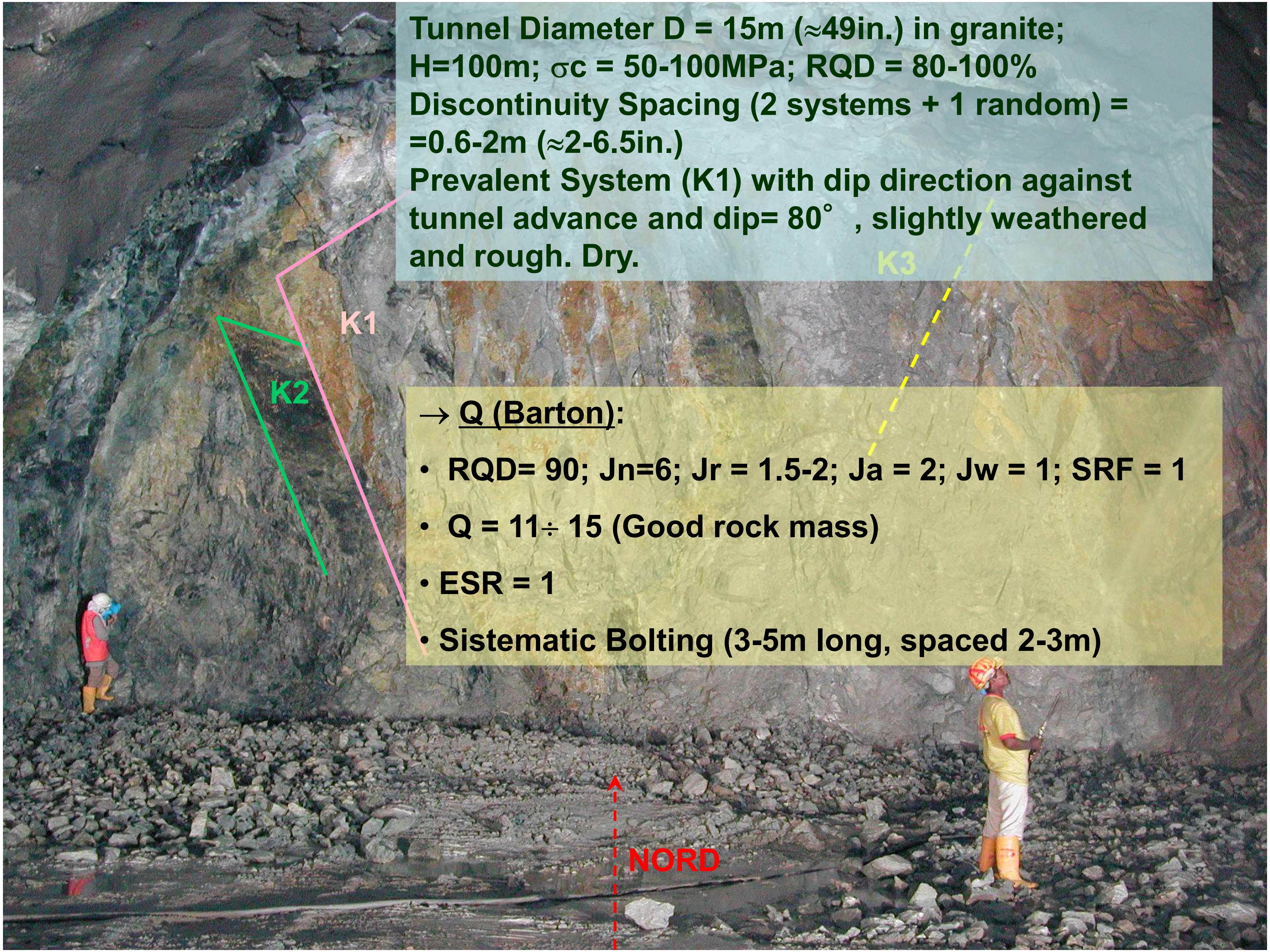
$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

IV: Q-System (PRO→*C2c*)



REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting, **sb**
3) Systematic bolting, and unreinforced or fibre reinforced shotcrete, 5-6 cm), **Sfr/B+S**
4) Fibre reinforced shotcrete and bolting, 6-9 cm, **Sfr+B**
5) Fibre reinforced shotcrete and bolting, 9-12 cm, **Sfr (E700) +B**
6) Fibre reinforced shotcrete and bolting, 12-15 cm, **Sfr (E700) +B**
7) Fibre reinforced shotcrete > 15 cm + reinforced ribs of shotcrete and bolting, **Sfr (E1000) +RRS+B**
8) Cast concrete lining, **CCA** or **Sfr (E1000) +RRS+B**


Tunnel Diameter D = 15m (≈49in.) in granite;
H=100m; σc = 50-100MPa; RQD = 80-100%
Discontinuity Spacing (2 systems + 1 random) =
=0.6-2m (≈2-6.5in.)
Prevalent System (K1) with dip direction against tunnel advance and dip= 80° , slightly weathered and rough. Dry.
K1
K2
K3
→ Q (Barton):
• RQD= 90; Jn=6; Jr = 1.5-2; Ja = 2; Jw = 1; SRF = 1
• Q = 11÷ 15 (Good rock mass)
• ESR = 1
• Sistematic Bolting (3-5m long, spaced 2-3m)
NORD

GG Geomachanical Group

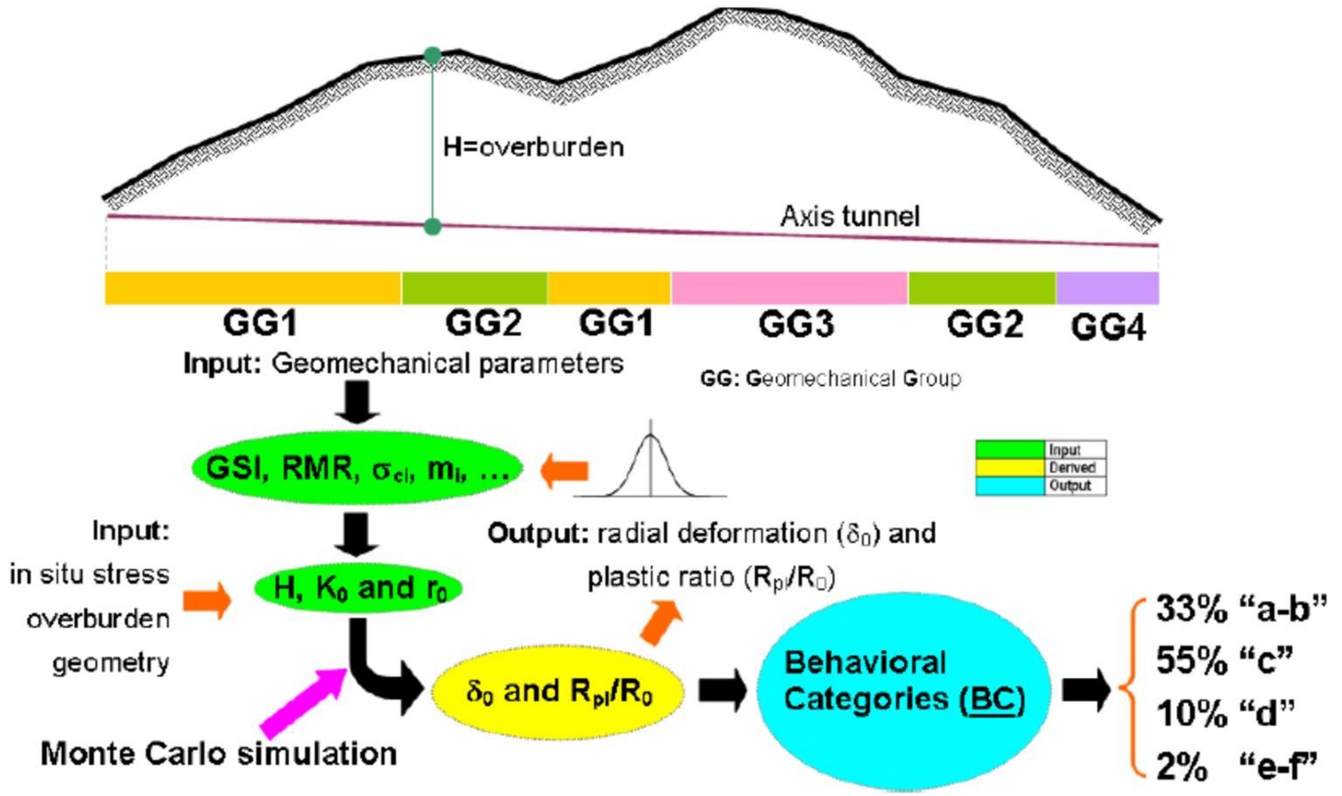
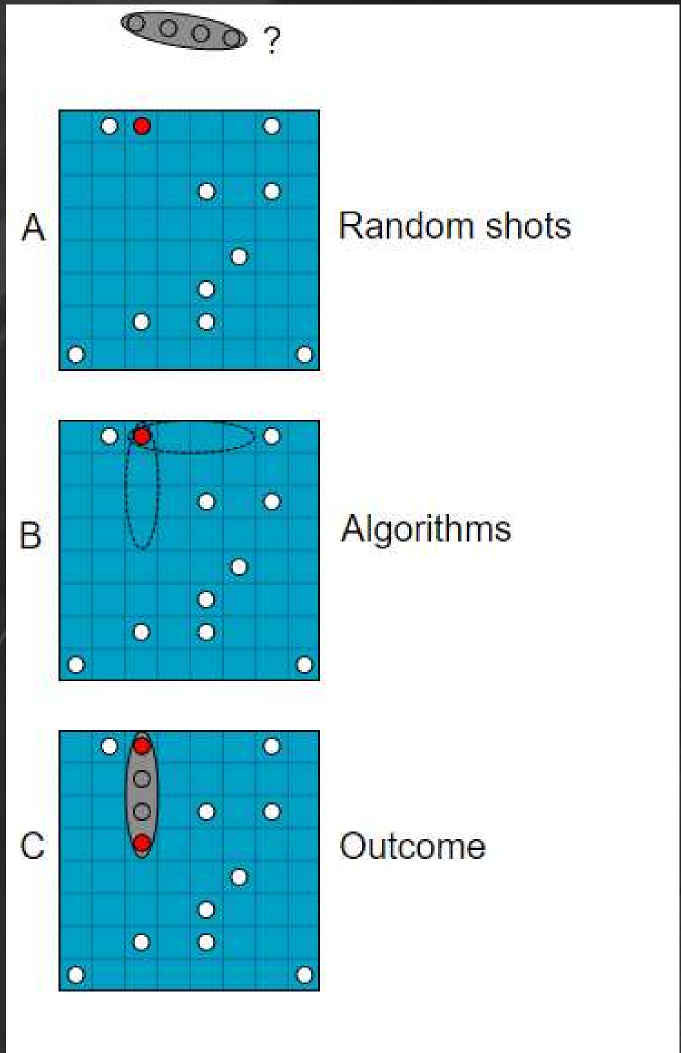
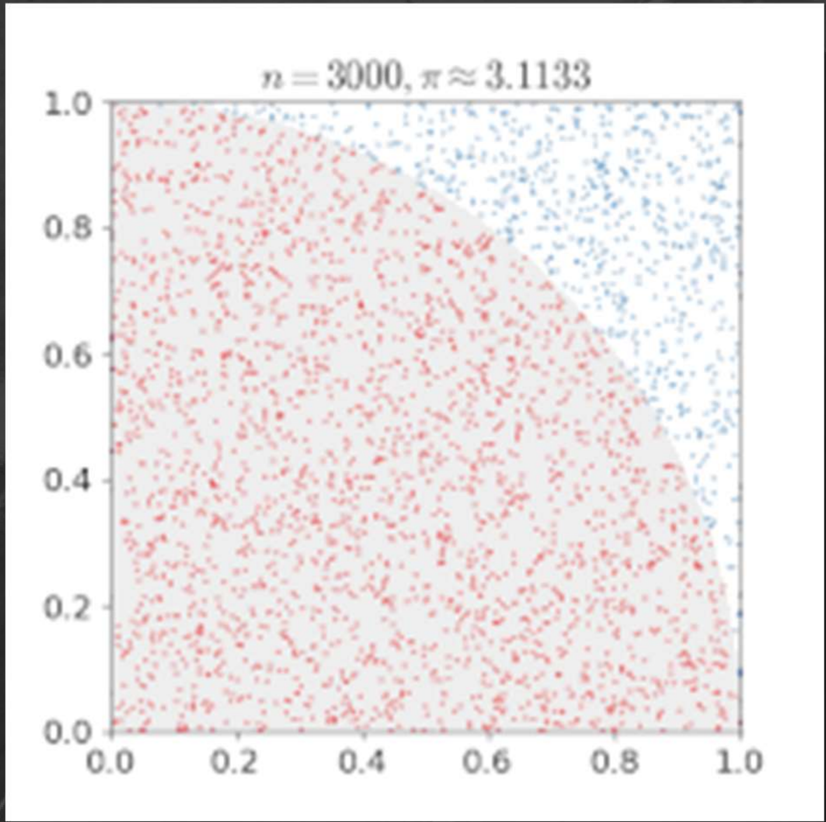


Figure 4.4 *- Definition of the behavioral classification approach*



Montecarlo Method si based on algorithm generating a series of numbers with same probability distribution we expect from phenomena we are investigating



Area of circle portion = π/4

The ratio between number casual hits inside and total number is roughly = π/4

We heave rocks and check if are inside or outside the circle portion.

More hits more reliable the value

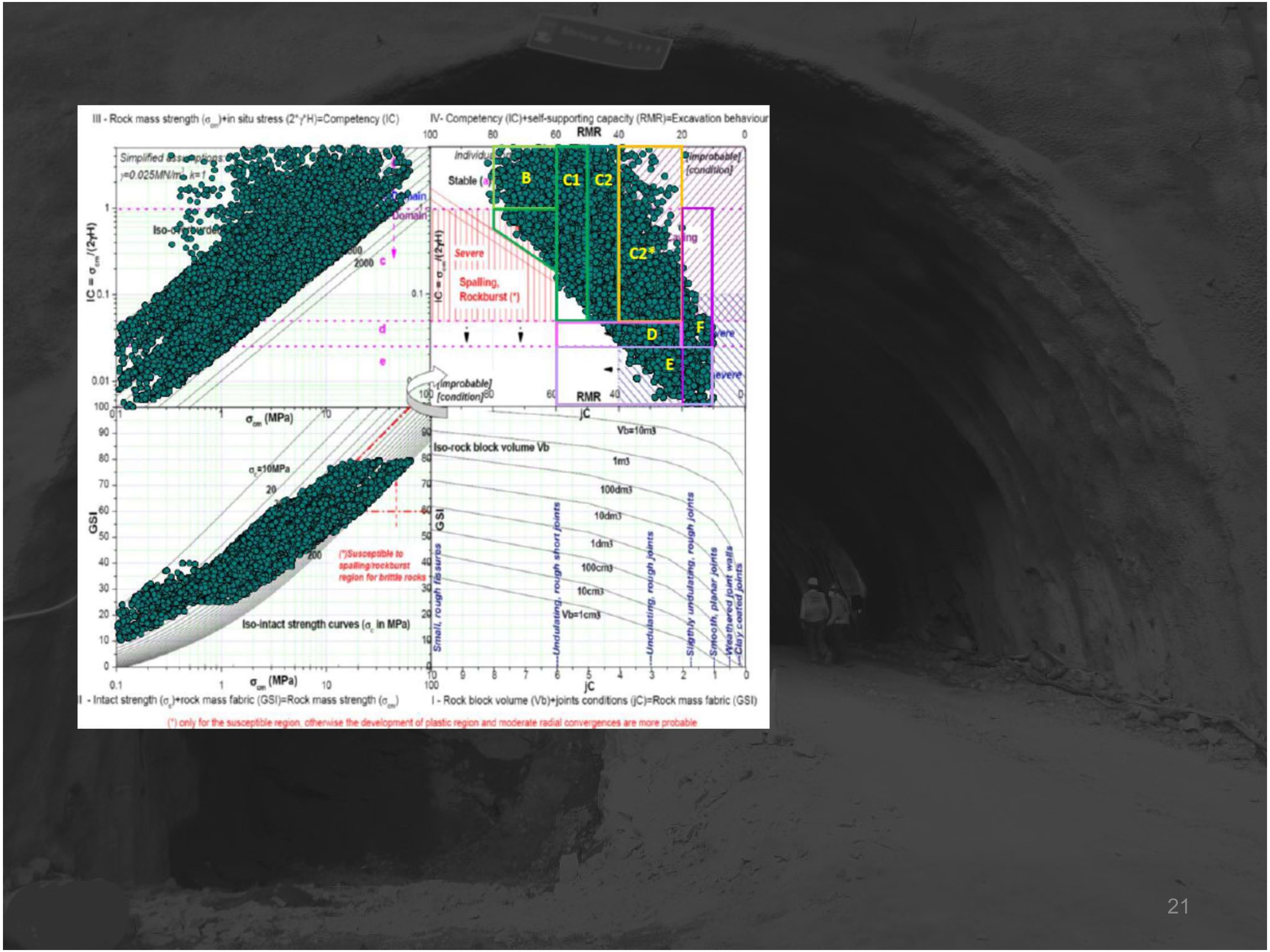
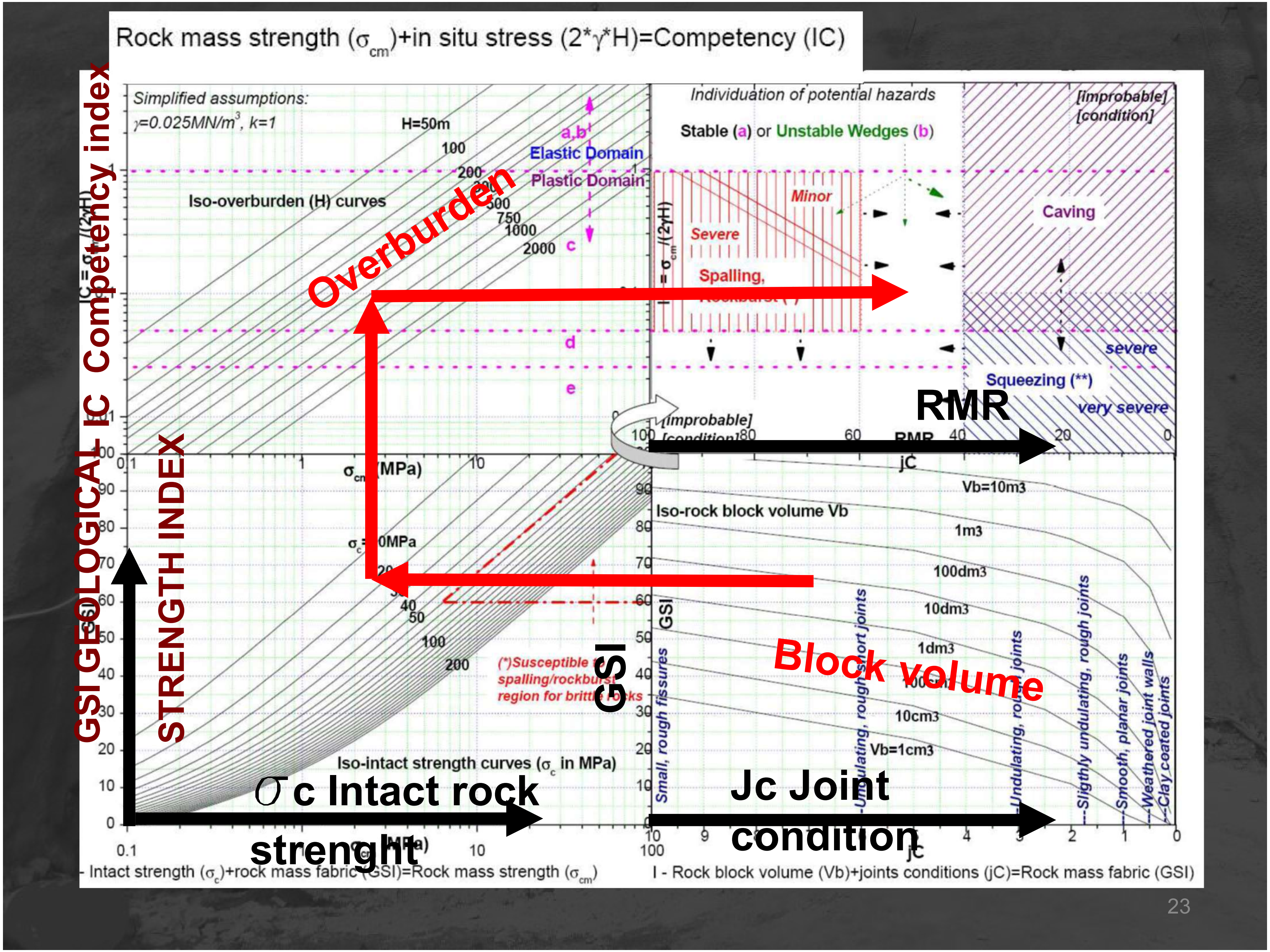
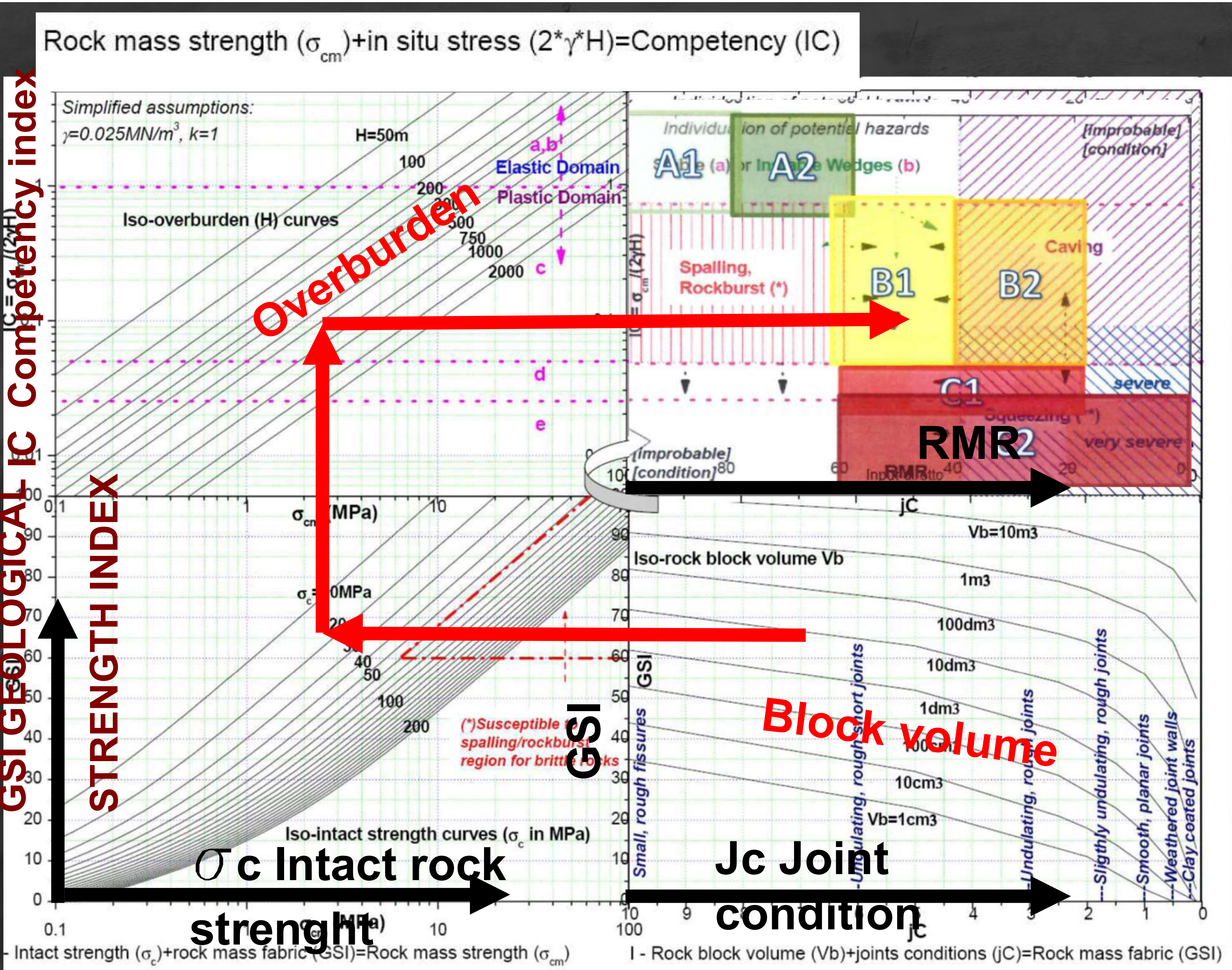

III - Rock mass strength (σcm)+in situ stress (2*γ*H)=Competency (IC)
IV- Competency (IC)+self-supporting capacity (RMR)=Excavation behaviour
II - Intact strength (σc)+rock mass fabric (GSI)=Rock mass strength (σcm)
I - Rock block volume (Vb)+joints conditions (jC)=Rock mass fabric (GSI)
B
C1
C2
C2*
D
E
F
Stable
Spalling, Rockburst (*)
Iso-rock block volume Vb
Iso-intact strength curves (σc in MPa)
(*)Susceptible to spalling/rockburst region for brittle rocks
(*) only for the susceptible region, otherwise the development of plastic region and moderate radial convergences are more probable

Table 2-3: Main Tunnel. Tunnel N.4, 5, 6, 7. Support application percentages and lengths

Support Class	B	C1	C2	C2*	D	E	F	TOTAL	
Prevalent Hazard	Wedge instability	Wedge Instability / Rockfall / Minor Spalling-Rockburst	Rockfall	Caving	Squeezing	Severe Squeezing	Severe Caving		
Tunnel	Total length (%)	Total length (%)	Total length (%)	Total length (%)	Total length (%)	Total length (%)	Total length (%)	Total length (%)	Total length (m)
Tunnel 4	3%	32%	23%	19%	10%	10%	3%	100%	2015
Tunnel 5	6%	49%	20%	7%	6%	10%	2%	100%	9766
Tunnel 6	0%	6%	11%	71%	4%	4%	4%	100%	232.5
Tunnel 7	0%	5%	10%	44%	18%	20%	3%	100%	935
In Tunnel 4, from Pk 33+390 to Pk 33+420 (30 m) it is applied the Support Class C2* for double line railway.									
In Tunnel 7, from Pk 46+865 to Pk 47+085 (220 m) it is applied the Support Class C2* for double line railway.									
In Tunnel 7, from Pk 47+085 to Pk 47+106.5 (21.5 m) it is applied the Support Class C2* for double line railway with platform.									
In Tunnel 7, from Pk 47+106.5 to Pk 47+200 (93.5 m) it is applied the Support Class F for double line railway with platform.									



Rock mass strength (σ_{cm})+in situ stress ($2*\gamma*H$)=Competency (IC)
Simplified assumptions:
γ=0.025MN/m^3, k=1
H=50m
Iso-overburden (H) curves
Elastic Domain
Plastic Domain
Overburden
Individuation of potential hazards
Stable (a) or Unstable Wedges (b)
[improbable] [condition]
Minor
Severe
Spalling,
Caving
severe
Squeezing (**)
very severe
RMR
IC Competency index
GSI GEOLOGICAL STRENGTH INDEX
Iso-rock block volume Vb
Vb=10m3
1m3
100dm3
10dm3
1dm3
10cm3
Vb=1cm3
Block volume
GSI
(*)Susceptible to spalling/rockburst region for brittle rocks
Iso-intact strength curves (σ_c in MPa)
σc Intact rock strenght
Jc Joint condition
Small, rough fissures
Undulating, rough short joints
Undulating, rough joints
Slightly undulating, rough joints
Smooth, planar joints
Weathered joint walls
Clay coated joints
Intact strength (σ_c)+rock mass fabric (GSI)=Rock mass strength (σ_{cm})
I - Rock block volume (Vb)+joints conditions (jC)=Rock mass fabric (GSI)



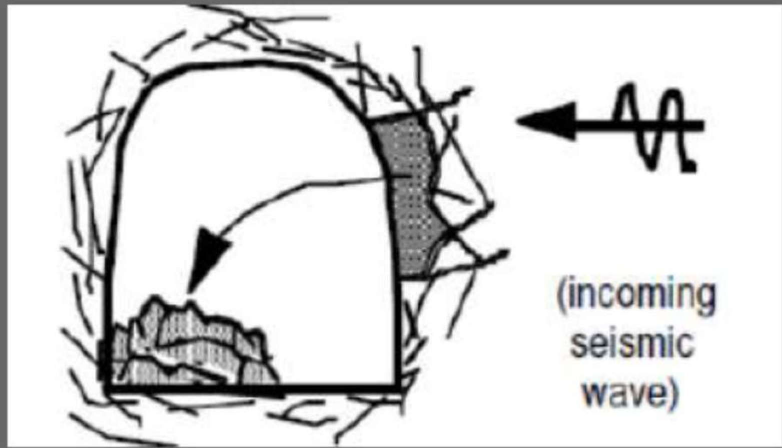
Rock mass strength (σ_{cm})+in situ stress ($2^*\gamma^*H$)=Competency (IC)
Simplified assumptions:
γ=0.025MN/m^3, k=1
H=50m
Iso-overburden (H) curves
Elastic Domain
Plastic Domain
Overburden
Individuation of potential hazards
A1
A2
B1
B2
C1
Spalling, Rockburst (*)
Caving
severe
very severe
[improbable] [condition]
RMR
jC
GSI GEOLOGICAL STRENGTH INDEX
IC Competency index
Iso-rock block volume Vb
Vb=10m3
1m3
100dm3
10dm3
1dm3
10cm3
Vb=1cm3
Block volume
GSI
(*)Susceptible to spalling/rockburst region for brittle rocks
Iso-intact strength curves (σ_c in MPa)
σc Intact rock strenght
Jc Joint condition
Small, rough fissures
Smooth, planar joints
Weathered joint walls
Clay coated joints
Intact strength (σ_c)+rock mass fabric (GSI)=Rock mass strength (σ_{cm})
I - Rock block volume (Vb)+joints conditions (jC)=Rock mass fabric (GSI)

Severe squeezing

Fig. 3.2: Very severe squeezing behaviour in the S.Martin La Porte adit to the base tunnel of the new railway link Turin-Lyon (→ case-history ch1): up to more than 2m of diametral convergence with consequent necessity of tunnel re-shaping (Photo: courtesy of J. Piraud (Antea)).

Rockburst

Failure mode is dominated by energy transmitted from remote seismic sources and the fracture rate due to strainbursting



Example of severe event with failure of support in andesitic rock. Probably combined 1-2 mechanism (Estimated released Energy 25-30kJ/m2)

Basic element for classification is face mapping

BIENIAWSKI'S -1989, ROCK MASS RATING (RMR) SYSTEM

Construction of balance tunneling works of Tunnel T1 from km 30.000 to km 33.160 including construction of Br. No. 34, hydraulic protection measures of the Nallah at the T1 Adit Portal and drainage of the T1 Adit on the Katra Dharam Section of USBR Link Project, in the State of J&K

Tunnel T1P2

Face Mapping Sheet No.	7	Date:	19-05-2015	Face Chainage:	33+038.00

General Characteristics

Excavation method:	NATM	Distance from the Portal (m):	122.00	Unsupported Length(m):	3.0m
Excavation Chainaige	33+040.00	Excavation Approach:	Full Face		

GEOLOGICAL FACE MAPPING AND RMR CLASSIFICATION (GFM)

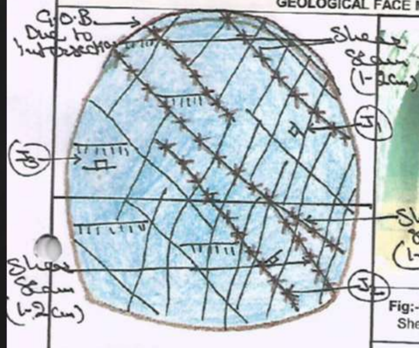


Fig:-1 Higly jointed Dolomite and also Shear Vein is clearly visible at face

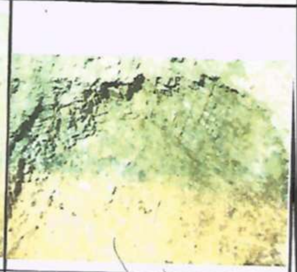


Fig:-2 Cross Joint Pattern resulting wedge Formation

Drive Direction N 170°

LEGENDS: Dolomite, Quartzite, Slate/Shale, Thrust Zone, Shear Seam, Shear Zone, Seepage, Persistent & Non P Joints, Dip/ Strike

ROCKMASS RATING SYSTEM (AFTER BIENIAWSKI- 1989)

1	(σ_c) Strength of Intact Rock (MPa)	Values:	50-100
		Rating:	7
2	RQD (%)	Values:	25%-50%
		Rating:	8
3	Spacing of Discontinuities	Values:	200-600
		Rating:	10
4	Condition of Discontinuities		
	Discontinuity Length (Persistence) (in m)	Values:	3-10
		Rating:	2
	Discontin. Separation (Aperture) (in mm)	Values:	1-5
		Rating:	1
	Discontinuity Roughness	Values:	Slightly rough
		Rating:	3
	Discontinuity Infilling (gouge)	Values:	Soft filling <5mm
		Rating:	2
	Discontinuity Weathering	Values:	Moderately Weathered
		Rating:	3
5	Ground Water Seepage (lit/min/10m of tunnel length)	Values:	Damp
		Rating:	10
6	Adjustment for Discontinuities orientation	Values:	Fair
		Rating:	-5
TOTAL RATING:			41
RMR CLASS:			III

Geological Discription:- The rock mass encountered at the excavated face is light greyish to greyish, very fine grained, moderately weathered (W_2), highly jointed and fractured, moderately hard Dolomite, Cherty Dolomite is also present at few places. RQD varies in between 45% - 50%, slightly rough with planner to undulatery with clay infillings. Several Shear seams (approx 1-3cm thick) present at face, three plus random joint set is counted, Joint set-1 and Joint set-2 cutting each other perpendicularly, resulting minor wedge formation at crown and SPL. Joint set-1 and joint set-2 dipping outward and joint set-3 is dipping inward. Face is damp and some minor inflow of water is also observed near face from bottom.

Attitude of Discontinuities:

J1: 059/64° J2: 271/45°

J3: 335/80° Random: Yes

Geotechnical parameters:

σ_c 50-100 RMR 41 GSI 30-40 O.Burden 65-75m

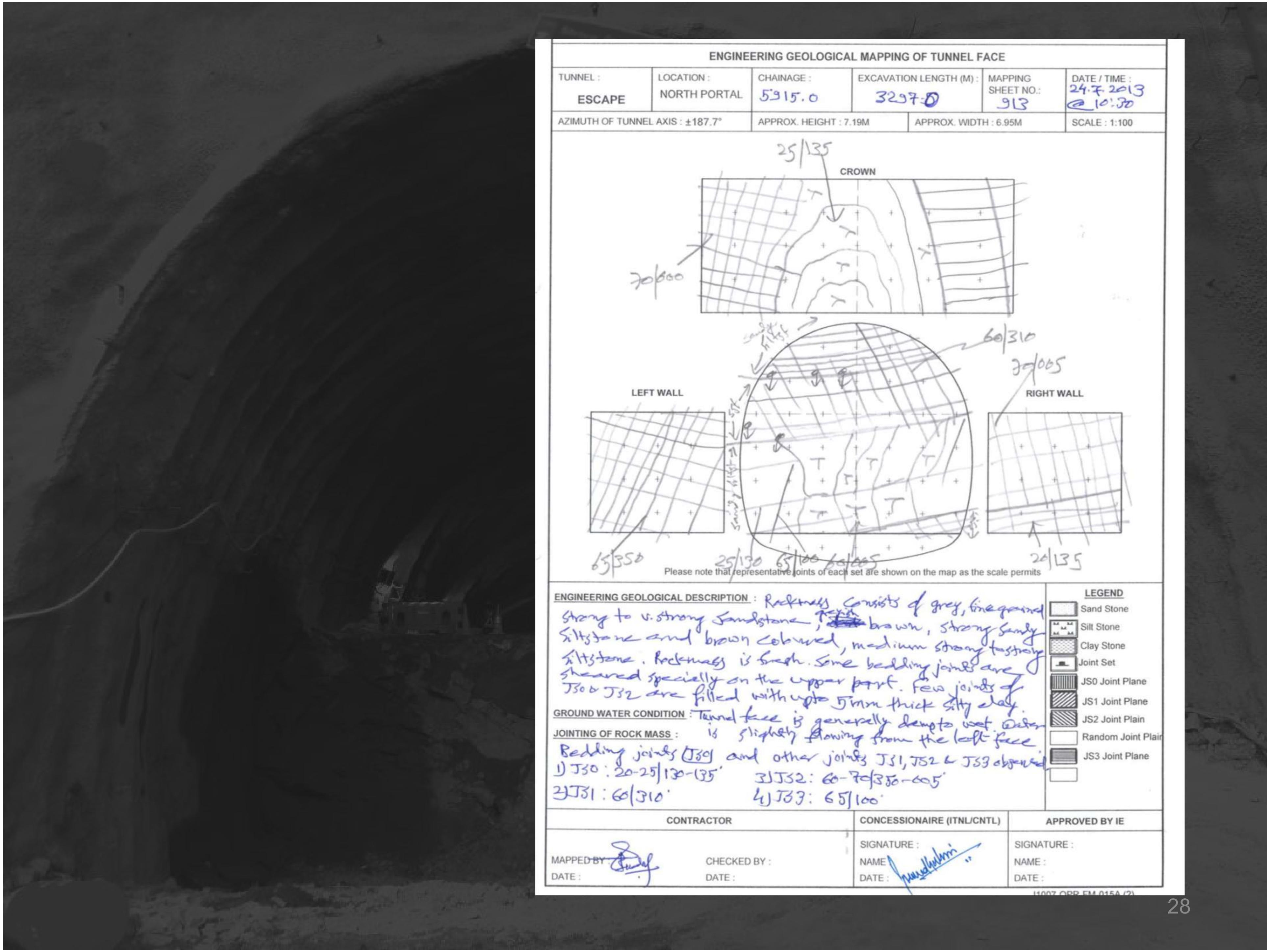
GDE Class Category: C1

Overbreak: Geological No Constructional: No

KRCL Remark:

DDC Remark:

Prepared by:	Reviewed by:	Approved by:
ITCons	GEODATA ENGINEERING	KONKAN RAILWAY CORPORATION LIMITED
Name: Mrigank Shekhar & Rohit Sharma	Name: Biswa Chaudhary	Name:
Sign: Mrigank Shekhar	Sign:	Sign:
Date: 20/05/2015	Date:	Date:



ENGINEERING GEOLOGICAL MAPPING OF TUNNEL FACE

TUNNEL :	LOCATION :	CHAINAGE :	EXCAVATION LENGTH (M) :	MAPPING SHEET NO.:	DATE / TIME :
ESCAPE	NORTH PORTAL	5915.0	3297.0	913	24.7.2013 @ 10:30

AZIMUTH OF TUNNEL AXIS : ±187.7°	APPROX. HEIGHT : 7.19M	APPROX. WIDTH : 6.95M	SCALE : 1:100

Please note that representative joints of each set are shown on the map as the scale permits

ENGINEERING GEOLOGICAL DESCRIPTION : Rockmass consists of grey, finegrained strong to v. strong Sandstone, ~~greyish~~ brown, strong sandy siltstone and brown coloured, medium strong to strong siltstone. Rockmass is fresh. Some bedding joints are sheared specially on the upper part. Few joints of JS0 & JS2 are filled with upto 5mm thick silty clay.

GROUND WATER CONDITION : Tunnel face is generally damp to wet. Water is slightly flowing from the left face

JOINTING OF ROCK MASS :

Bedding joints (JS0) and other joints JS1, JS2 & JS3 observed.

1) JS0 : 20-25/130-135°
2) JS1 : 60/310°
3) JS2 : 60-70/350-005°
4) JS3 : 65/100°

LEGEND

- Sand Stone
- Silt Stone
- Clay Stone
- Joint Set
- JS0 Joint Plane
- JS1 Joint Plane
- JS2 Joint Plain
- Random Joint Plain
- JS3 Joint Plane

CONTRACTOR		CONCESSIONAIRE (ITNL/CNTL)	APPROVED BY IE
MAPPED BY : DATE :	CHECKED BY : DATE :	SIGNATURE : NAME : DATE :	SIGNATURE : NAME : DATE :

I1007 - CHENANI-NASHRI TUNNEL PROJECT

ENGINEERING GEOLOGICAL MAPPING - DATA SHEET

UNNEL:	LOCATION:	CHAINAGE :	EXCAVATION LENGTH (M) :	MAPPING SHEET NO.:	DATE/TIME :
ESCAPE	N. PORTAL	5915.0	3297.0	913	24.7.2013 @ 10:30

EOLOGICAL DESCRIPTION OF THE ROCK MASS :

See 1st page for description.

ISCONTINUITIES / JOINT SETS	DIP & DIP DIRECTION	APERTURE (mm)	ROUGHNESS	PERSISTANCE CONTINUITY (cm)	SPACING (mm)	FILLING TYPE/ THICKNESS	DEGREE OF WEATHERING
JS0		<0.1-5	Rough-Sr.	300-700	40-800	Silty clay	Fresh
JS1		<0.1	Rough	100-400	100-600	–	"
JS2		<0.1-2	Rough-Sr	100-700	60-600	Silty clay	"
JS3		<0.1	Rough	100-400	200-800	–	"

blocky & slabby. m³ to 50X50X60cm.

DILATION OF ROCKMASS :

- Discontinuities closed ☑
- Discontinuities partially open ☑
- Discontinuities mostly open ☐

DEGREE OF WEATHERING :

- ☑ F
- ☐ SW
- ☐ MW
- ☐ HW
- ☐ CW
- ☐ RS

REMARKS

SHAPE / LOCATION AND CAUSES OF OVERBREAK :

logical overbreak has occurred at crown.

ENERAL REMARKS :

Rockmass is friable.

Rock class as per Specification : B_1

" " " Russo chart : B_1

Rockmass is friable

Rock class as per Specification : B_1

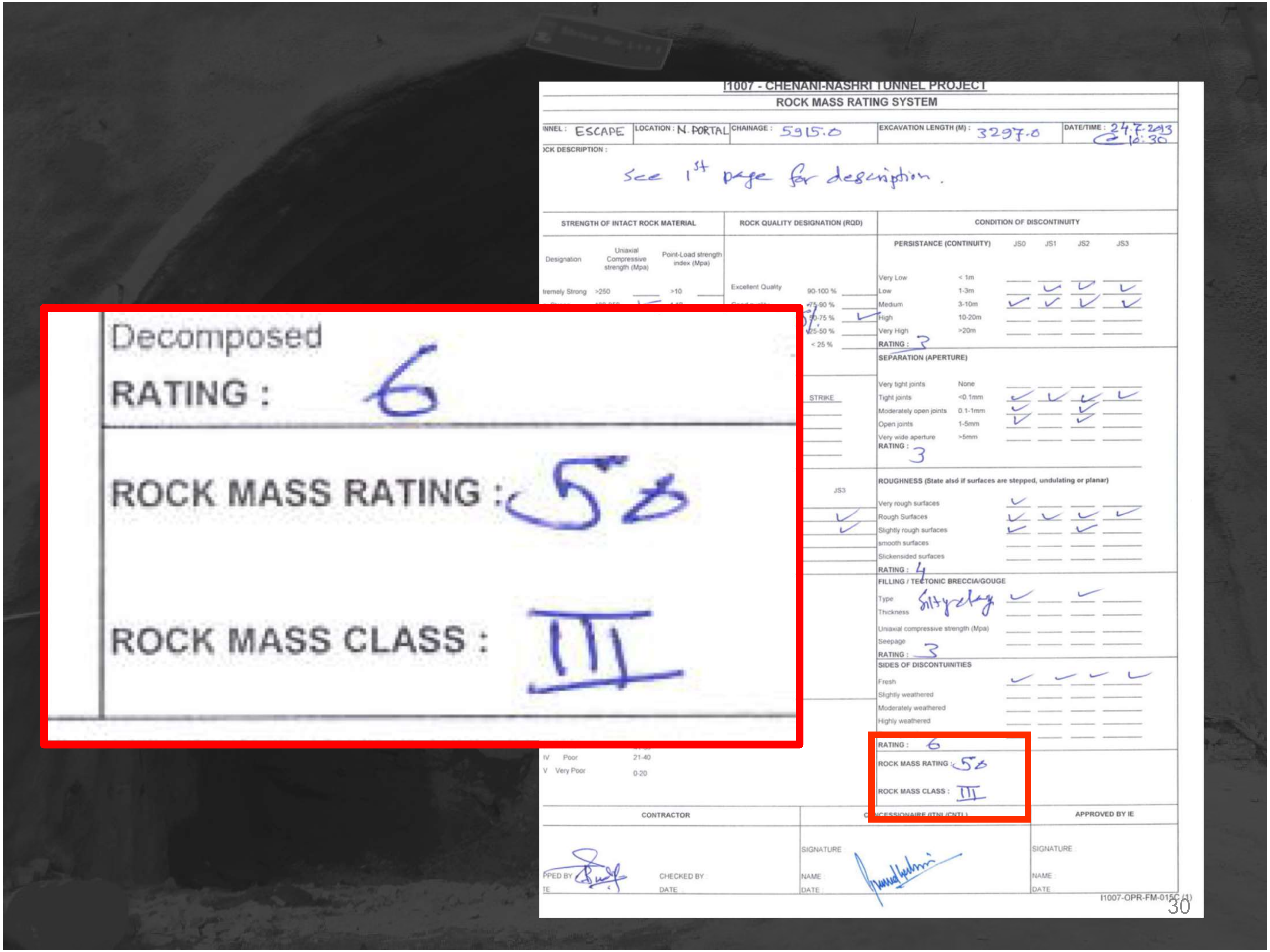
" " " Russo chart : B_1

DETAILS OF ROCK / SOIL SAMPLING:

PHOTOGRAPHIC RECORDS: FACE ☐ CROWN ☐ LEFT WALL ☐ RIGHT WALL ☐

CONTRACTOR	CONCESSIONAIRE (ITNL/CNTL)	APPROVED BY IE
PPED BY: TE: CHECKED BY: DATE:	SIGNATURE: NAME: DATE:	SIGNATURE: NAME: DATE:

I1007-OPR-FM-015B (2)



I1007 - CHENANI-NASHRI TUNNEL PROJECT

ROCK MASS RATING SYSTEM

NNEL : ESCAPE	LOCATION : N. PORTAL	CHAINAGE : 5915.0	EXCAVATION LENGTH (M) : 3297.0	DATE/TIME : 24.7.2013 @ 10:30

CK DESCRIPTION :

See 1st page for description.

STRENGTH OF INTACT ROCK MATERIAL

Designation	Uniaxial Compressive strength (Mpa)	Point-Load strength index (Mpa)
tremely Strong	>250	>10

ROCK QUALITY DESIGNATION (RQD)

Excellent Quality	90-100 %	
	75-90 %	
	50-75 %	✓
	25-50 %	
	< 25 %	

STRIKE

JS3

IV	Poor	21-40
V	Very Poor	0-20

CONDITION OF DISCONTINUITY

PERSISTANCE (CONTINUITY)

		JS0	JS1	JS2	JS3
Very Low	< 1m				
Low	1-3m		✓	✓	✓
Medium	3-10m	✓	✓	✓	✓
High	10-20m				
Very High	>20m				

RATING : 3

SEPARATION (APERTURE)

		JS0	JS1	JS2	JS3
Very tight joints	None				
Tight joints	<0.1mm	✓	✓	✓	✓
Moderately open joints	0.1-1mm	✓		✓	
Open joints	1-5mm	✓		✓	
Very wide aperture	>5mm				

RATING : 3

ROUGHNESS (State also if surfaces are stepped, undulating or planar)

	JS0	JS1	JS2	JS3
Very rough surfaces	✓			
Rough Surfaces	✓	✓	✓	✓
Slightly rough surfaces	✓		✓	
smooth surfaces				
Slickensided surfaces				

RATING : 4

FILLING / TECTONIC BRECCIA/GOUGE

		JS0	JS1	JS2	JS3
Type	Silty clay	✓		✓	
Thickness					
Uniaxial compressive strength (Mpa)					
Seepage					

RATING : 3

SIDES OF DISCONTUINITIES

	JS0	JS1	JS2	JS3
Fresh	✓	✓	✓	✓
Slightly weathered				
Moderately weathered				
Highly weathered				

RATING : 6

ROCK MASS RATING : 58

ROCK MASS CLASS : III

CONTRACTOR	CONCESSIONAIRE (TNL/CNTL)	APPROVED BY IE
PPED BY / TE / CHECKED BY / DATE	SIGNATURE / NAME / DATE	SIGNATURE / NAME / DATE

I1007-OPR-FM-015C (1)

Decomposed

RATING : 6

ROCK MASS RATING : 58

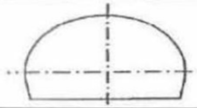
ROCK MASS CLASS : III

Sheet No. :

REQUIRED EXCAVATION & SUPPORT SHEET (RESS)

Position

- ☐ Top heading
- ☐ Bench ☐ Invert
- ☐ LHS ☐ RHS



Tunnel	CP19
Heading	FF
From Tunnel Meter (TM)	6.5
To Tunnel Meter (TM)	
Round No.	

General	
Rock Class	B1
Deformation Tolerance (d)	50mm
Round Length of Excavation	1.5 to 2.5m
Max/Min Ring Closure Distance	1.5 to 2.5m

Reference Drawings

I1007-GDE-TL-3420 (A)
I1007-GDE-TL-3410 (2)
I1007-GDE-C-3008 (4)

Note : Indicate any changes to designed support system in the table below

Support	Description	Top Heading	Bench	Invert
Face Shotcrete Sealing	Thickness/Type	50-100mm (if required)		
Face Wire Mesh	Grade / Dimension			
Face Rock Bolts	Type / Nos. / Length			
Face Supporting Body	Dimension L/W/H			
Sector Excavation	Numbers			
Elephant Footing	Width			
Wire Mesh 1st Layer	Grade / Dimension	NA*		
Wire Mesh 2nd Layer	Grade / Dimension			
Lattice Girder	Type	I1007-GDE-TL-3410 (2)		
Shotcrete Sealing	Thickness/Type			
Shotcrete 1st Layer	Thickness/Type	100 mm (*)		
Shotcrete 2nd Layer	Grade / Thickness	150 mm (*)		
Rock Bolts (roof / walls)	Type / Nos. / Length	No. 10/11, Swellex L= 5m (**)		
Forepoling	Type / Nos. / Length			

Remarks: * As per I1007-GDE-ENG-RPT-C-3006(D), Fibre reinforced shotcrete to be used
**Incline bolts according to joint orientation
Spilling + lattice girder cut and support to be performed from MT before XCP excavation.

CONTRACTOR	DESIGN CONSULTANT	CONCESSIONAIRE(ITNL/CNTL)	APPROVED BY IE
Name: D MEDCALF	Name: K. N. Adhikari	Name:	Name:
Sign: David Medcalf	Sign: KNAdhikari	Sign:	Sign:
Date: 1st August 2013	Date: 01-08-2013	Date:	Date:

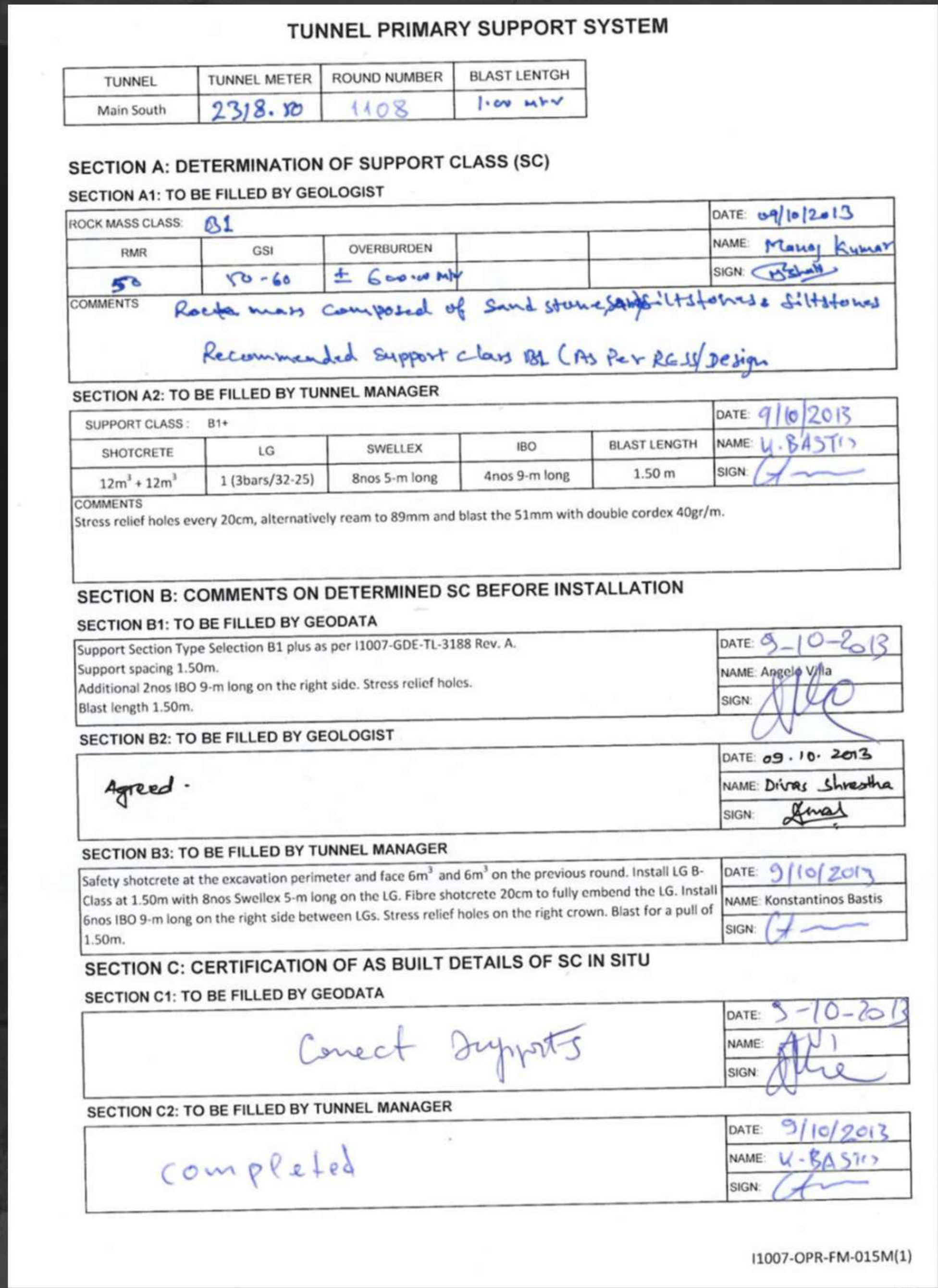
RESS
RMR
Required
Excavation
Support
Sheet

B1 support class

Deformation tolerance 50 mm
Round lenght 1.5 to 2.5
Face shotcrete 50 mm
Lattice girder YES
Wire mesh no (FRC)
Shotcrete 1° layer
Shotcrete 2° layer 150 mm
Rockbolts 10/11 swellex 5 m

TPSS
Tunnel Primary Support System

RECORD of what really was performed on site



TUNNEL PRIMARY SUPPORT SYSTEM

TUNNEL	TUNNEL METER	ROUND NUMBER	BLAST LENTGH
Main South	2318.50	1108	1.00 mtr

SECTION A: DETERMINATION OF SUPPORT CLASS (SC)

SECTION A1: TO BE FILLED BY GEOLOGIST

ROCK MASS CLASS: B1					DATE: 09/10/2013
RMR	GSI	OVERBURDEN			NAME: Manoj Kumar
50	50 - 60	± 600.00 mtr			SIGN:

COMMENTS Rock mass composed of Sand stone, siltstones & siltstones
Recommended support class B1 (As per RGSS/Design

SECTION A2: TO BE FILLED BY TUNNEL MANAGER

SUPPORT CLASS : B1+					DATE: 9/10/2013
SHOTCRETE	LG	SWELLEX	IBO	BLAST LENGTH	NAME: K. BASTIS
$12m^3 + 12m^3$	1 (3bars/32-25)	8nos 5-m long	4nos 9-m long	1.50 m	SIGN:

COMMENTS
Stress relief holes every 20cm, alternatively ream to 89mm and blast the 51mm with double cordex 40gr/m.

SECTION B: COMMENTS ON DETERMINED SC BEFORE INSTALLATION

SECTION B1: TO BE FILLED BY GEODATA

Support Section Type Selection B1 plus as per I1007-GDE-TL-3188 Rev. A. Support spacing 1.50m. Additional 2nos IBO 9-m long on the right side. Stress relief holes. Blast length 1.50m.	DATE: 9-10-2013 NAME: Angelo Villa SIGN:

SECTION B2: TO BE FILLED BY GEOLOGIST

Agreed.	DATE: 09.10.2013 NAME: Divas Shrestha SIGN:

SECTION B3: TO BE FILLED BY TUNNEL MANAGER

Safety shotcrete at the excavation perimeter and face $6m^3$ and $6m^3$ on the previous round. Install LG B-Class at 1.50m with 8nos Swellex 5-m long on the LG. Fibre shotcrete 20cm to fully embend the LG. Install 6nos IBO 9-m long on the right side between LGs. Stress relief holes on the right crown. Blast for a pull of 1.50m.	DATE: 9/10/2013 NAME: Konstantinos Bastis SIGN:

SECTION C: CERTIFICATION OF AS BUILT DETAILS OF SC IN SITU

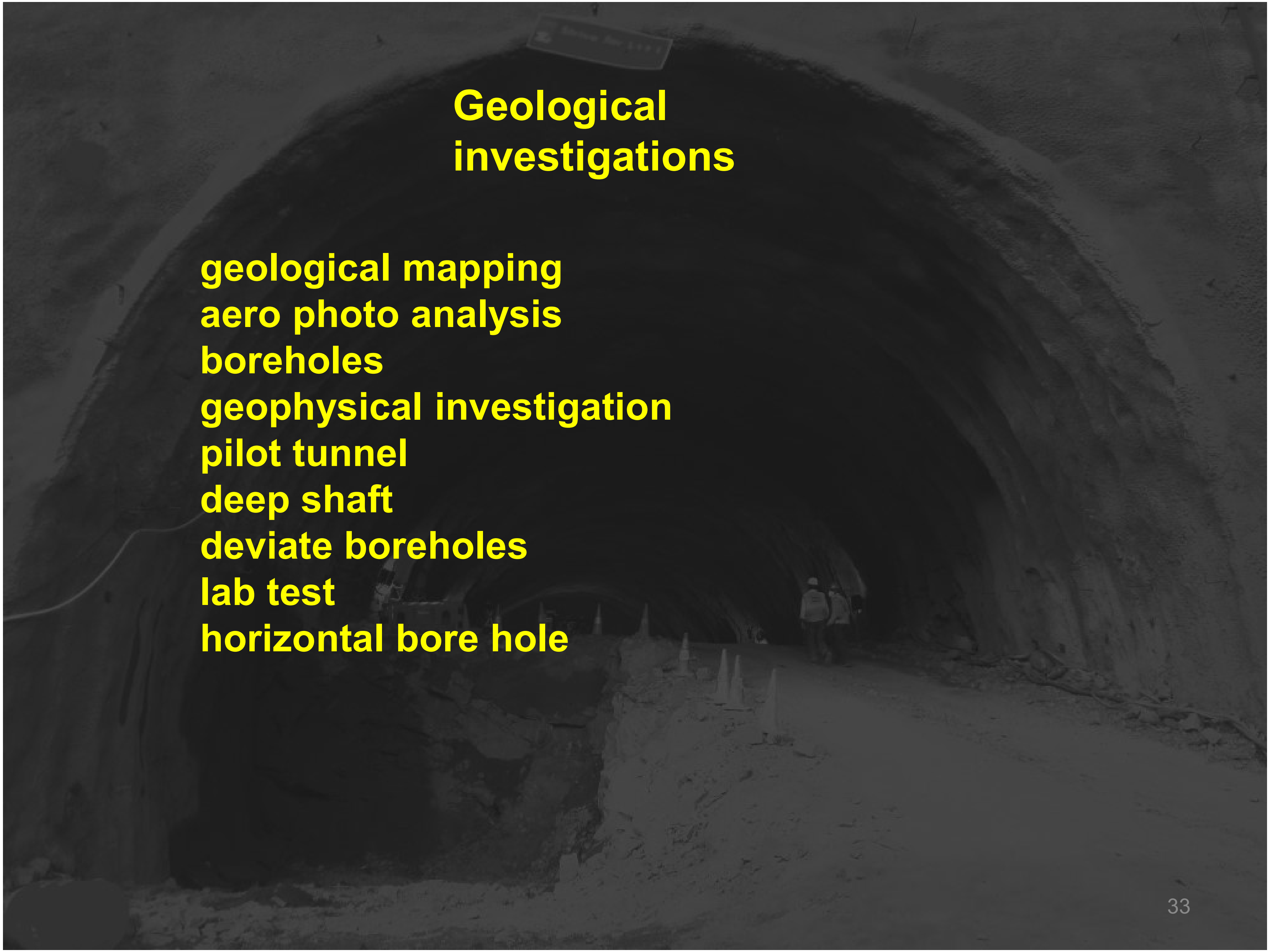
SECTION C1: TO BE FILLED BY GEODATA

Correct supports	DATE: 9-10-2013 NAME: AVI SIGN:

SECTION C2: TO BE FILLED BY TUNNEL MANAGER

completed	DATE: 9/10/2013 NAME: K. BASTIS SIGN:

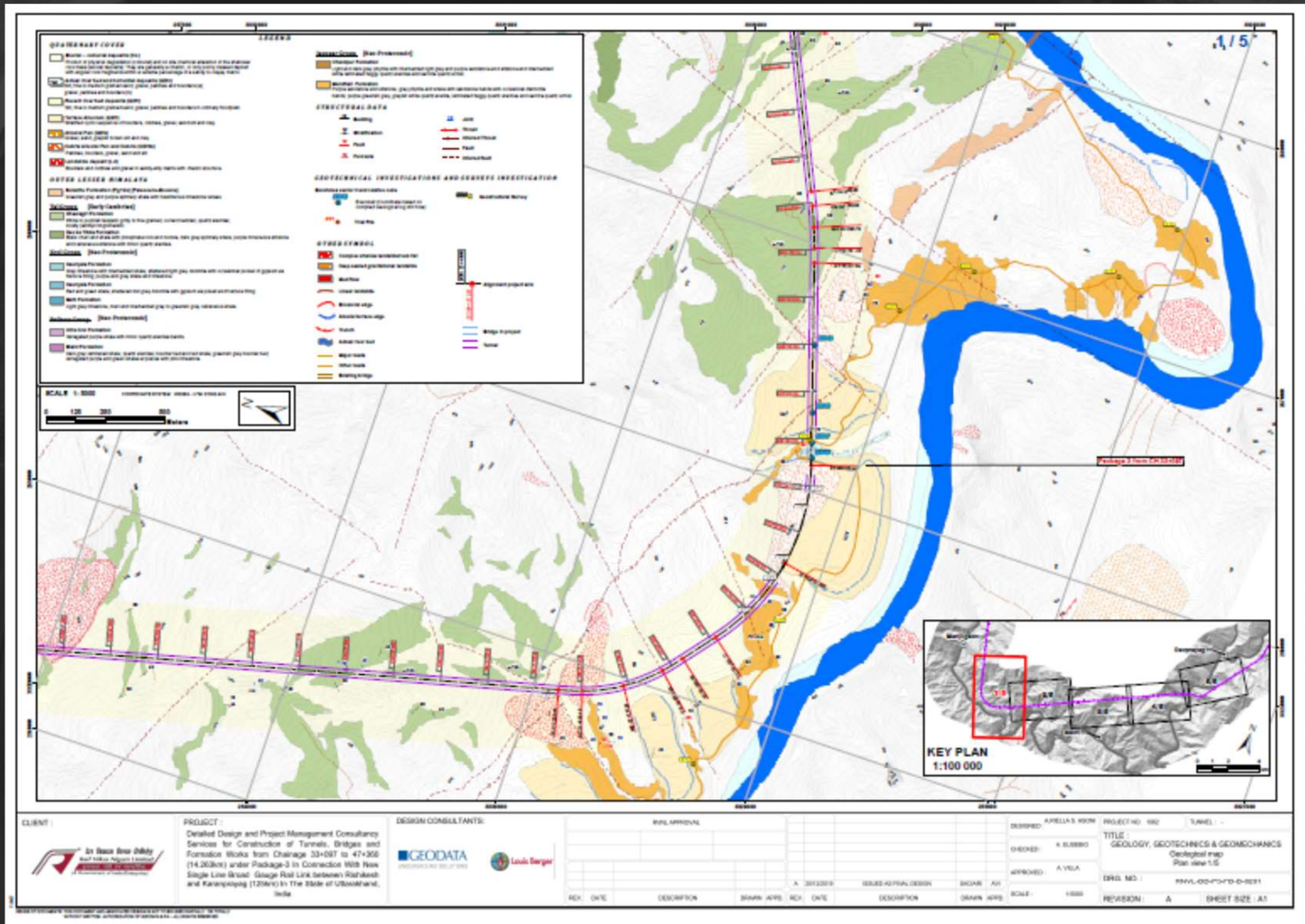
I1007-OPR-FM-015M(1)



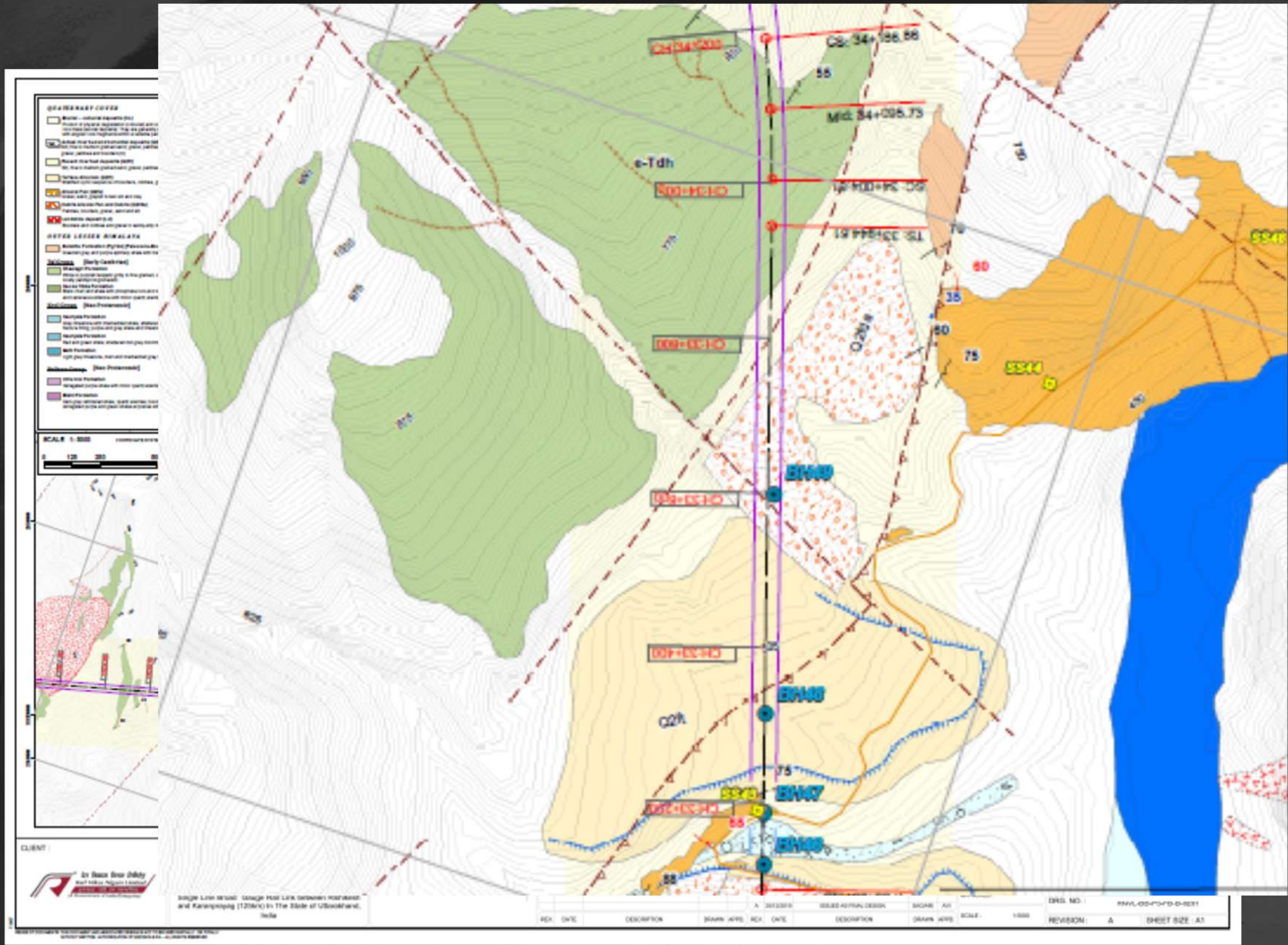
Geological investigations

geological mapping
aero photo analysis
boreholes
geophysical investigation
pilot tunnel
deep shaft
deviate boreholes
lab test
horizontal bore hole

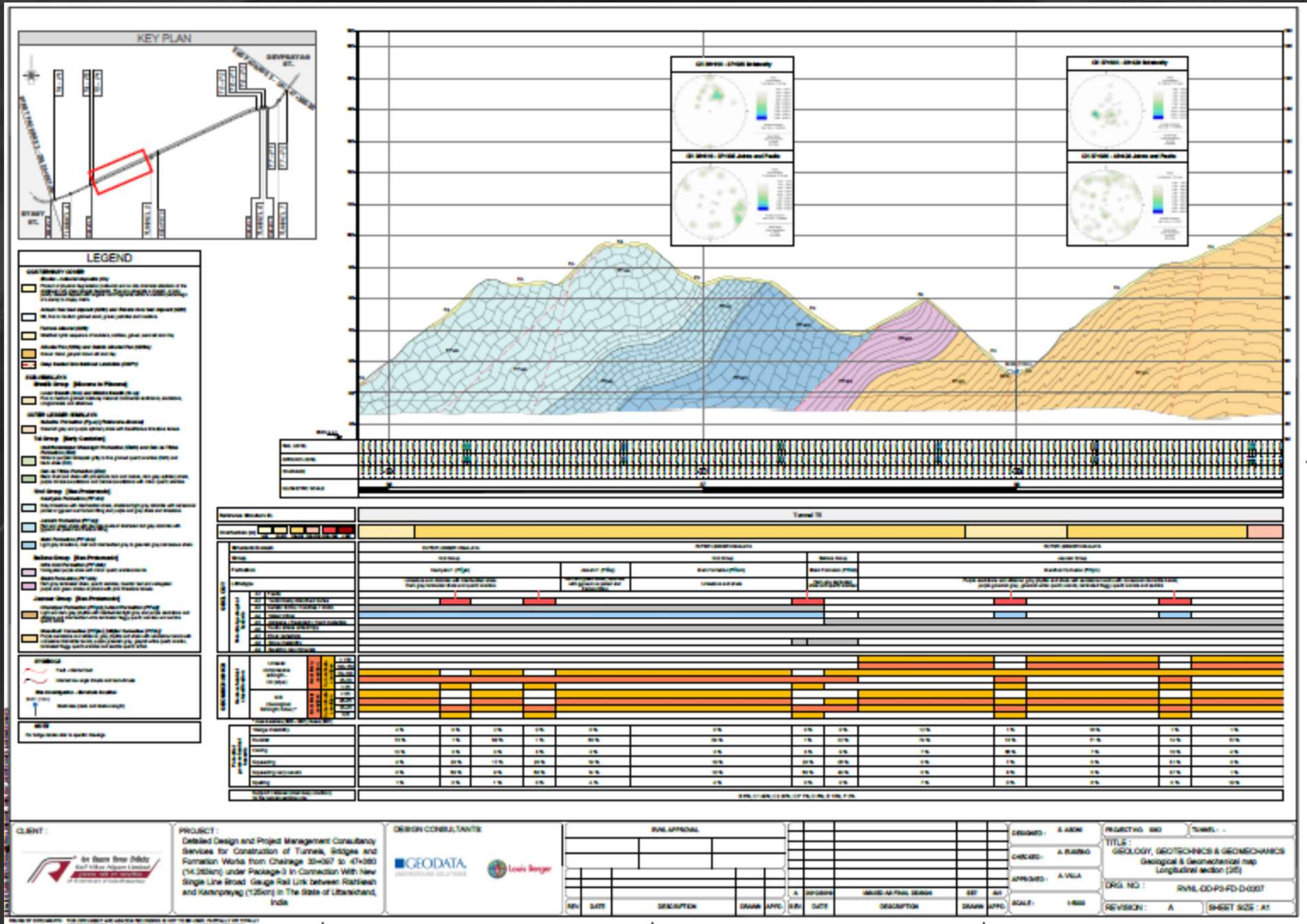
Geological map



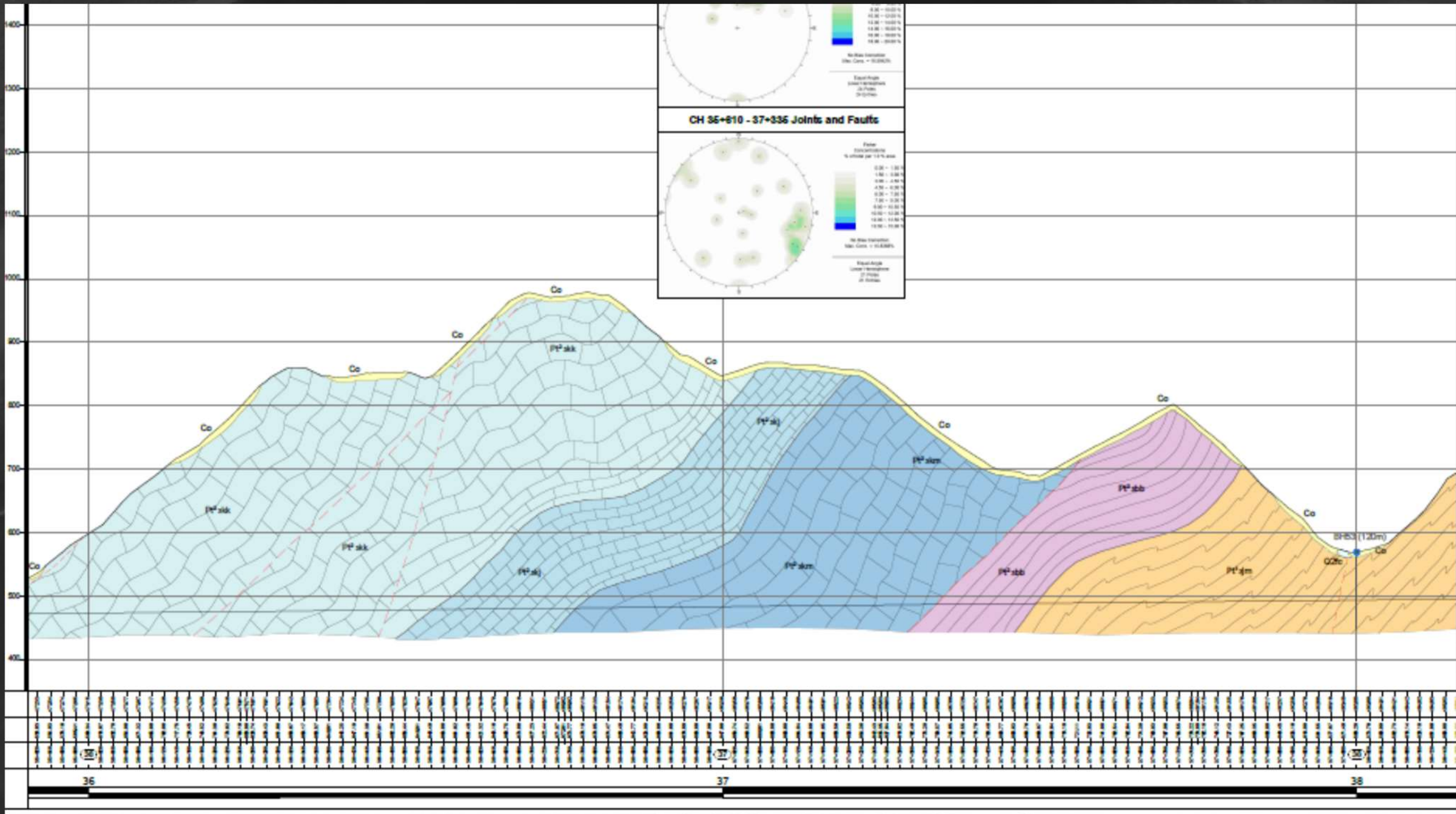
Geological map



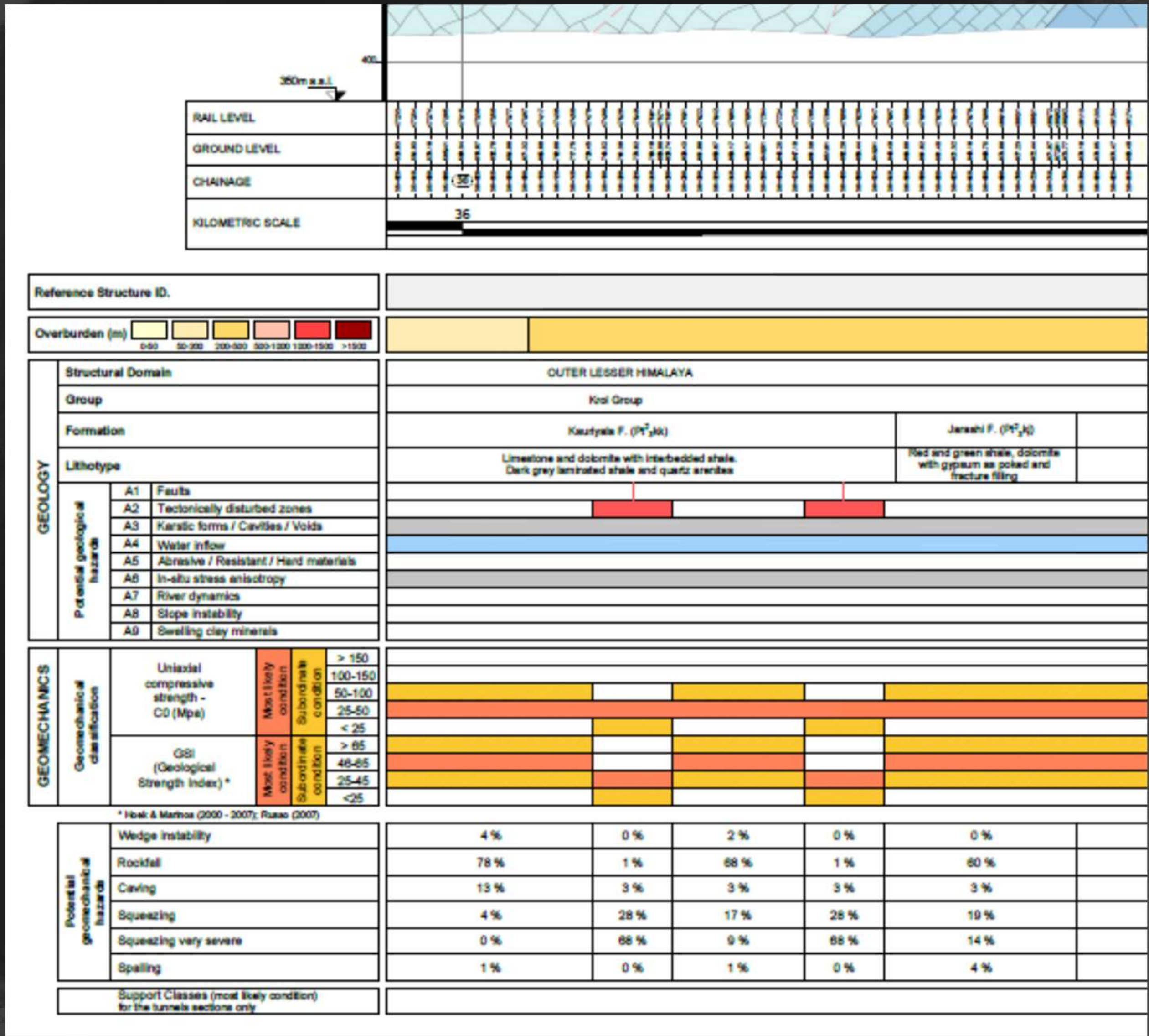
Geological profile



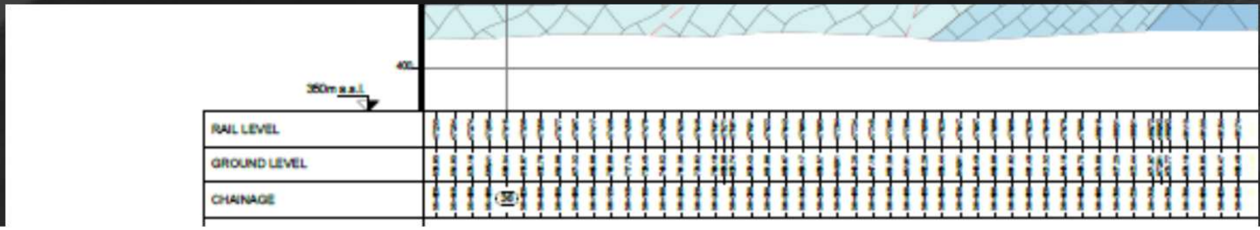
Geological profile



Geological profile



Geological profile

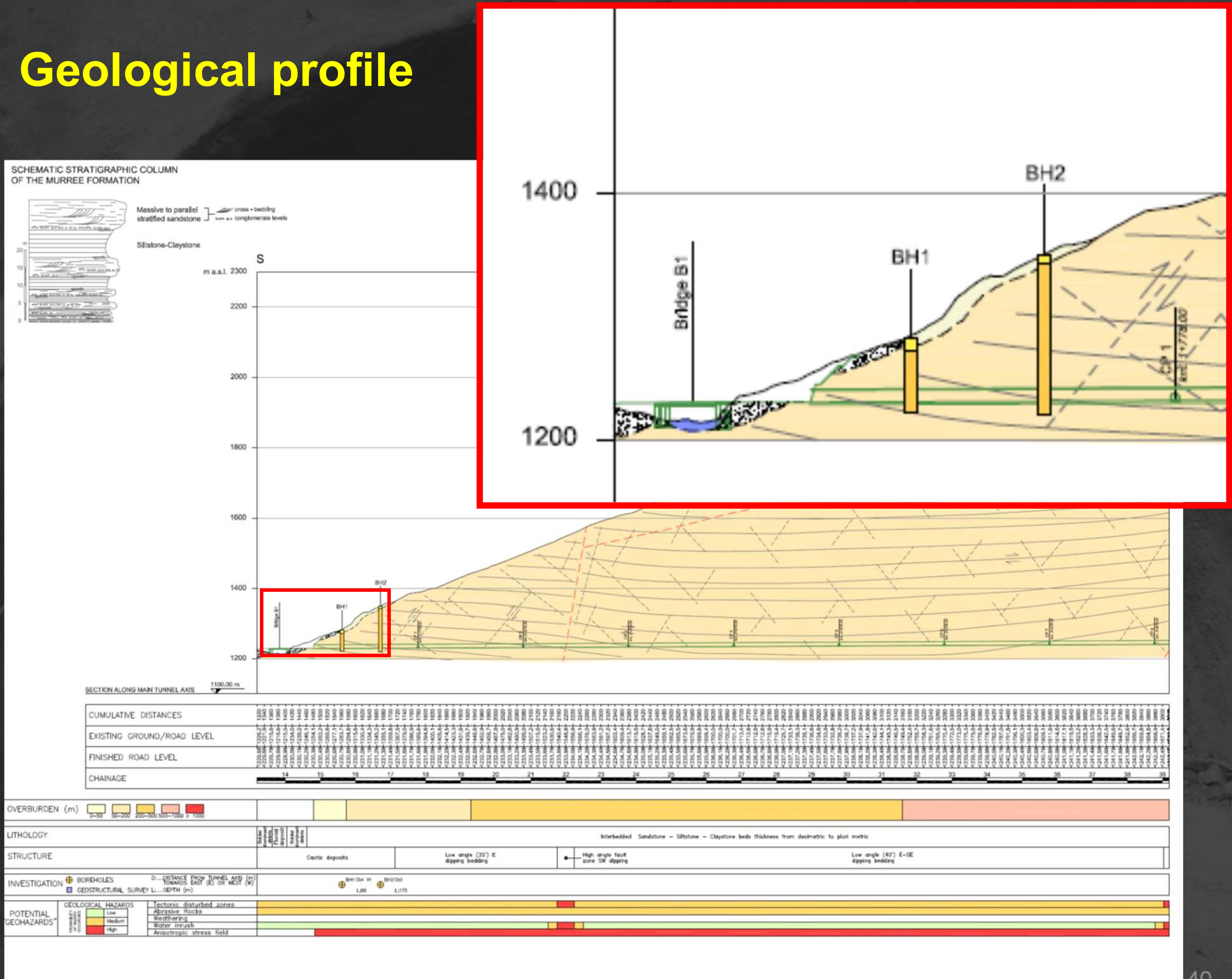


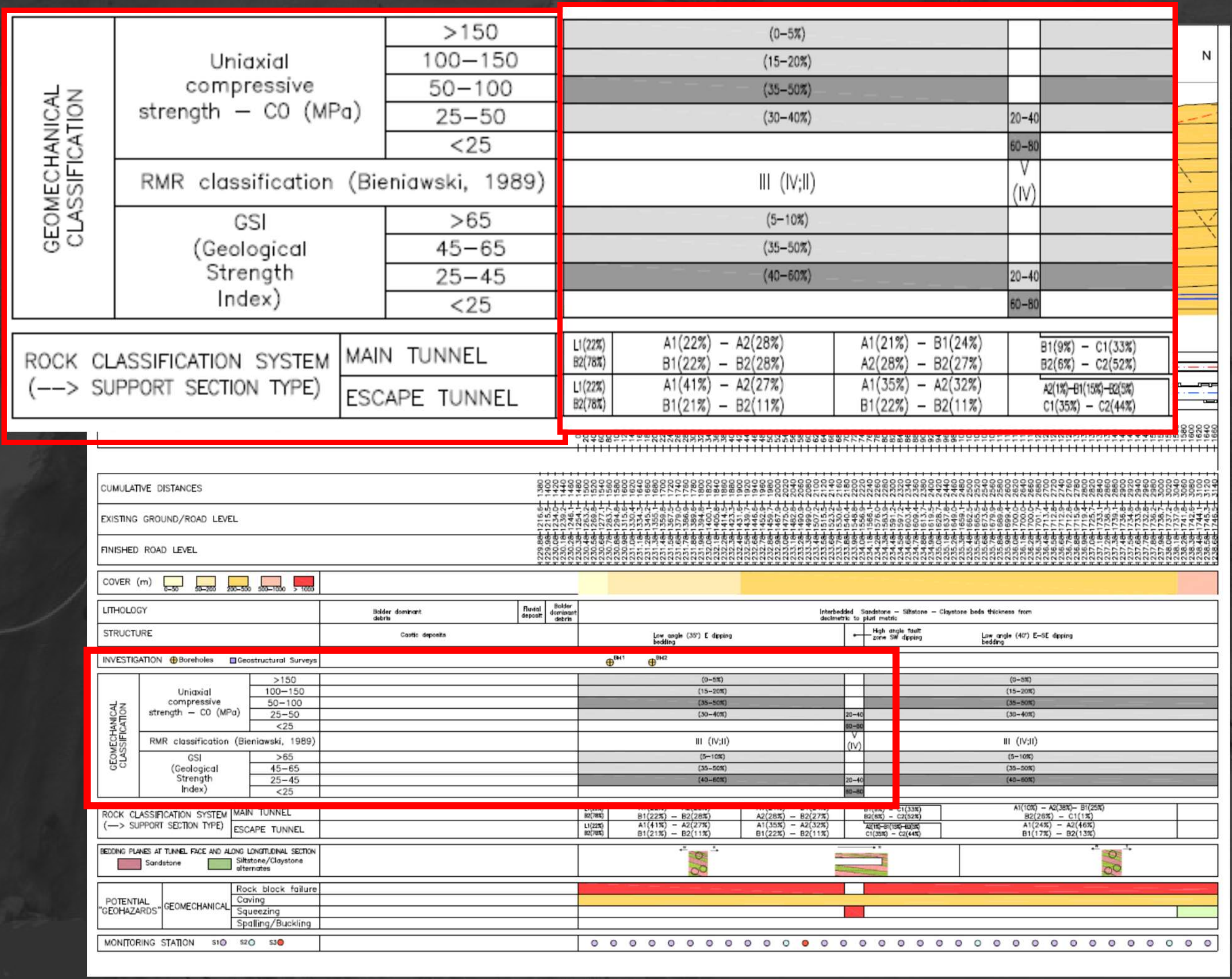
GEOMECHANICS				
Geomechanical classification	Uniaxial compressive strength - C0 (Mpa)	Most likely condition / Subordinate condition	> 150	
			100-150	
			50-100	
			25-50	
			< 25	
	GSI (Geological Strength Index) *	Most likely condition / Subordinate condition	> 65	
			46-65	
			25-45	
			<25	

* Hoek & Marinos (2000 - 2007); Russo (2007)

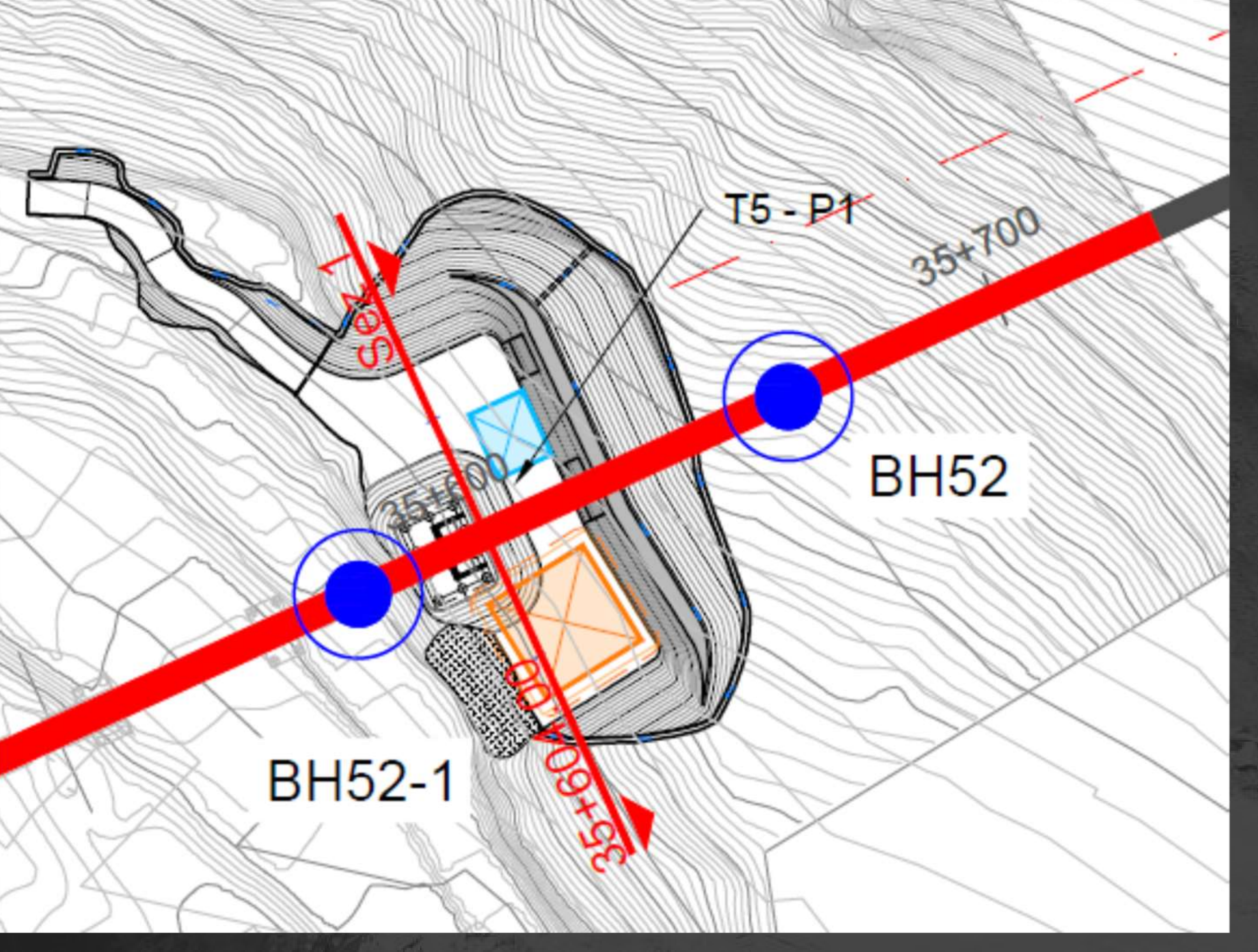
Potential geomechanical hazards				
	Wedge instability	4 %	0 %	
	Rockfall	78 %	1 %	
	Caving	13 %	3 %	
	Squeezing	4 %	28 %	
	Squeezing very severe	0 %	68 %	
	Spalling	1 %	0 %	
	Support Classes (most likely condition) for the tunnels sections only			

Geological profile

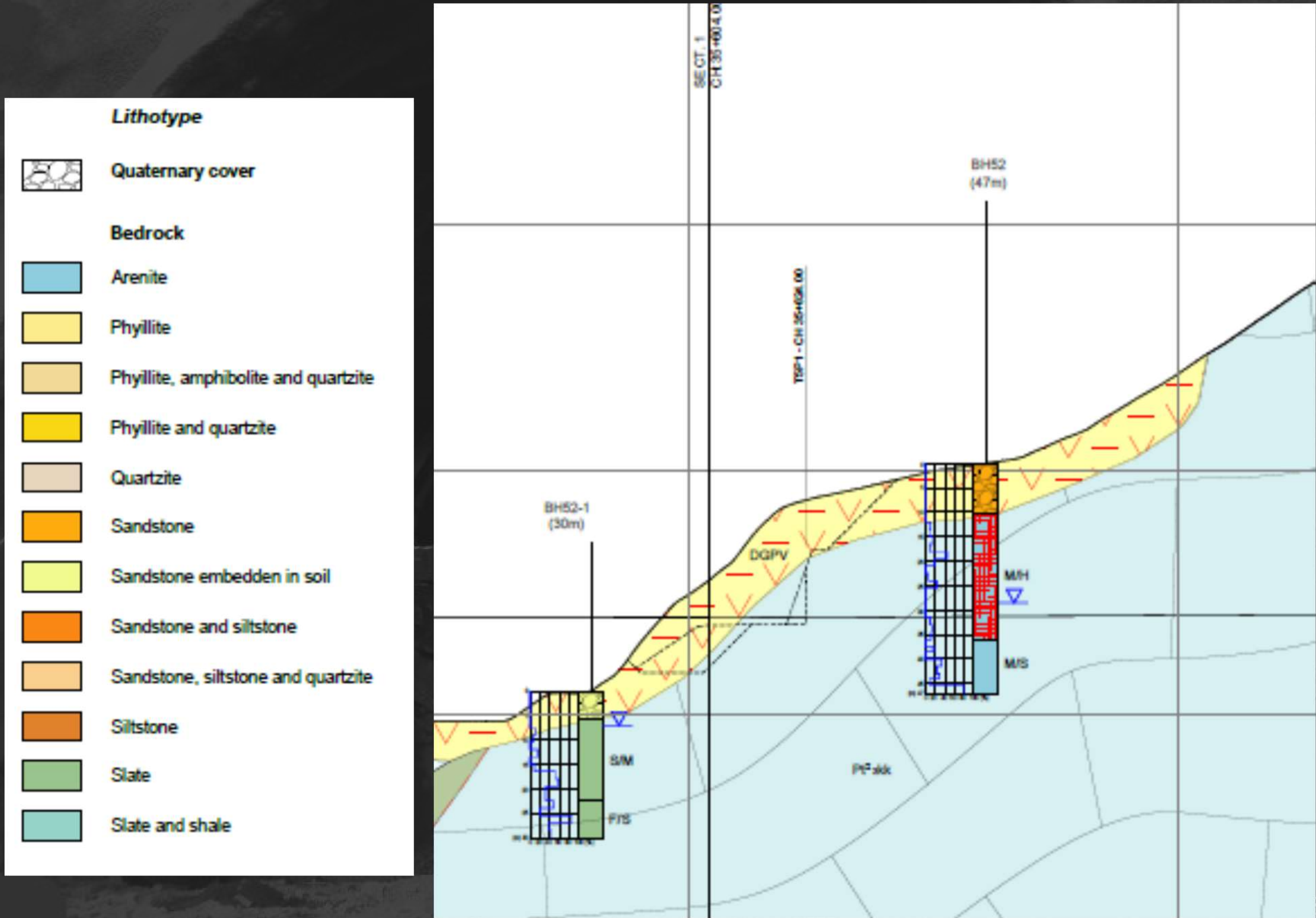



GEOMECHANICAL CLASSIFICATION
Uniaxial compressive strength – C0 (MPa)
>150
100–150
50–100
25–50
<25
RMR classification (Bieniawski, 1989)
GSI (Geological Strength Index)
>65
45–65
25–45
<25
(0–5%)
(15–20%)
(35–50%)
(30–40%)
20–40
60–80
III (IV;II)
V (IV)
(5–10%)
(35–50%)
(40–60%)
ROCK CLASSIFICATION SYSTEM (--> SUPPORT SECTION TYPE)
MAIN TUNNEL
ESCAPE TUNNEL
L1(22%) B2(78%)
A1(22%) – A2(28%) B1(22%) – B2(28%)
A1(21%) – B1(24%) A2(28%) – B2(27%)
B1(9%) – C1(33%) B2(6%) – C2(52%)
A1(41%) – A2(27%) B1(21%) – B2(11%)
A1(35%) – A2(32%) B1(22%) – B2(11%)
A2(1%)–B1(15%)–B2(5%) C1(35%) – C2(44%)
N
CUMULATIVE DISTANCES
EXISTING GROUND/ROAD LEVEL
FINISHED ROAD LEVEL
COVER (m)
LITHOLOGY
STRUCTURE
INVESTIGATION Boreholes Geostructural Surveys
BEDDING PLANES AT TUNNEL FACE AND ALONG LONGITUDINAL SECTION
Sandstone
Siltstone/Claystone alternates
POTENTIAL "GEOHAZARDS"
GEOMECHANICAL
Rock block failure
Caving
Squeezing
Spalling/Buckling
MONITORING STATION

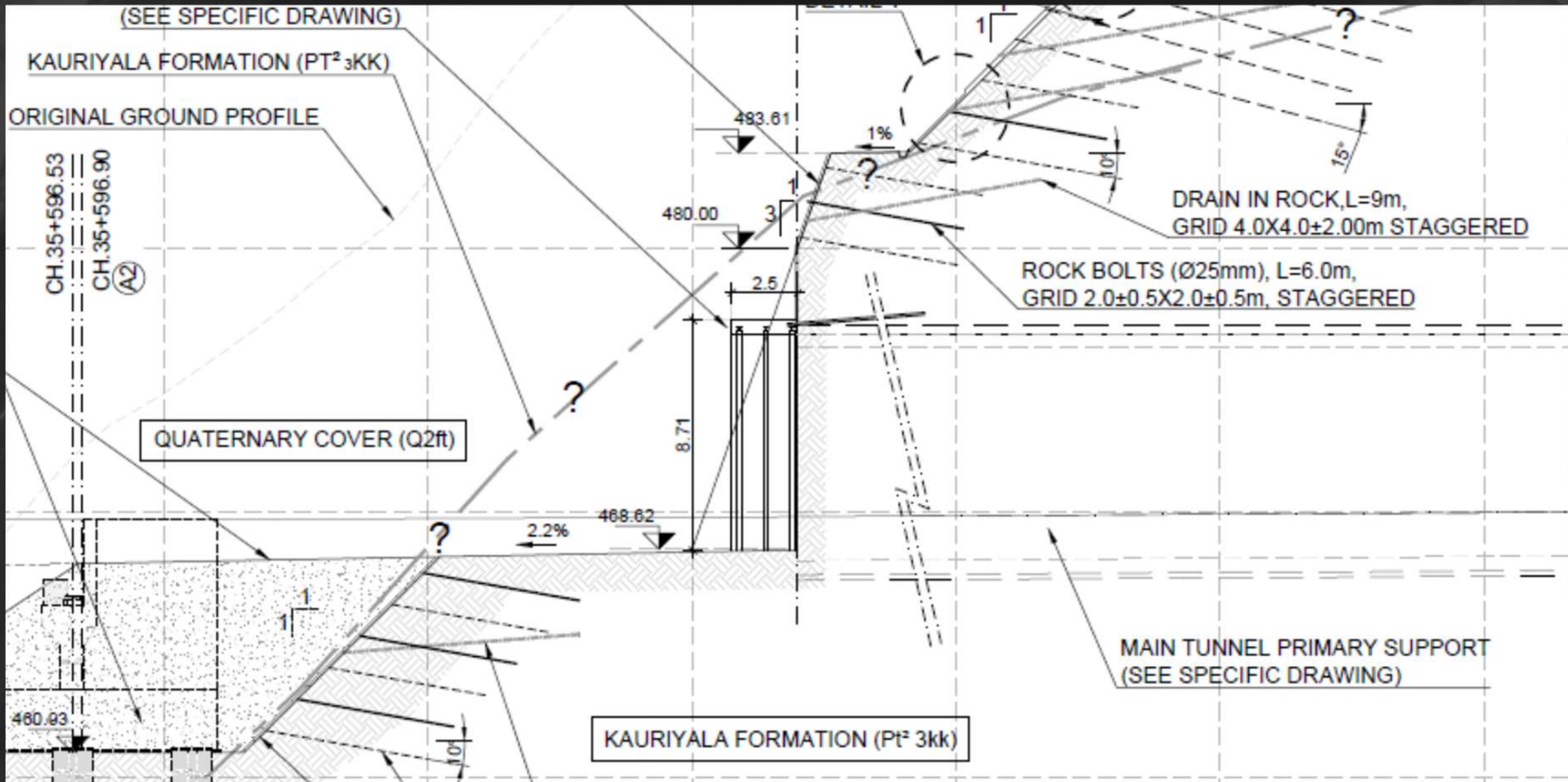
Geological investigations at portals



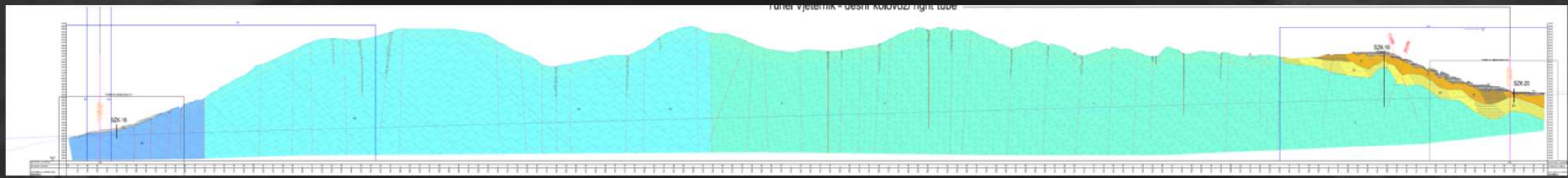
Geological investigations



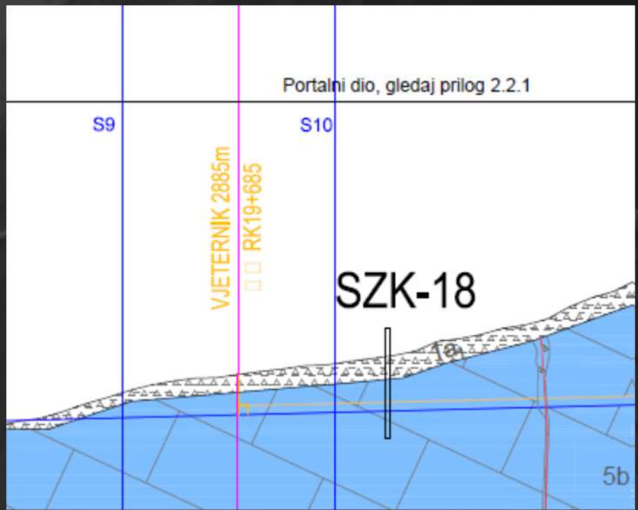
Portal design

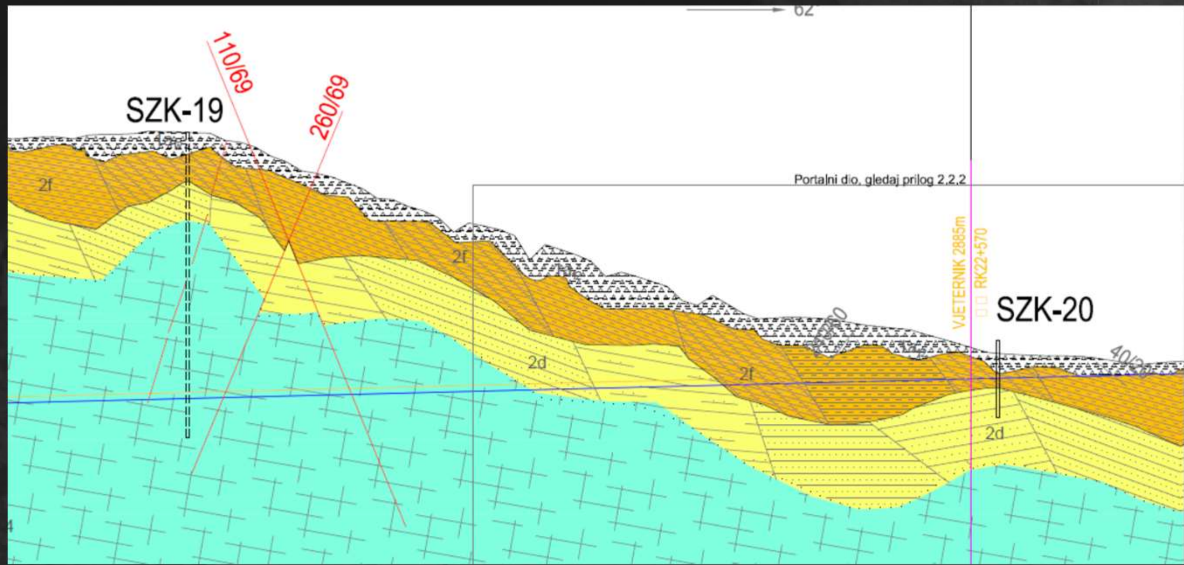


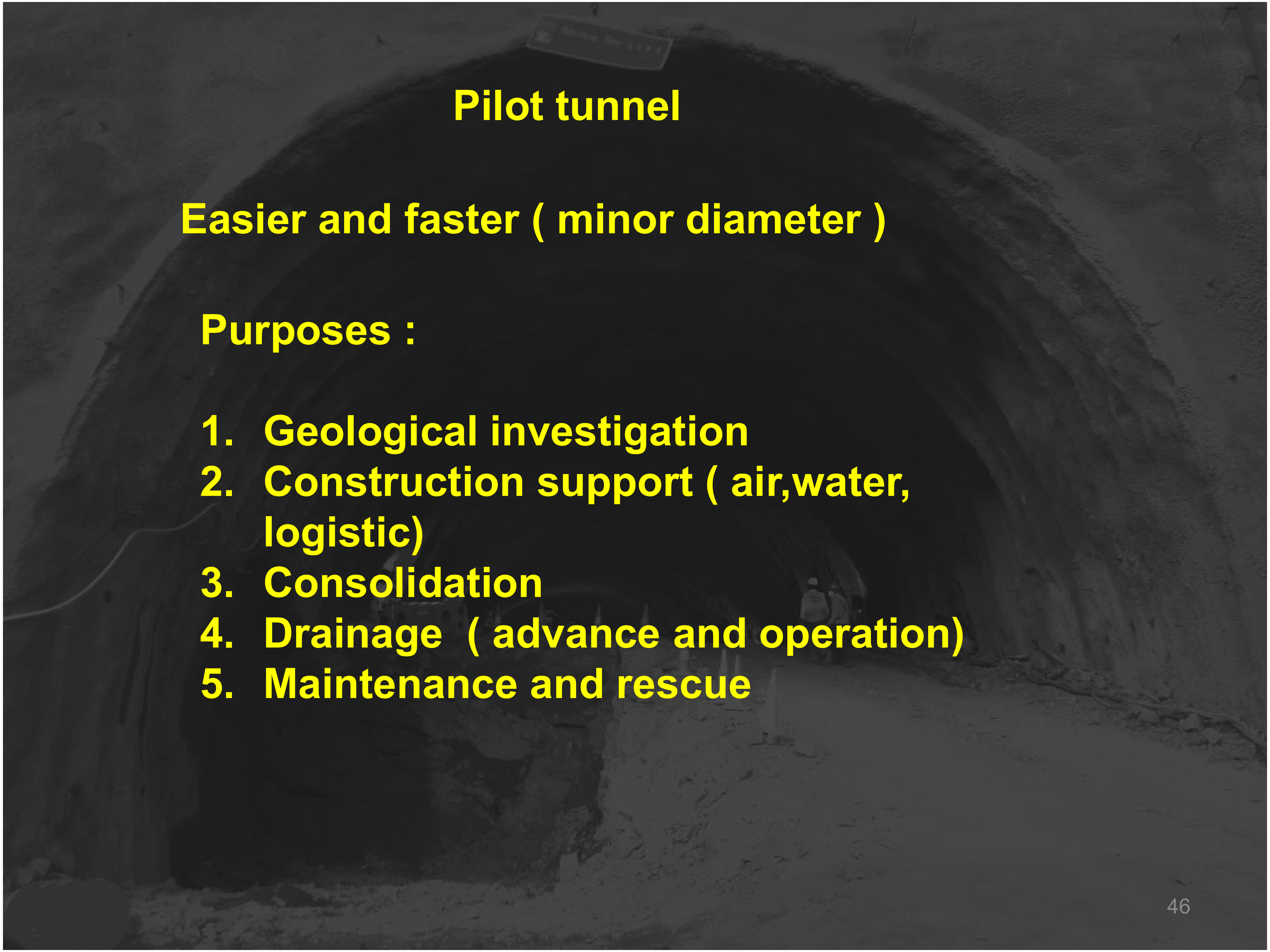
Bore hole location



Vjeternik tunnel : contact limestone - flysch







Pilot tunnel

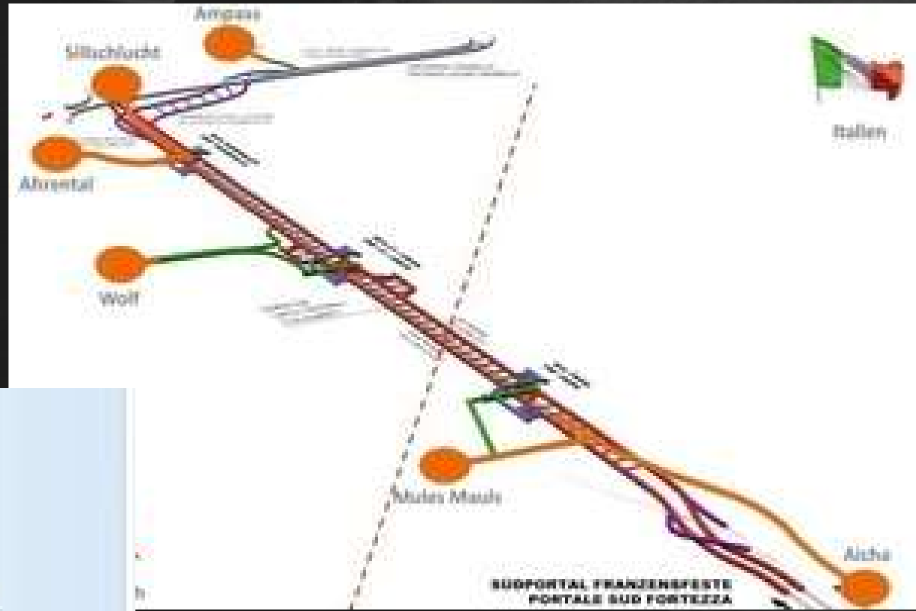
Easier and faster (minor diameter)

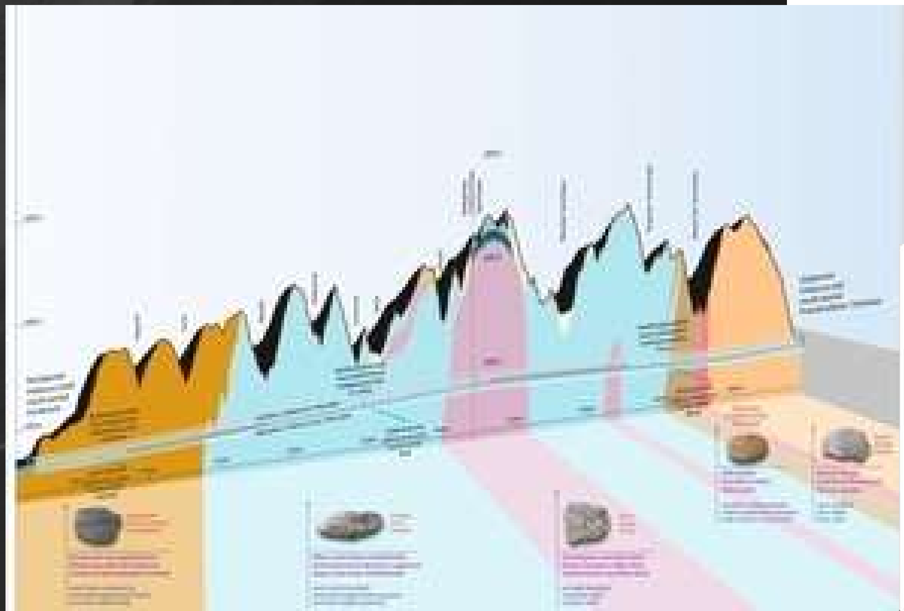
Purposes :

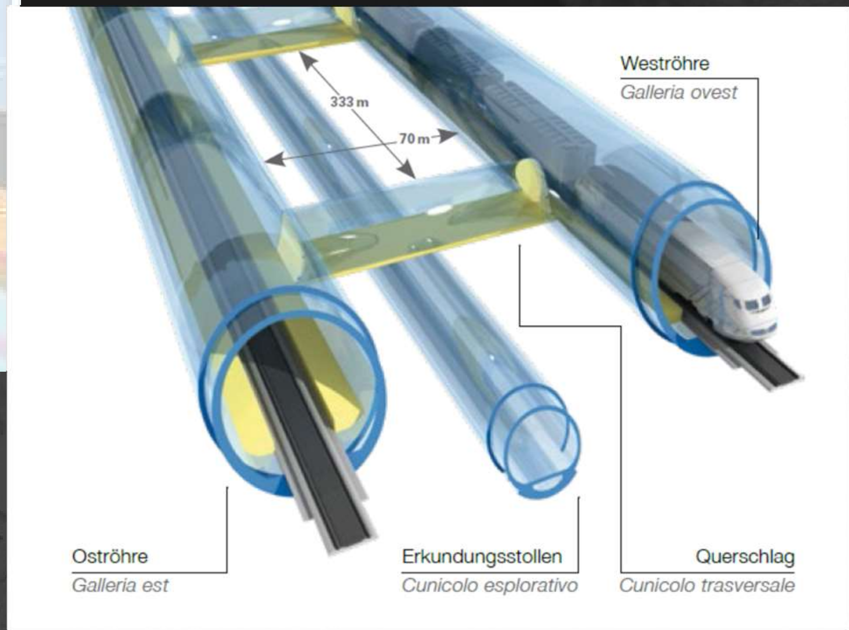
1. Geological investigation
2. Construction support (air,water, logistic)
3. Consolidation
4. Drainage (advance and operation)
5. Maintenance and rescue

Pilot tunnel

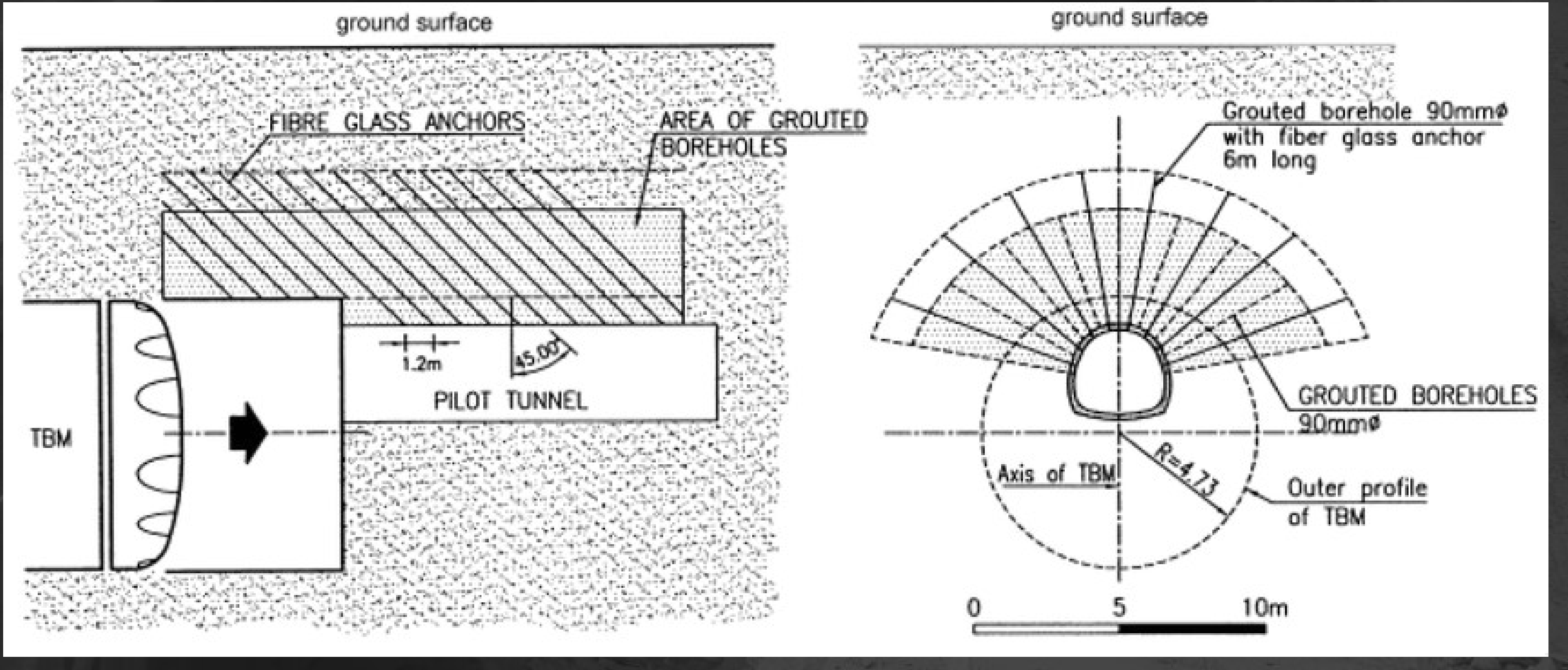
BBT Brenner base tunnel
L = 55+9
main tunnel D 10,65 m
pilot D 6,80 m



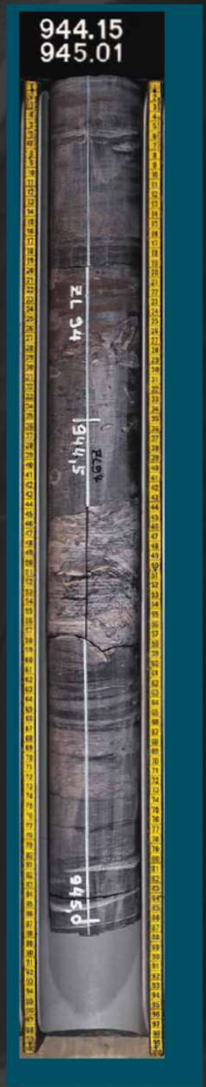


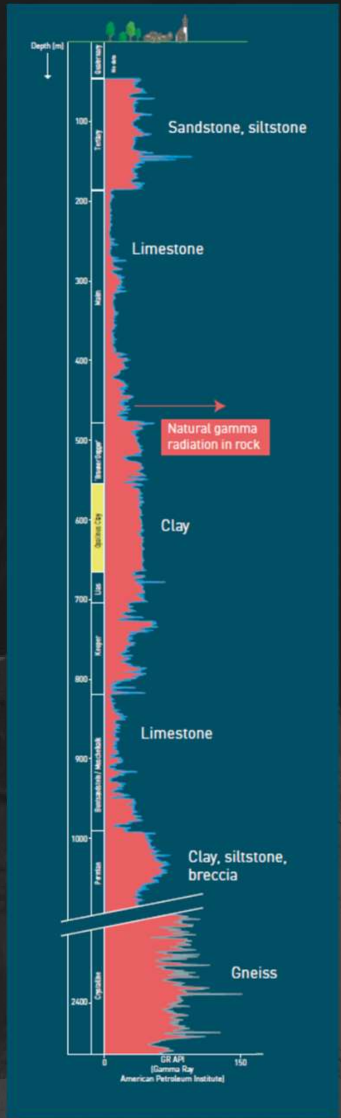


Pilot tunnel



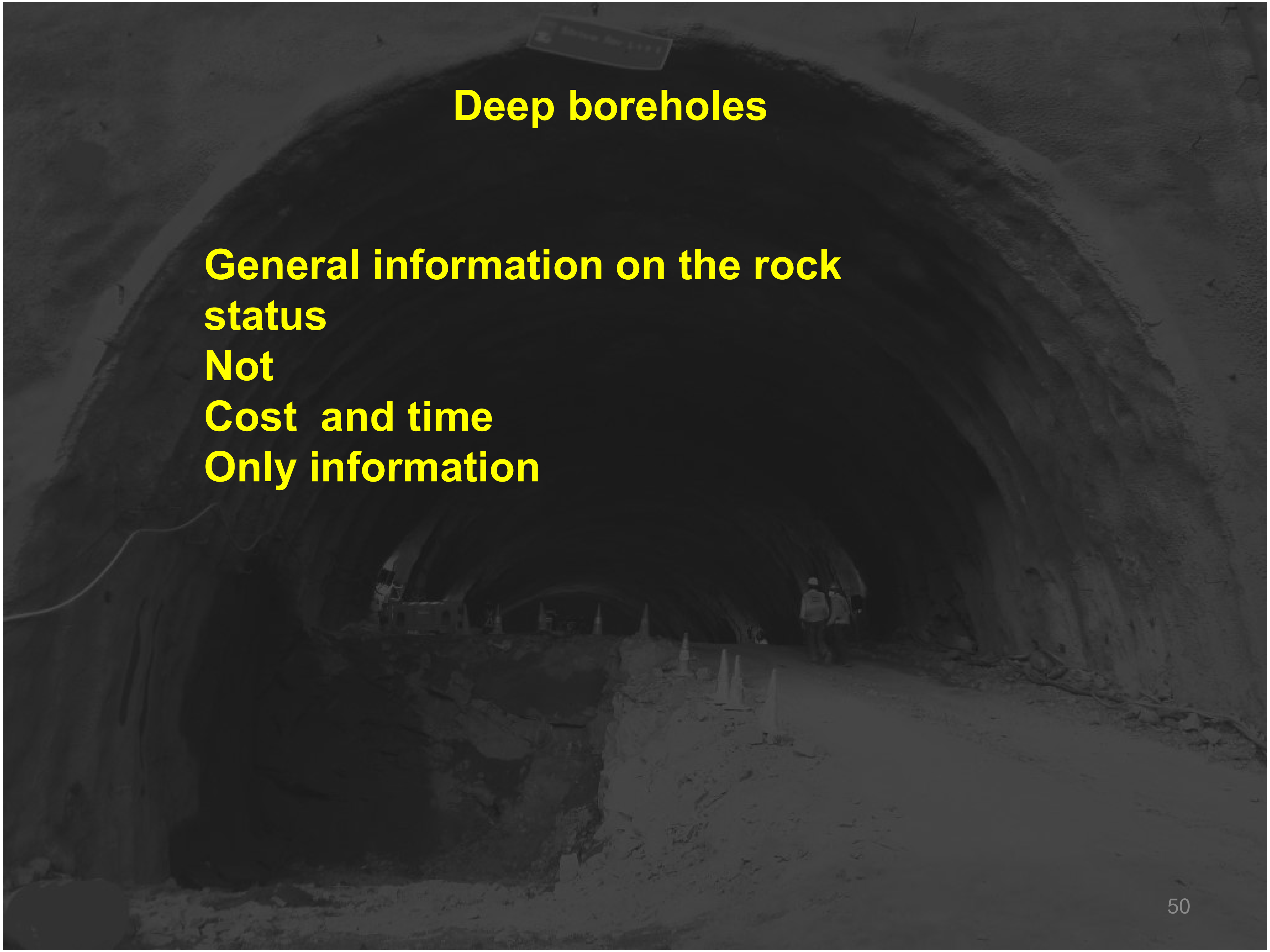
Deep boreholes





Deep bore holes in Zurich area till 2400 m depth

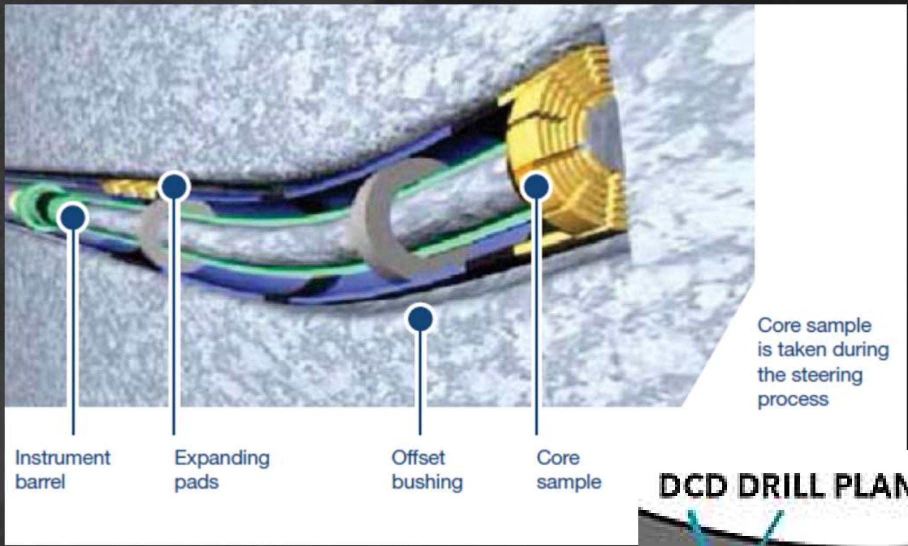
Overburden of Mount Blanc tunnel 2480 m

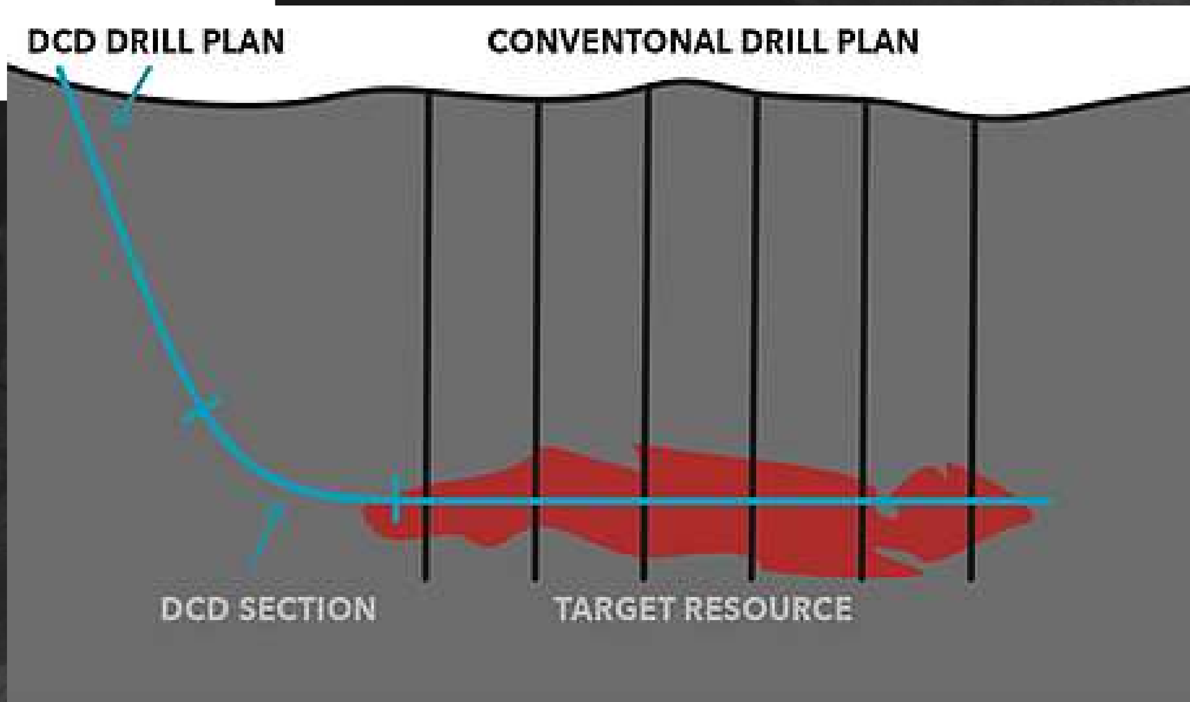


Deep boreholes

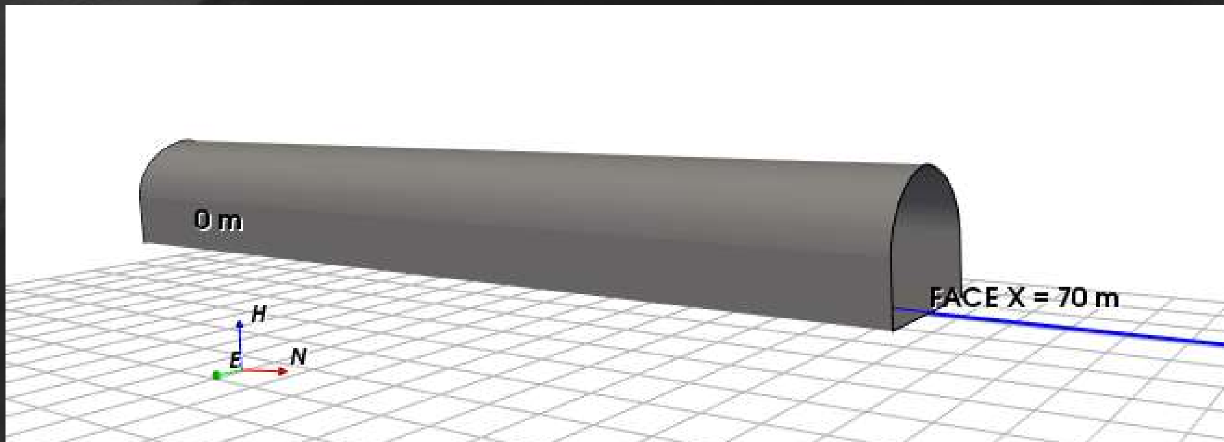
General information on the rock status
Not
Cost and time
Only information

Deviate bore hole

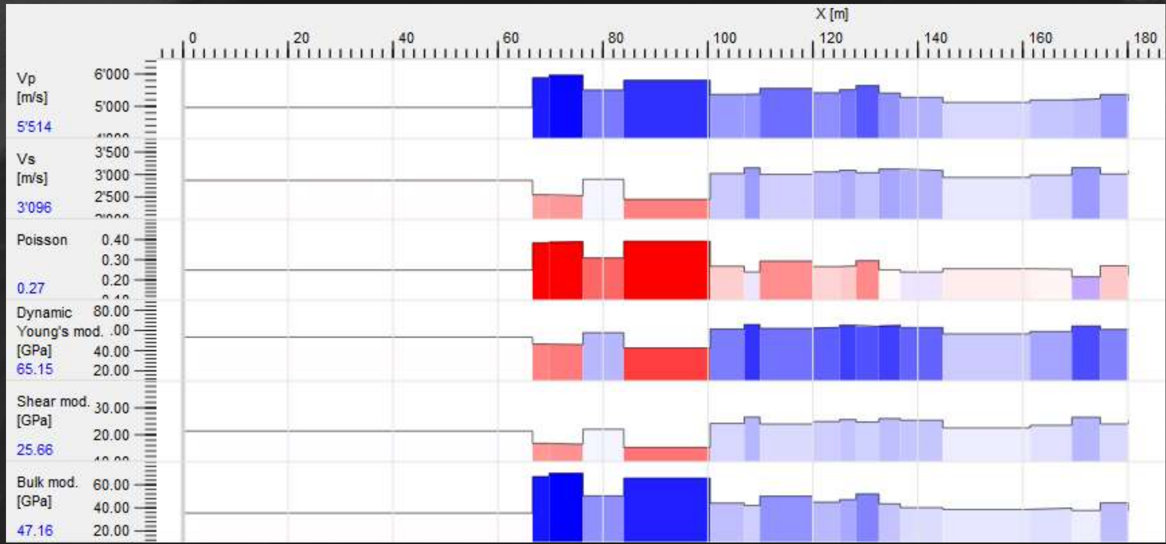


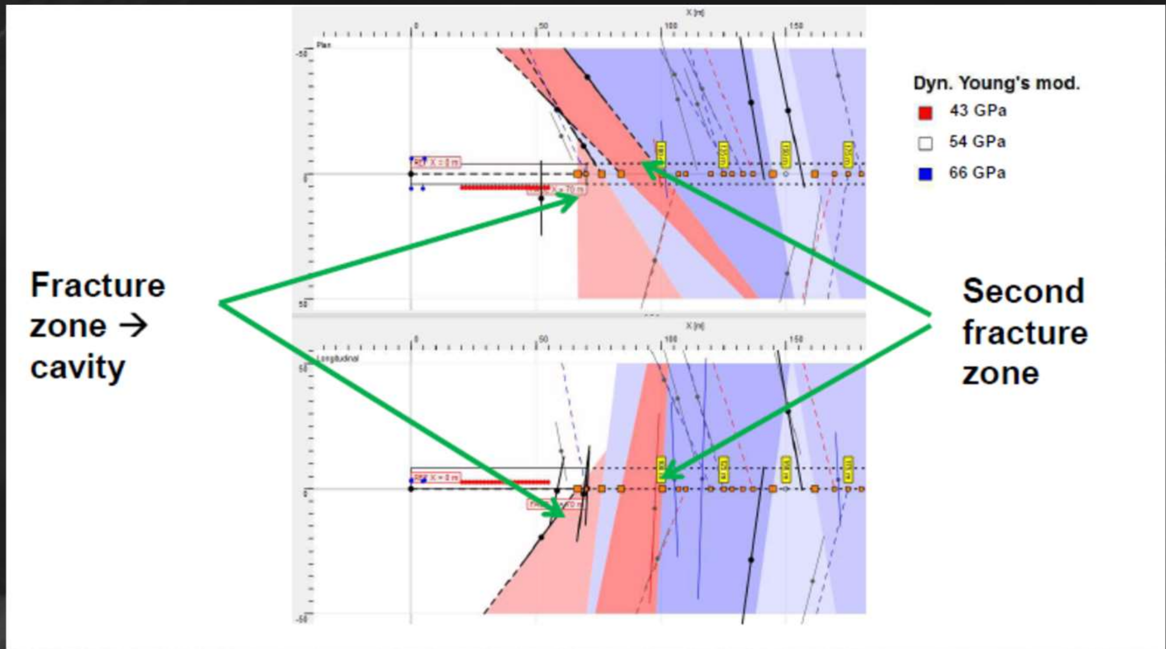


Tunnel T1 P2 seismic



Tunnel T1 P2 sismica





Tunnel T1 P2 sismica