ASSOCIATION INTERNATIONALE DES TUNNELS ET DE L'ESPACE SOUTERRAIN
AITES | ITA
INTERNATIONAL TUNNELLING AND UNDERGROUND SPACE ASSOCIATION

Lombardi

Geomechanical Hazard Based Design for Deep Rail Tunnels in The Himalayas - Case Study

NEW RAIL LINK BETWEEN RISHIKESH AND KARANPRAYAG – PACKAGE 1 & 8

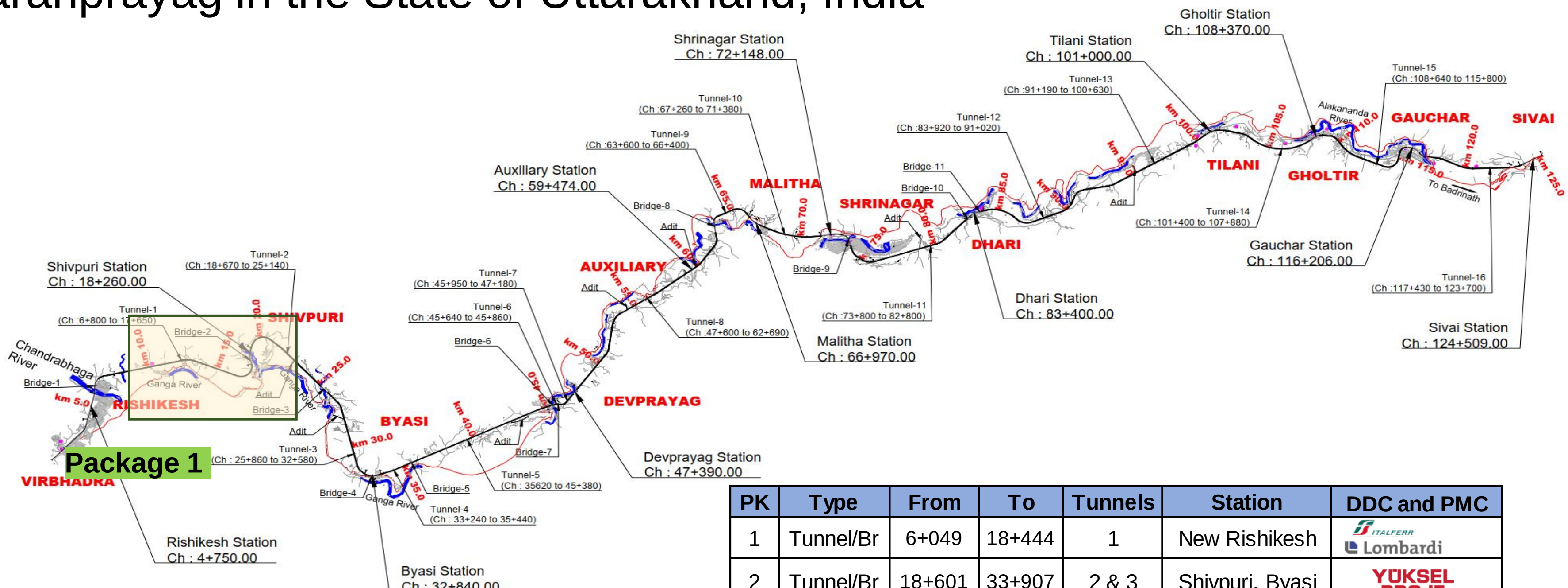
MMRDA Conference Hall, Mumbai, 24.06.2022

Content

- Project – Layout, Schematics and Challenges
- Functional Cross Sections
- Design Phase Development
- Design Criteria
- Design Verification

The Project

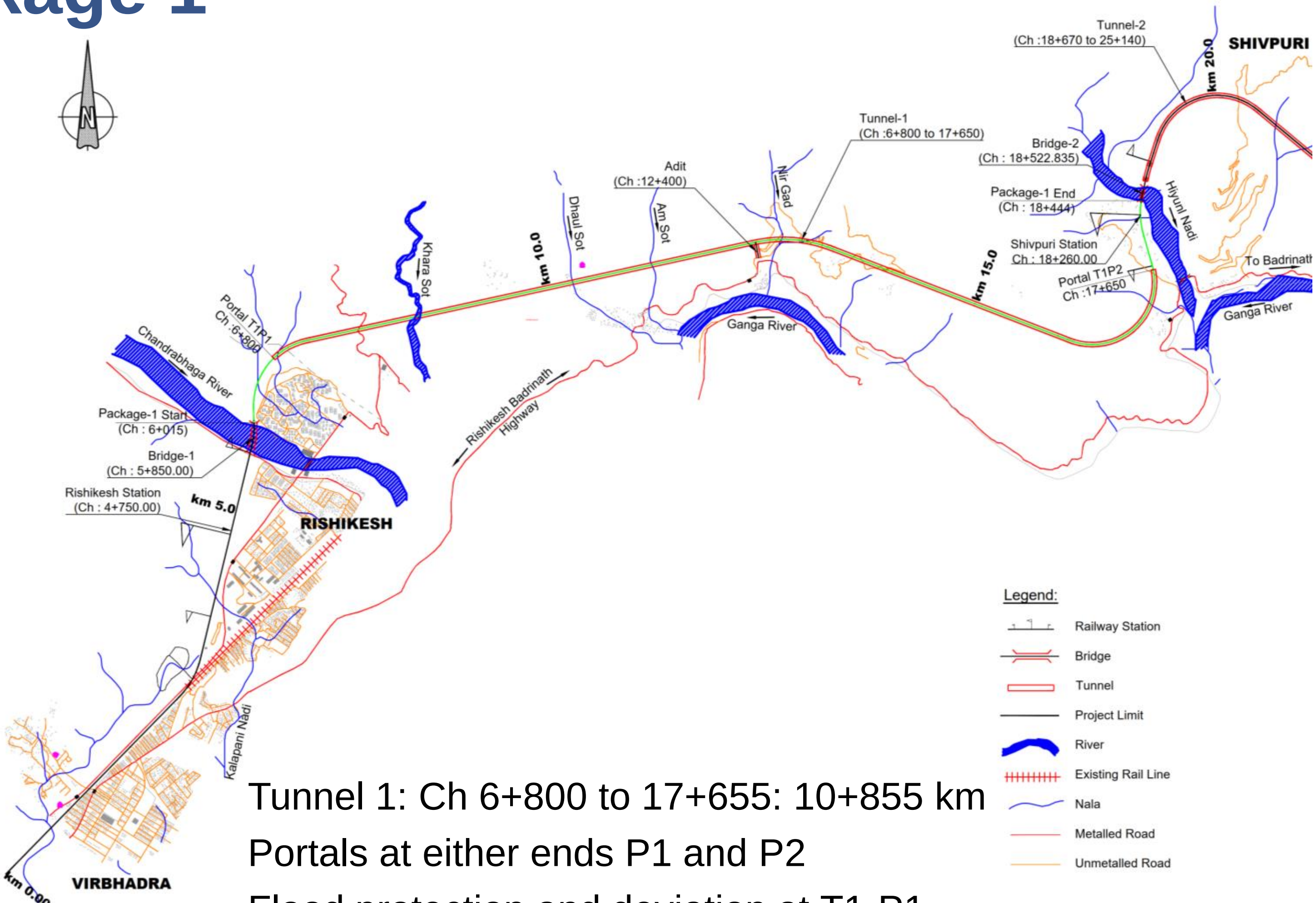
125 km long New Broad Gauge Rail Link Between Rishikesh and Karanprayag in the State of Uttarakhand, India



PK	Type	From	To	Tunnels	Station	DDC and PMC
1	Tunnel/Br	6+049	18+444	1	New Rishikesh	Italferr / Lombardi
2	Tunnel/Br	18+601	33+907	2 & 3	Shivpuri, Byasi	YÜKSEL PROJE
3	Tunnel/Br	33+907	47+630	4, 5, 6 &7	Byasi, Devprayag	GEODATA
4	Tunnel/Br	47+360	63+117	8	Devprayag	ALTINOK
5	Tunnel/Br	63+460	73+018	9, 10	Srinagar, Maletha	YÜKSEL PROJE
6	Tunnel/Br	73+489	83+899	11	Dhaari	AECOM
7	Tunnel/Br	83+899	101+310	12, 13	Tilani	AECOM
8	Tunnel/Br	101+310	116+911	14, 15	Golthir, Gaucher	Italferr / Lombardi
9	Tunnel/Br	117+365	125+172	16 &16A	Sivai	ALTINOK

- 13 stations & 16 tunnels
- 105.47 km Main Tunnels
- 98.54 km Escape Tunnels
- 35 bridges, 16 major bridges
- Divided into 9 Packages

Package 1



Tunnel 1: Ch 6+800 to 17+655: 10+855 km

Portals at either ends P1 and P2

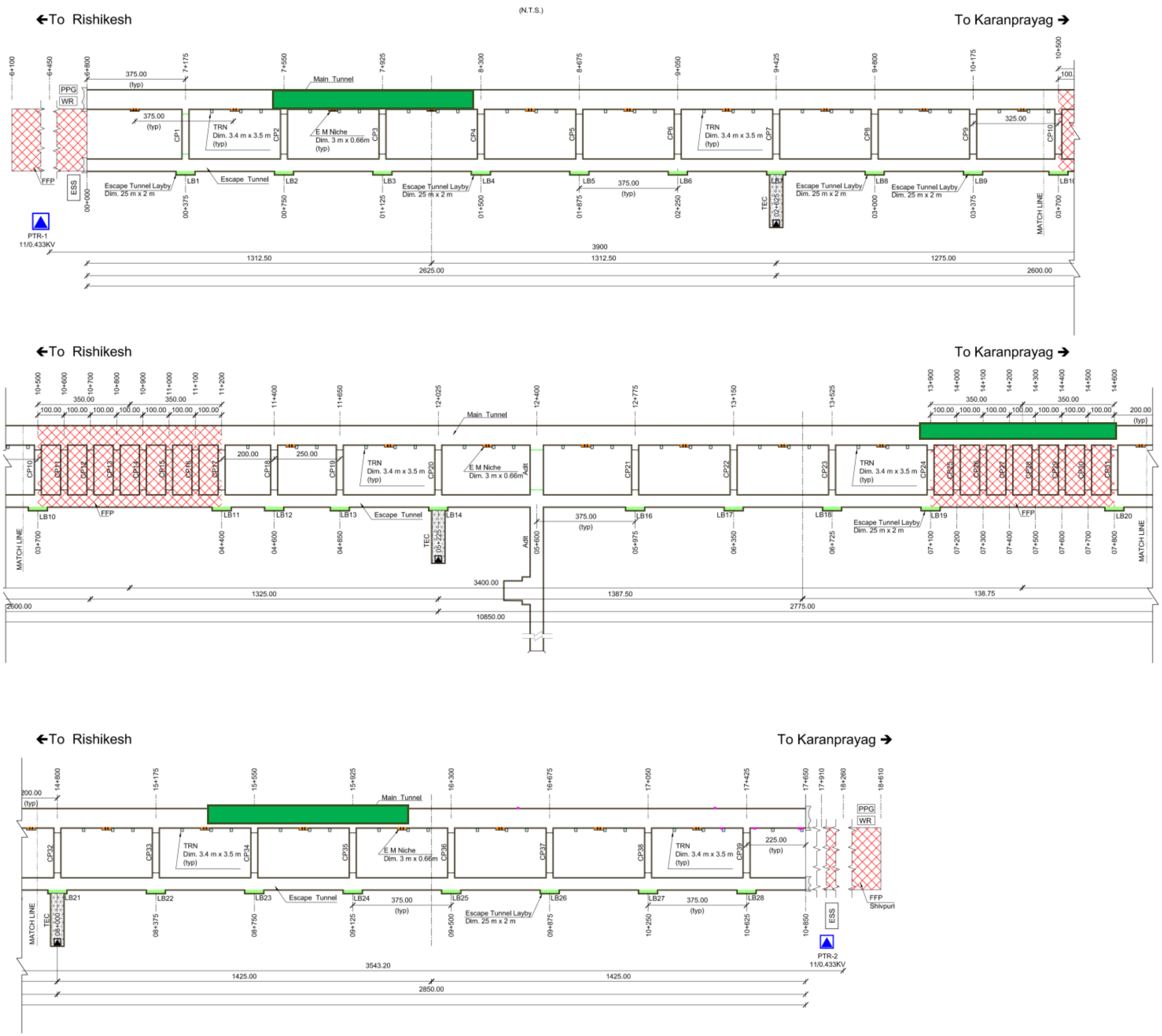
Flood protection and deviation at T1-P1

1 construction adit: Ch 12+400 km

Shivpuri station Yard (proof check and supervision included)

3 minor bridges and culverts (proof check and supervision included)

Tunnel Schematics – General arrangement



Legend :

(E&M Niche symbol)	E&M Niche
WR	Water reserve for fire fighting system
PPG	Pressurization pump for fire fighting system
LB	Escape tunnel layby
E M Niche	Electro-mechanical niche
CP	Cross passage
TEC	Technical room
TB	Turning bay
T1P1	Tunnel 1 Portal 1
T1P2	Tunnel 1 Portal 2
(Portal symbol)	Portal
(Fire fighting point symbol)	Fire fighting point (FFP)

Technical rooms every 2.5 km

Cross passages every 375 m

Cross-Passages every 100m at FFP

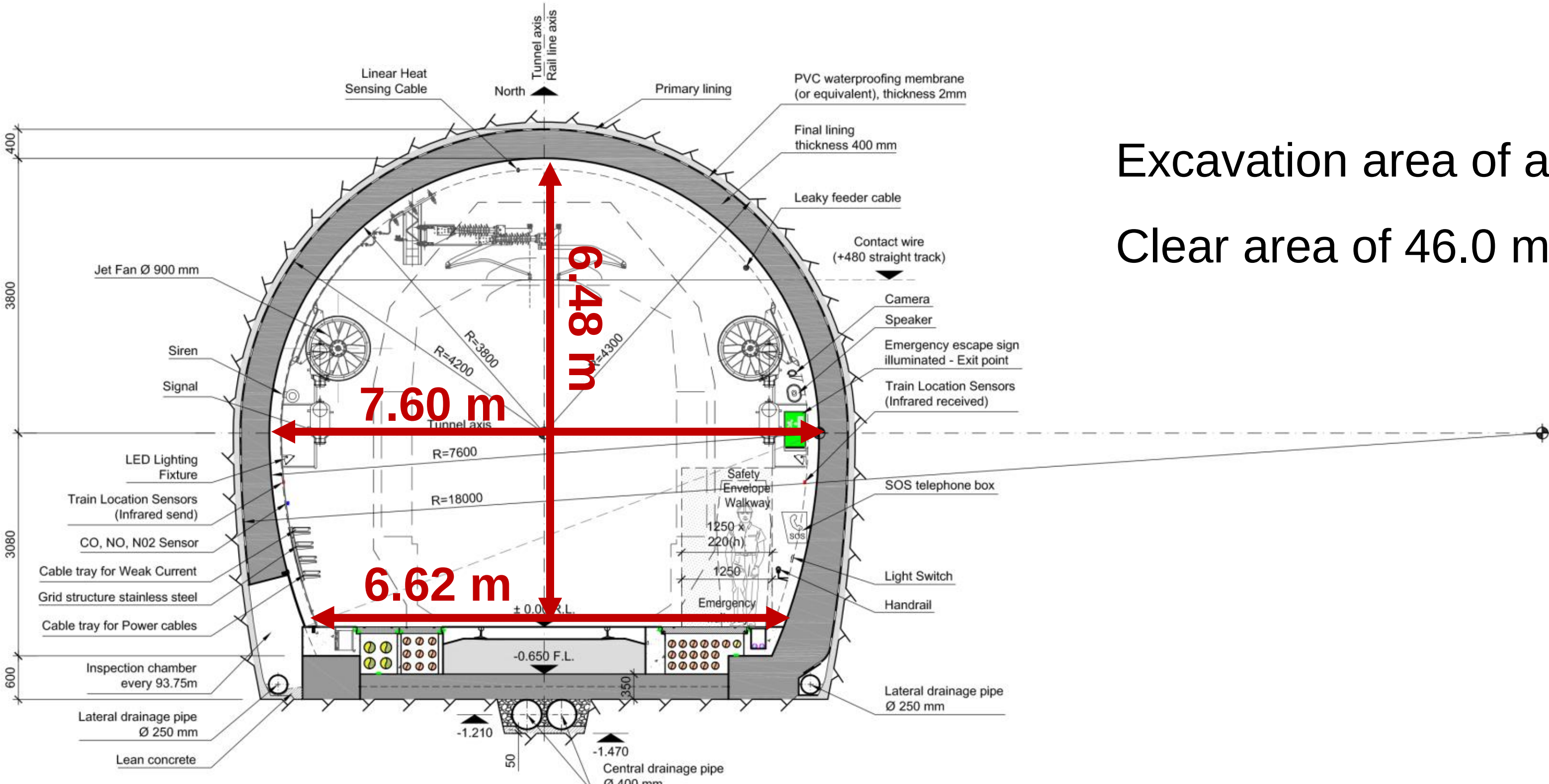
Firefighting (TBC) and E&M niches

Challenges – Geological and Geomechanical

- Generally difficult and **complex excavation conditions**
- **Major tectonic features** in the tunnel : Main Boundary Thrust, Garhwal Syncline – possibility of presence of faults and sheared zones are high
- Existence of most common and probably problematic rock type – **shales** through out the tunnel
- Tunnel passes through at least 4 lateral valleys (and streams) – posing **water ingress** problems; **karstic phenomena** in limestone deposits
- Most challenging - in its initial part (ch 6+800 to 8+569) composed nearly cohesionless **soil under low overburden**
- **Overburden** reaches values of 715 m
- The design in general suffers however of a general **lack in investigation data**

Tunnel 1 is more challenging with respect to those posed by the nature than the logistics.

Cross section – MT without invert



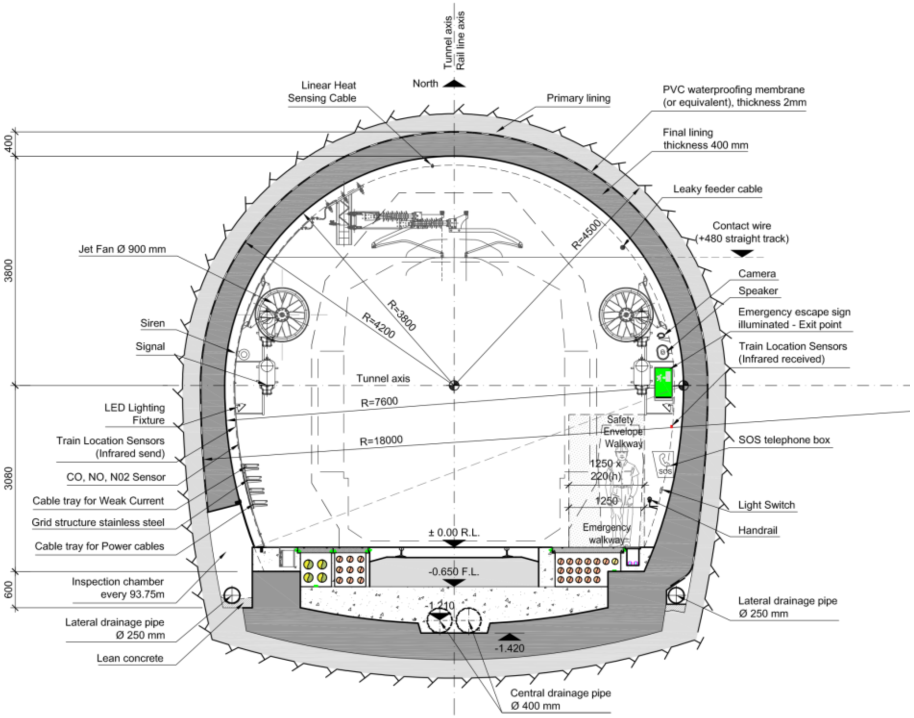
Excavation area of about 60.0 m^2

Clear area of 46.0 m^2

- Excavation and primary support according to the extrados geometry and the corresponding support class
- Final lining to be cast in place with steel reinforced concrete or SFRC
- At the intrados of the primary support one layer of geotextile to be installed so as to protect the waterproofing membrane from puncturing
- Double layer waterproofing membrane shall be installed.
- Ballast Less slab with height of 650mm and width of 2800mm (out of scope of works of the DDC, confirmation is required by the Client)

Cross section – MT

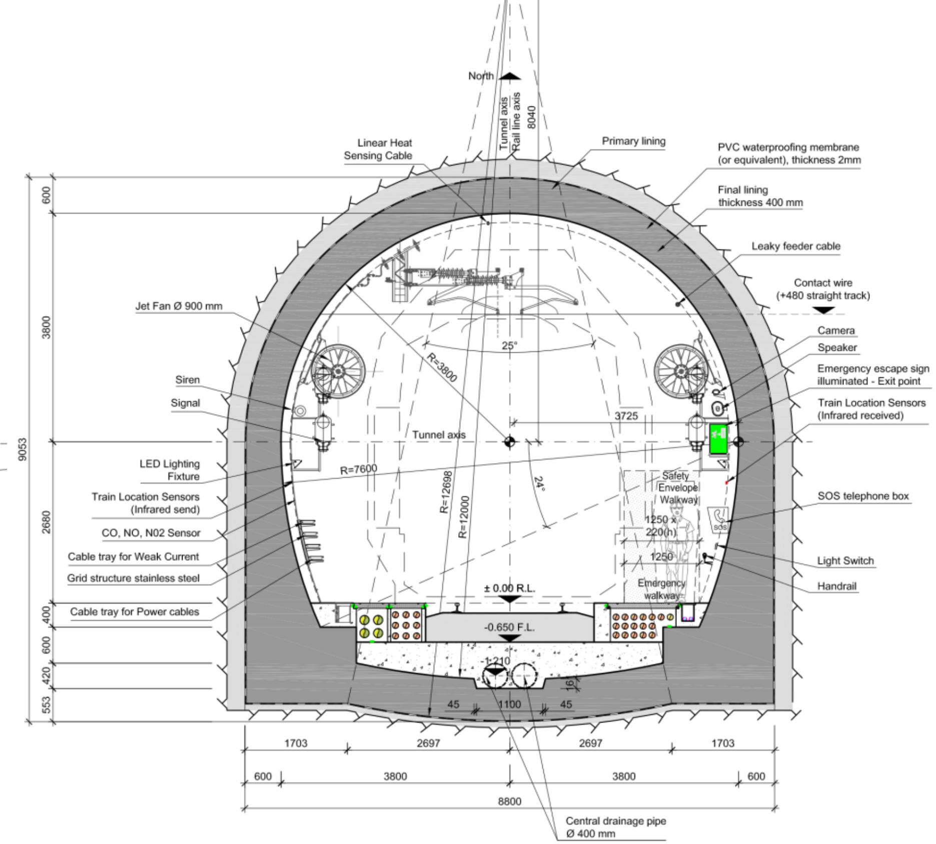
Main Tunnel with Invert



Excavation area of about $72.0m^2$

Clear area of $46.0\ m^2$

Main Tunnel Shallow soil cover

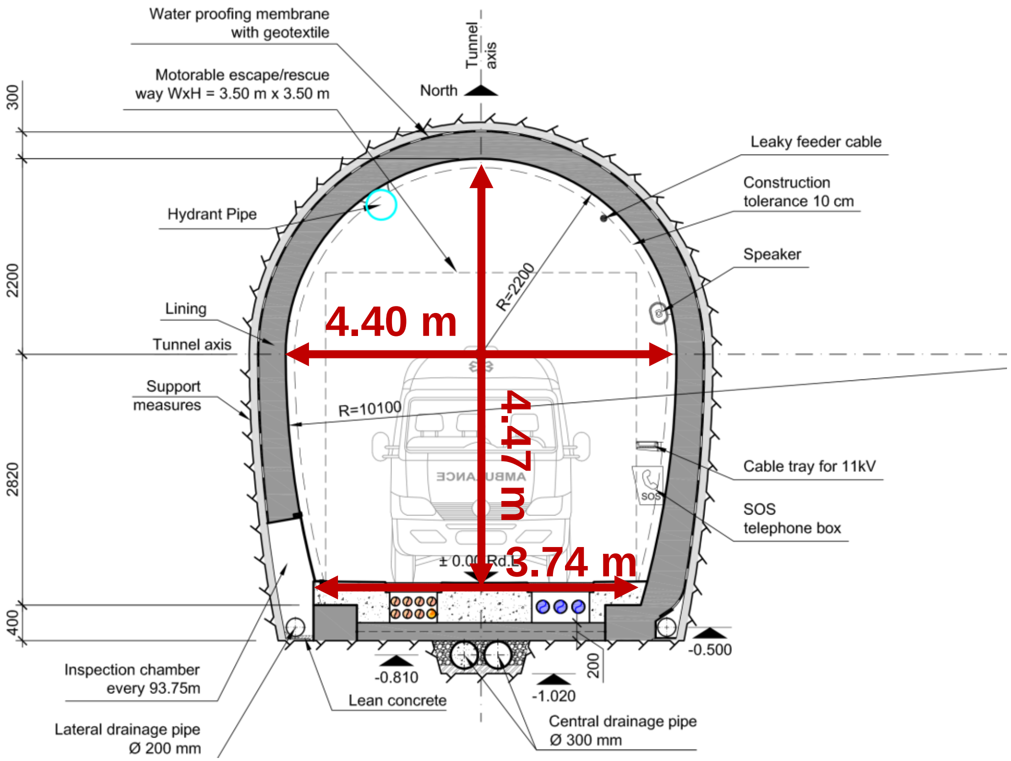


Excavation area of about $77.8m^2$

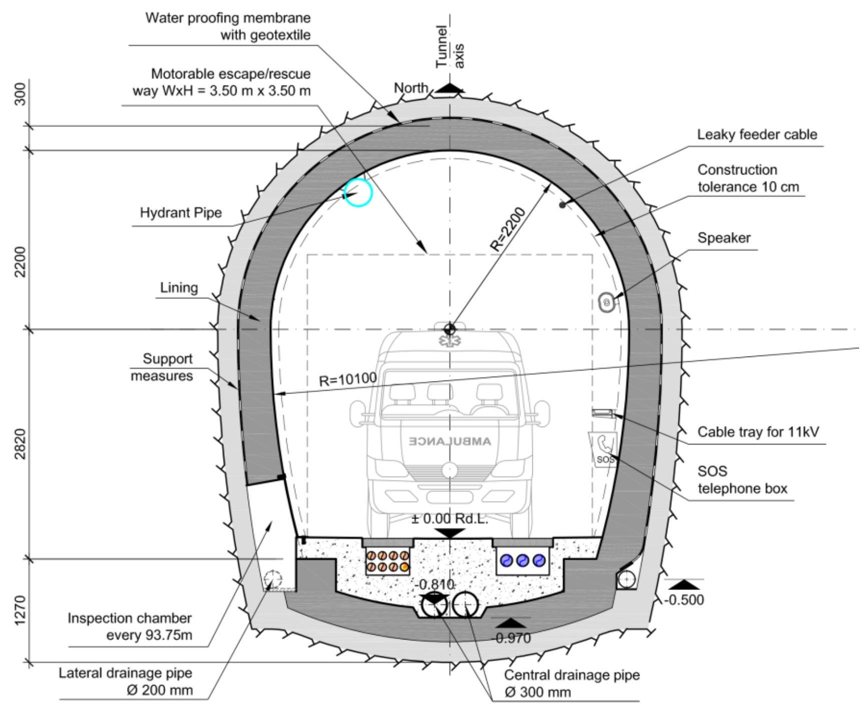
Clear area of $46.0\ m^2$

Cross section – ET

Escape Tunnel without Invert



Escape Tunnel with Invert



Excavation area of about 27.2 m^2

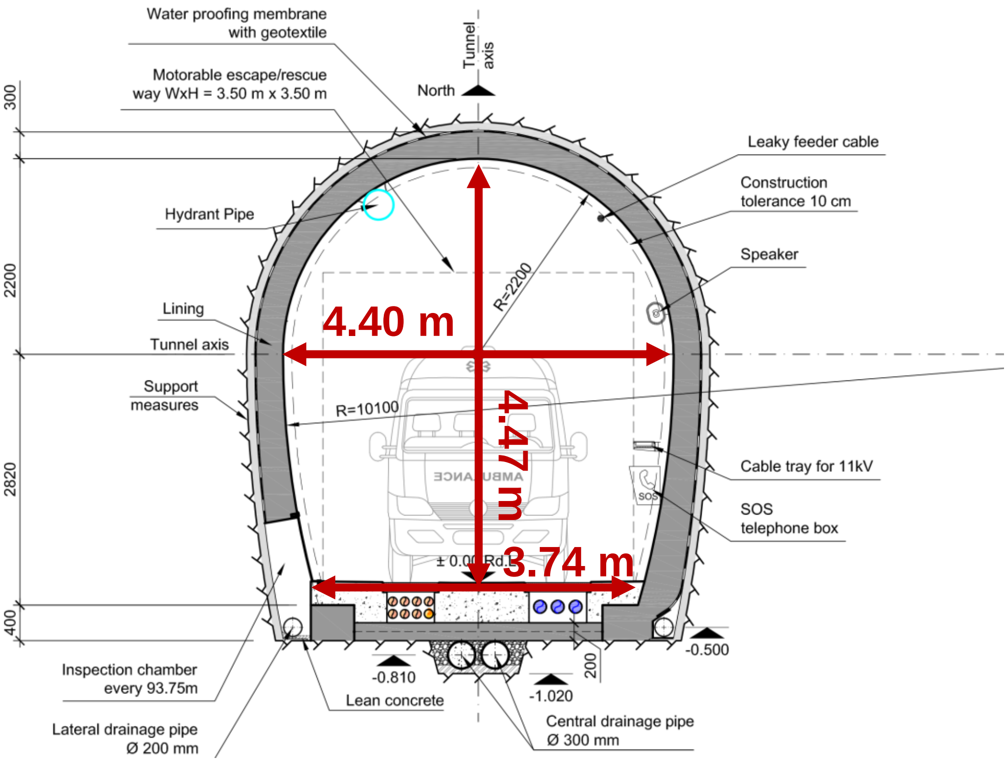
Clear area of 18.4 m^2

Excavation area of about 33.9 m^2

Clear area of 18.4 m^2

Cross section – CP

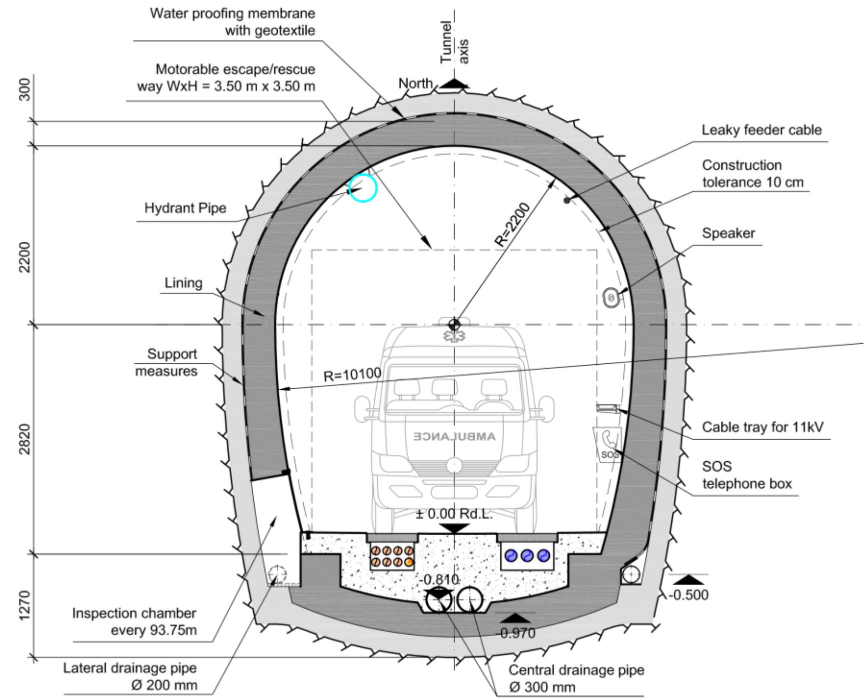
Cross Passage without Invert



Excavation area of about 27.2 m^2

Clear area of 18.4 m^2

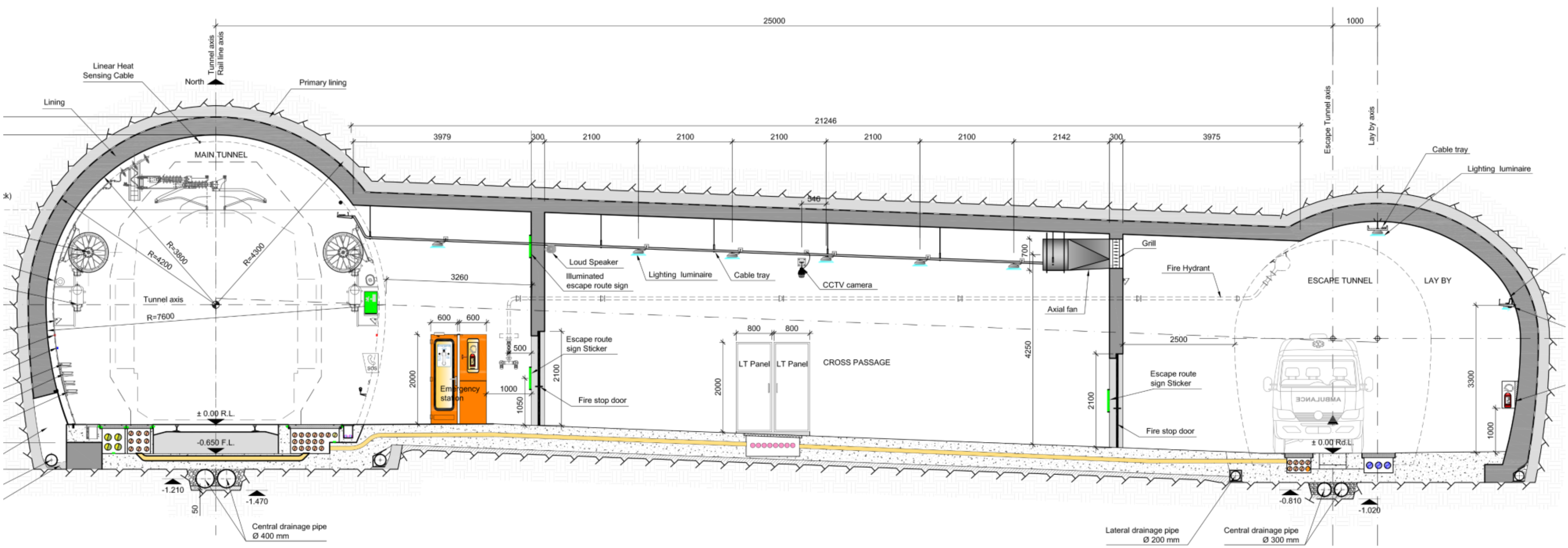
Cross Passage with Invert



Excavation area of about 33.9 m^2

Clear area of 18.4 m^2

Cross section – MT/CP/ET/Layby



Layby section at the junction CP-ET

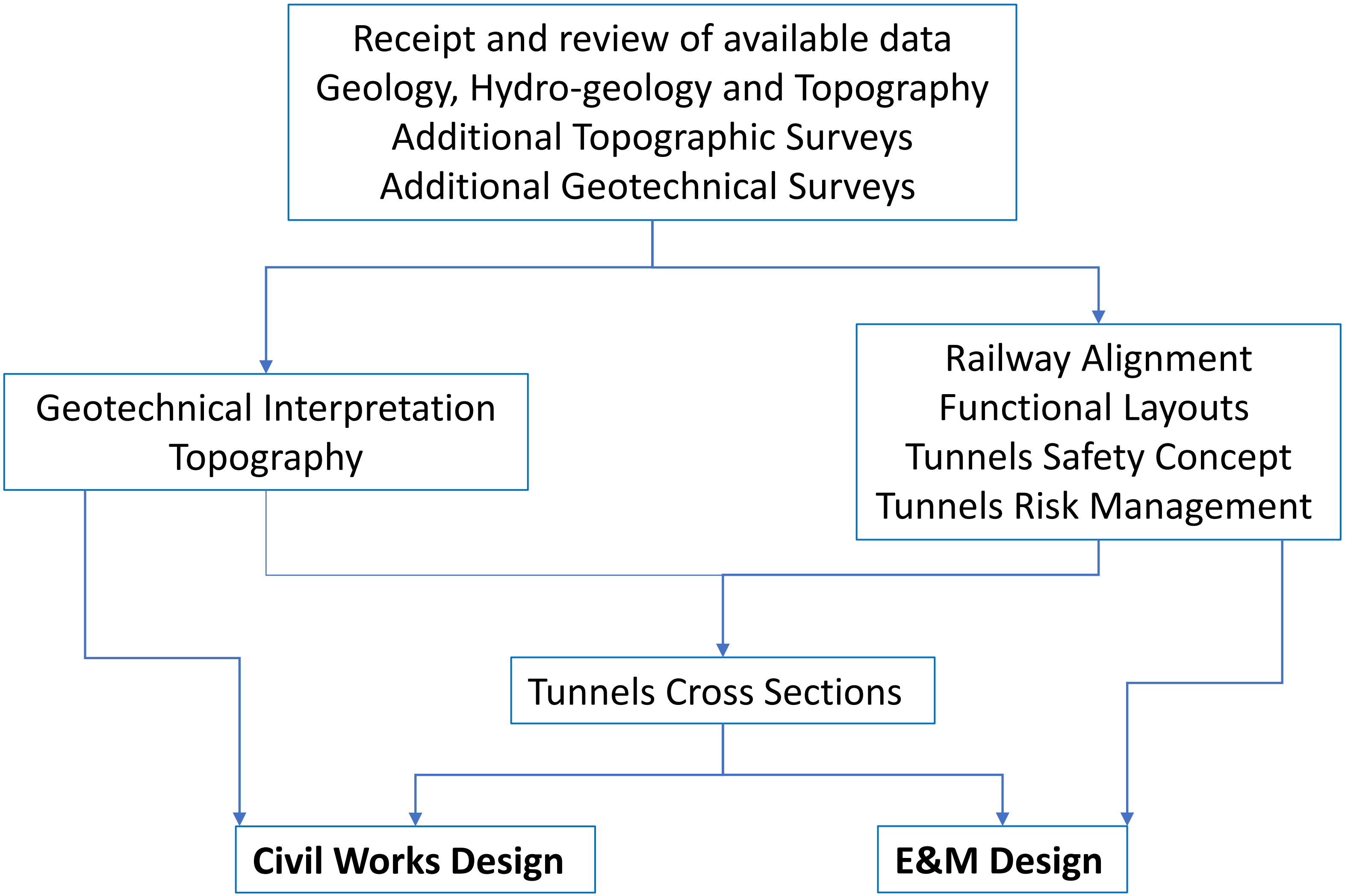
Double door concept for self rescue

LT panels in the ET

Attention to the rooting of the cables from the ET to the MT – requirement of enlarged E&M shafts

Hydrant connection point

Design phase development



Design phase development

Civil Works Design

E&M Design

Underground Structure Design

Geotechnical and geomechanical Design
Design Criteria
GBR
Tunnel Design
Rock Support Design
Final lining Design
Drainage Design
Technical Rooms, Niches, Firefighting system
Portals and portal structures

Overground Structures Design

Access Roads Alignment and related structures
Minor Bridges
Culverts + Other Drainage Works
Master Layout of Shivpuri Station
Access Roads Lighting
Utilities + Rail/Road Earthworks
Earthworks for Station Yards and Emergency Areas
Construction Sites

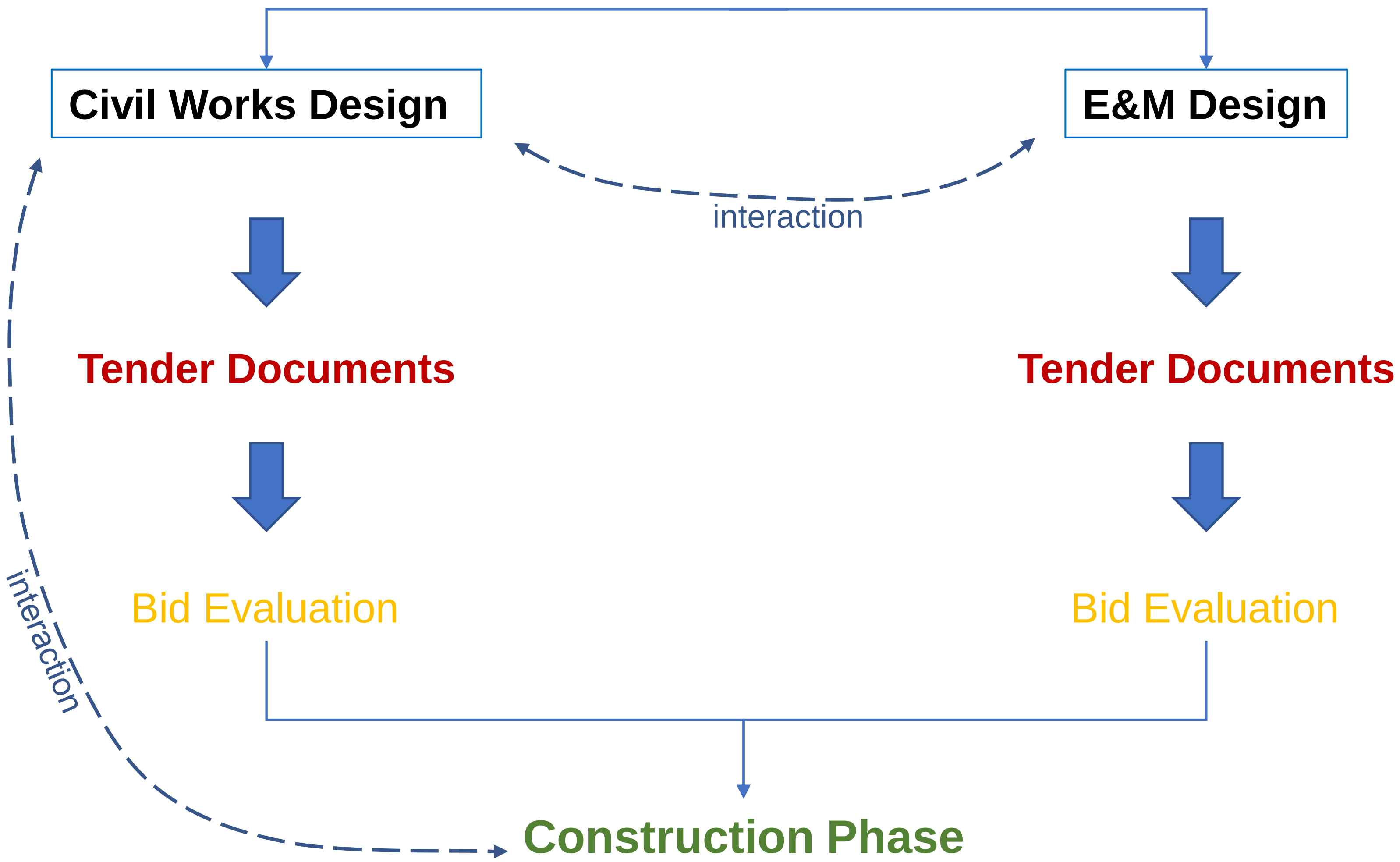
E&M Design

Design Criteria
Electric Traction / OHE
One (1) Electric Substation (ESS)
Power Distribution, Earthing and Bonding
Power Supply for MEP equipment
MEP equipment for Tunnels
MEP equipment for Stations and Technological Buildings
Telecommunication Systems (related to Safety - concept)
Tunnel ventilation design

Environmental Study and Mitigation Measures

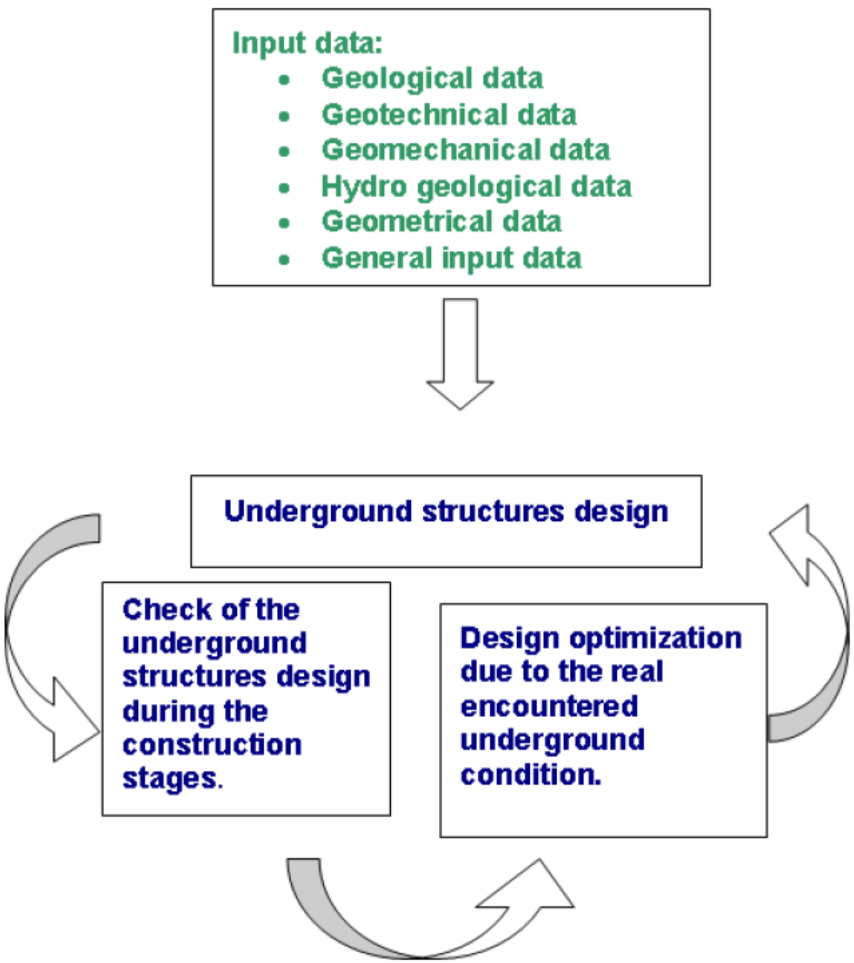
Quality (QA/QC)

Design phase development

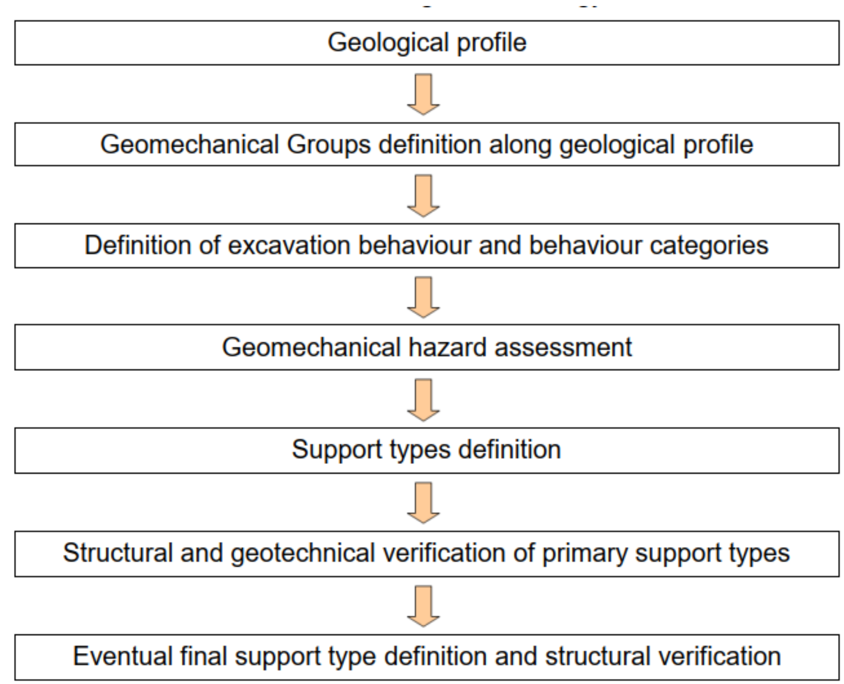


Design phase development

Observational Method

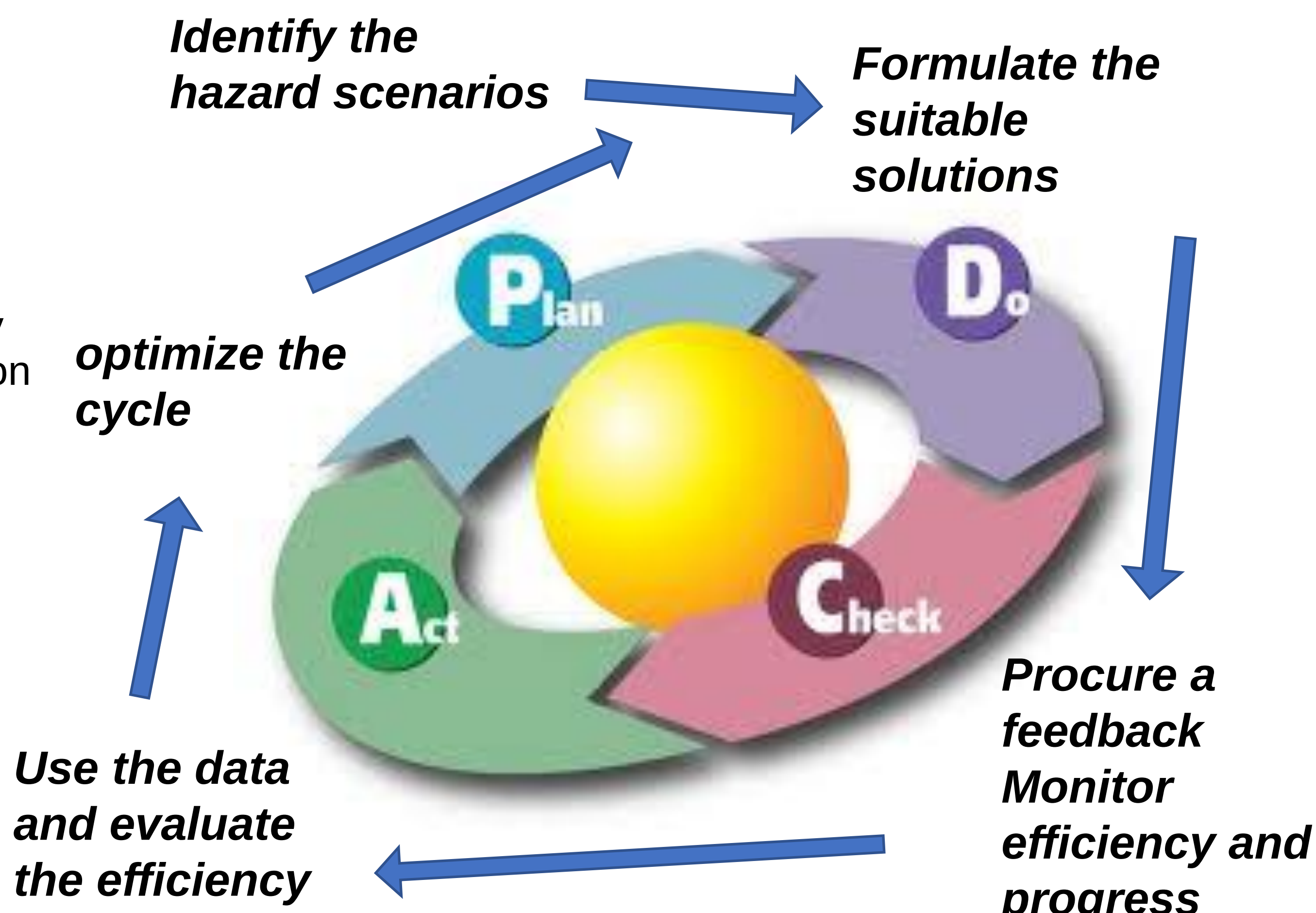


Design Methodology



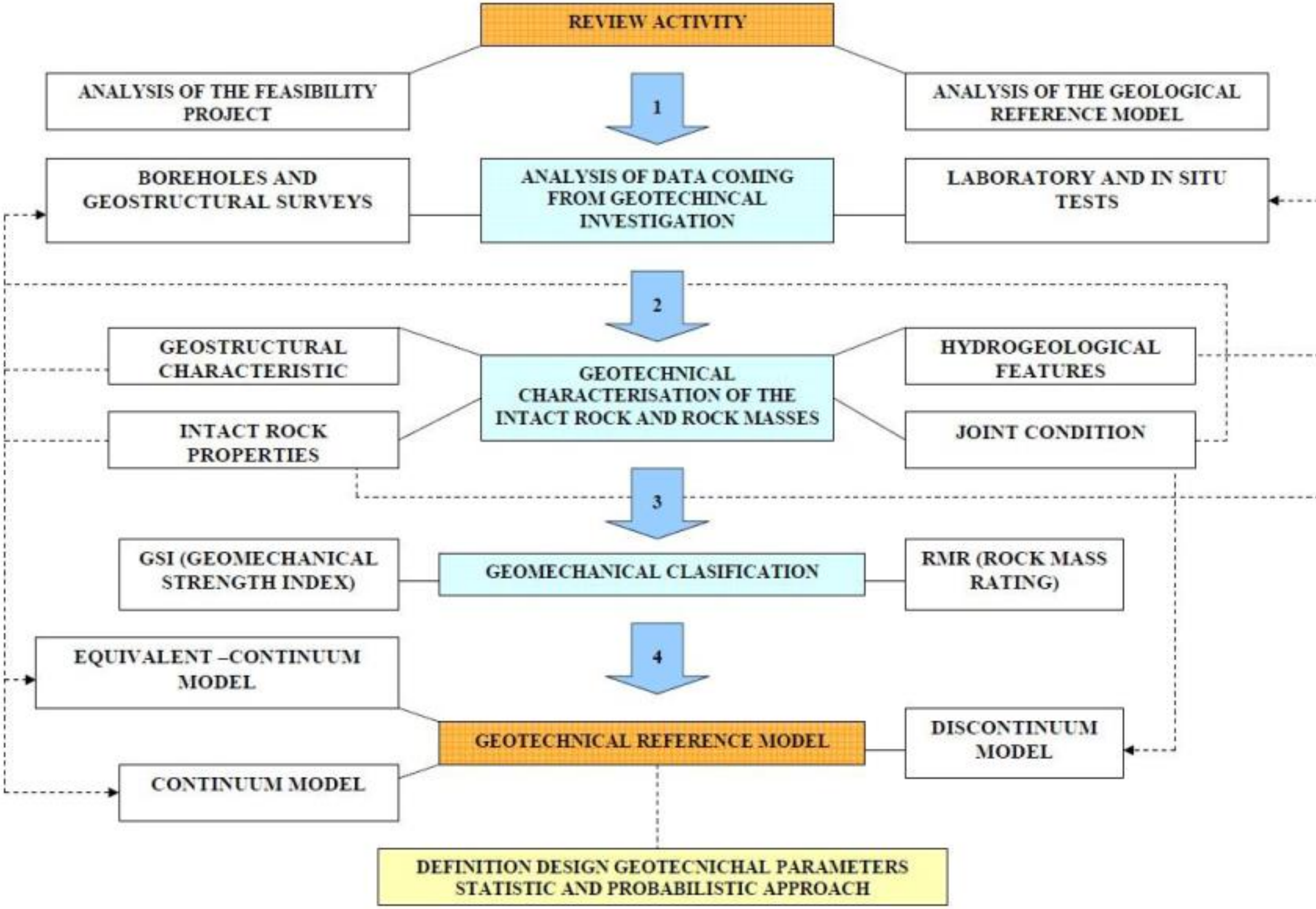
Observational Method – Origin (industrial)

- Field measurement – Surface mapping & monitoring
- Back analysis – from monitoring
- Assessment of stability and design/ construction methods
- Construction Phase – support selection



PDCA quality cycle, 1951, Deming (development plan for the Japanese industry)

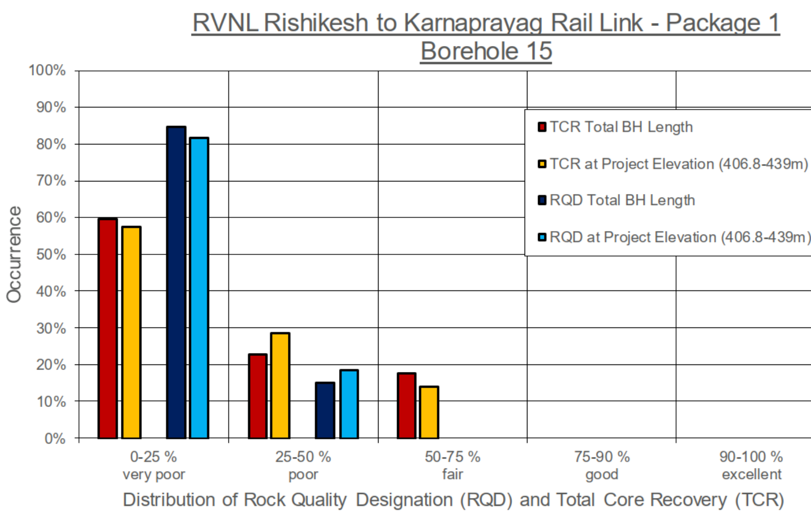
Geomechanical characterization of rock mass

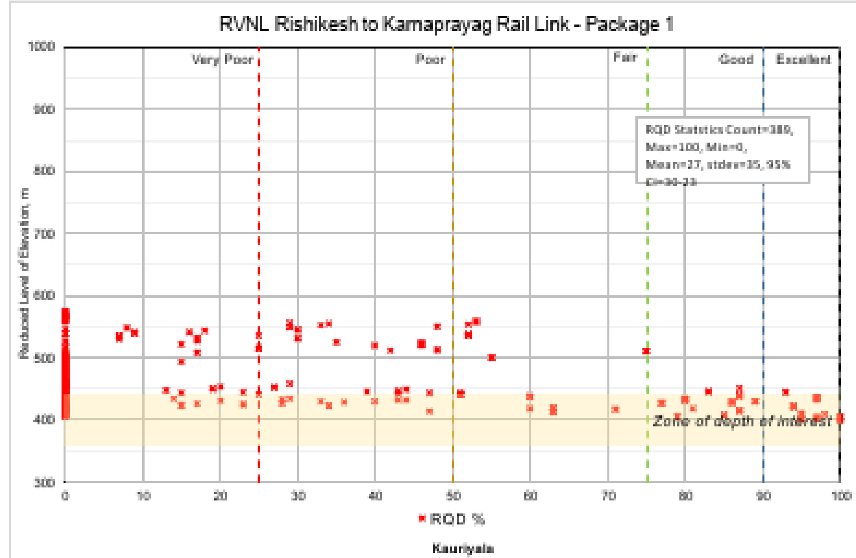


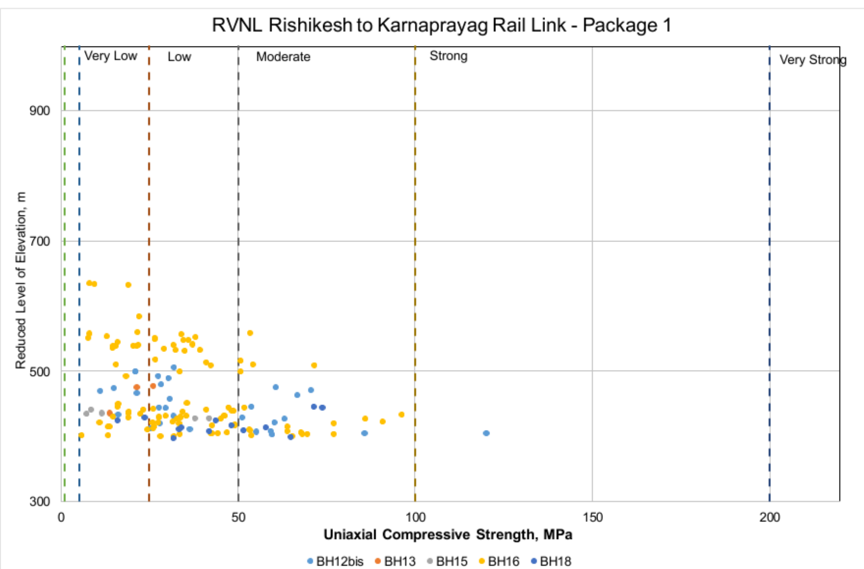
Geomechanical characterization of rock mass

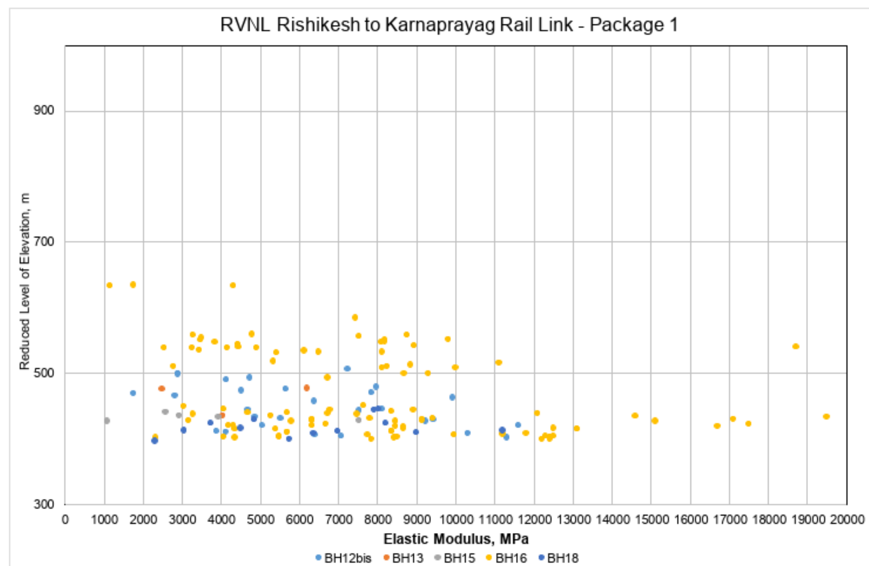
- Geostructural characterization of rock masses
- Intact rock parameters
- Geostructural analysis of discontinuities
- Shear strength of rock discontinuities
- Geomechanical Characterization
  - GSI (Geological Strength Index) - utilized for rockmass parameter calculation and to identify stress related hazards
  - RMR is utilized to complete the analysis of expected excavation behavior, mainly for its correlation with self-supporting capacity of rockmass
- Equivalent Mohr Coulomb parameters of rock mass

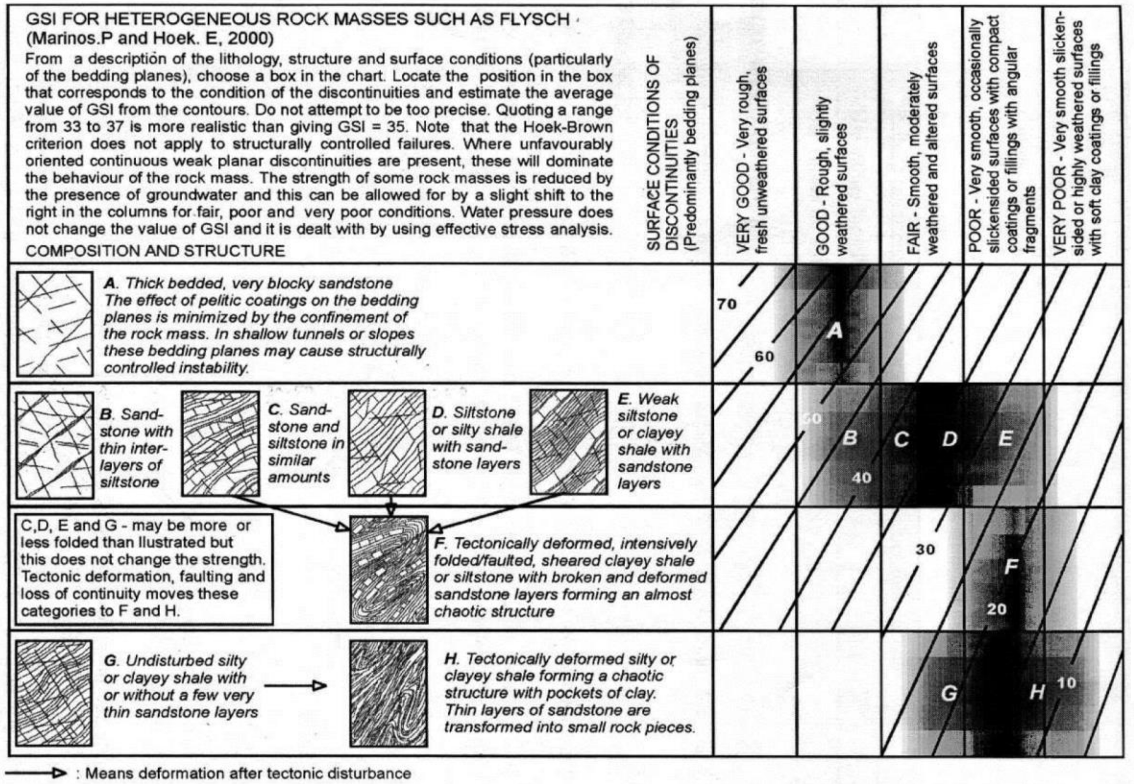
Rock mass parametrization

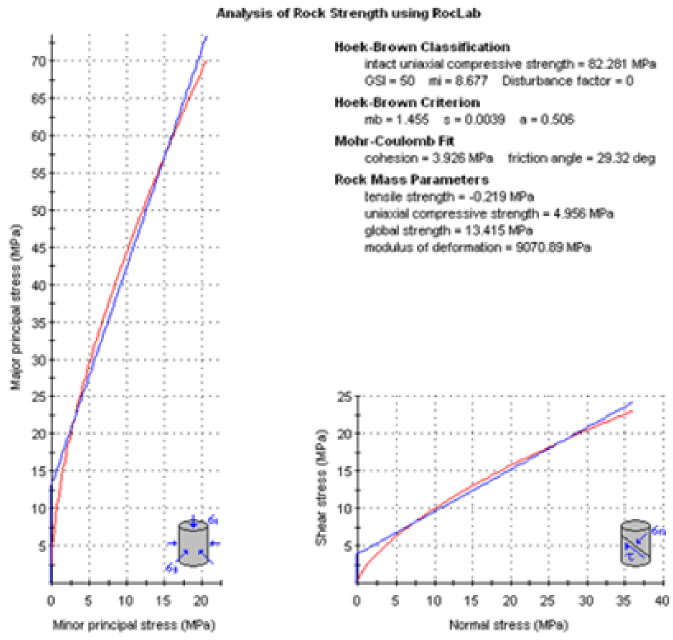


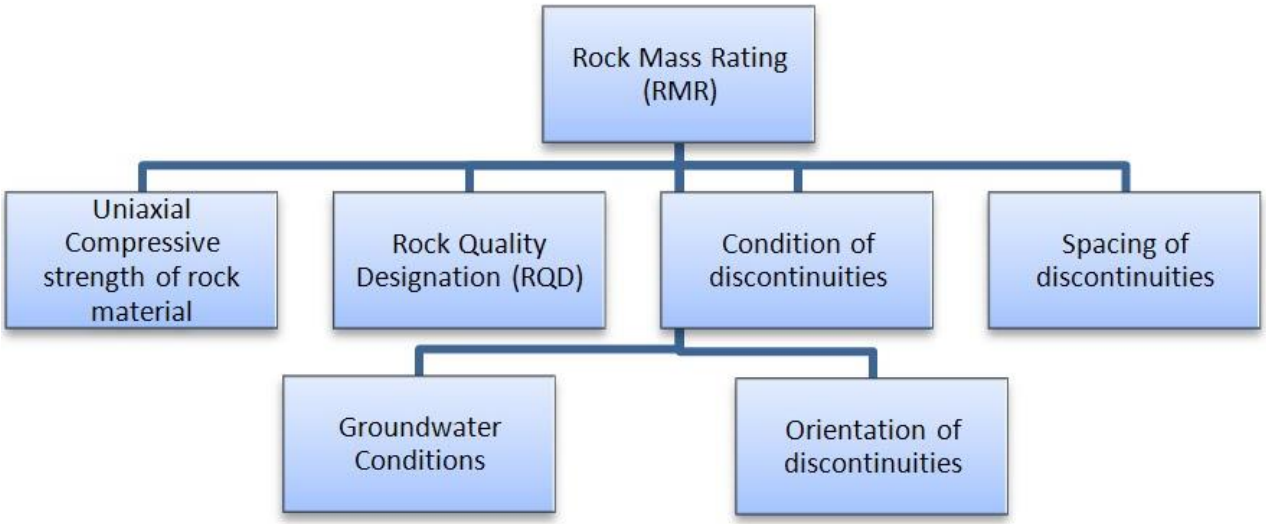




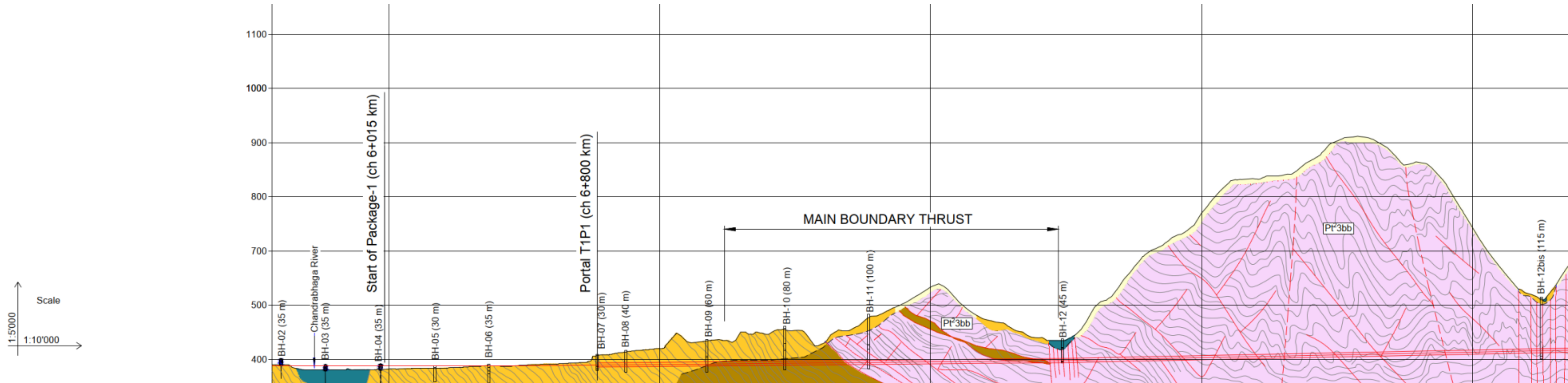



GSI FOR HETEROGENEOUS ROCK MASSES SUCH AS FLYSCH
(Marinos.P and Hoek. E, 2000)
From a description of the lithology, structure and surface conditions (particularly of the bedding planes), choose a box in the chart. Locate the position in the box that corresponds to the condition of the discontinuities and estimate the average value of GSI from the contours. Do not attempt to be too precise. Quoting a range from 33 to 37 is more realistic than giving GSI = 35. Note that the Hoek-Brown criterion does not apply to structurally controlled failures. Where unfavourably oriented continuous weak planar discontinuities are present, these will dominate the behaviour of the rock mass. The strength of some rock masses is reduced by the presence of groundwater and this can be allowed for by a slight shift to the right in the columns for fair, poor and very poor conditions. Water pressure does not change the value of GSI and it is dealt with by using effective stress analysis.
COMPOSITION AND STRUCTURE
SURFACE CONDITIONS OF DISCONTINUITIES (Predominantly bedding planes)
VERY GOOD - Very rough, fresh unweathered surfaces
GOOD - Rough, slightly weathered surfaces
FAIR - Smooth, moderately weathered and altered surfaces
POOR - Very smooth, occasionally slickensided surfaces with compact coatings or fillings with angular fragments
VERY POOR - Very smooth slicken-sided or highly weathered surfaces with soft clay coatings or fillings
A. Thick bedded, very blocky sandstone
The effect of pelitic coatings on the bedding planes is minimized by the confinement of the rock mass. In shallow tunnels or slopes these bedding planes may cause structurally controlled instability.
B. Sand-stone with thin inter-layers of siltstone
C. Sand-stone and siltstone in similar amounts
D. Siltstone or silty shale with sand-stone layers
E. Weak siltstone or clayey shale with sandstone layers
C,D, E and G - may be more or less folded than illustrated but this does not change the strength. Tectonic deformation, faulting and loss of continuity moves these categories to F and H.
F. Tectonically deformed, intensively folded/faulted, sheared clayey shale or siltstone with broken and deformed sandstone layers forming an almost chaotic structure
G. Undisturbed silty or clayey shale with or without a few very thin sandstone layers
H. Tectonically deformed silty or clayey shale forming a chaotic structure with pockets of clay. Thin layers of sandstone are transformed into small rock pieces.
70
60
A
50
B
C
D
E
40
30
F
20
G
H
10
: Means deformation after tectonic disturbance


Analysis of Rock Strength using RocLab
Hoek-Brown Classification
intact uniaxial compressive strength = 82.281 MPa
GSI = 50 mi = 8.677 Disturbance factor = 0
Hoek-Brown Criterion
mb = 1.455 s = 0.0039 a = 0.506
Mohr-Coulomb Fit
cohesion = 3.926 MPa friction angle = 29.32 deg
Rock Mass Parameters
tensile strength = -0.219 MPa
uniaxial compressive strength = 4.956 MPa
global strength = 13.415 MPa
modulus of deformation = 9070.89 MPa
Major principal stress (MPa)
Minor principal stress (MPa)
Shear stress (MPa)
Normal stress (MPa)


Rock Mass Rating (RMR)
Uniaxial Compressive strength of rock material
Rock Quality Designation (RQD)
Condition of discontinuities
Spacing of discontinuities
Groundwater Conditions
Orientation of discontinuities

Geotechnical Parameters of Rock Mass



Chainage [m]	Project elevation [m asl]
5+600	387.86
5+700	388.00
5+800	388.00
5+900	388.00
6+000	388.00
6+100	388.00
6+200	388.00
6+300	388.00
6+400	388.00
6+500	388.00
6+600	388.39
6+700	388.86
6+800	389.33
6+900	389.80
7+000	390.27
7+100	390.74
7+200	391.22
7+300	391.69
7+400	392.16
7+500	392.63
7+600	393.10
7+700	393.57
7+800	394.05
7+900	394.52
8+000	394.99
8+100	395.46
8+200	395.93
8+300	396.40
8+400	396.88
8+500	397.35
8+600	398.29
8+700	399.32
8+800	400.35
8+900	401.38
9+000	402.41
9+100	403.44
9+200	404.47
9+300	405.50
9+400	406.52
9+500	407.55
9+600	408.58
9+700	409.61
9+800	410.64
9+900	411.67
10+000	412.70
10+100	413.73
10+200	414.76
10+300	415.79

Group	Parameter									
Geometry	Overburden, Min.-Max. [m]			12-51	34-56	25-54	34-136	31-37	44-396	88-127
Geology	Tectonic unit		Quaternary		Sub-Himalaya					
	Stratigraphic group		Quaternary		Siwalik Group		Baliana Group			
	Stratigraphic formation		Quaternary		Lower-middle Siwalik		Blaini			
	Rock, Soil type		Boulders, pebbles, gravel in silty sand		Sandstones and conglomerates		Dark grey laminated shales and quartz arenites			
	Fault / fracture zone					Main Boundary Thrust Fault Zone		Fault Zone	Disturbed Zone; Disturbed Zone	Fault Zone
Section number			-	1	2	3	4	5	6	7
Section length			785.00	421.08	315.20	169.14	764.58	99.05	1631.39	160.23
Intact rock properties (intervals referred to the main lithology)	Unconfined compressive strength [MPa]	A	-	-	30÷50	30÷50	10÷50	10÷50	10÷100	10÷100
	Elastic modulus, Ei [GPa]	B	-	-	0.3÷0.5	0.3÷0.6	1÷20	1÷20	1÷20	1÷20
	Structural anisotropy	C	-	-						
	Specific weight [kN/m³]	D	-							
Rock mass properties	Deformation modulus, Erm [GPa]	E	-	-	0.4	0.4	0.7	0.7	1.8	1.3
	Friction Angle (φ) [°]	F	-	-	41	42	32	41	30	37
	Cohesion [MPa]	G	-	-	0.2	0.2	0.3	0.2	0.9	0.4
Discontinuities – Bedding / Foliation	Orientation (axis relative) [°]	H	-	-						
Discontinuities – Characteristic strength	Friction angle, φ [°]	I	-	-	30	30	33	34	33	32
	Cohesion [kPa]	J	-	-	0.00	0.00	30	28	39	76
Hydrogeology	Circulation type	K	-	-						
	Water pressure [bar]	L	-	-						
	Permeability [Lugeon units]	M	-	-						
	Expected condition	N	-	-						
Abrasivity [CAI]			-		2÷6		1÷3			
Temperature [°]			-	-	16	16	18	16	25	18

Geotechnical Parameters of Rock Mass

				1	2	3	4
Intact Rock Properties (Intervals Referred to the Main Lithology)	A	Unconfined Compressive Strength [MPa]	MPa	Very high, > 100	Medium, 50 - 100	Low, 10 - 50	Very low, < 10
	B	Deformation Modulus (Ei) [GPa]	Gpa	Very high, > 75	High, 50 - 75	Medium, 25 - 50	Low, < 25
	C	Structure Anisotropy	-	Massive (isotropic)	Low Anisotropy	Medium Anisotropy	Strong Anisotropy
	D	Specific Weight [kN/m^3]	kN/m^3				
Rock Mass Properties	E	Deformation Modulus (Em) [GPa]	Gpa	High, > 25	Medium, 10 - 25	Low, 2 - 10	Very low, < 2
	F	Friction Angle (φ) [°]	-	High, > 40	Medium, 30 - 40	Low, 20 - 30	Very low, < 20
	G	Cohesion [MPa]	MPa	High, > 2	Medium, 0.2 - 2	Low, 0.02 - 0.2	Very low, < 0.02
Discontinuities – Bedding / Schistosity	H	Orientation (axis relative) [°]	-	Very favourable	Favourable	Unfavourable	Very Unfavourable
Discontinuities – Characteristic Strength	I	Friction Angle (φ) [°]	-	High, > 40	Medium, 30 - 40	Low, 20 - 30	Very low, < 20
	J	Cohesion [kPa]	MPa	High, > 2	Medium, 0.2 - 2	Low, 0.02 - 0.2	Very low, < 0.02
Hydrogeology	K	Circular Type	-	none	Pores	Fractures	Karst
	L	Water Pressure[bar]	Bar	Low, < 1	Medium, 1 - 5	High, 5 - 10	Very high, > 10
	M	Permeability (Lugeon) [L/m/min]	L/m/min	Very Low, < 1	Low, 1 - 5	Medium, 5 - 20	High, > 20
	N	Condition	-	Dry	Dripping a few small spring	Frequent smaller some large springs	Frequent larger springs large water flow

Geotechnical Parameters of Rock Mass

Indicative distribution of RMR classes in the tunnel stretch

	RMR I	RMR II	RMR III	RMR IV	RMR V	Soil	Total
%	1.6 %	2.4 %	42.4 %	40.9 %	8.8 %	3.9 %	100.0%
m	177 m	265 m	4,598 m	4434 m	954 m	421 m	10,850 m

Suggested preliminary characteristic parameters for soil

Project area	Typical soil	γ [kN/m³]	ϕp [°]	c [kPa]	ν [-]
Before Portal 1	GP-GM	19-21	35-40	0	0.3
Portal 1	SP-SM	18-20	34-37	0	0.3
Tunnel 1 in soil	SM	19	32-34	0	0.3
Portal 2	SP-SM	18-20	34-37	0	0.3

Hazard Definition

SITUATIONS - SCENARIOS

Block failure

Excavation face instability

"Plastic" deformations

High/low overburden

Ravelling material

Spalling - Rockburst

High water inflow

Aggressive water

Time dependant behaviour

Swelling

Modification of the rock characteristics

Strain softening/hardening

More ...

Particular pore pressure conditions

RECOVERY OF THE INFORMATION INVESTIGATION

↓

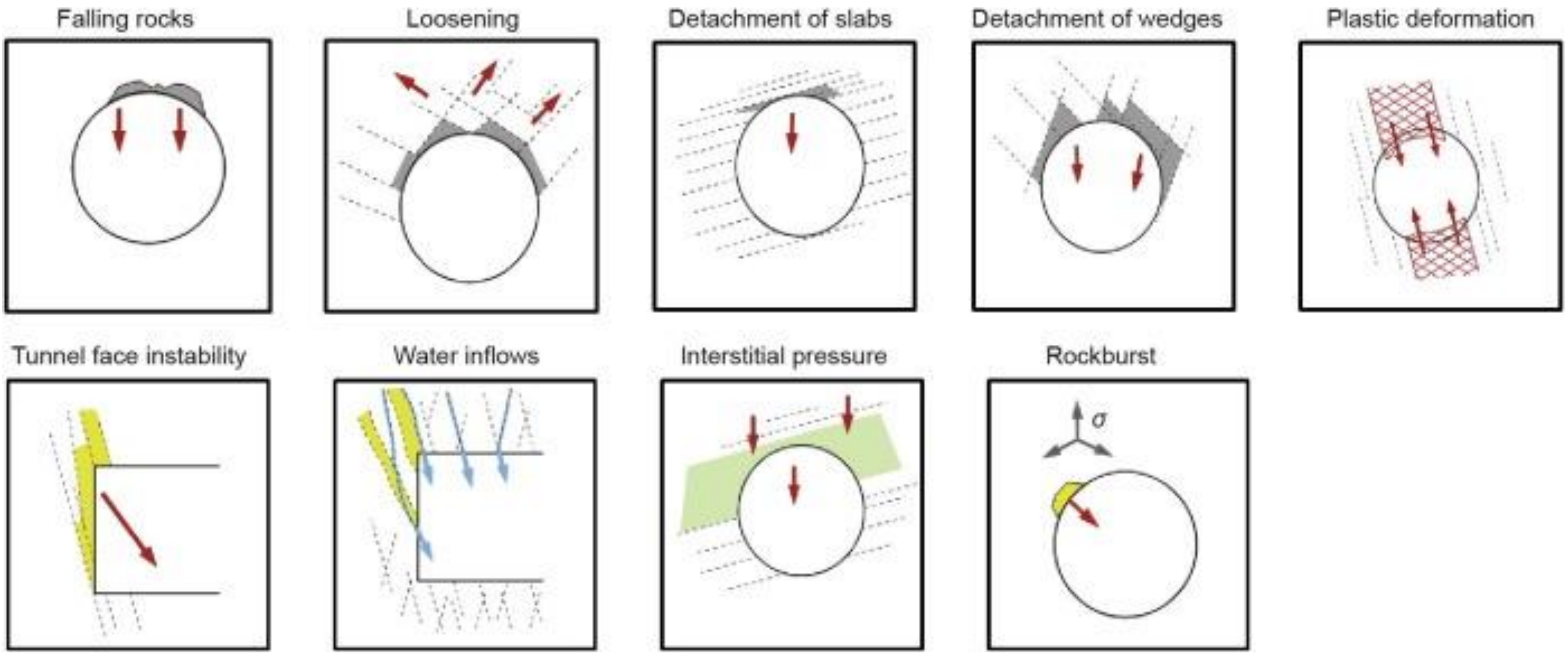
STUDY OF THE CONDITIONS

↓

SOLUTIONS:

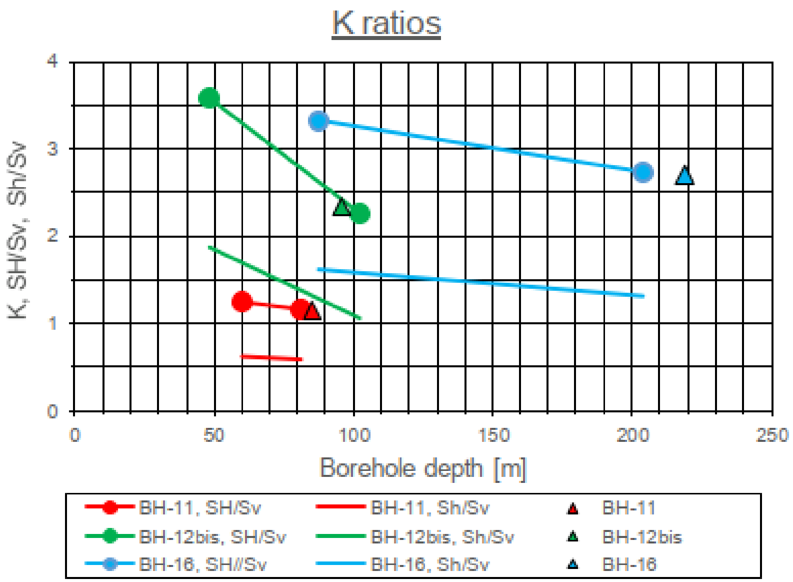
METHODS and MEASURES For dealing with the hazards

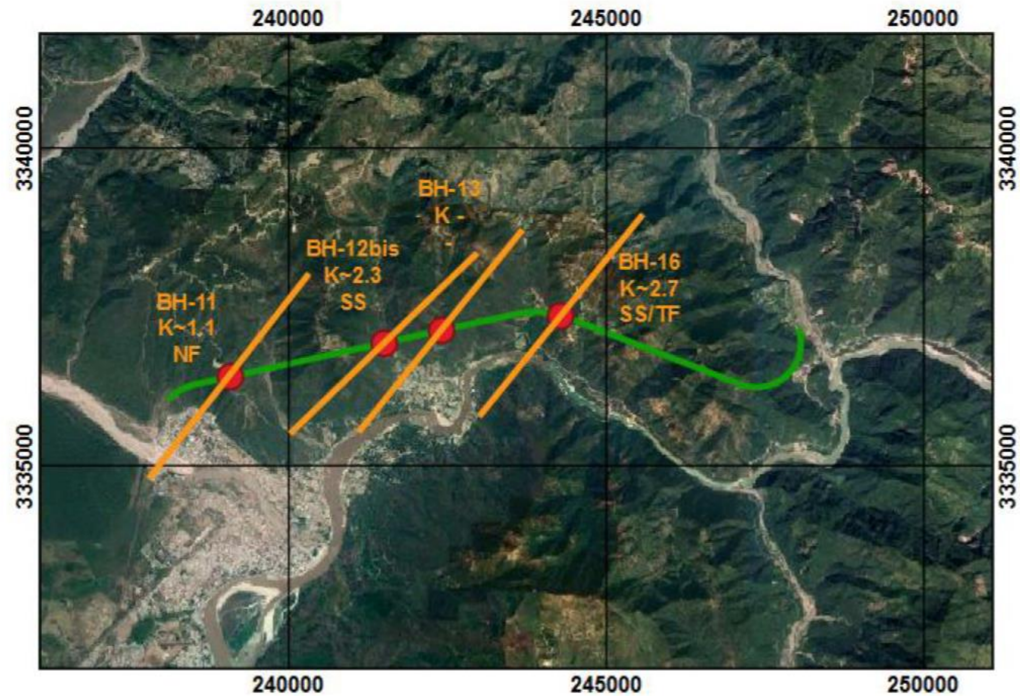
Risk Scenarios

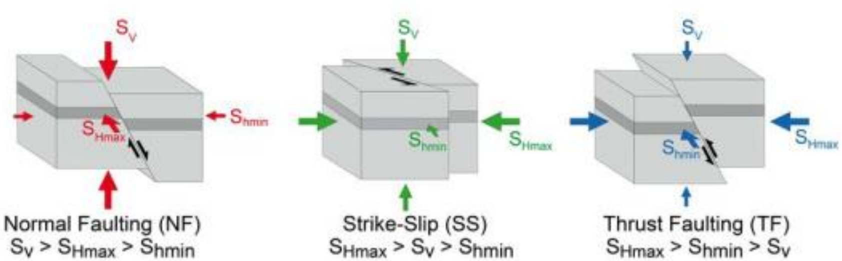


Hazard Scenario Assessment

In-situ Stress







- Major horizontal stress - 032 and 055°, i. e. NE-SW directed, which is the push of the MBT.
- Anisotropic stress state
- K reaches values of up to 2.7; K_{design} = 2.0

Hazard Scenario Assessment

Seismic Loads

The project lies in seismic zone IV (Figure 5.1) with accelerations of PGA= 0.24 g for the Maximum Credible Earthquake (MCE, 2% exceedance probability in 50 years) and PGA= 0.18 g for the Design Base Earthquake (DBE, 10% exceedance probability in 50 years).

Groundwater conditions

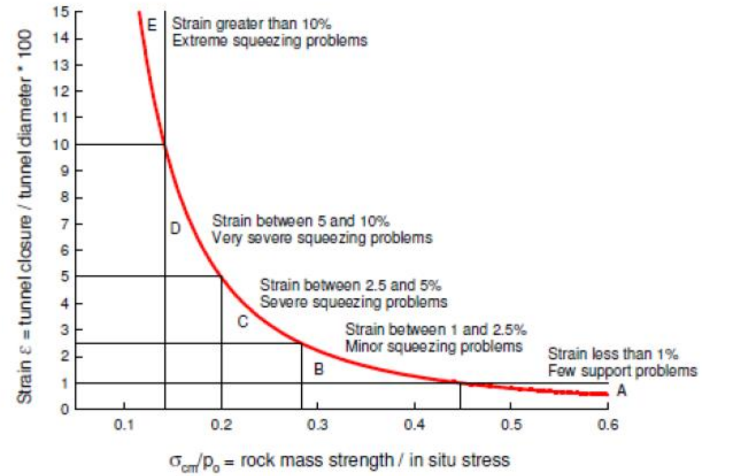
Problem where the tunnel passes under lateral valley - mostly correspond to fault zones. Several lithologies have limestone- karst phenomena and related water inflow.

Lithology	Lugeon					
	# of observations	Max	Min	Average	Conductivity classification	Rock mass discontinuity condition
Boulder	1	14.2	14.2	14.2	moderate	few partly open
Calcareous shale/marl	3	34.86	30.24	32.96	medium	some open
Dolomitic limestone	4	6.27	2.8	4.84	low	tight
Quartz arenite	2	33.48	28.96	31.22	medium	some open
Sand/silt	6	46.67	13.3	19.8	medium	some open
Shale	18	61.73	2.7	16.54	medium	some open
Siltstone	5	3.3	1.42	2.32	low	tight
Weak shale	0	-	-	-	-	-

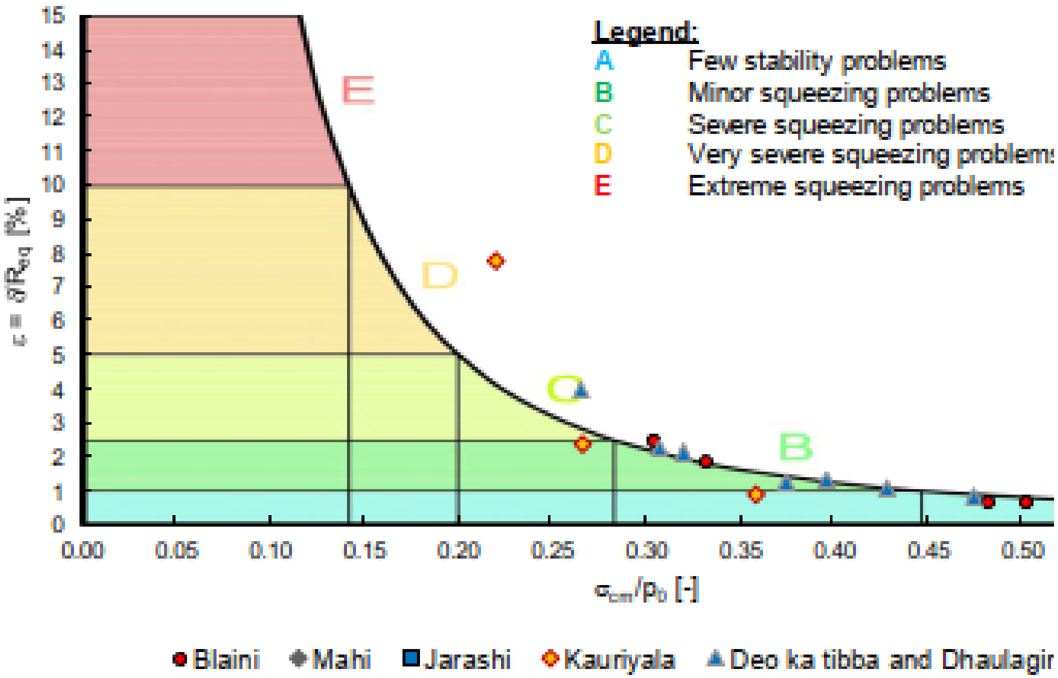
Hazard Scenario Assessment

Squeezing

- Overall squeezing potential are not very significant.
- Minor squeezing problems may be observed in Blaini and Kauriyala
- In fault zones squeezing/ caving in



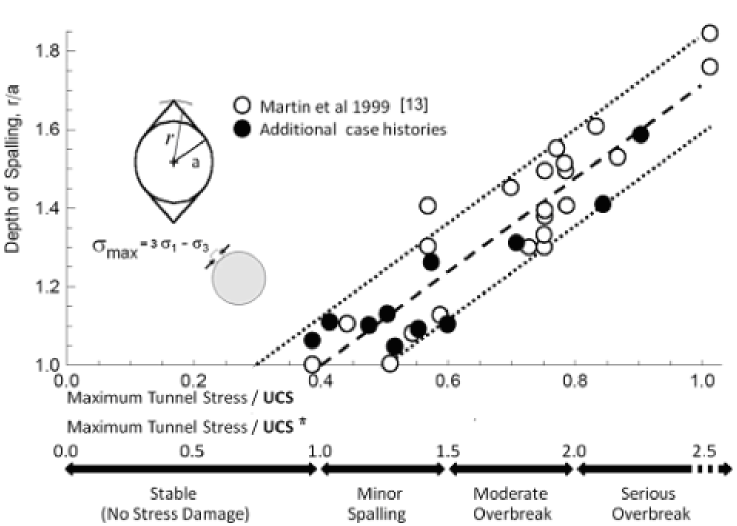
	Strain ε %	Geotechnical issues	Support types
A	Less than 1	Few stability problems and very simple tunnel support design methods can be used. Tunnel support recommendations based upon rock mass classifications provide an adequate basis for design.	Very simple tunnelling conditions, with rockbolts and shotcrete typically used for support.
B	1 to 2.5	Convergence confinement methods are used to predict the formation of a 'plastic' zone in the rock mass surrounding a tunnel and of the interaction between the progressive development of this zone and different types of support.	Minor squeezing problems which are generally dealt with by rockbolts and shotcrete; sometimes with light steel sets or lattice girders are added for additional security.
C	2.5 to 5	Two-dimensional finite element analysis, incorporating support elements and excavation sequence, are normally used for this type of problem. Face stability is generally not a major problem.	Severe squeezing problems requiring rapid installation of support and careful control of construction quality. Heavy steel sets embedded in shotcrete are generally required.
D	5 to 10	The design of the tunnel is dominated by face stability issues and, while two-dimensional finite analyses are generally carried out, some estimates of the effects of forepoling and face reinforcement are required.	Very severe squeezing and face stability problems. Forepoling and face reinforcement with steel sets embedded in shotcrete are usually necessary.
E	More than 10	Severe face instability as well as squeezing of the tunnel make this an extremely difficult three-dimensional problem for which no effective design methods are currently available. Most solutions are based on experience.	Extreme squeezing problems. Forepoling and face reinforcement are usually applied and yielding support may be required in extreme cases.



Hazard Scenario Assessment

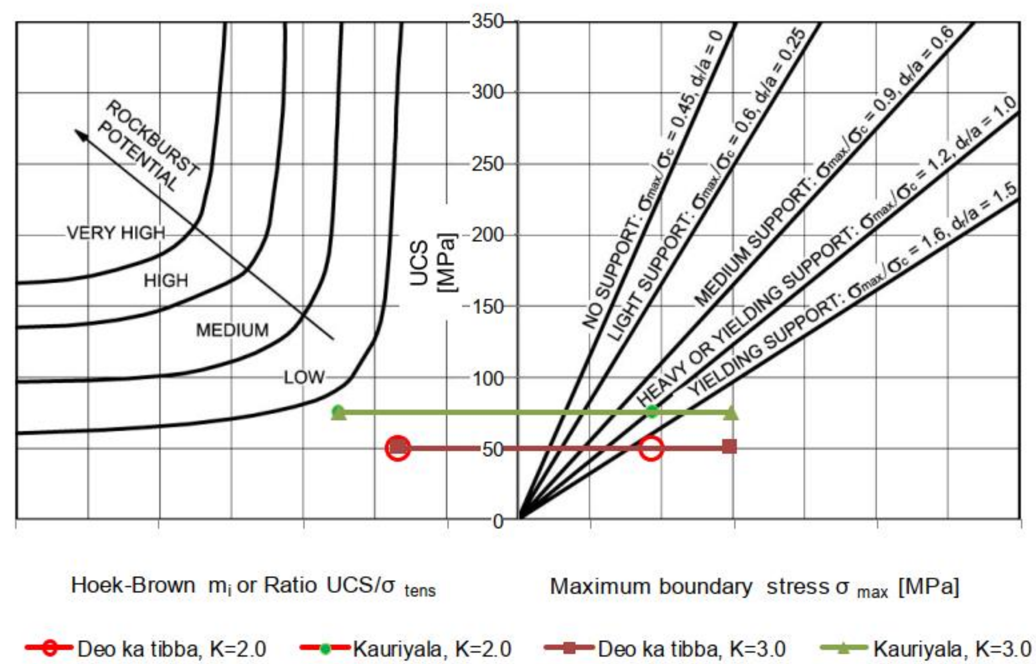
Spalling/ Rockburst

- Checked for generally higher overburdens – brittle failures
- The stress within the surrounding rock mass increases and failure occurs when the stress exceeds the strength of the rock mass



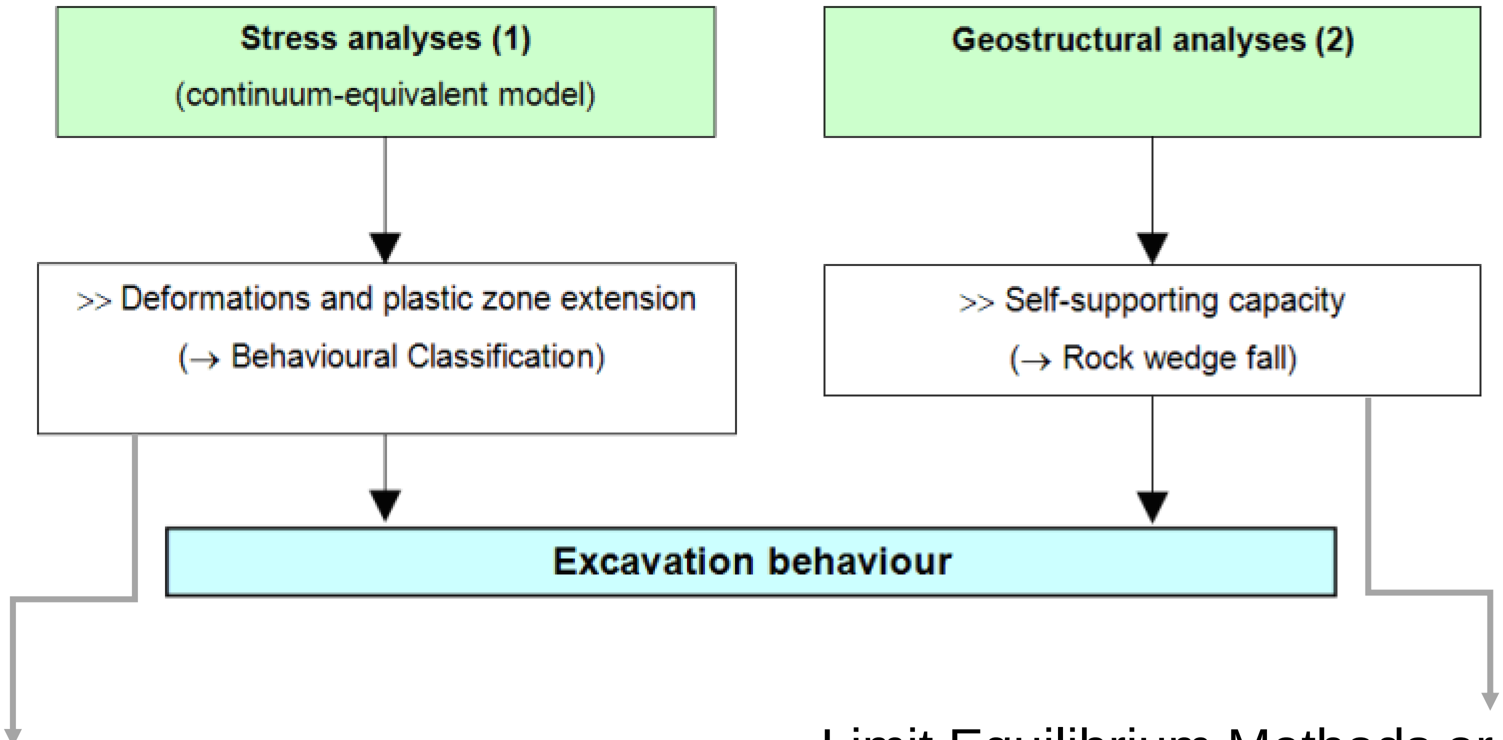
Note: UCS* = insitu spalling strength (typically UCS*=30-60% of UCS=σ_{ci}).

Spalling classification according Diederichs 2010



Hazard Scenario Assessment

Excavation Behavior Analysis



Ground Reaction Curves (GRC)

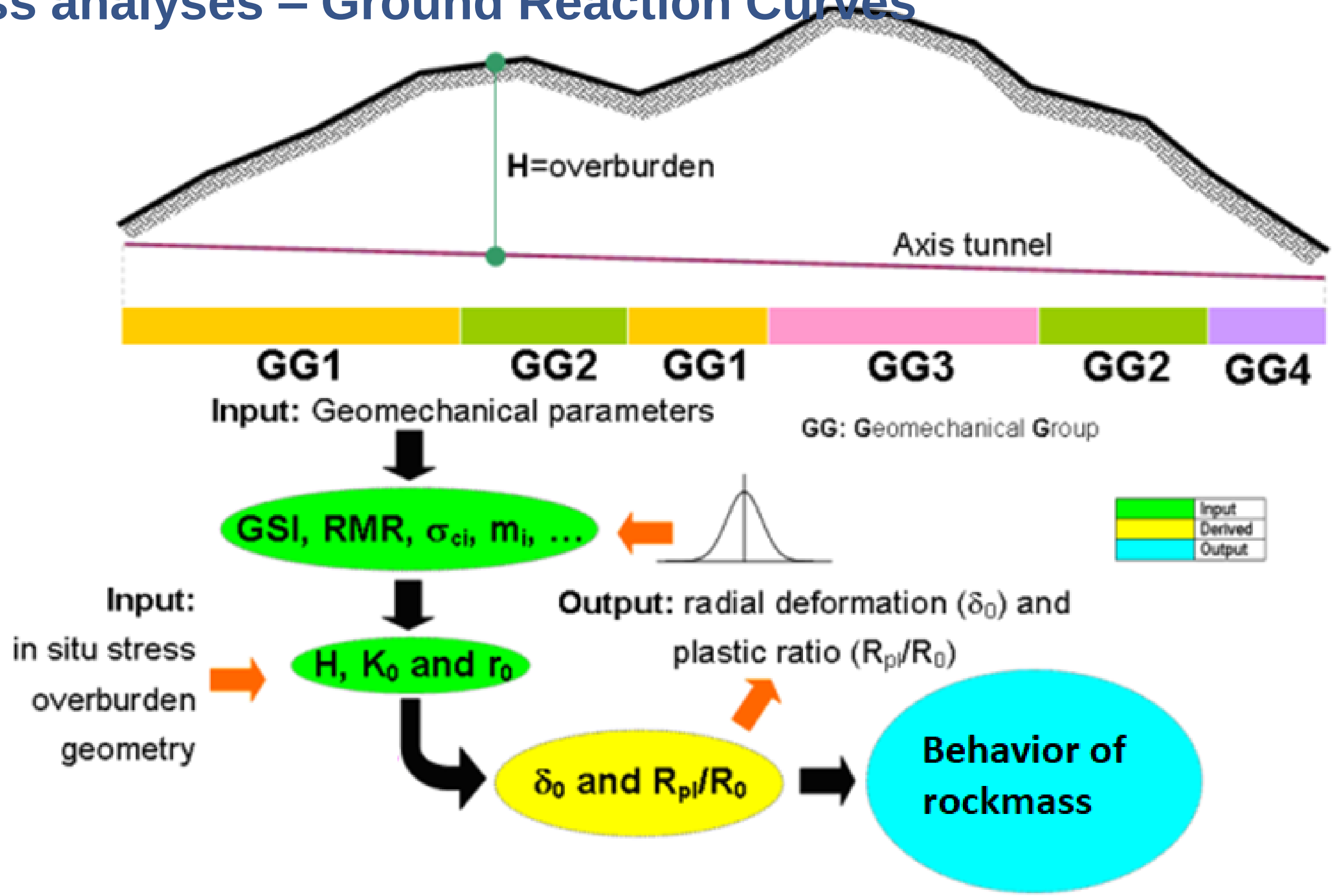
To express the expected behavior in terms of deformations and/or extent of the plasticized zone

Limit Equilibrium Methods or Empirical Methods

Using both rockmass spatial patterns of discontinuities orientation and geomechanical properties

Hazard Scenario Assessment

Stress analyses – Ground Reaction Curves

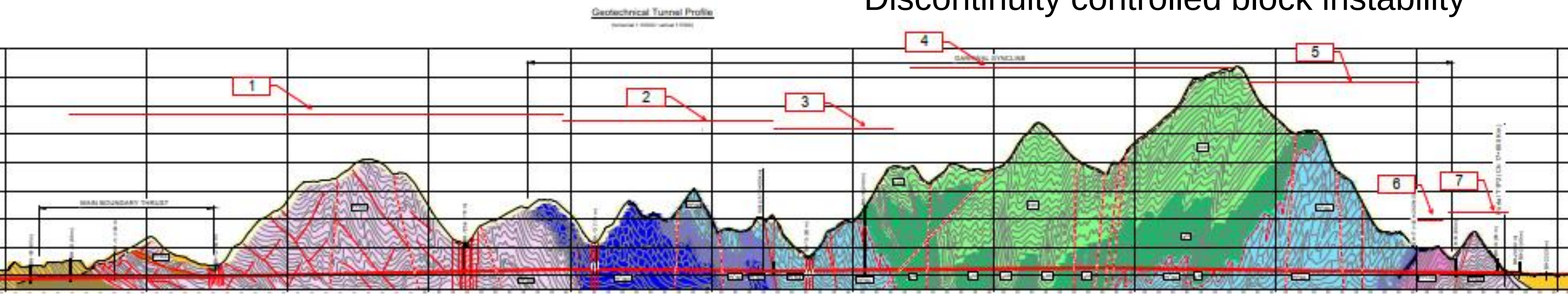


Indicative →

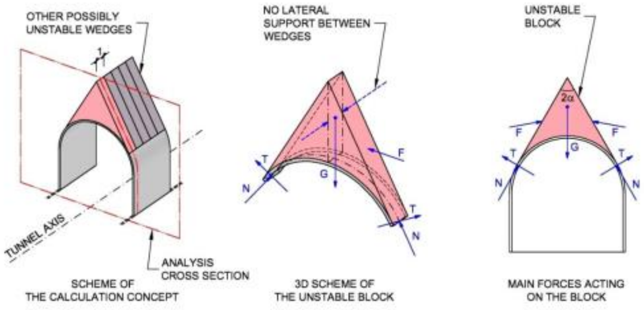
Hazard Scenario Assessment

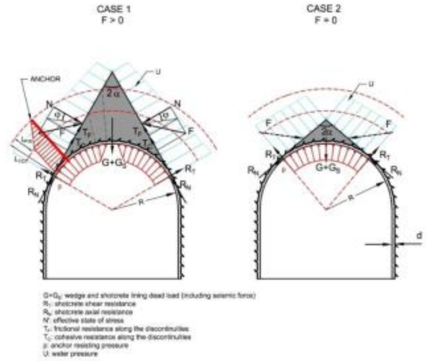
Geostructural analyses - Limit Equilibrium Methods

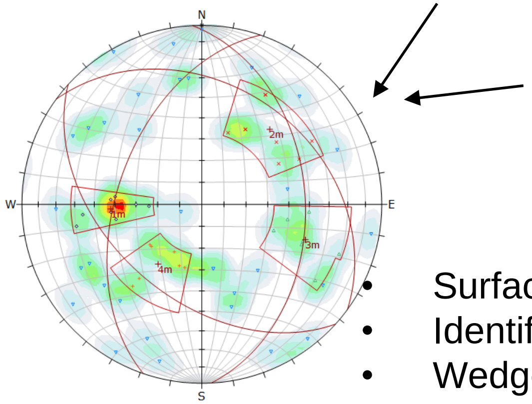
Discontinuity controlled block instability



DATASHEET FOR ROCK QUALITY PARAMETERS					
Name of Project: Construction of tunnels, bridges, and formation works from Chainage 06+015 to 18+444 (12.429km) under Package-1 in connection with new single line broad gauge rail link between Rishikesh and Karnaprayag (125km) in the state of Uttarakhand, India					
Location	at CH. 17+00 near approch road for P2				
Outcrop No./GPS Point No.	118	N: 248333	E:3336807	Elevation:393mt	
Joint Set No.	J1	J2	J3	J4	Rating
Dip Amount/Dip Direction	45/195	56/035	56/010		
UCS (MPa)	5-25				2
RQD (%)	<25				3
Spacing of Discontinuity (mm)	<6	60-200	<6		8
Condition of Discontinuity: Persistence of Discontinuity (m)	3-10	<1	<1		2
Condition of Discontinuity: Aperture/Opening of Discontinuity (mm)	<0.1	0.1-1.0	0.1-1.0		5
Condition of Discontinuity: Roughness Of Discontinuity	Smooth	Slight rough	Slight rough		1
Condition of Discontinuity: Infilling of Discontinuity	Soft<5mm	Soft<5mm	Soft<5mm		2
Condition of Discontinuity: Weathering/Alteration of Discontinuity	Slight weathered	Slight weathered	Slight weathered		3
Water Condition	Dry				15
Orientation Of Discontinuity	Fair				-5
Rock Mass Rating					36
Geological Strength Index					36
Rock Class as per Bieniawski					IV (Poor Rock)
Rock Mass description	Fine grain, black coloured, thinly bedded Shale with alternates bands of Quartz arenite.				
Special Structure/Feature	Folded starta				
Remarks:					
Date:18.03.2019					





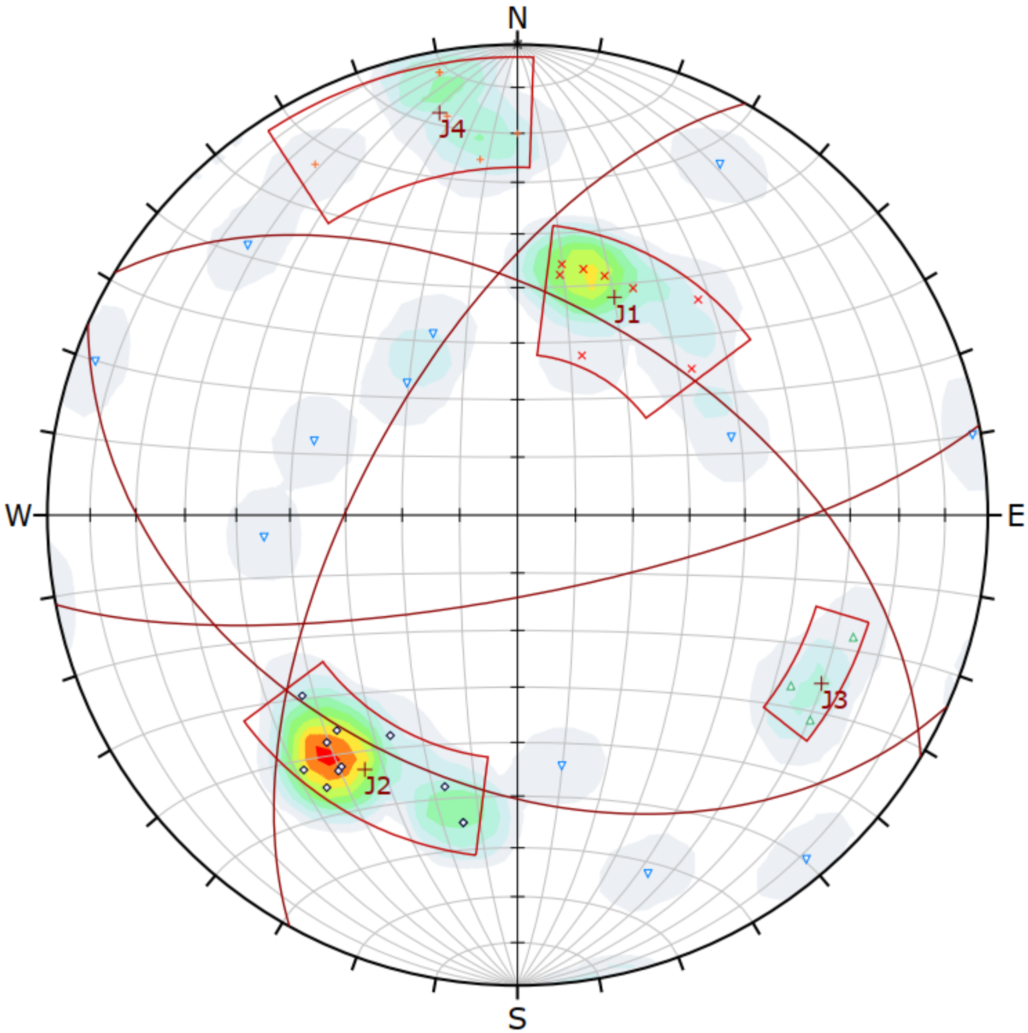


- Surface survey mapping
- Identifying the lithological grouping
- Wedge instability by block theory

Hazard Scenario Assessment

Geostructural analyses using DIPS

Grey Shales_2



Symbol	Set	Quantity
◇	1	11
×	2	8
△	3	3
+	4	6
▽	[no data]	12

Color	Density Concentrations
	0.00 - 1.50
	1.50 - 3.00
	3.00 - 4.50
	4.50 - 6.00
	6.00 - 7.50
	7.50 - 9.00
	9.00 - 10.50
	10.50 - 12.00
	12.00 - 13.50
	13.50 - 15.00

Contour Data	Pole Vectors
Maximum Density	14.08%
Contour Distribution	Fisher
Counting Circle Size	1.0%

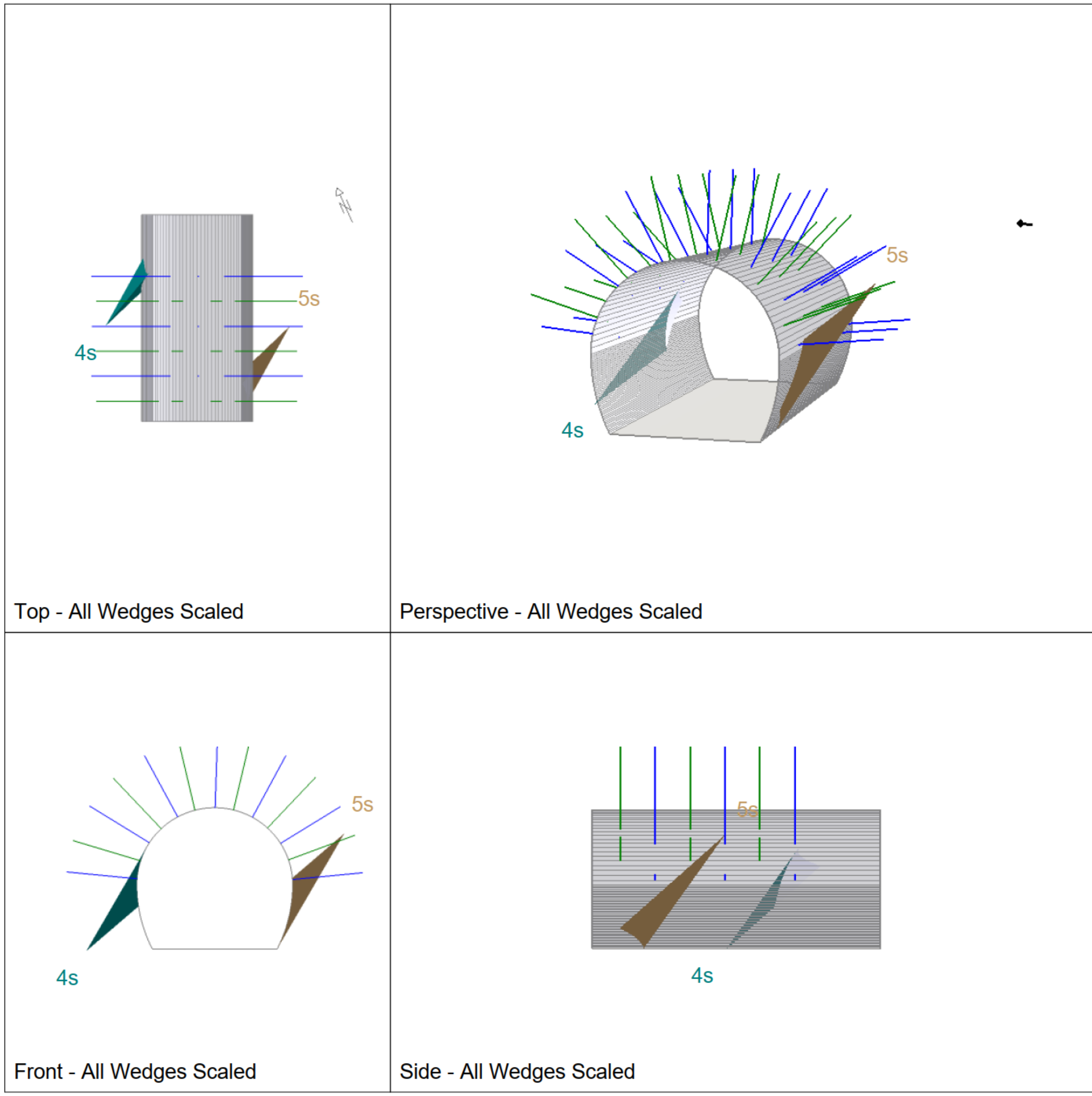
	Color	Dip	Dip Direction	Label
Mean Set Planes				
1m		53	31	J2
2m		42	204	J1
3m		63	299	J3
4m		76	169	J4

Plot Mode	Pole Vectors
Vector Count	40 (40 Entries)
Hemisphere	Lower
Projection	Equal Area

Summarizing the joint sets for one selected formation from the surface survey mapping results

Hazard Scenario Assessment

Geostructural analyses - Limit Equilibrium Methods - UNWEDGE

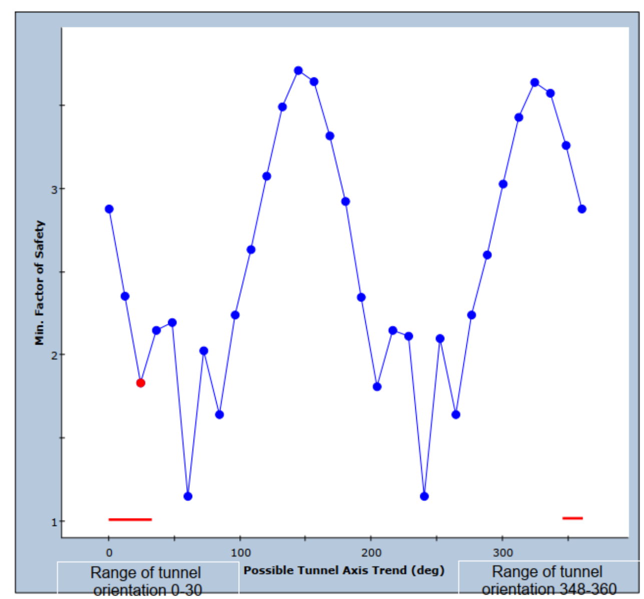


Wedge Information

Lower Left wedge [4]
- Factor of Safety: stable
- Wedge Weight: 0.060 MN
- Resisting Force: 0.000 MN
- Apex Height: 3.49 m
- Scaled by: Apex Height

Lower Right wedge [5]
- Factor of Safety: 1.835
- Wedge Weight: 0.072 MN
- Resisting Force: 0.105 MN
- Apex Height: 3.48 m
- Scaled by: Apex Height

Optimization for Tunnel Axis Plunge = 0°



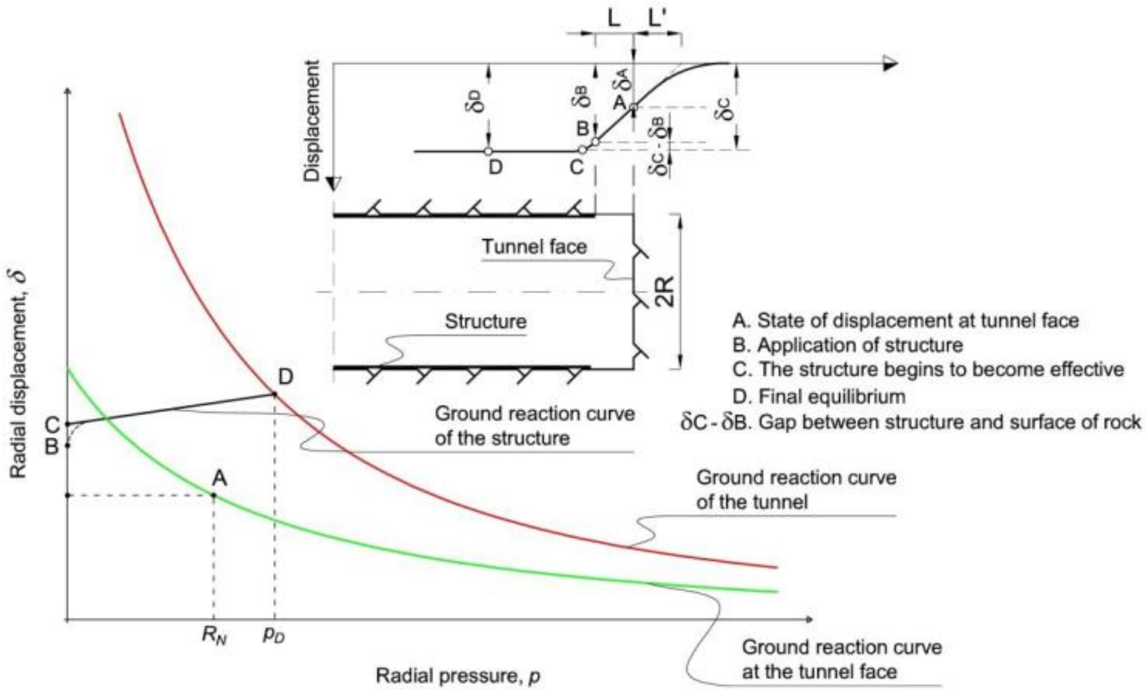
Current Tunnel Axis Trend = 24°

Hazard Scenario Assessment

Stress analyses

Lombardi's in-house GRC evaluation tool

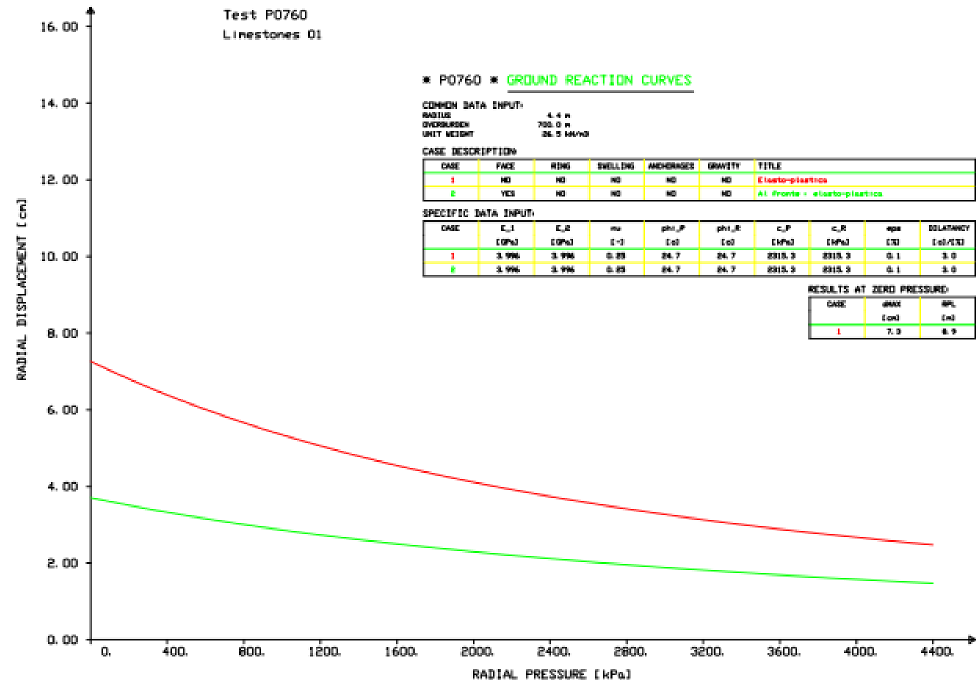
- M-C criteria with strain softening or strain hardening;
- Dilatancy as a function of plastic strain
- Rock swelling
- Effect of gravity: curves for displacement on crown level, side wall and invert;
- Systematic bolting
- Rock around the tunnel with different parameters - consolidation grouting or of blasting damages
- The ground reaction curve at the tunnel face
- Output as AutoCAD file and a text report

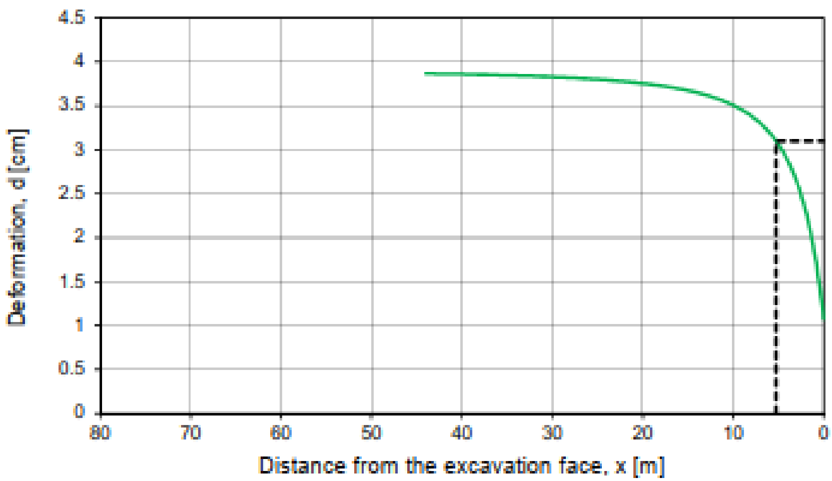


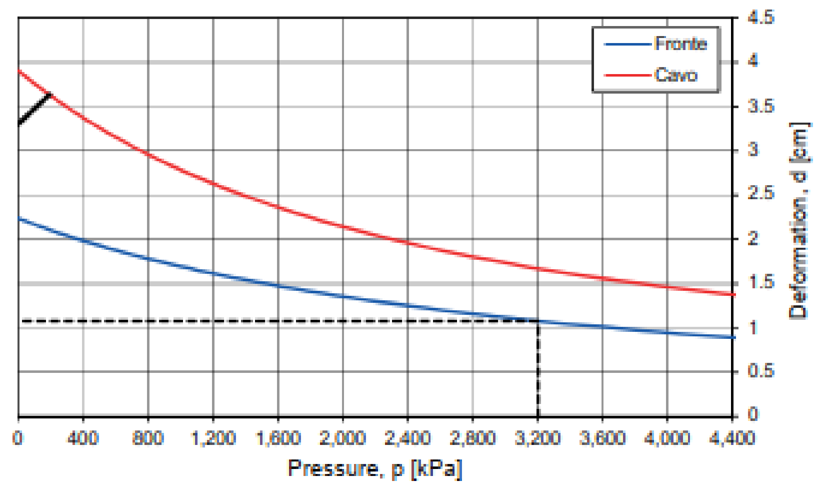
Hazard Scenario Assessment

Stress analyses

Determination of equilibrium pressure on the tunnel - Support wise







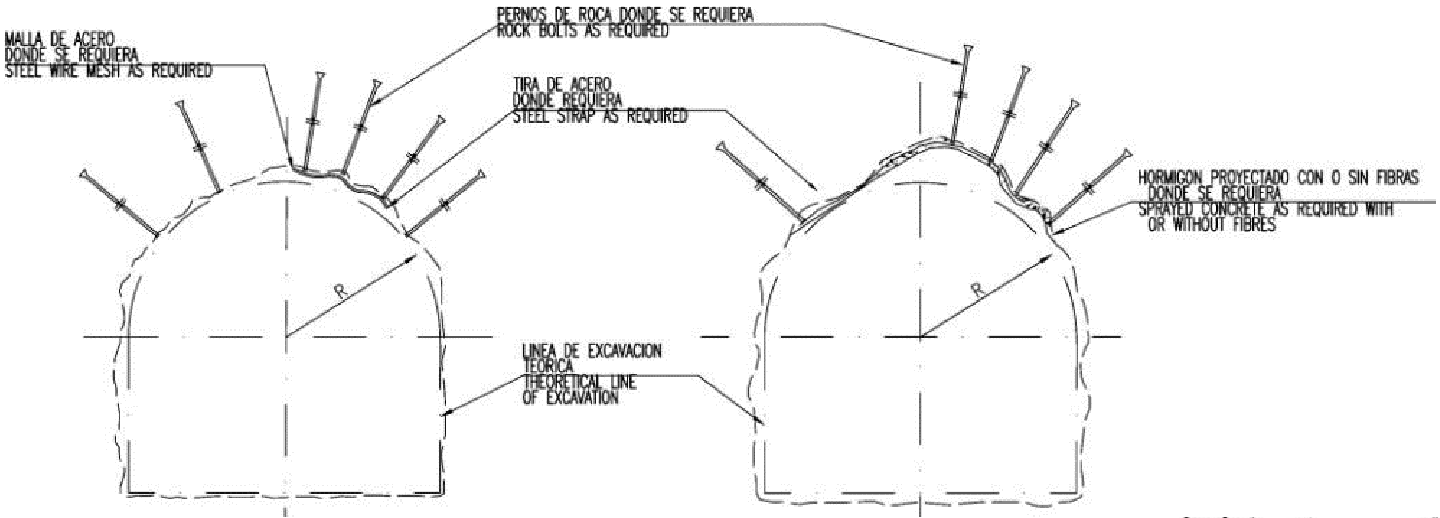
Hazard Scenario Assessment

Stress analyses

Tunnel	Section Type	Wedge Load [kPa]	Equilibrium Pressure [kPa]	Water Pressure [kPa]	Remarks
MT	A2	120	-	50	- A 5.0 m water head is considered in all cases for final lining design - The equilibrium pressure is the same as that considered for primary lining with ULS load factor 1.35 - B2 is checked for wedge load cases also as it is a transition case from geo-structural controlled and stress-controlled excavation behaviours
	B1, B2	120	130	50	
	C1	-	200	50	
	C2	-	200	50	
	C2b	-	400	50	
	D	-	120	50	
ET & CP	A		-	50	
	B	-	60	50	
	C & Cb	-	110	50	
Layby	A & B	-	120	50	
	C	-	200	50	
	S	-	550	50	
FFP/ Home Signal	B	-	150	50	

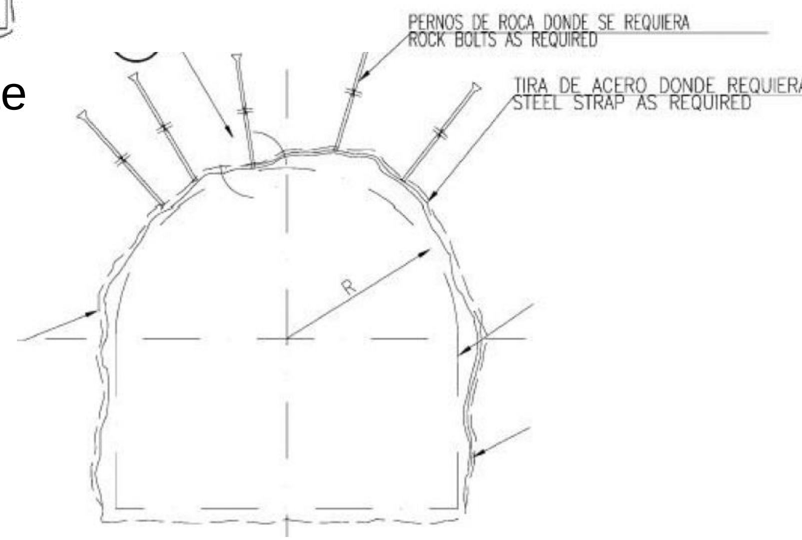
Support Type Definition

Basic Design Solution



Spot Bolting, steel mesh with/ without shotcrete

<u>Support types 1 and 2 :</u>
Mainly for geostructural
hazards – Wedge stability

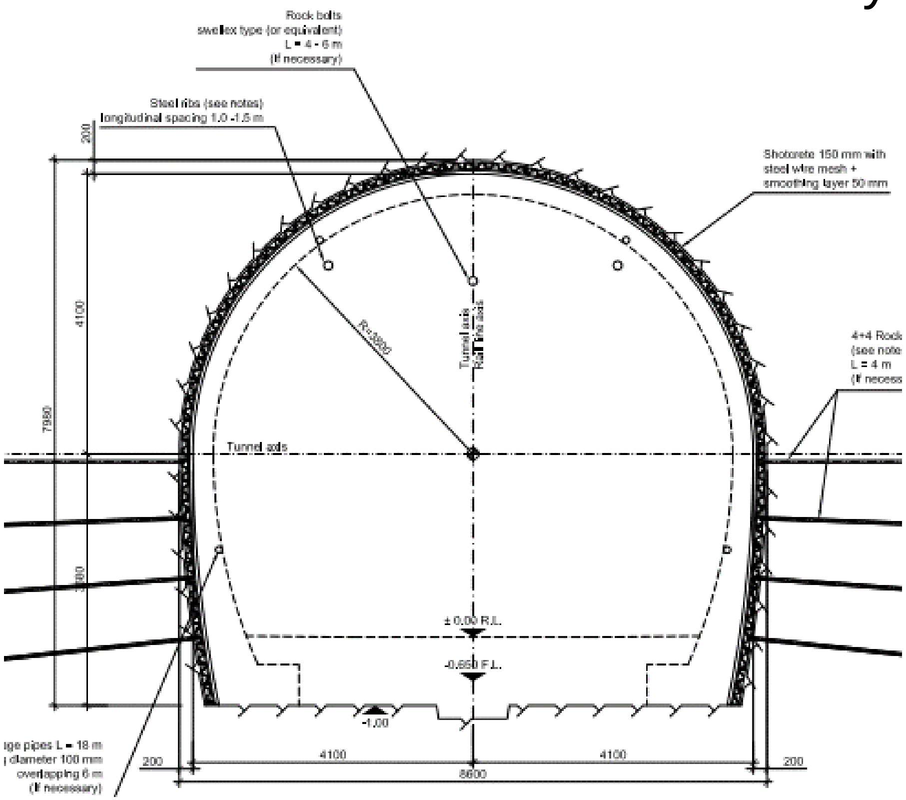


Pattern Bolting, steel mesh with/ without shotcrete

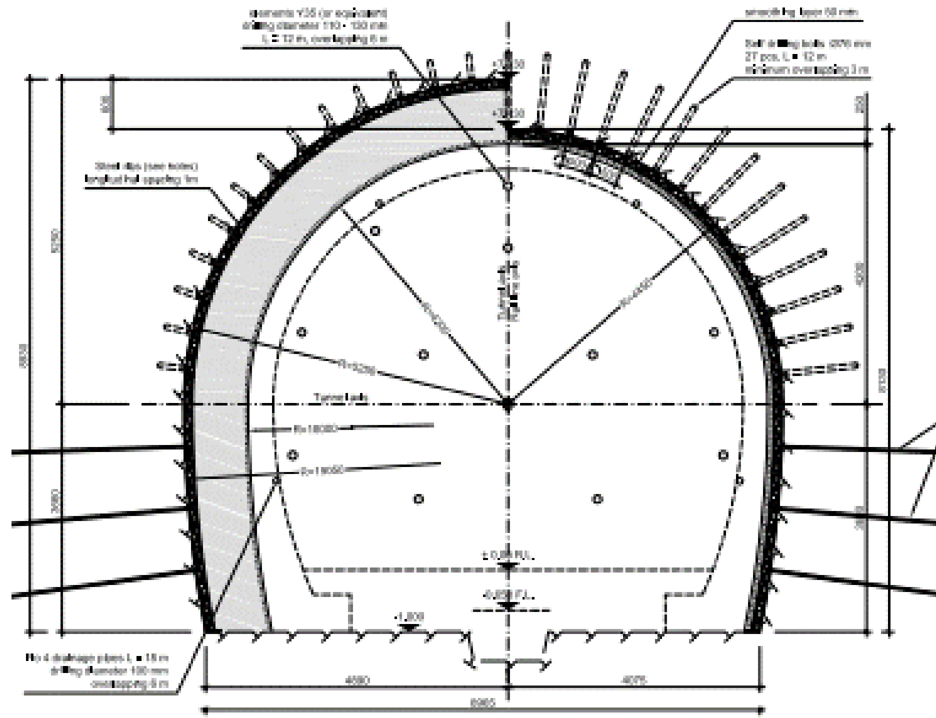
Support Type Definition

Basic Design Solution

<u>Support types 3 and 4 :</u>
Mainly for stress-controlled failures



Steel arch with shotcrete (bolts if required)

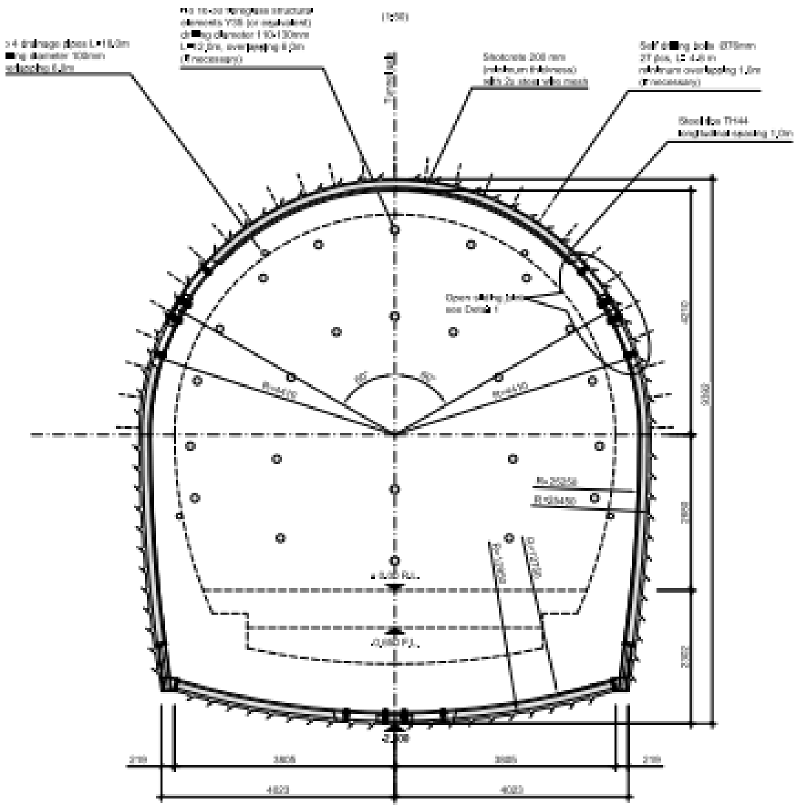


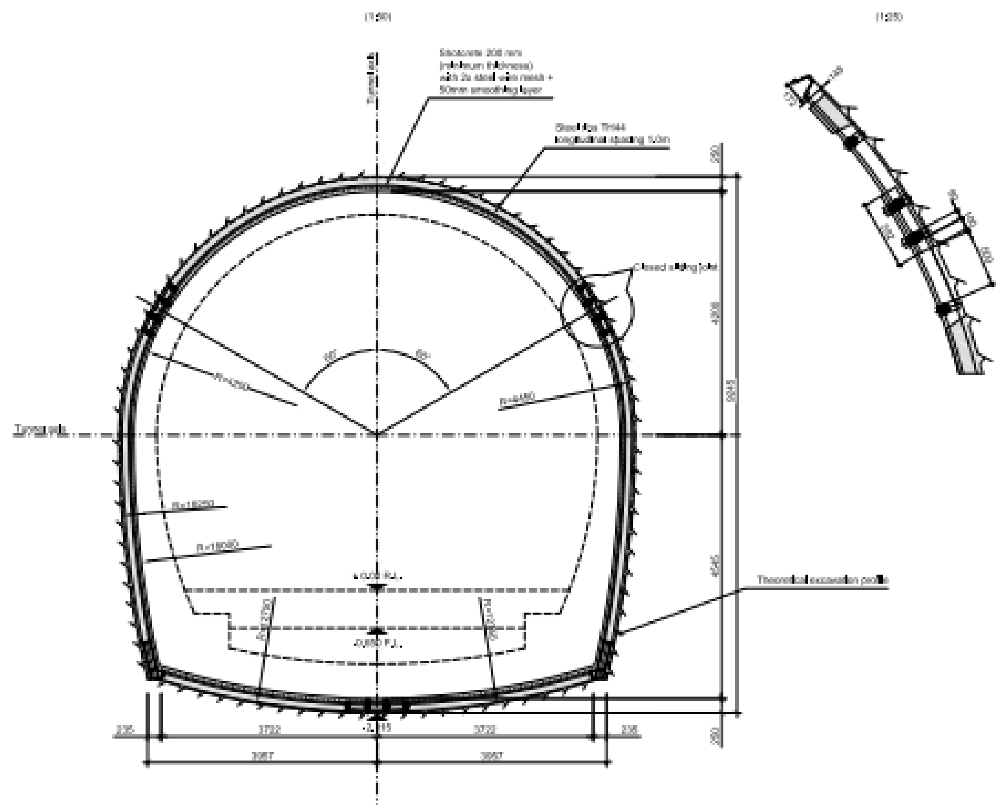
Forepoling and Steel arch with shotcrete (bolts if required) – in case pre support is required – stability before the next blast round

Support Type Definition

Basic Design Solution

<u>Support types 5 :</u>
Mainly for stress-controlled failures – yielding support – for squeezing or caving in situations



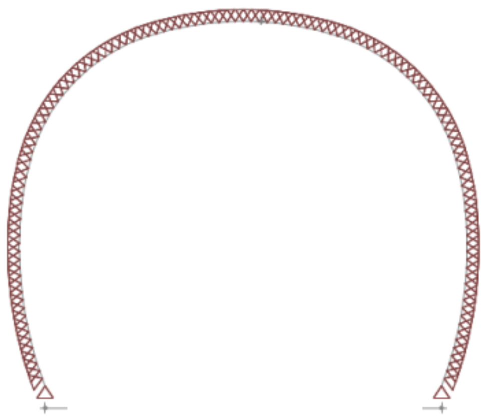


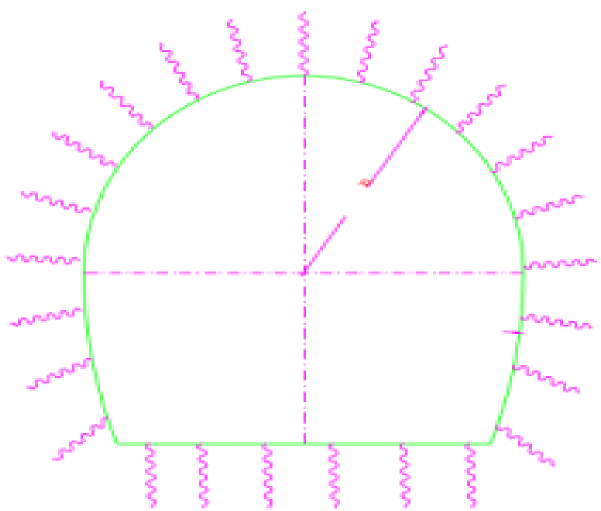
TH Ribs – to allow deformations
Invert

Support Type Definition

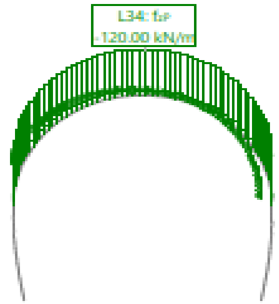
Support type	Hazard scenario	Verification procedure	Structural adequacy
A2	Block instability	Unwedge	STATIK and FAGUS
B1	Block instability	Unwedge	STATIK and FAGUS
B2	Block instability	Unwedge	STATIK and FAGUS
	Earth pressure	Ground reaction curve	
C1	Elasto - Plastic or Plastic Deformations	Ground reaction curve	STATIK and FAGUS
	Unstable face	Excel Calculation	
C2	Unacceptable deformations	Ground reaction curve	STATIK and FAGUS
	Unstable face	Excel Calculation	
C2b	Squeezing, unacceptable deformations	Finite Element Analyses	FAGUS
	Unstable face	Excel Calculation	
S2, S3 and D	Risk of collapse, full face excavation not possible	Finite Element Analysis	FAGUS
		Pre-support	

Support Type Verifications

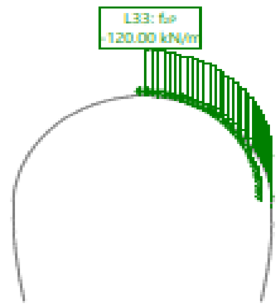




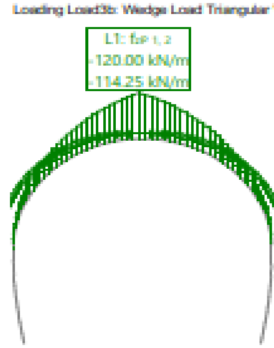
Loading Load3: Wedge Load Similar WL-S

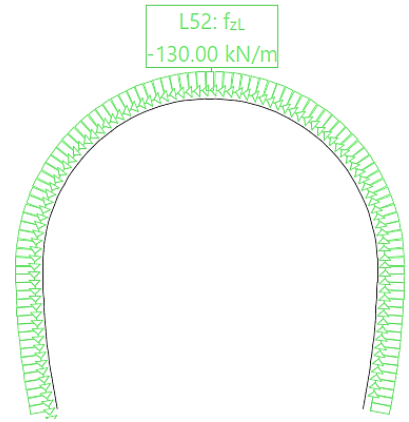


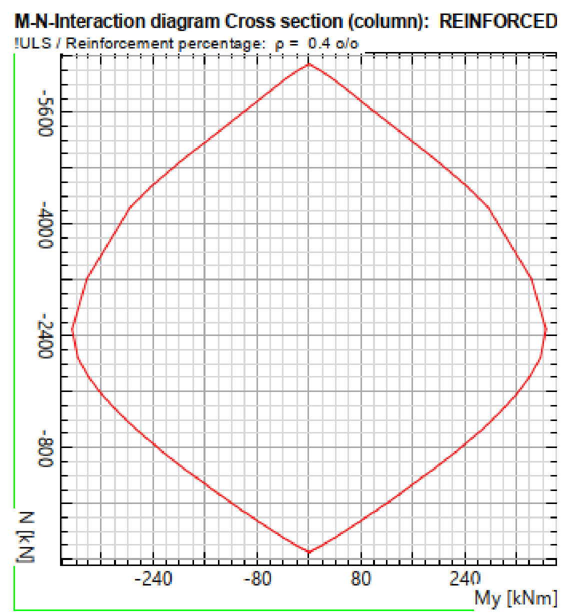
Loading Load3a: Wedge Load Non-Similar WL-NS



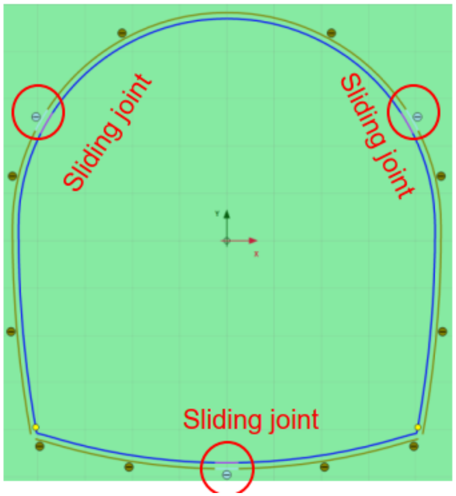
Loading Load3b: Wedge Load Triangular WL-T



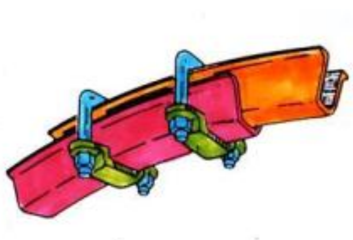




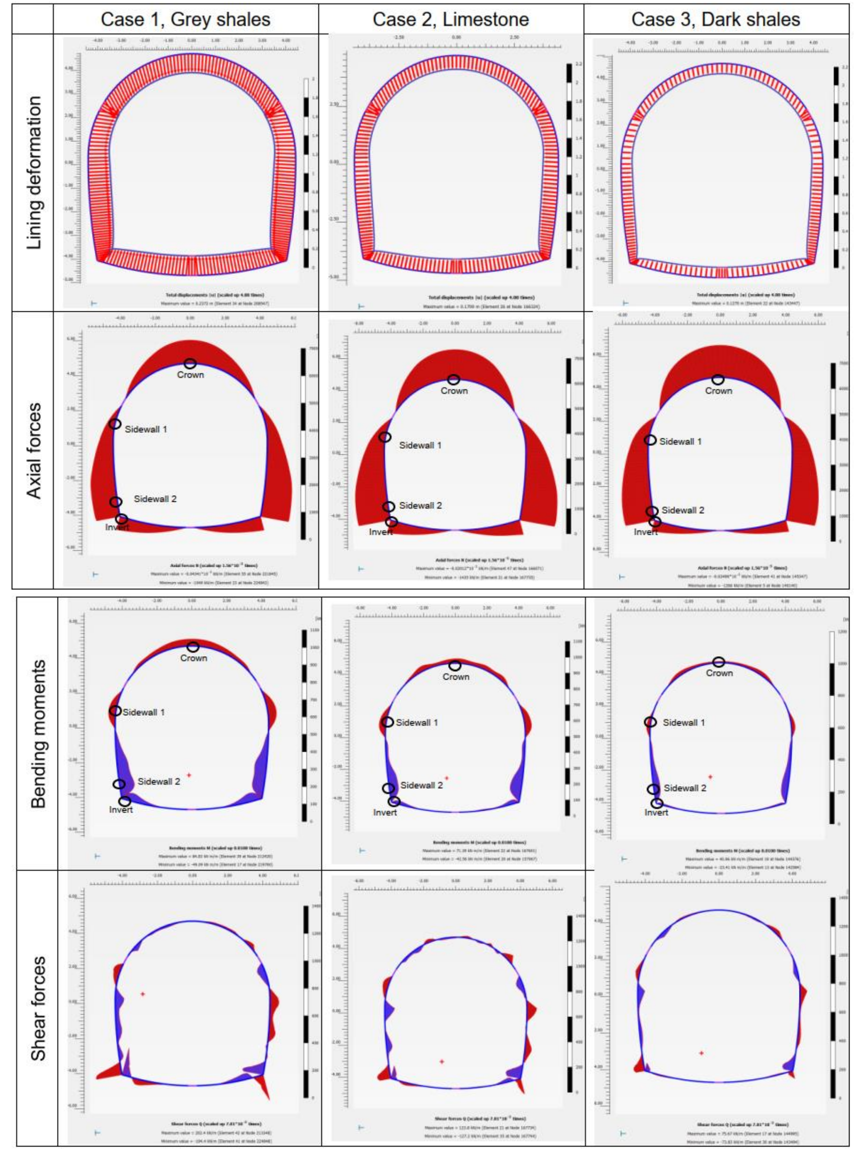
Support Type Verifications



FEM Model of the support
with TH ribs – C2b

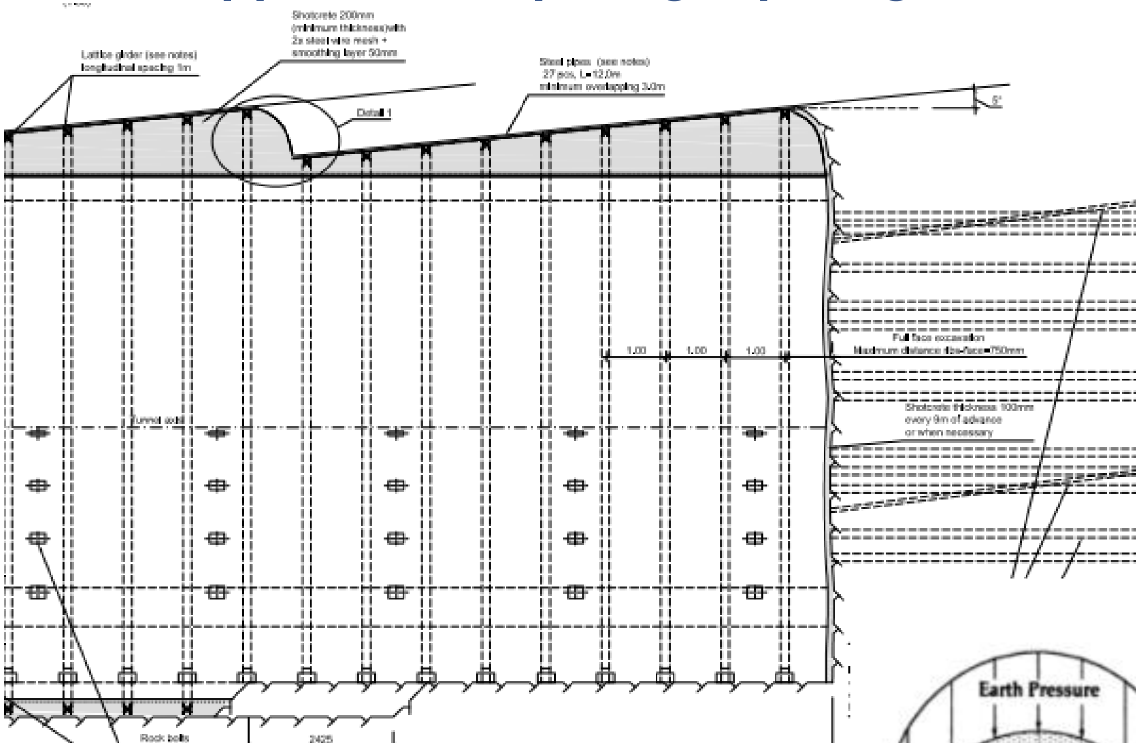


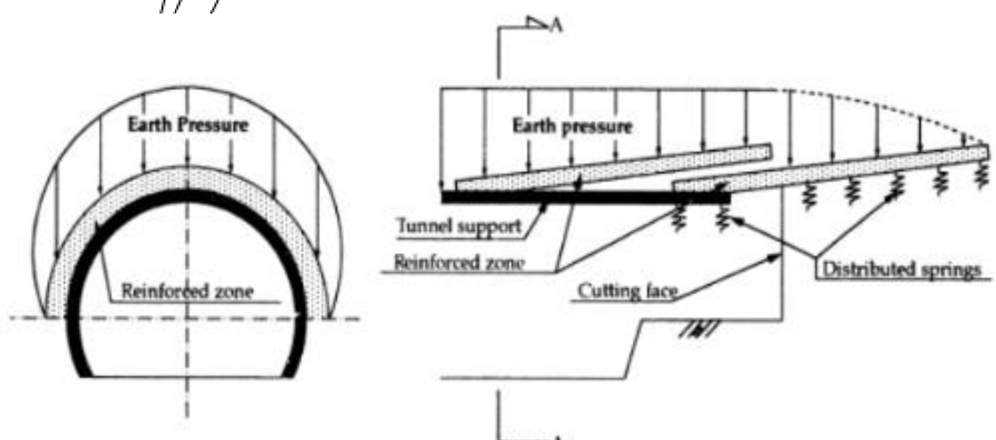
Evaluation of support
capacity in PLAXIS



Support Type Verifications

Pre support – Forepoling/ Spilling



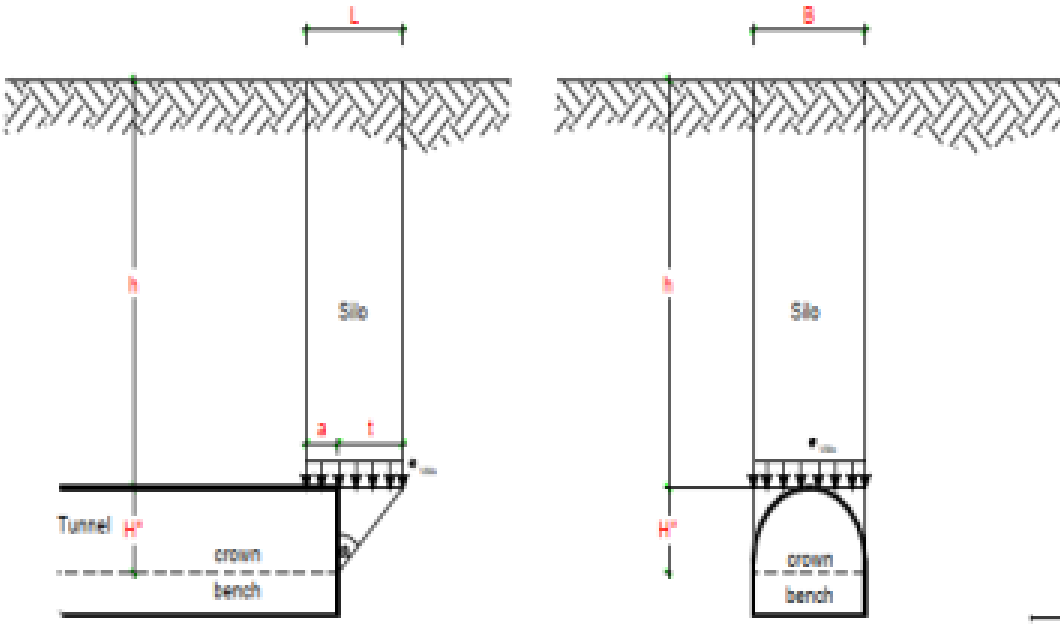


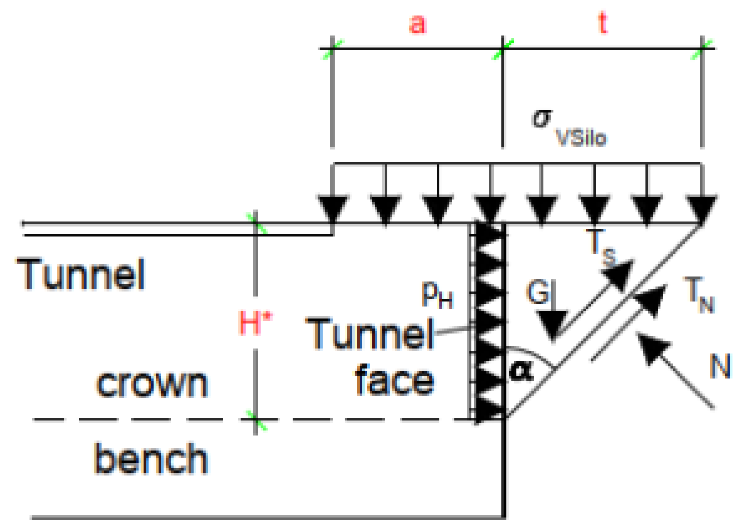
a) transverse view
(A-A section)

b) longitudinal view

Support Type Verifications

Pre-Support - Face Stability

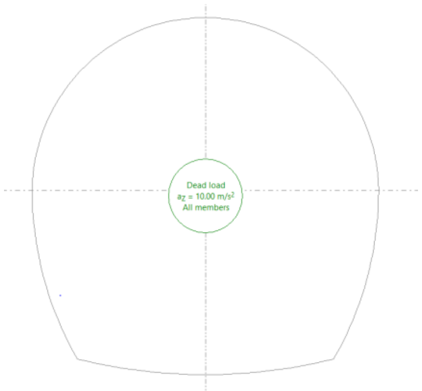




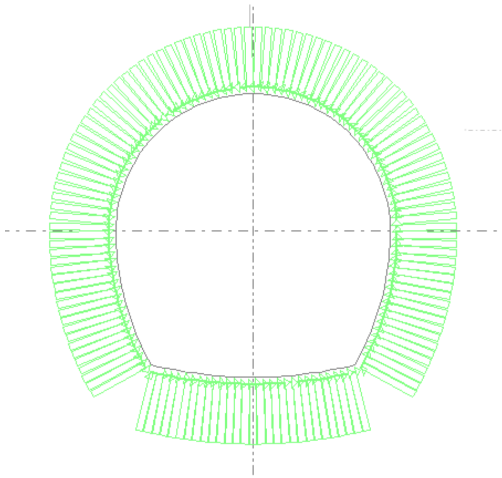
Vertical pressure at the face has been evaluated by using the Terzaghi analytical models

Final / Permanent Support

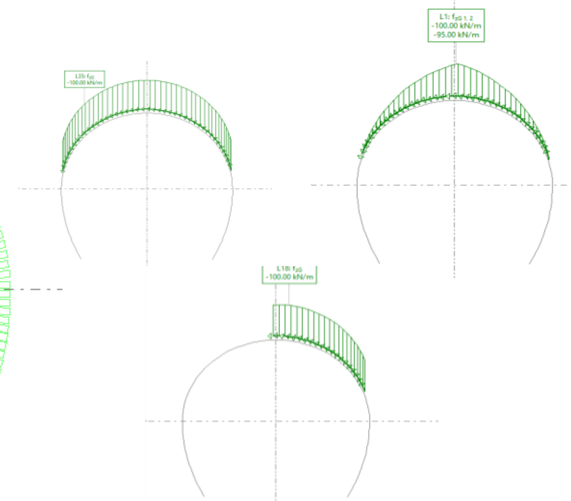
Loads



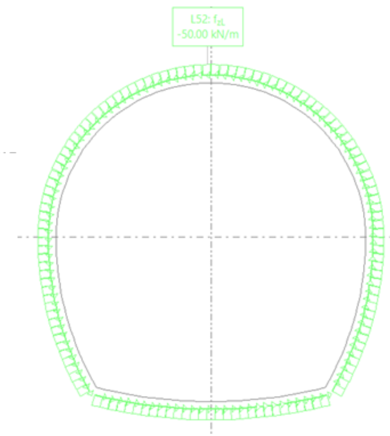
Self Weight



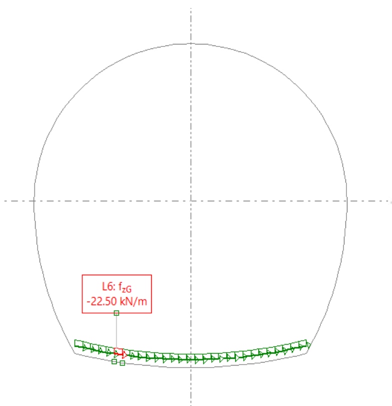
Lining Pressure



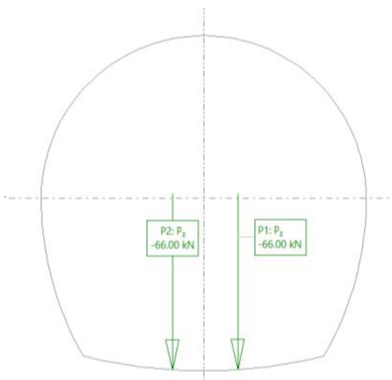
Wedge Loads



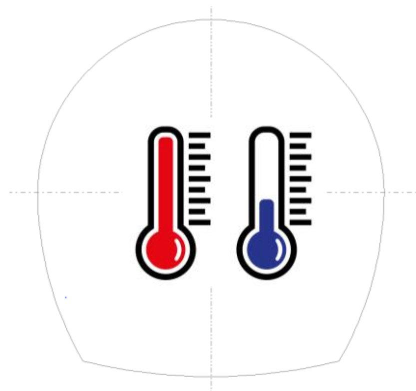
Water Pressure



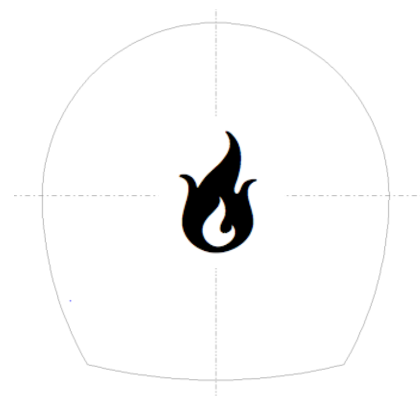
BLT Load



Train Load



Temperature Load



Fire Check

Final / Permanent Support

Load Combinations

Load Cases	Description
Case 1	Self-Weight + Lining Pressure + Water Pressure
Case 2	Self-Weight + Ballast Load + Traffic Load
Case 3	Self-Weight + Lining Pressure + Water Pressure + Ballast Load + Traffic Load
Case 4	Self-Weight + Lining Pressure + Ballast Load + Traffic Load

ULS Load Factors

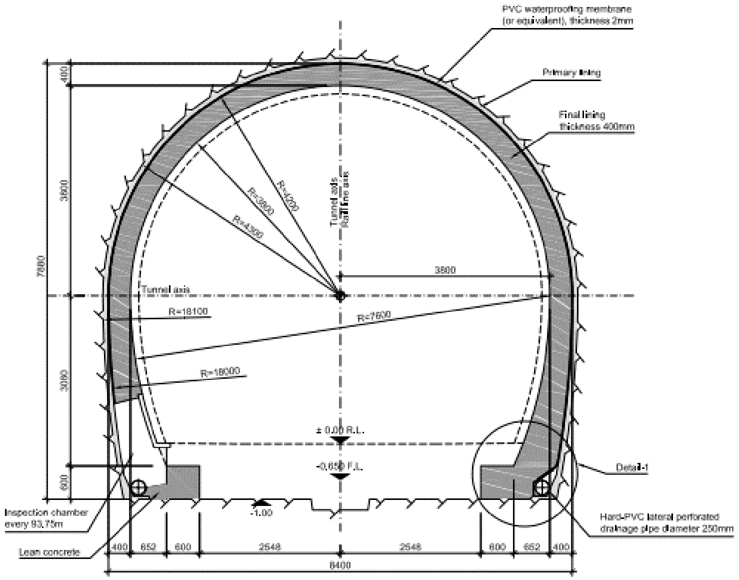
Combination	Self-Weight	Lining Pressure/ Asymmetrical Wedge load	Water Pressure
Comb. 1	1.35	1.35	1.35

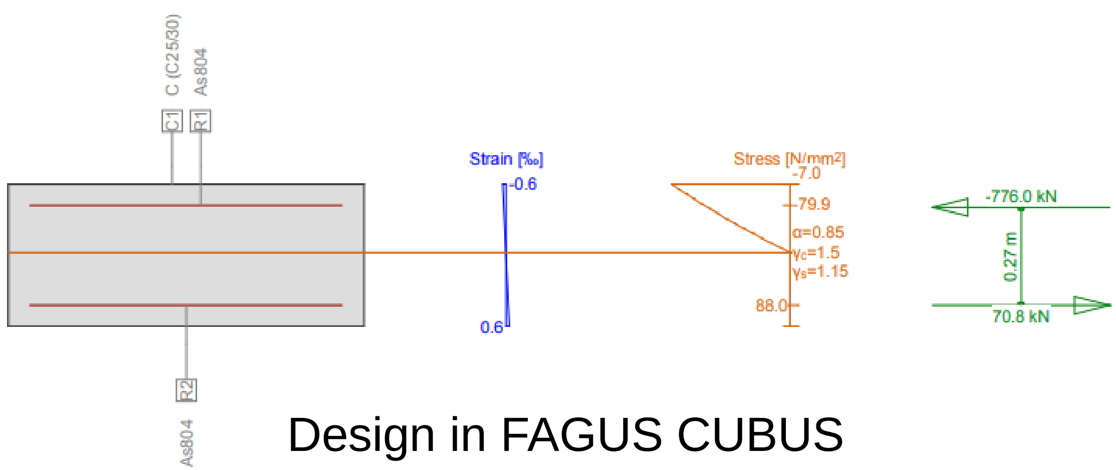
SLS Load Factors

Combination	Self-Weight	Lining Pressure/ Asymmetrical Wedge load	Water Pressure	Temperature load
Comb. 1	1.0	1.0	1.0	
Comb. 2	1.0	1.0	1.0	0.5

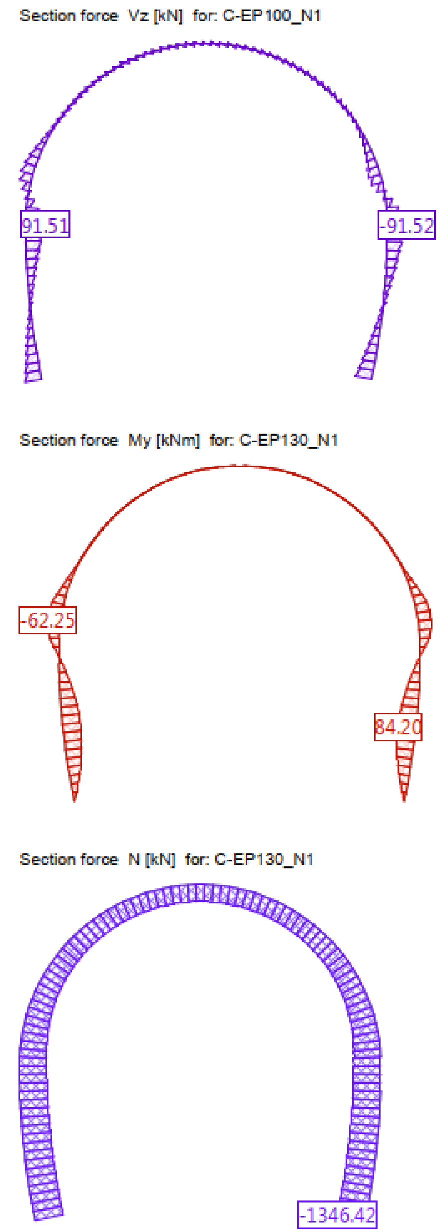
Final / Permanent Support

Concrete lining





Design in FAGUS CUBUS

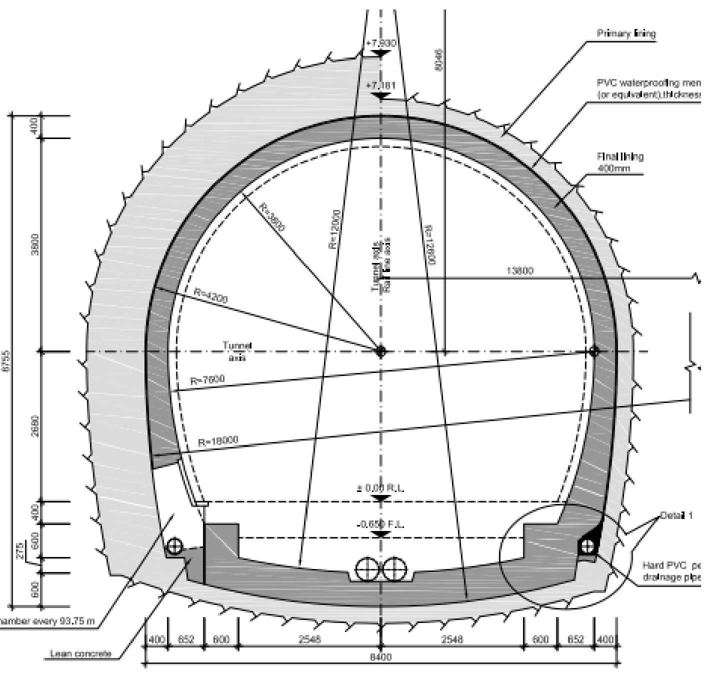


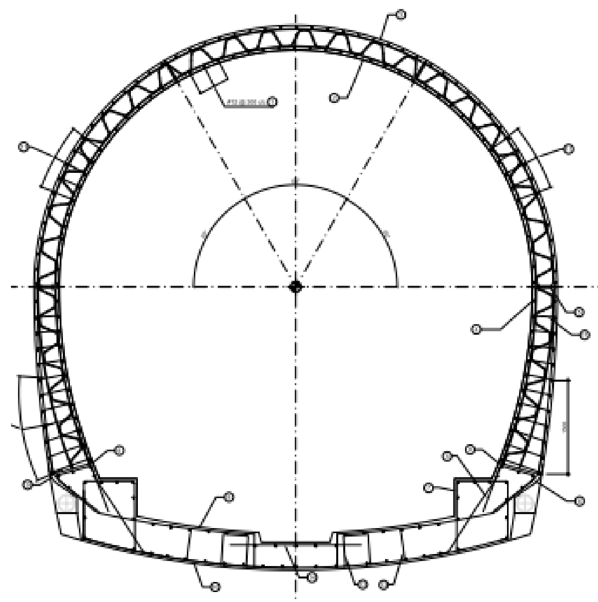
Analysis in STATIK CUBUS

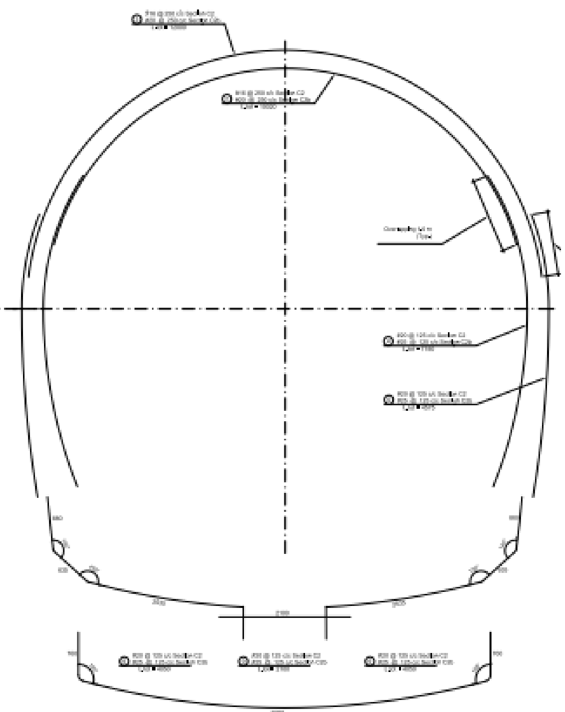
Final / Permanent Support

Other Checks

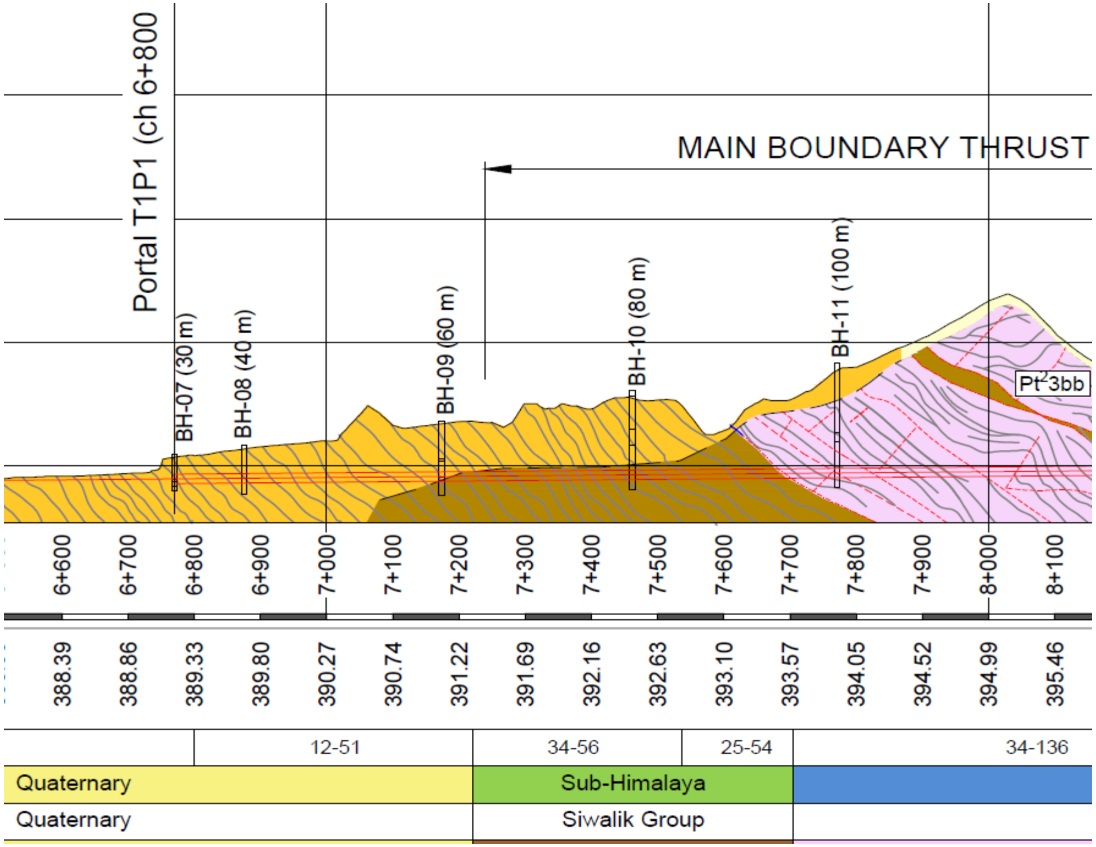
- Minimum cover
- Limit State Collapse in shear
- Crack width calculation/ serviceability checks
- Minimum lap and development of the reinforcement







Tunnel in Soil



- Between Ch 6+800 and Ch 7+700 approx.
- Quaternary Sediments: pebbles in silty sand matrix
- Siwalik Group: sedimentary rock of clastic origin (siltstone, sandstone, conglomerate) with variable and uncertain level of compaction, cementation and lithification

Unit	γ_{sat} (kN/m³)	E' (MPa)	v' (-)	c' (kPa)	Φ' (°)	K_0 (-)
QD	19.0	E' = 20 +1.0 z z ≤ 20m E' = 40 z > 20m	0.3	0	33	0.46
SG	26.5	430	0.3	200	41	1.1
ASG	24	120	0.3	30	33	0.46

Tunnel in Soil

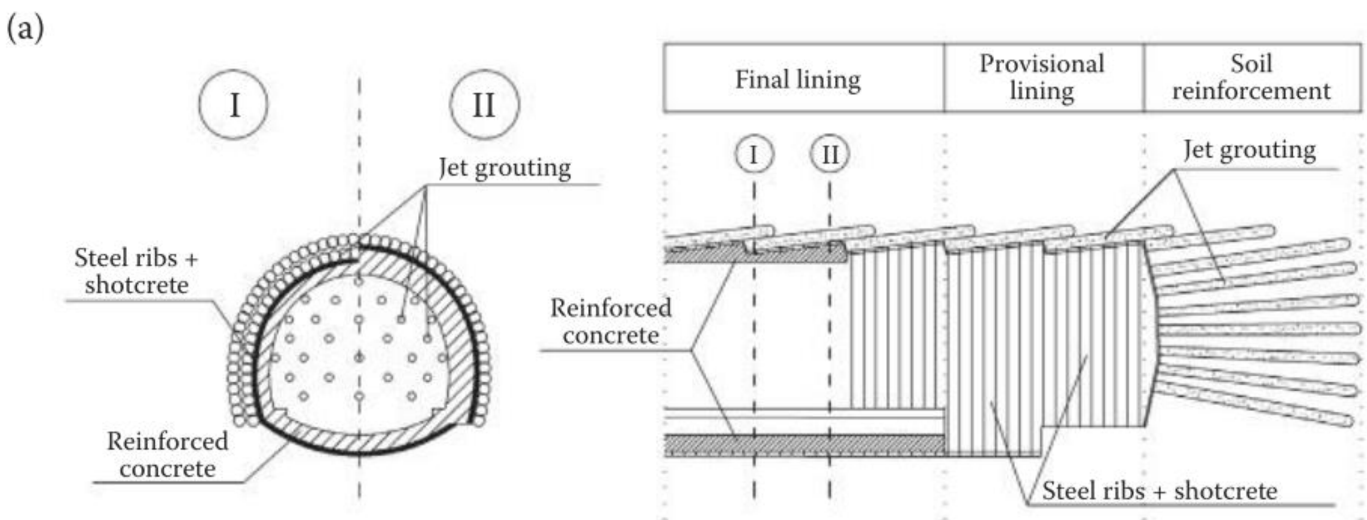
Guidelines for the application of the typical section

Zone	Chainage	S1	S2	S3
Z1	6+800 to 7+250	0%	70%	30%
Z2	7+250 to 7+550	10%	20%	70%
Z3	7+550 to 7+700	50%	40%	10%
Total m	900m	105	435	360

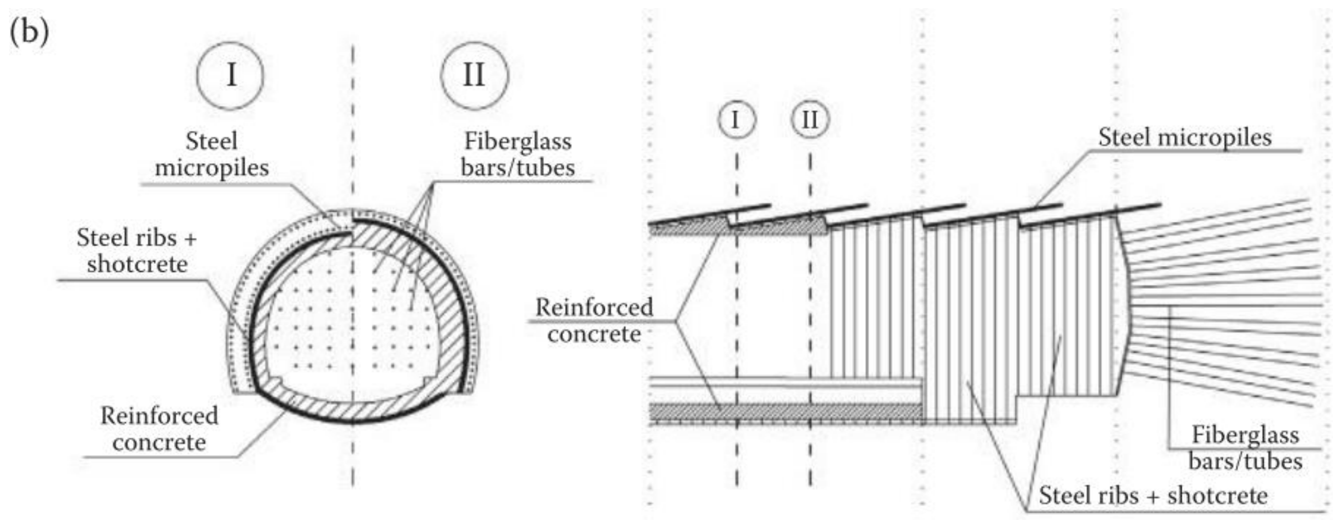
Tunnel	Material	GSI	O/b	Prevalent typical section	Radial displacements		Axial force	
					Maximum expected value	Alarm value	Maximum expected value	Alarm value
-	-	-	m	-	mm	mm	kN/m	kN/m
MT	SG	>30	55	S1	15	25	1950	2400
MT	ASG	<=30	55	S3	60	70	2050	2500
MT	QD	-	50	S2	30	40	1670	2000
MT	QD	-	20	S2	15	25	720	1000
ET	SG	>30	55	S1	15	25	1140	1500
ET	ASG	<=30	55	S3	30	40	1090	1500
ET	QD	-	50	S2	15	25	880	1200
ET	QD	-	15	S2	15	25	310	500

Tunnel in Soil

Pre-support : Canopy techniques



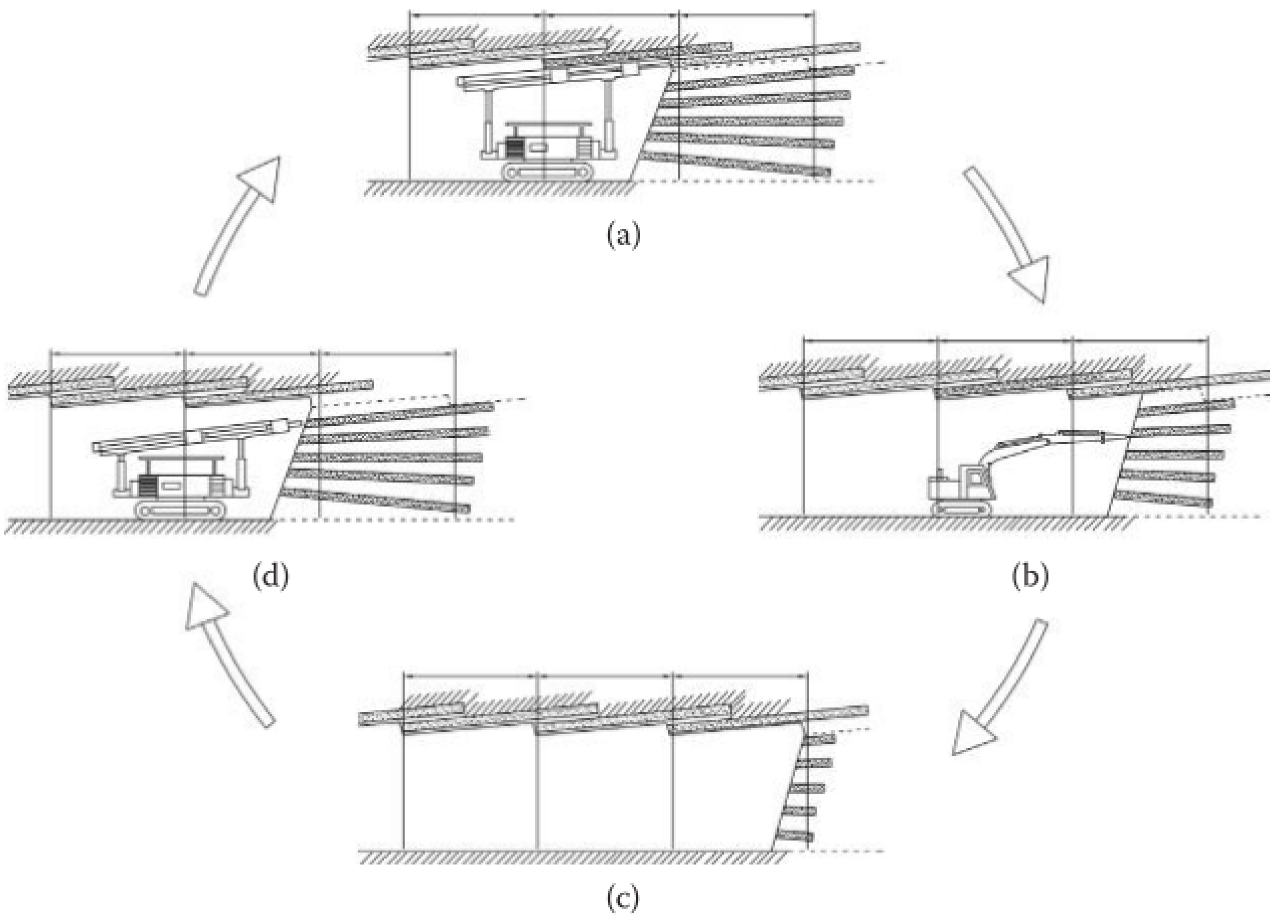
a) reinforcement by jet grouted columns



b) reinforcement by steel micropiles and fiberglass bars or tubes

Tunnel in Soil

Pre-support : Canopy techniques – jet grouting columns



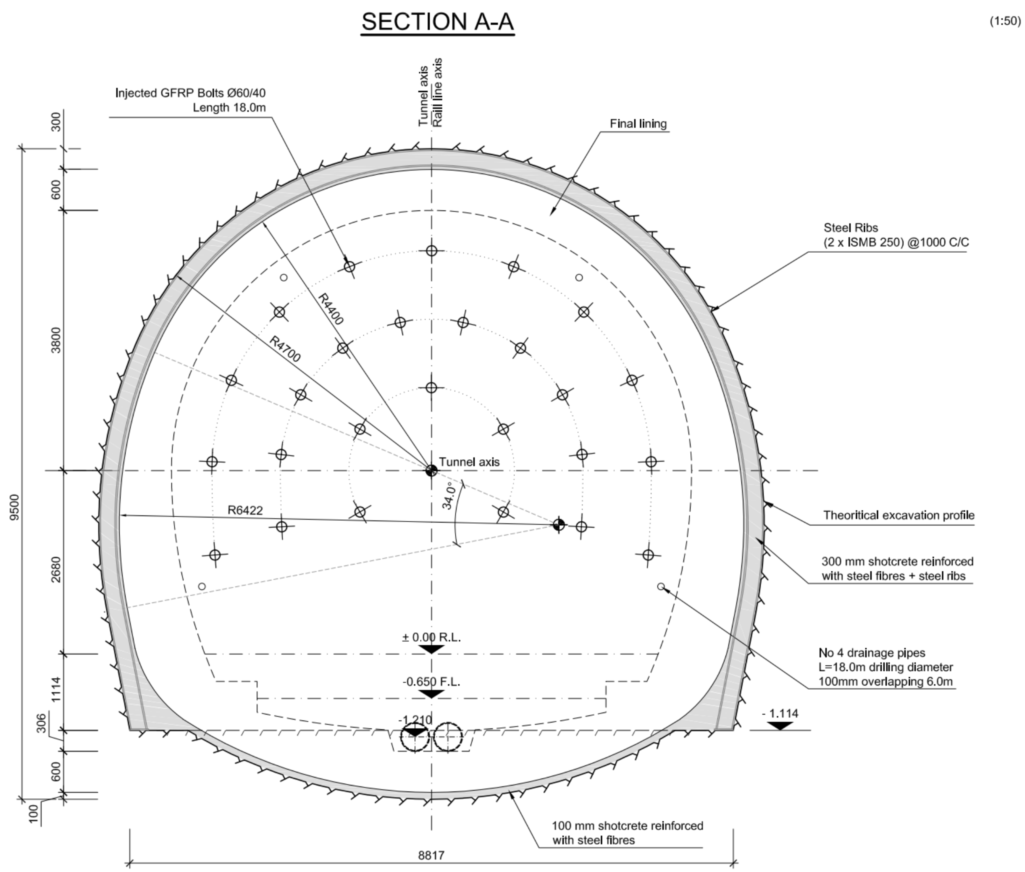
(a) Reinforcement of the tunnel contour by jet grouting and/or steel micropiles

(b) Excavation

(c) Excavation completed

(d) Face rnfmt by jet grouting and/or fiberglass bars or tubes (optional)

Support Type Definition



Section type S1

- Face stabilisation with injected GFRP bolts Φ60/40, 18m long
- No contour stabilization, non-varying section

Primary lining

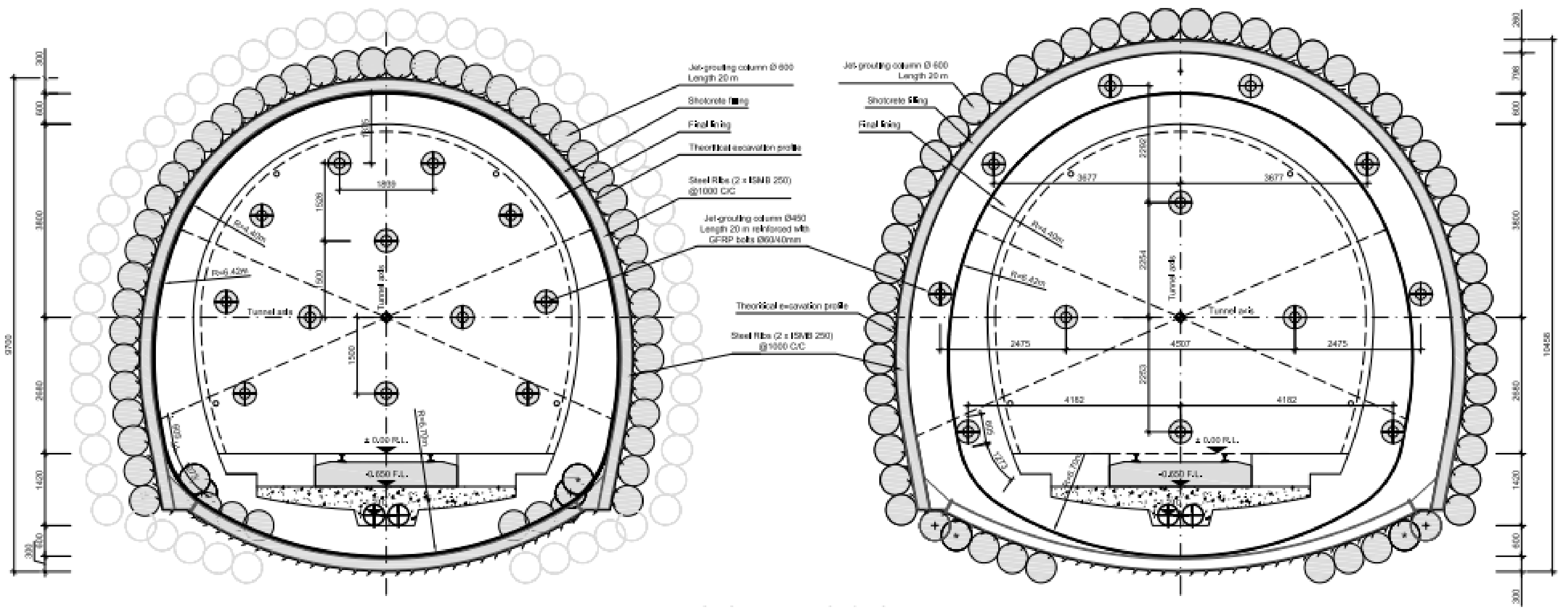
- Primary lining in sprayed concrete (SC) with **2xISMB 250** steel ribs at 1m spacing

Secondary lining

- Reinforced concrete

Tunnel in soil (Quatenary and Siwalik Group with GSI >30)

Support Type Definition



Tunnel in soil (Quatenary Group)

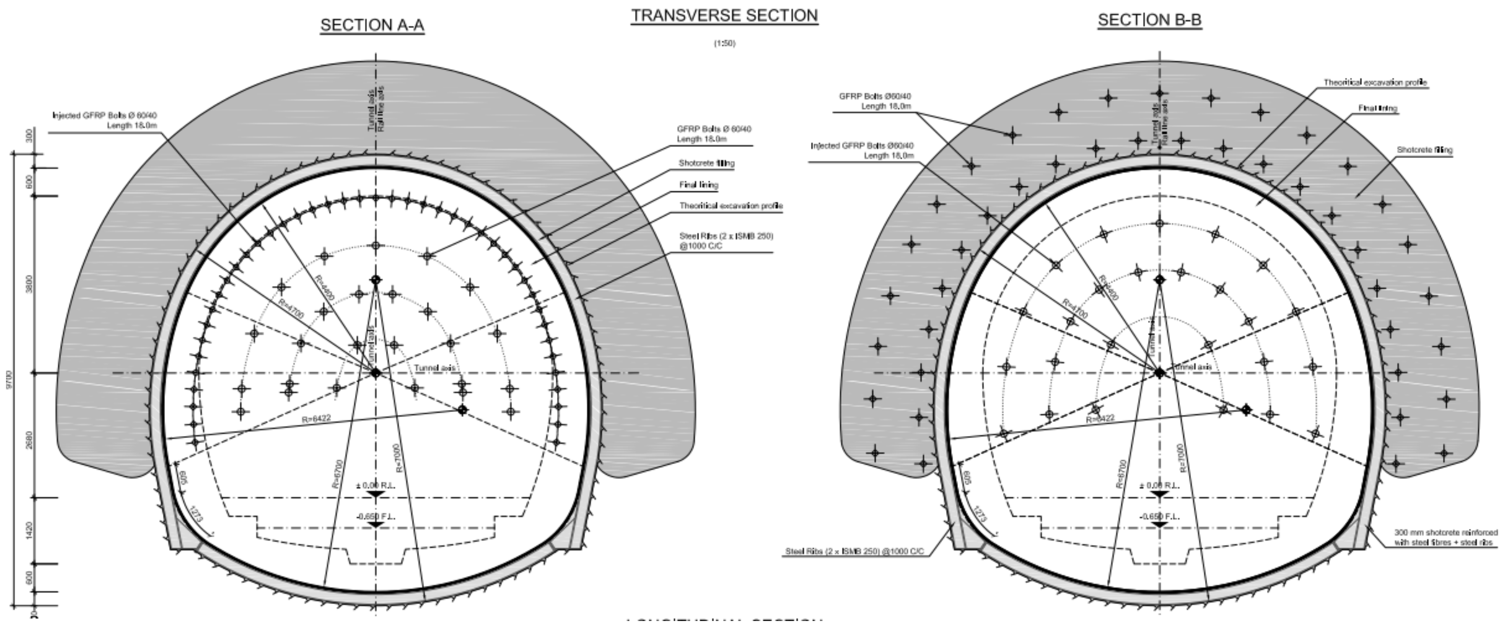
Section type S2 – Jet-grouting

- Face stabilisation with Φ450mm JG columns reinforced with GFRP bolts, 20m long
- Contour stabilisation with Φ600mm JG columns, 20m long

Primary lining - sprayed concrete (SC) with **2xISMB 250** steel ribs at 1m spacing

Secondary lining - Reinforced concrete

Support Type Definition



Tunnel in soil (Siwalik Group)

Section type S2 – Jet-grouting

- Face stabilisation with grouted GFRP bolts Φ60/40, 18m long
- Contour stabilisation with grout-injected GRP hollow bolts 60/40 mm, 18m long

Primary lining - sprayed concrete (SC) with **2xISMB 250** steel ribs at 1m spacing

Secondary lining - Reinforced concrete

Tunnel in Soil

Guidelines for the application of the typical section

- For each geotechnical formation, the prevalent typical section will be applied as a starting point.

- Measured value of displacements <= ~50% of expected value → proceed with same section

- Measured value of displacements << ~50% of expected value → possibility to adopt a lighter typical section

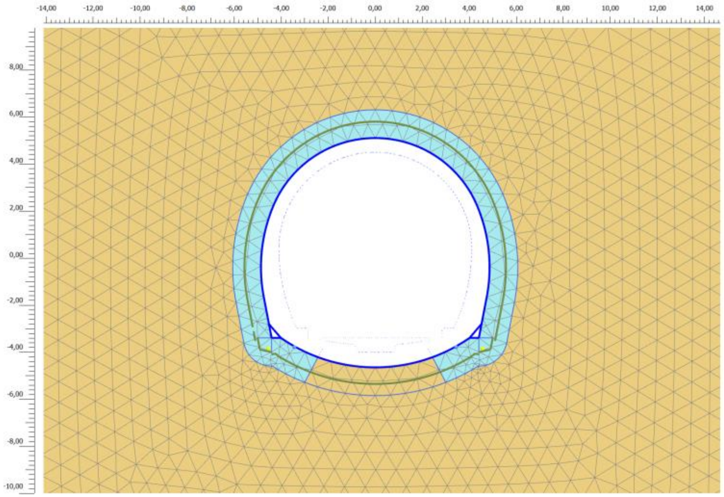
- Measured value of displacements/ stresses > ~50% of expected value and <alarm value → possibility to adopt a heavier section

- Measured value of displacements/ stresses > alarm value → adopt a heavier section, increase the frequency of monitoring, or evaluate new heavier

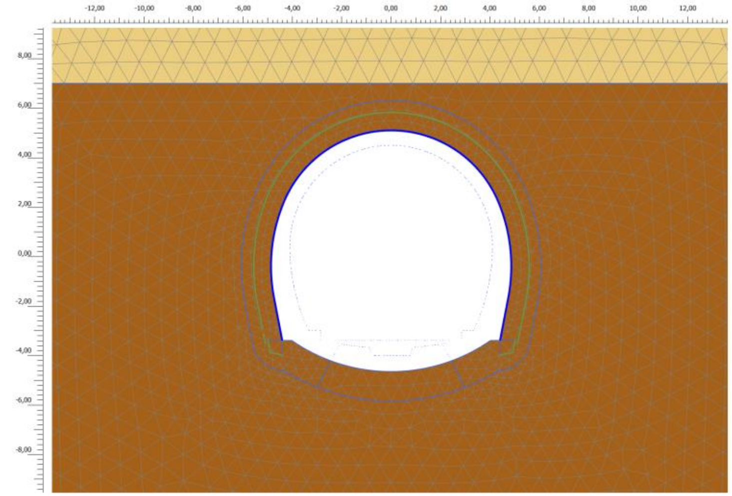
Tunnel in Soil

Stress analyses – Plaxis, stress analysis of continuum – FEM

Main Tunnel in Quaternary deposits



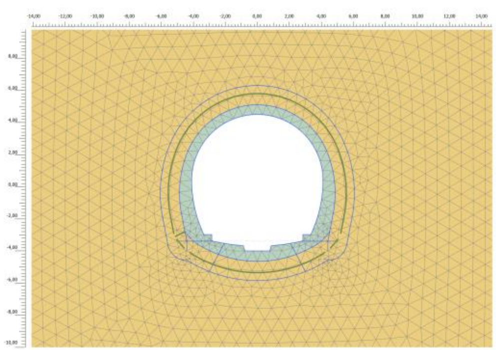
Main Tunnel in Siwalik Group

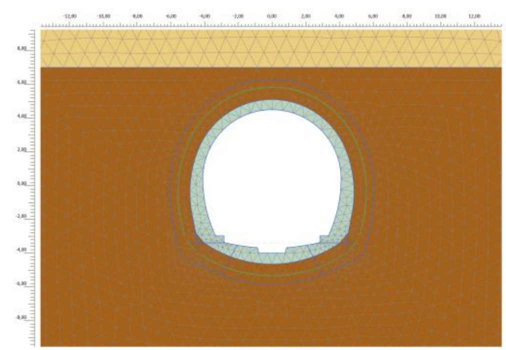


Primary lining, steel ribs and hardened sprayed concrete + Temporary invert

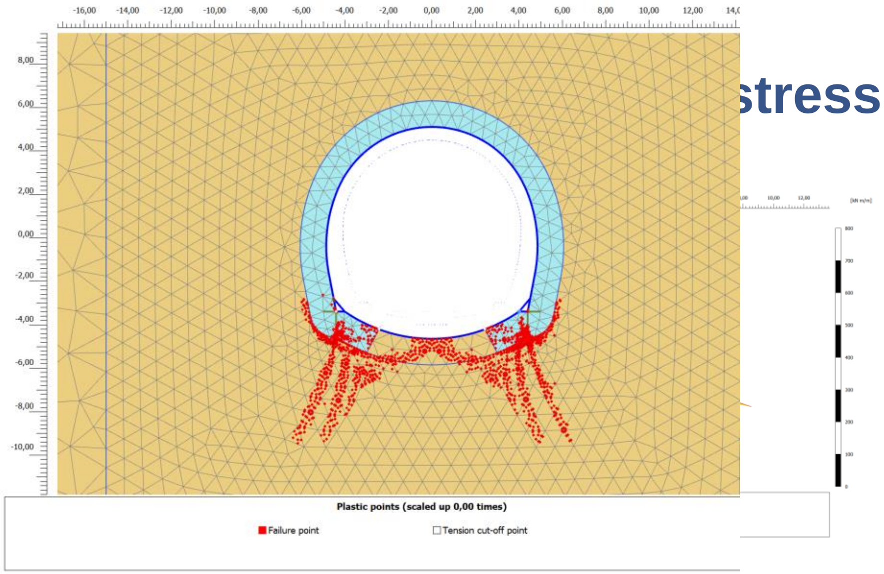
Primary lining, steel ribs and hardened sprayed concrete + invert excavation

Secondary lining installation and long-term condition (groundwater load)

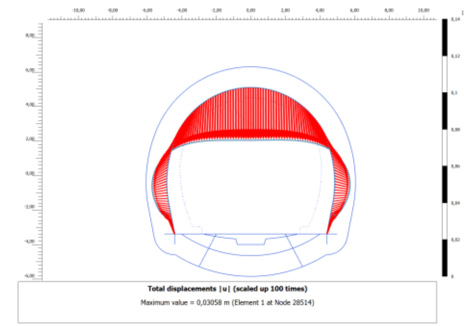




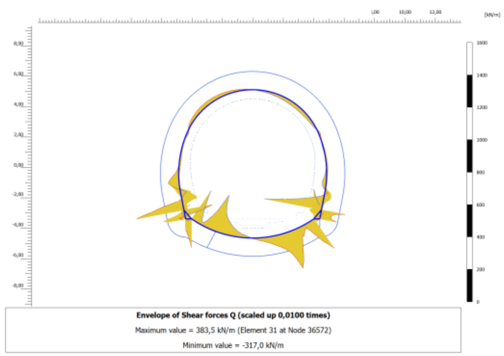
stress analysis of continuum – FEM



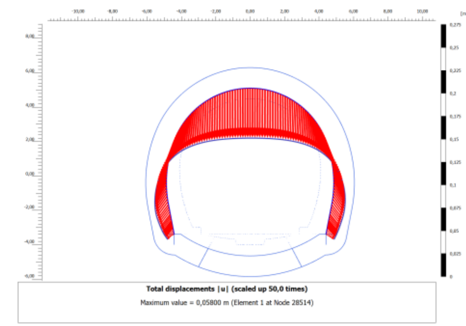
Total displacements of the temporary lining at the installation phase



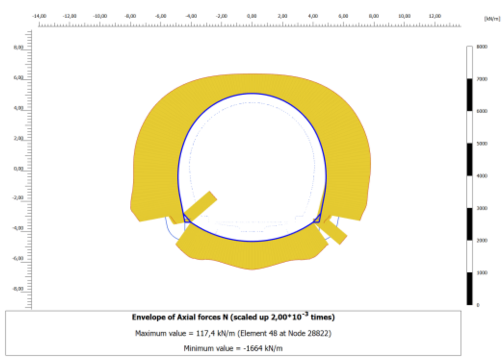
Shear force envelope



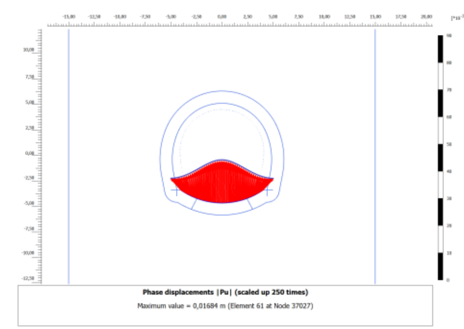
Total displacements of the temporary lining



Axial force envelope

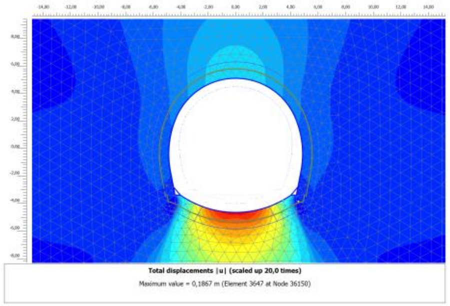


Phase displacements of the temporary invert

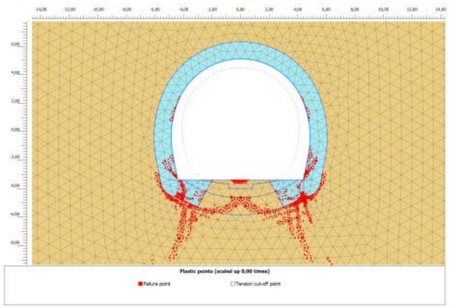


Stress analyses – Plaxis, stress analysis of continuum – FEM

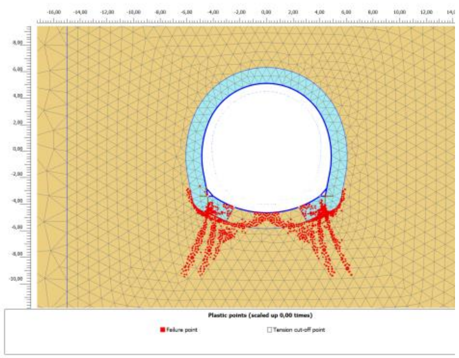
Total displacement of the ground



Plastic Points (before the installation of the invert)



Plastic Points (before the installation of the final lining)



- ✓ For the main tunnel in QD, displacement is about 6 cm, part of this (~ 3 cm), will happen ahead of the tunnel excavation, and can't be measured during the monitoring phase
- ✓ Part of the heave at the bottom of the excavation can be unrealistic effect due to the relative low stiffness of the modelled soil in unloading phase
- ✓ The consolidated ground around the excavation behave mainly elastically. Plasticity develop mainly at the bottom of the temporary lining base, but the collapse condition is far
- ✓ The monitoring system will be used to confirm the calculation hypothesis, with an observational approach, as it will be described better hereafter.

Summary of the application principle

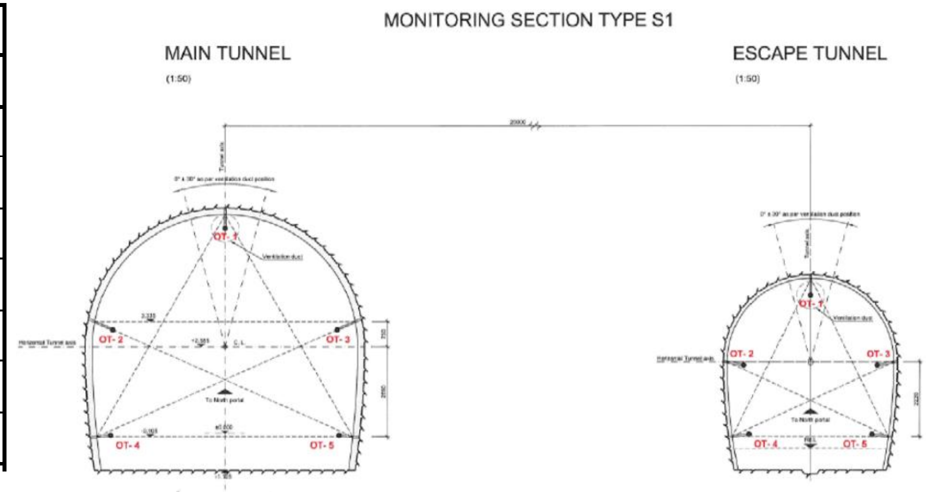
The table below represents the anticipated excavation behavior and hazards with respect to RMR classes and overburden

<table>
<tr><th rowspan="2">RMR</th><th colspan="10">Overburden</th></tr>
<tr><th colspan="2">0 - 50</th><th colspan="2">50 - 200</th><th colspan="2">200 - 400</th><th colspan="2">400 - 600</th><th colspan="2">600 - 800</th></tr>
<tr><td rowspan="2">80 - 100</td><td></td><td></td><td></td><td></td><td colspan="4">Stable excavation (1)
(A1, A2)</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Stable excavation with potential Rockburst*
(A1)</td></tr>
<tr><td rowspan="2">60 - 80</td><td></td><td></td><td></td><td colspan="5">Stable excavation, some unstable wedges (1) & (2)
(A2)</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Stable rock with potential Spalling, minor Rockburst*
(A1, A0)</td></tr>
<tr><td rowspan="3">40 - 60</td><td></td><td></td><td colspan="6">Unstable wedges (3)
(A2, B1)</td><td></td><td></td></tr>
<tr><td colspan="8">Unstable wedges, elasto-plastic deformation (4)
(B2, C1)</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="7">Plastic deformations (4) & (5)
(C1, C2)</td></tr>
<tr><td rowspan="2">20 - 40</td><td colspan="4">Unacceptable deformations, unstable face (5)
(C2)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="7">Squeezing, unacceptable deformations, unstable face (5) or #
(C2, C2b)</td></tr>
<tr><td>Soil / Fault</td><td colspan="8">Risk of collapse, full face excavation not possible without counter measures (5) or (6)
(S2, S3, D)</td><td></td><td></td></tr>
</table>

Monitoring - Underground

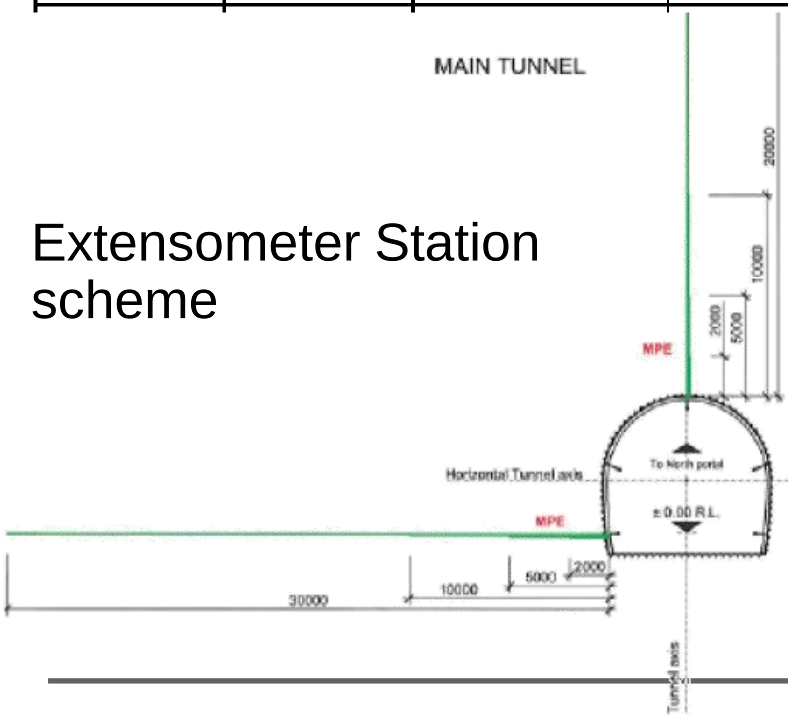
Indicative

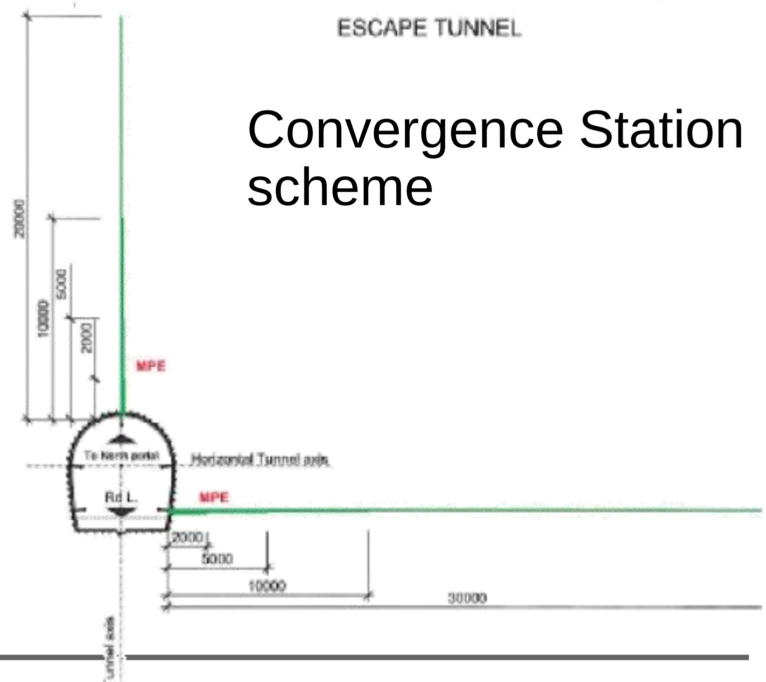
Tunnel	Section type	Threshold radial convergence values Alert (cm)	Alarm (cm)
MT / Adits	A1 / A2	Negligible	Negligible
	B1	2	3
	B2	3	4.5
	C1	4.5	6
	C2	6	9
	D	6	9
	C2b	15	22



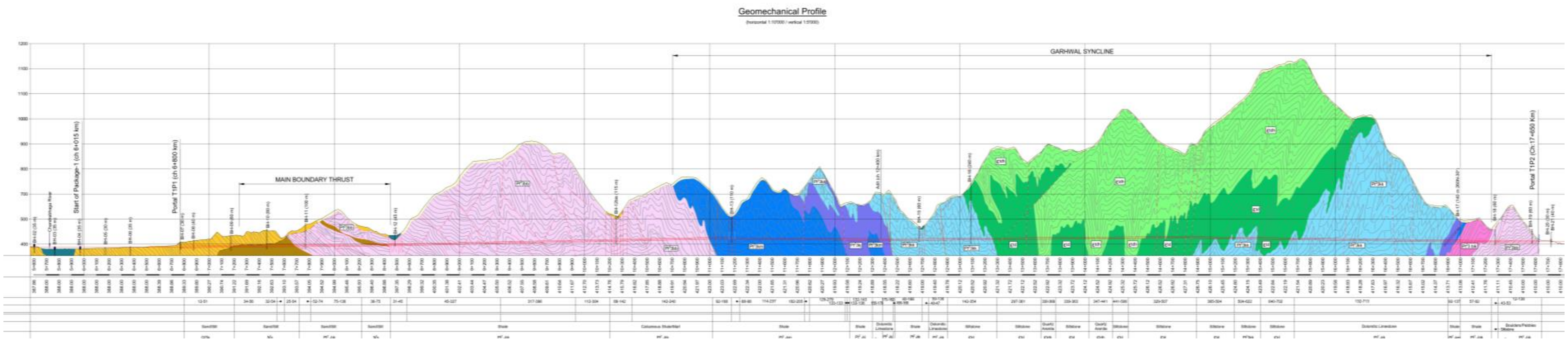
Convergence Station scheme

Extensometer Station scheme



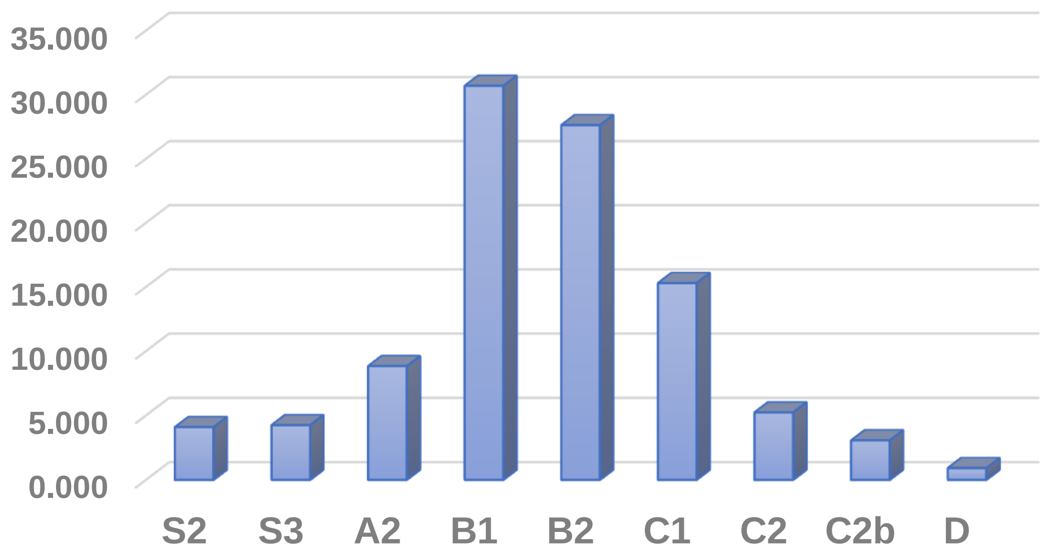


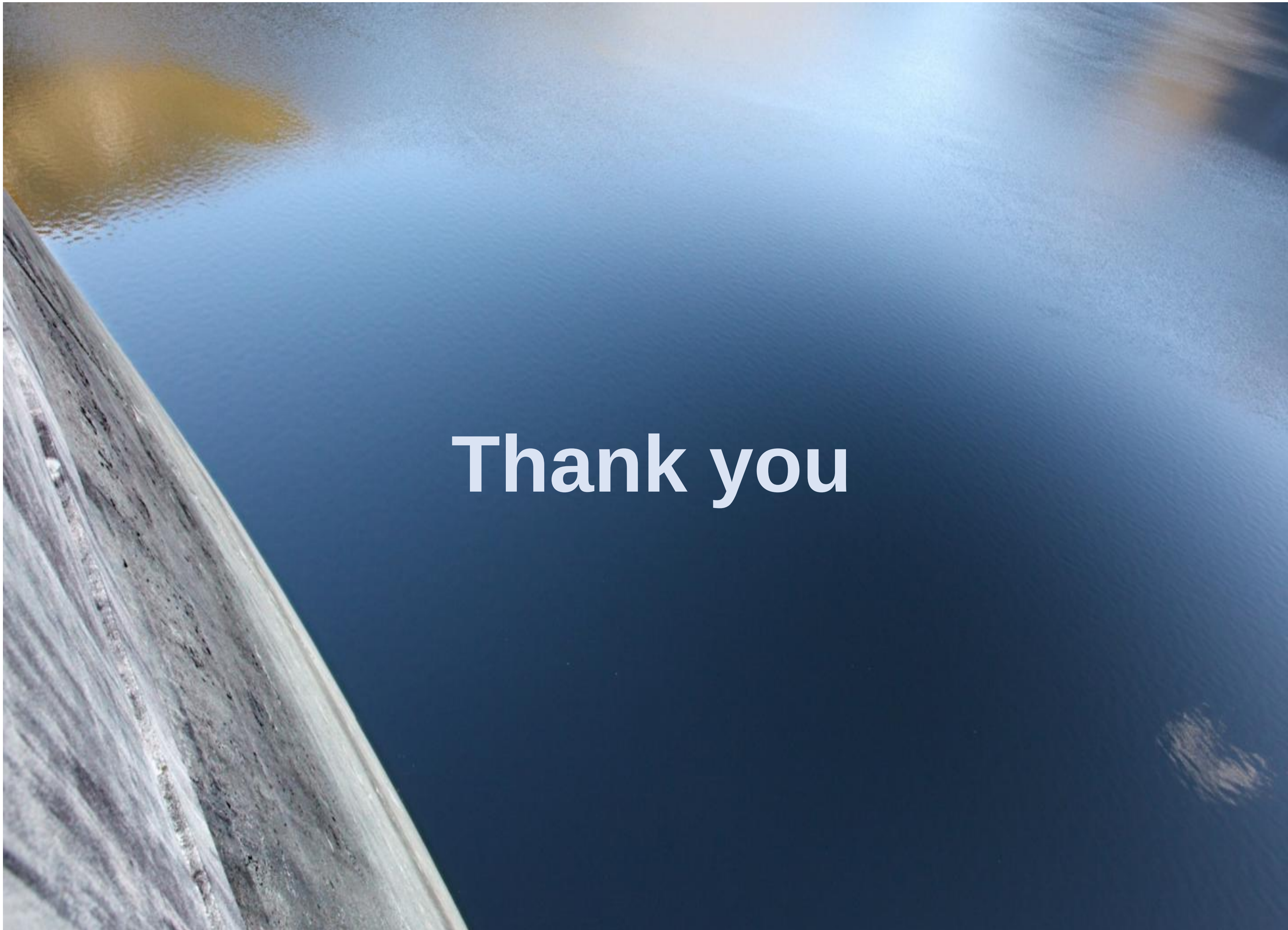
Distribution along the tunnel



Expected support classes

Class	Length [m]	%
S2	444.4	**4.1**
S3	461.0	**4.2%**
A2	958.4	**8.8%**
B1	3329.4	**30.7%**
B2	2996.8	**27.6%**
C1	1660.2	**15.3%**
C2	568.3	**5.2%**
C2b	332.5	**3.1%**
D	99.0	**0.9%**




Thank you