INFLUENCE OF CONSTRUCTION METHODS IN DESIGN APPROACH

by

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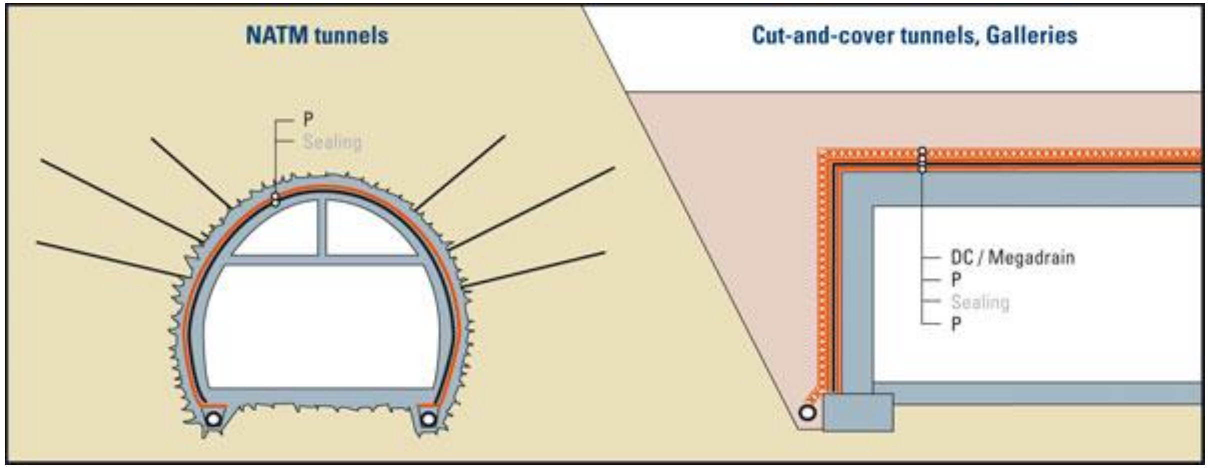
INTRODUCTION

•Methods of Tunneling

- Conventional Drill and Blast
- Cut and Cover
- New Austrian Tunneling Method (NATM)/SEM
- Tunnel Boring Machine (TBM)

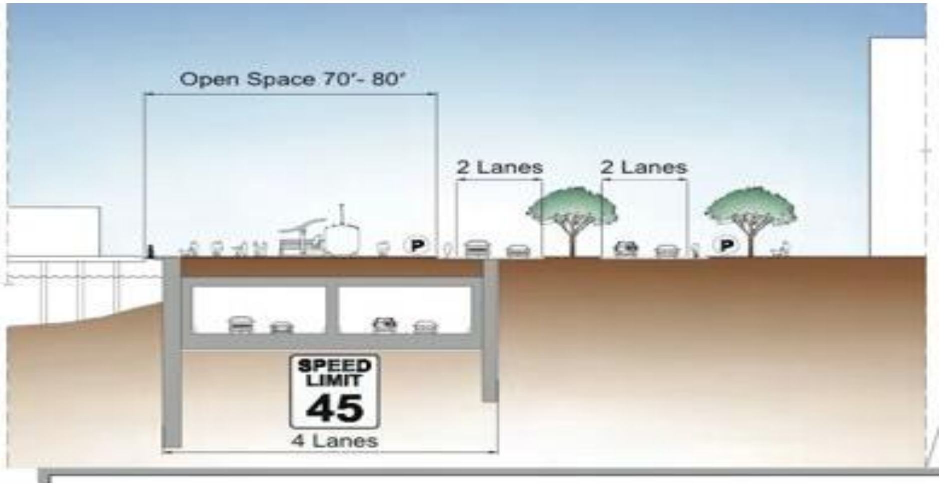


Conventional Tunnelling

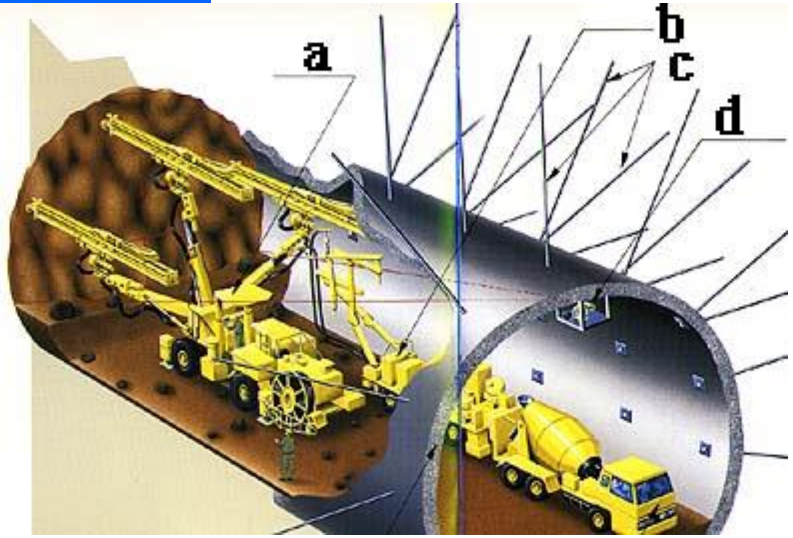
- Tunnel is excavated using drill and blast method
- Depending upon tunnel diameter, heading and benching is decided
- Tunnel is supported using shotcrete, rock bolts/anchors, steel ribs, lattice girders
- Tunnel lining Plain or reinforced is installed
- Drainage arrangement, curtain and consolidation grouting, water proofing

Cut & Cover Tunnel

- Tunnel is excavated using sheetpiles, diaphragm walls, soldier piles, secant piles
- Lateral support by struts, walers, anchors
- Then structure/tunnel is constructed
- Then the tunnel is backfilled

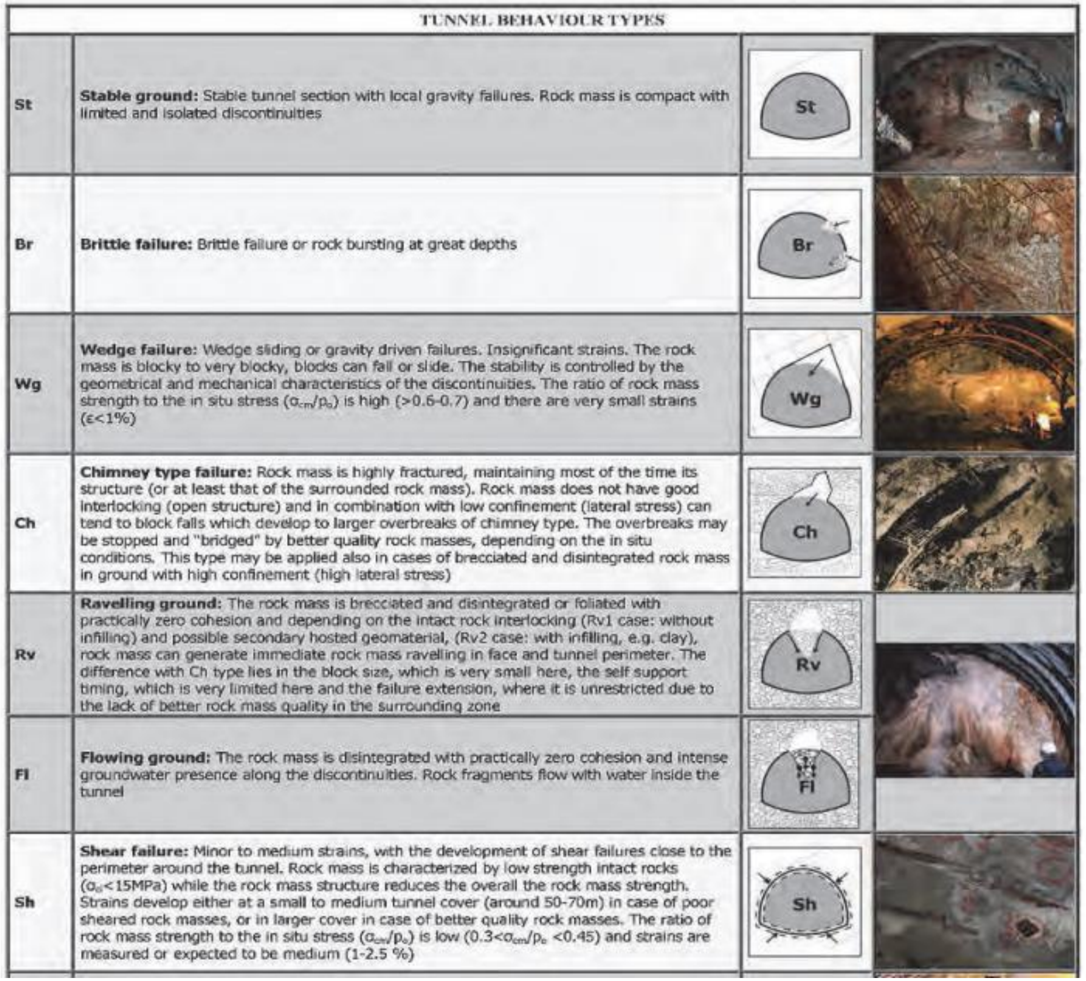


NATM Method



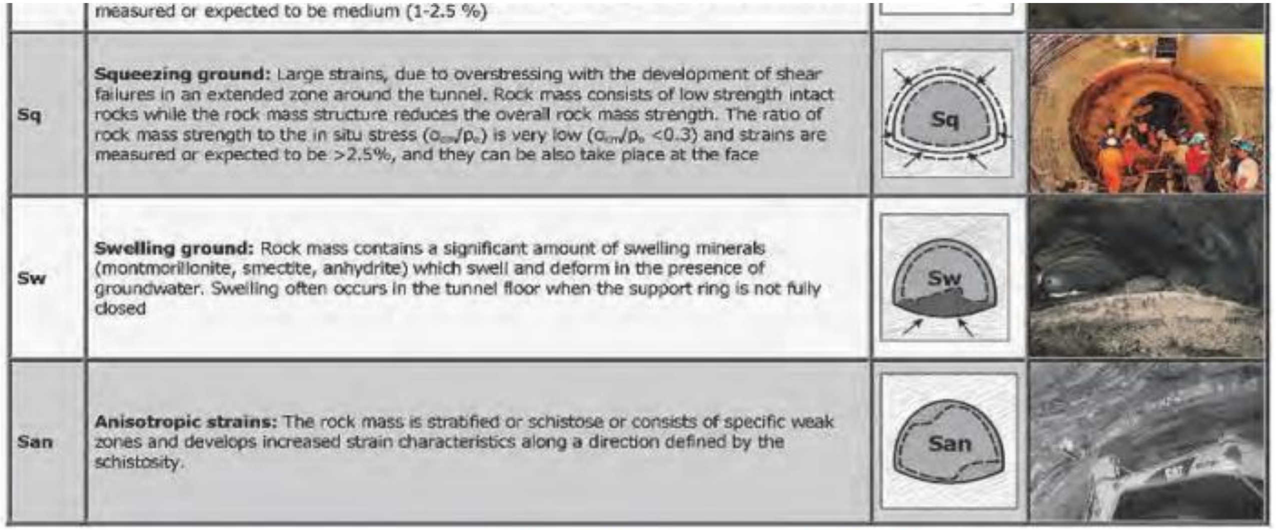
Basic principles of NATM

- (i) Mobilization of rock mass strength,
- (ii) Shotcrete protection to preserve the load-carrying capacity of the ring of rock mass,
- (iii) Monitoring the deformation of the excavated rock mass,
- (iv) Providing flexible but active supports and
- (v) Closing of invert to form a load-bearing support ring to control deformation of the rock mass.



TUNNEL BEHAVIOUR TYPES

St	**Stable ground:** Stable tunnel section with local gravity failures. Rock mass is compact with limited and isolated discontinuities	St
Br	**Brittle failure:** Brittle failure or rock bursting at great depths	Br
Wg	**Wedge failure:** Wedge sliding or gravity driven failures. Insignificant strains. The rock mass is blocky to very blocky, blocks can fall or slide. The stability is controlled by the geometrical and mechanical characteristics of the discontinuities. The ratio of rock mass strength to the in situ stress (σ_{cm}/p_o) is high (>0.6-0.7) and there are very small strains (ε<1%)	Wg
Ch	**Chimney type failure:** Rock mass is highly fractured, maintaining most of the time its structure (or at least that of the surrounded rock mass). Rock mass does not have good interlocking (open structure) and in combination with low confinement (lateral stress) can tend to block falls which develop to larger overbreaks of chimney type. The overbreaks may be stopped and "bridged" by better quality rock masses, depending on the in situ conditions. This type may be applied also in cases of brecciated and disintegrated rock mass in ground with high confinement (high lateral stress)	Ch
Rv	**Ravelling ground:** The rock mass is brecciated and disintegrated or foliated with practically zero cohesion and depending on the intact rock interlocking (Rv1 case: without infilling) and possible secondary hosted geomaterial, (Rv2 case: with infilling, e.g. clay), rock mass can generate immediate rock mass ravelling in face and tunnel perimeter. The difference with Ch type lies in the block size, which is very small here, the self support timing, which is very limited here and the failure extension, where it is unrestricted due to the lack of better rock mass quality in the surrounding zone	Rv
Fl	**Flowing ground:** The rock mass is disintegrated with practically zero cohesion and intense groundwater presence along the discontinuities. Rock fragments flow with water inside the tunnel	Fl
Sh	**Shear failure:** Minor to medium strains, with the development of shear failures close to the perimeter around the tunnel. Rock mass is characterized by low strength intact rocks (σ_{ci}<15MPa) while the rock mass structure reduces the overall rock mass strength. Strains develop either at a small to medium tunnel cover (around 50-70m) in case of poor sheared rock masses, or in larger cover in case of better quality rock masses. The ratio of rock mass strength to the in situ stress (σ_{cm}/p_o) is low ($0.3<\sigma_{cm}/p_o<0.45$) and strains are measured or expected to be medium (1-2.5 %)	Sh

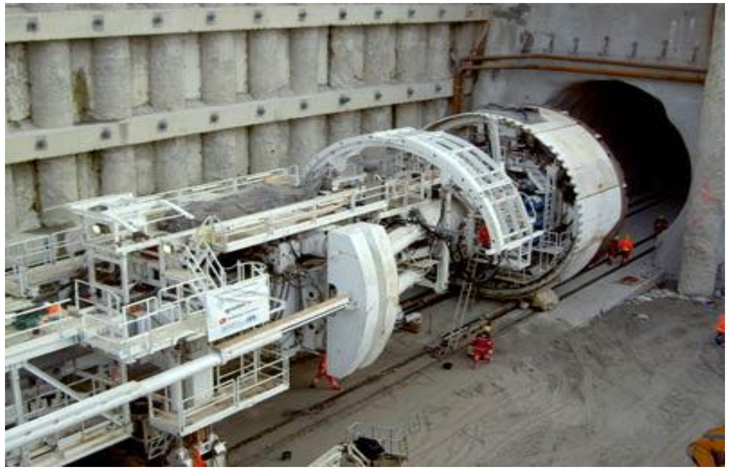


	measured or expected to be medium (1-2.5 %)	
Sq	**Squeezing ground:** Large strains, due to overstressing with the development of shear failures in an extended zone around the tunnel. Rock mass consists of low strength intact rocks while the rock mass structure reduces the overall rock mass strength. The ratio of rock mass strength to the in situ stress (σ_{cm}/p_o) is very low (σ_{cm}/p_o <0.3) and strains are measured or expected to be >2.5%, and they can be also take place at the face	Sq
Sw	**Swelling ground:** Rock mass contains a significant amount of swelling minerals (montmorillonite, smectite, anhydrite) which swell and deform in the presence of groundwater. Swelling often occurs in the tunnel floor when the support ring is not fully closed	Sw
San	**Anisotropic strains:** The rock mass is stratified or schistose or consists of specific weak zones and develops increased strain characteristics along a direction defined by the schistosity.	San

Fig. 11 Schematic diagram of tunnel behavior after Marinos [31]

TBM Tunnels

- Tunnel is excavated by TBM, earth balancing, slurry, shield type
- Rock/soil support in form of rock bolts, shotcrete and segmental lining
- Consolidation, curtain grouting, water proofing



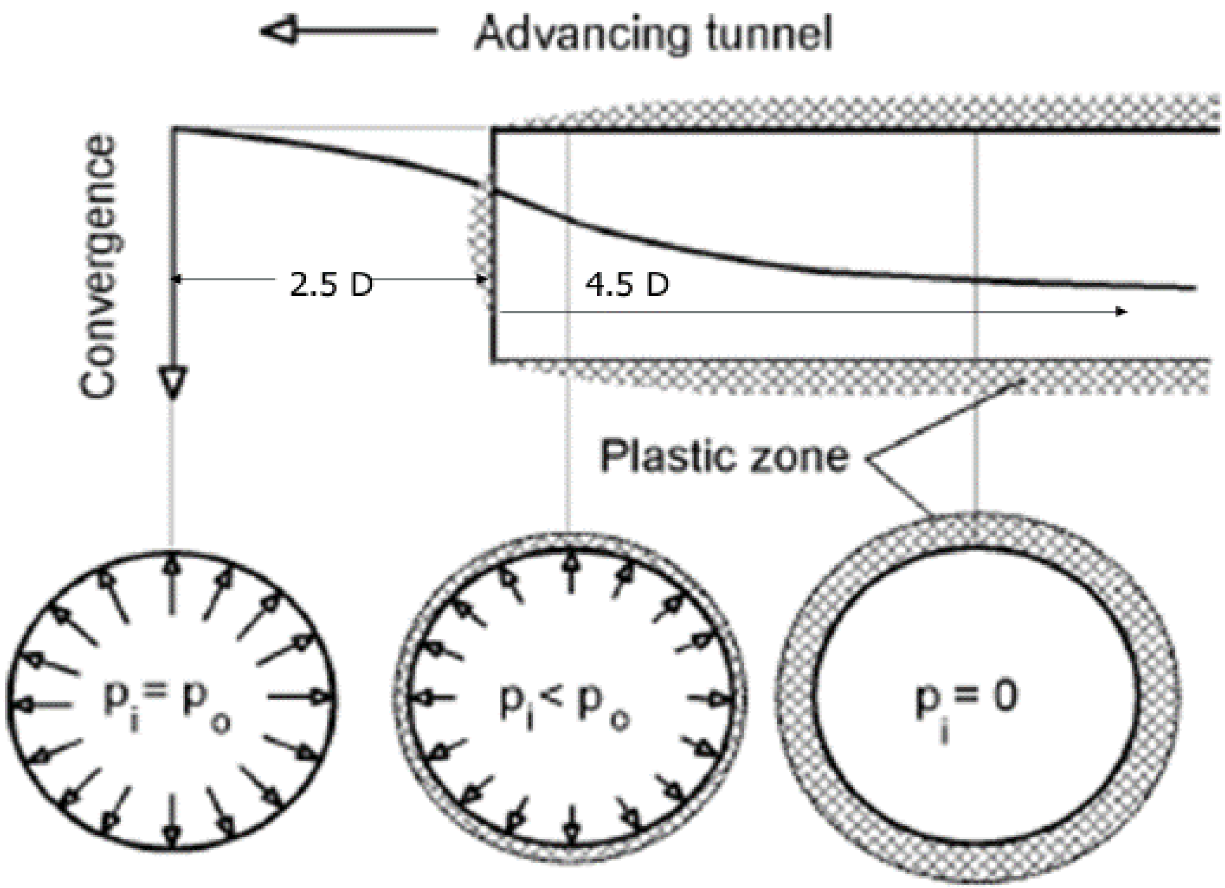
Various Analysis

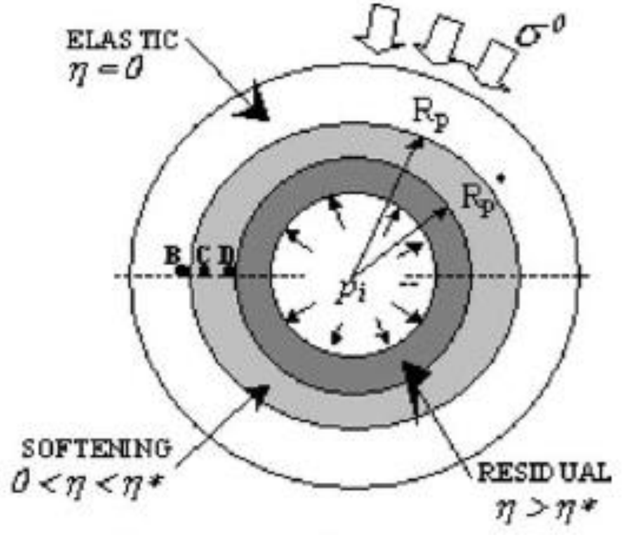
i. Numerical techniques like FEM, FDM, DEC can used for analysis of cavities with any possible geometrical shape, properties and support system
ii. Rock mass/soil is modeled using a mesh of Finite elements of appropriate size and spacing
iii. Joints can also be modeled using interface elements
iv. Mohr-Coulomb/Hoek-Brown or any other failure criterion can be used based on strata properties
v. Groundwater and pore pressures can be simulated along with seismic loads (if required)
vi. Stage wise softening , tunnel excavation & support installation can be simulated
vii. 3D modeling can include realistic effect of confinement loss in face-ahead of tunnel cavity

Input Parameters for Analysis

- Strength Parameters (c, phi, tensile strength, Dilatancy)
- Deformations parameters (E, v)
- Joint Parameters (c, phi, normal and shear stiffness)
- Permeability
- Density
- In-situ stresses

Basic Concept





Loads and Ground Reaction Curves

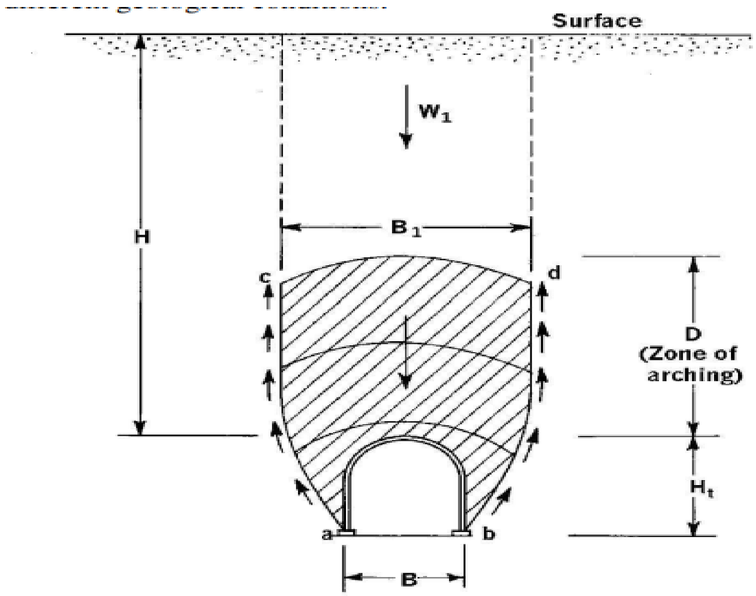


Fig. 1. – Terzaghi's ground arch concept. Reproduced from "Rock defects and loads on tunnel supports" published in 1946.

the radial convergence δ both increase as the support pressure decreases as illustrated in Fig. 2. Eventually, about two tunnel diameters behind the face, the support pressure p_i provided by the face has decreased to zero and the radial convergence δ reaches its final value.

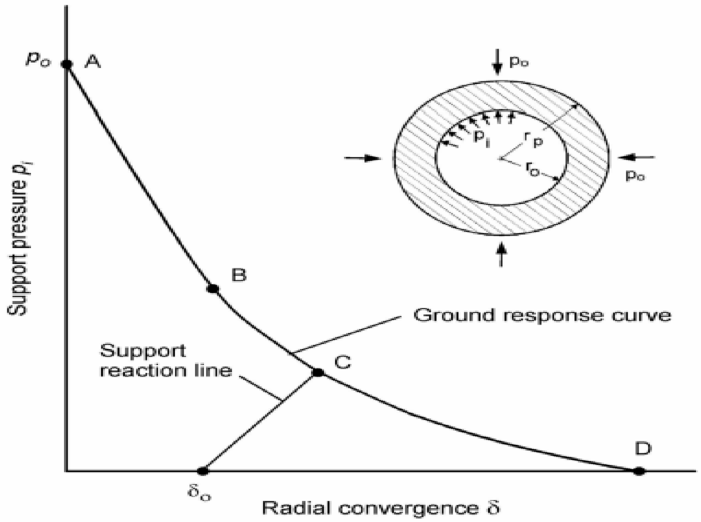
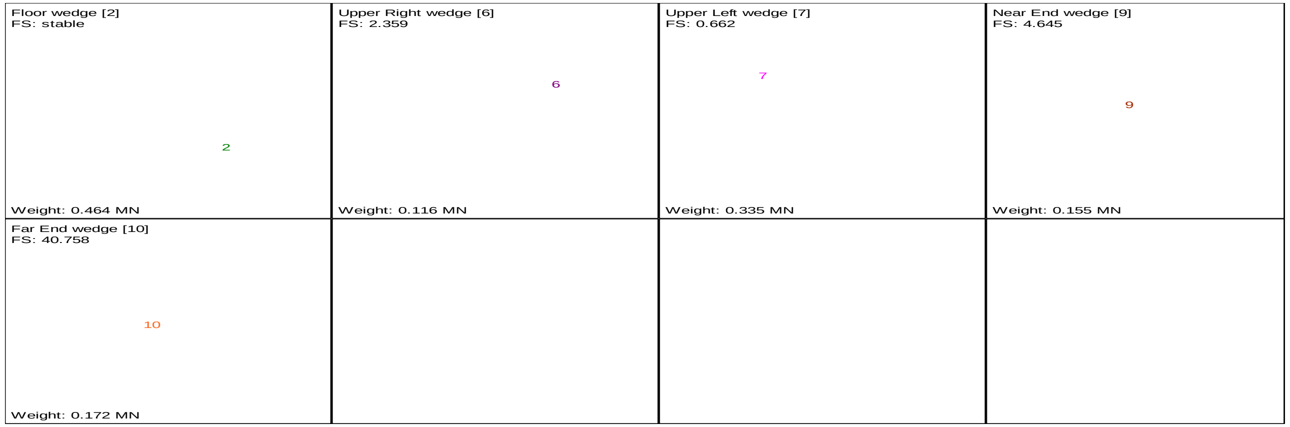


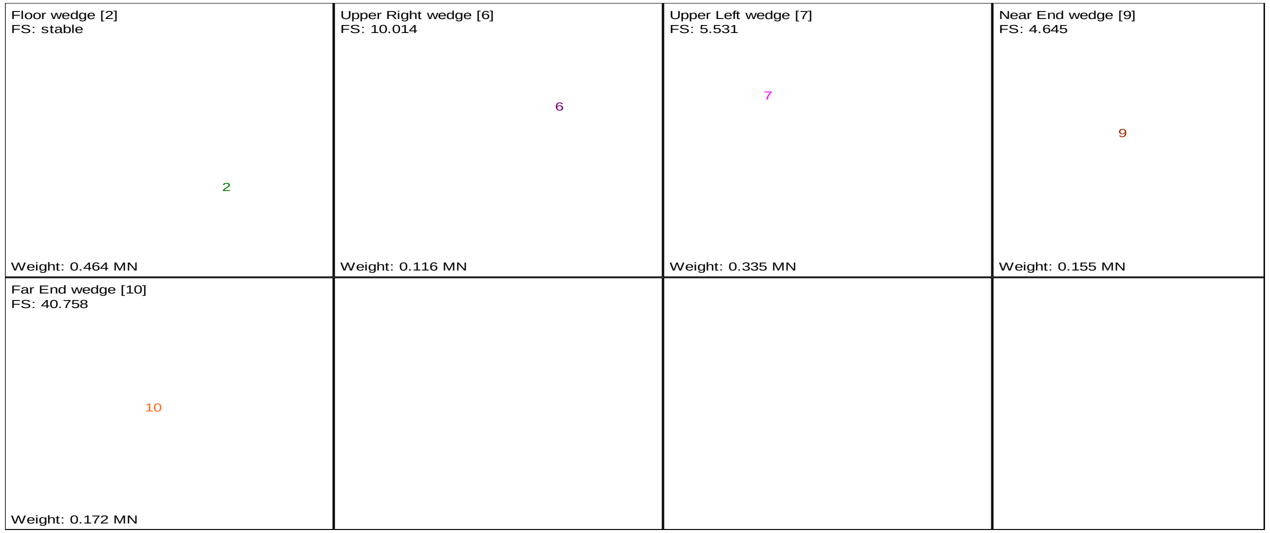
Table 1: Rockmass Parameters for Class V/ Shear Zone

Description		**Unit**	**Very Poor Rockmass/ Shear Zone**
Intact Rock Properties	UCS	MPa	50
	GSI		15
	mi		9
	Ei	MPa	30000
	v		0.25
Rock Mass Parameters	c (peak)	MPa	0.34
	Φ (peak)	deg	30.66
	c (residual)	MPa	0.22
	Φ (residual)	deg	22.01
	Tensile Strength	MPa	0.009
	Deformation Modulus	MPa	1093.47
Rock Mass Parameters Damage Zone (1 m for class V/ Shear zone)	c	MPa	0.141
	Φ	deg	14.863
	Tensile Strength	MPa	0.002
	Deformation Modulus	MPa	700.555

Unsupported



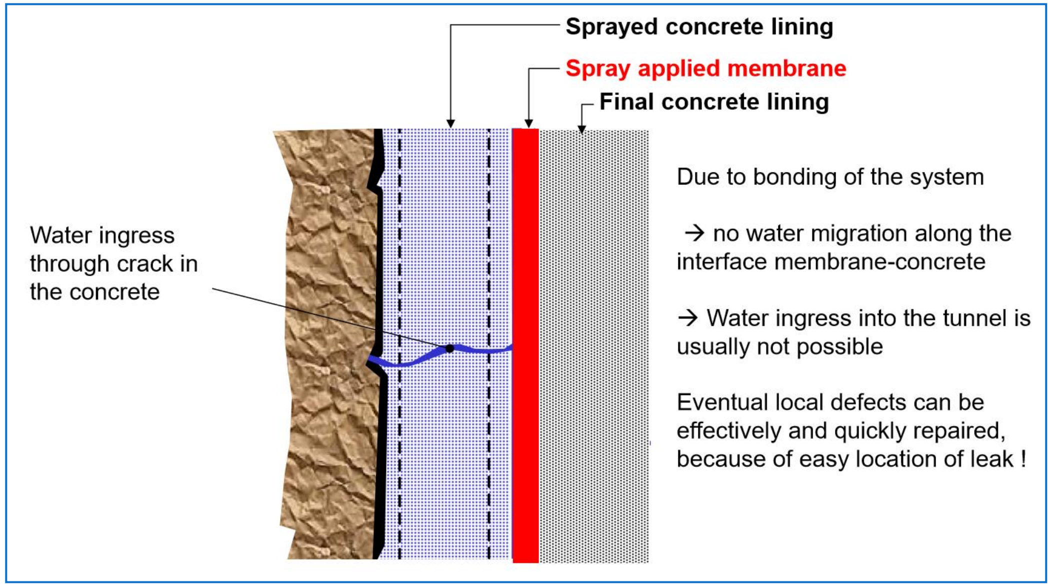
Supported



Hydro-geological conditions affect tunnel stability

- Additional water pressures are exerted
- Extreme conditions negatively affect durability of supports and strength of rock mass
- Drainage has to be provided to allow water to release. Drainage pumps have to be used in case of heavy flow
- Confined aquifers encountered during construction are dangerous & may cause flooding

Geo-composite application



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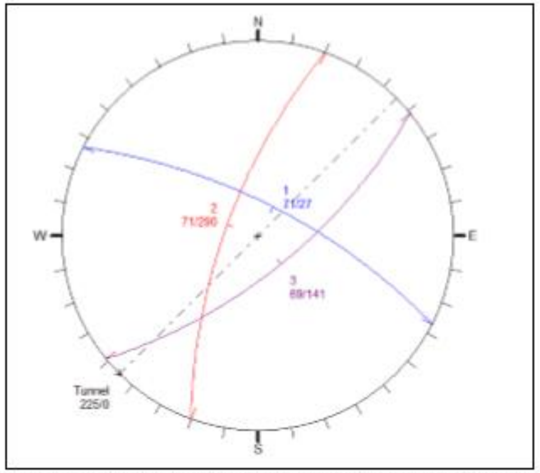


Figure 1: Stereographic Projection of Joints and Tunnel Alignment with Tunnel Direction of N225.30°

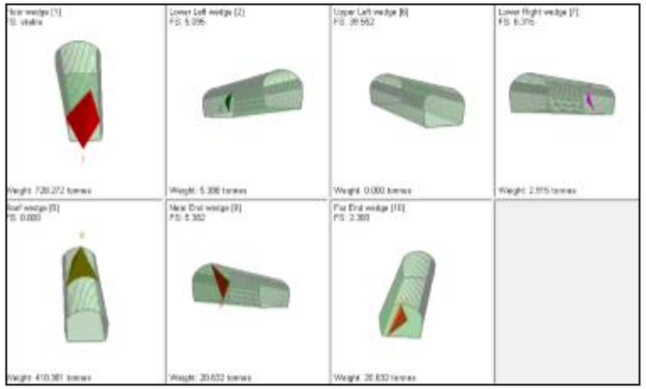


Figure 2: Alignment, Position and Factor of Safety of Wedges without Support System for Tunnel direction of N225.30°

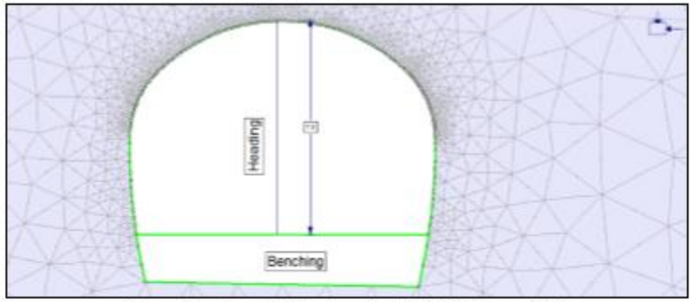


Figure 11: Discretization Boundary for Rock Classes I-IV

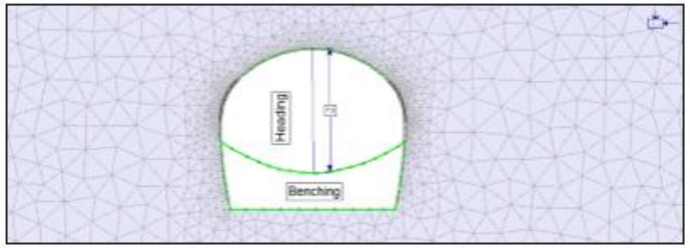


Figure 12: Discretization Boundary for Rock Class V

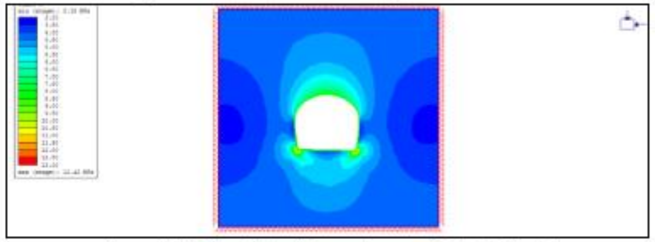
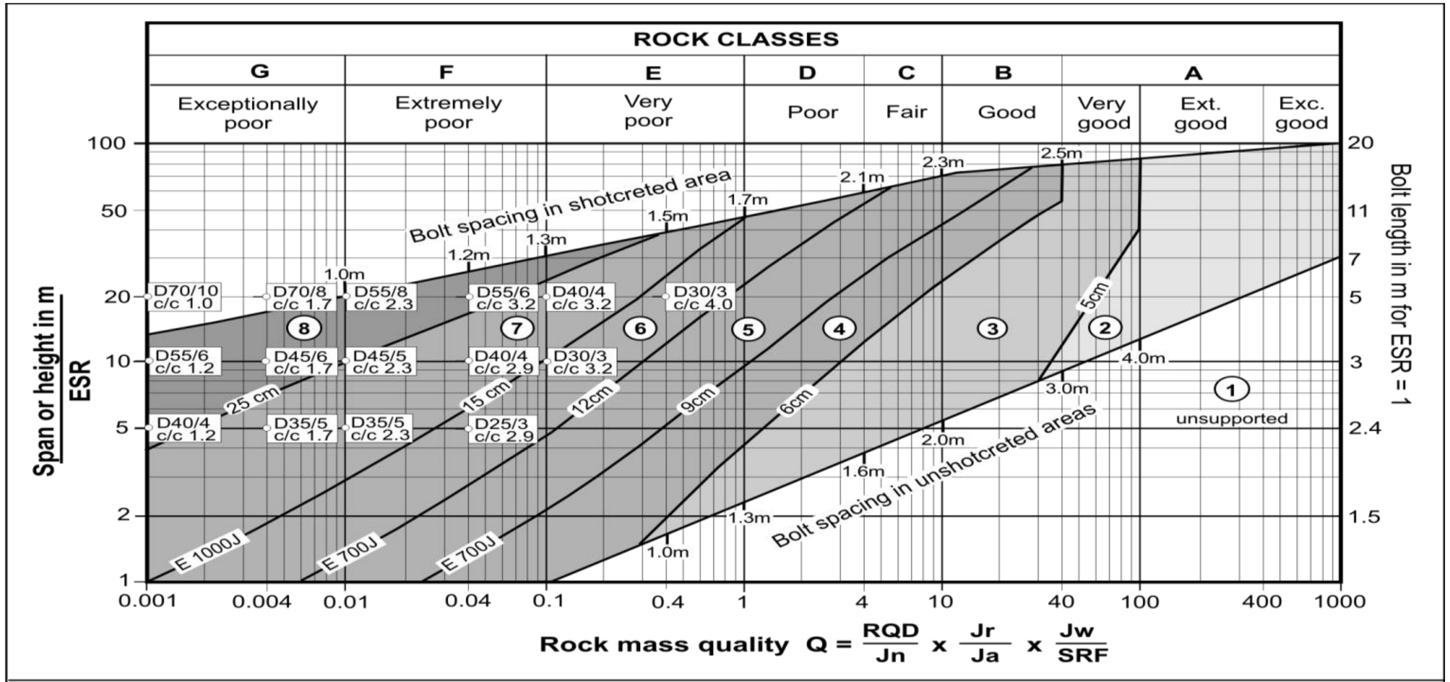


Figure 13: Major Principal Stress Contours for Rock Class I

i. Bartons' "Q" system method



REINFORCEMENT CATEGORIES:

1) Unsupported
2) Spot bolting
3) Systematic bolting and unreinforced or fibre reinforced shotcrete, 5 - 6cm thick
4) Fibre reinforced shotcrete 6 - 9cm, and bolting
5) Fibre reinforced shotcrete 9 - 12cm, and bolting
6) Fibre reinforced shotcrete 12 - 15cm, and bolting
7) Fibre reinforced shotcrete > 15cm + reinforced ribs of shotcrete and bolting
8) Cast concrete lining or reinforced ribs of shotcrete and bolting

D55/6 c/c 1.2 — 55cm thick reinforced rib of shotcrete with total 6 rebars in double layers. The distance betwee the ribs is 1.2m (The text box is related to the Q-value and span at the small circle on left side)

E = energy absorbtion in fibre reinforced shotcrete at 25mm deflection in plate test

(ii). Support system based on RMR

The RMR support table (for tunnels with 10m span)

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

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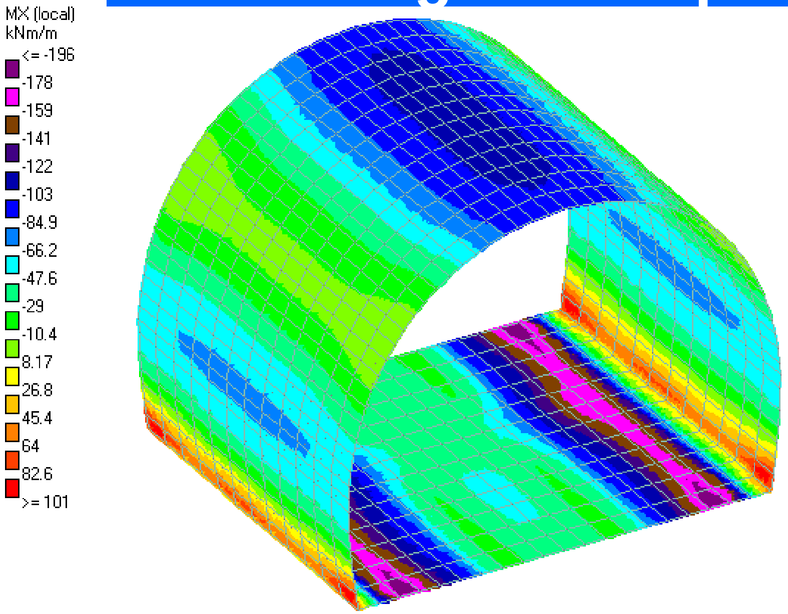
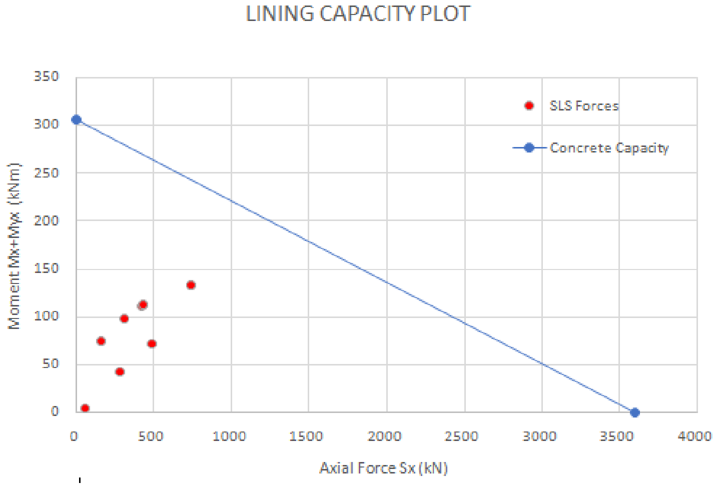
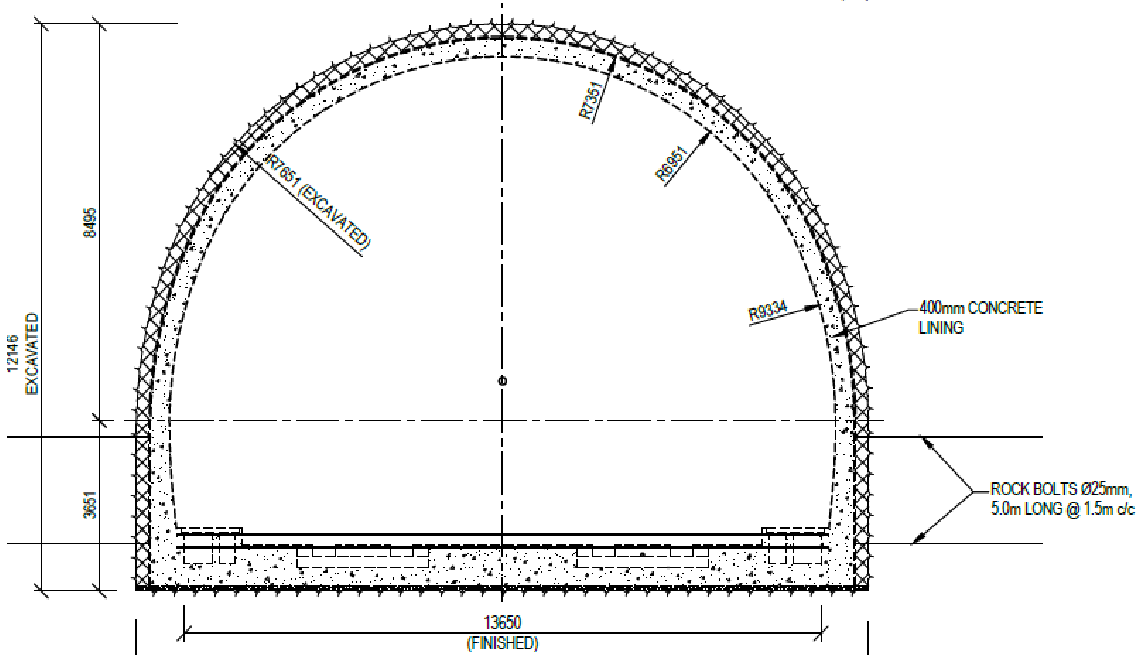
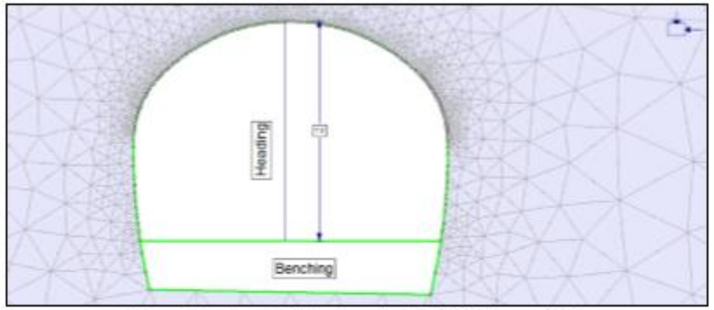




Modeling in Staad pro & final lining drawing



Numerical Models for Hard Ground and Soft Ground



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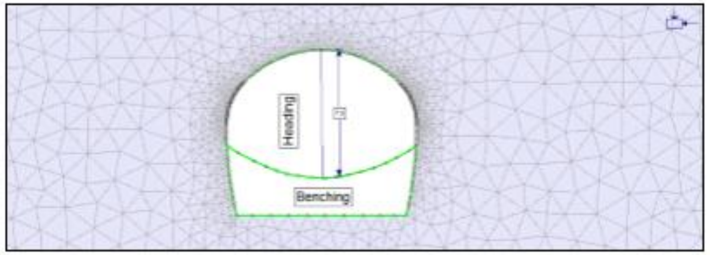
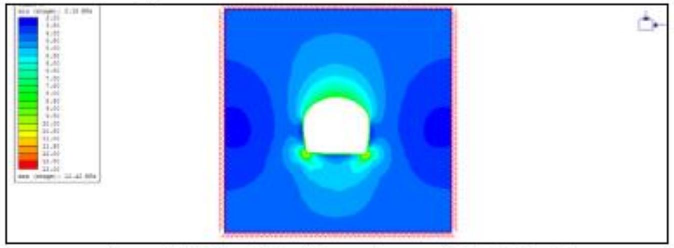


Figure 12: Discretization Boundary for Rock Class V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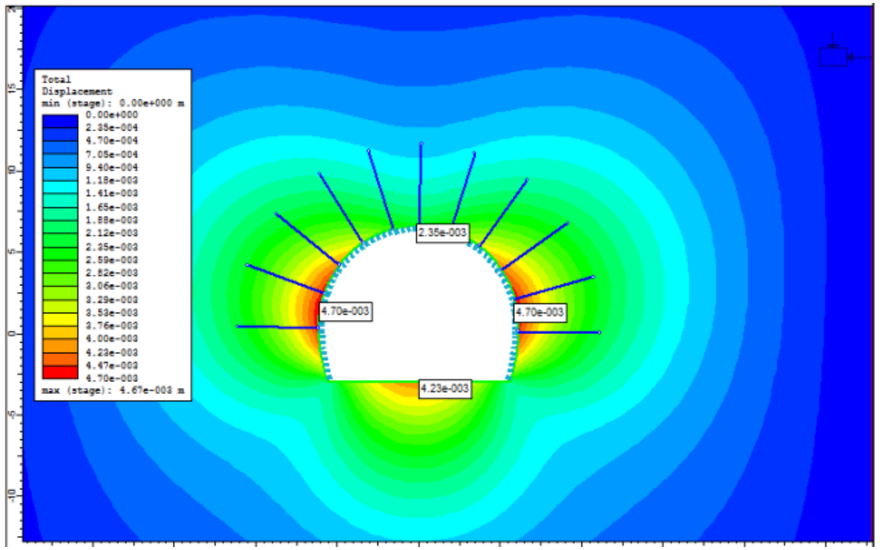

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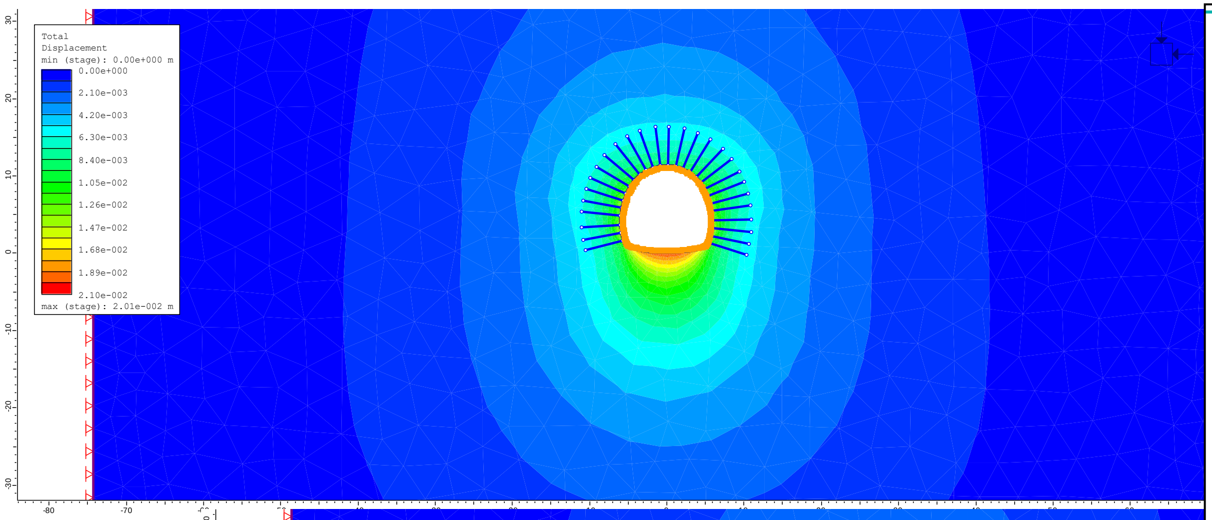
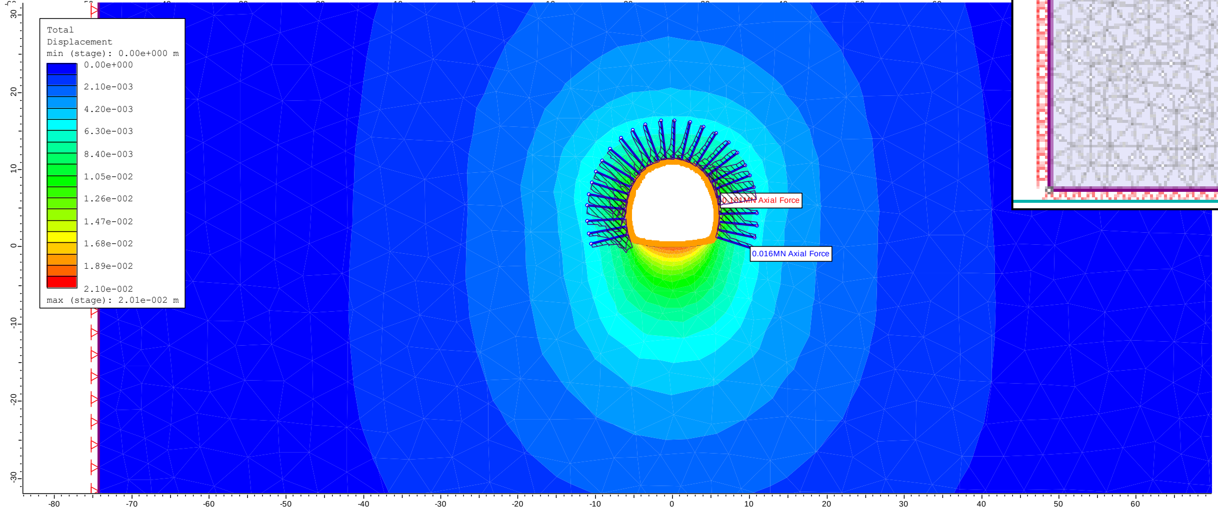
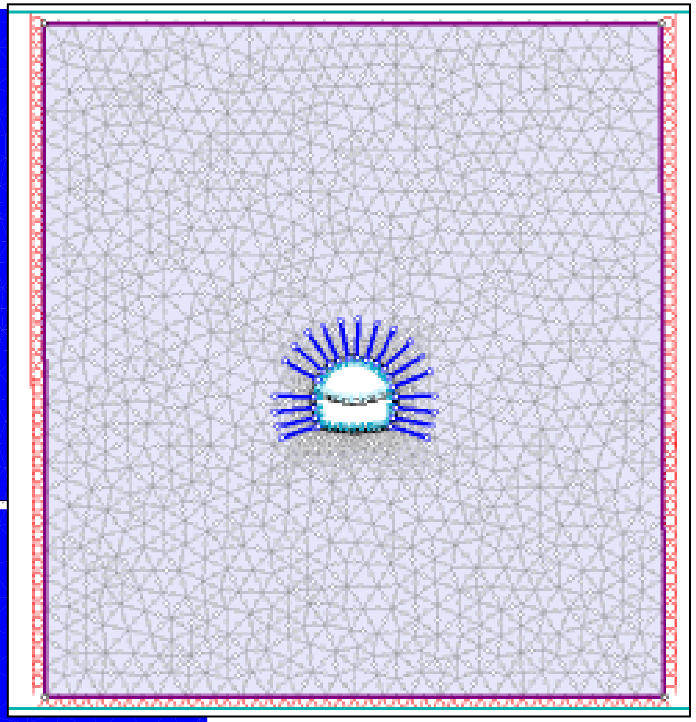
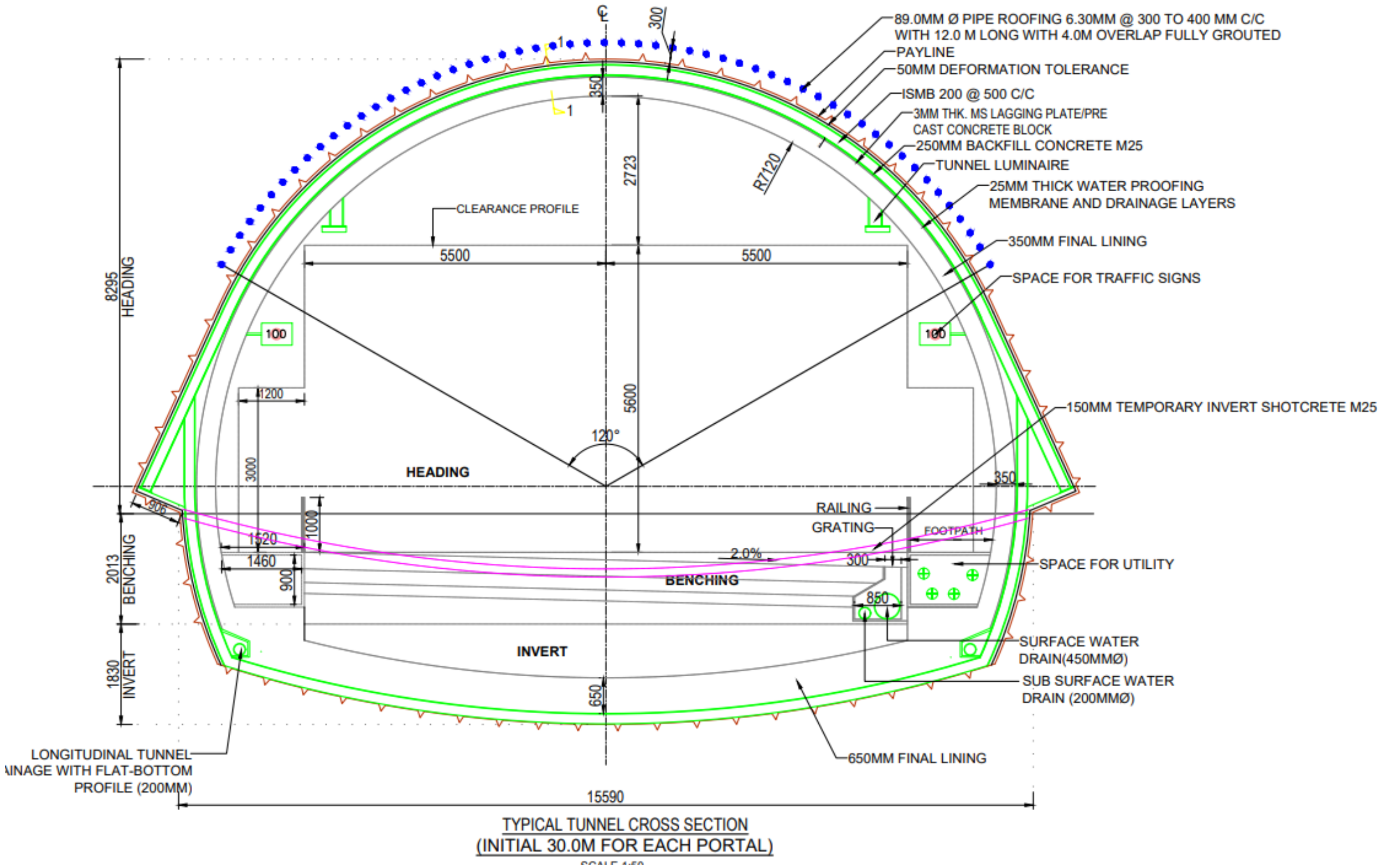
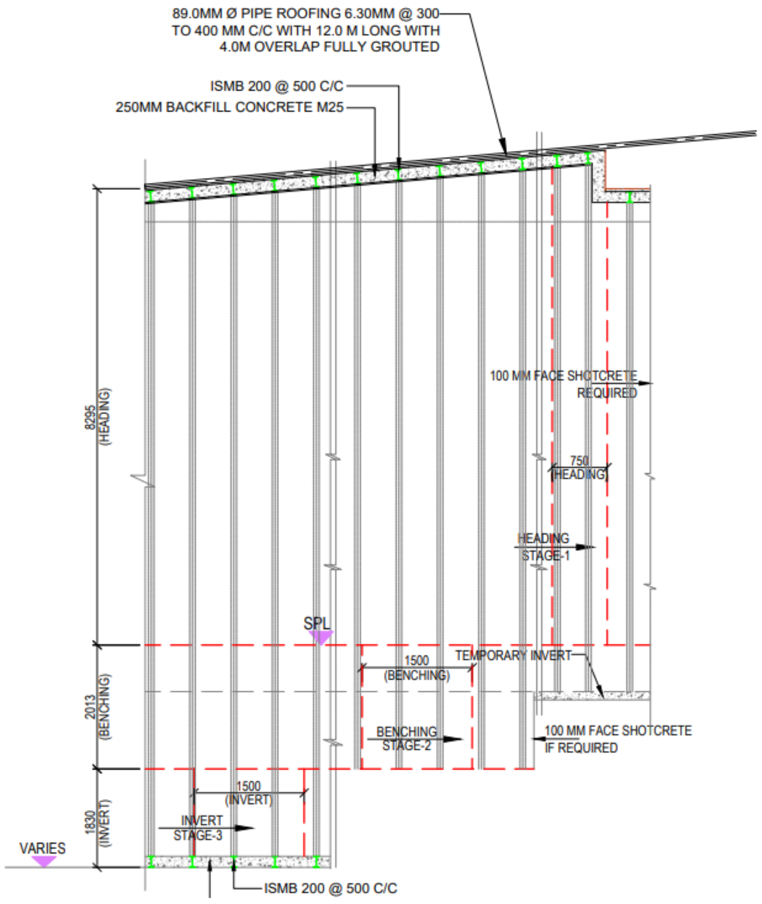




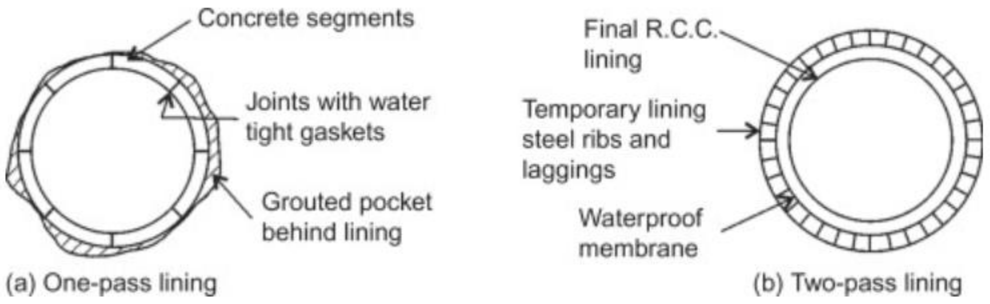


Typical Support System for Soft Ground





Segmental Concrete lining



- Normally segmental precast concrete segments used in soils, boulders & weak rock masses. The TBM is capable of placing them in position all around a circular tunnel with the help of a segment erector.
- Increased speed of construction
- Tapered rings for curve alignment & simultaneous grouting with tunneling
- Water tightness - extremely important and double gasket system and hydrophobic sealing is used
- Provides structural capacity to resist ground, water pressure and reaction frame to push TBM ahead (if TBM used)

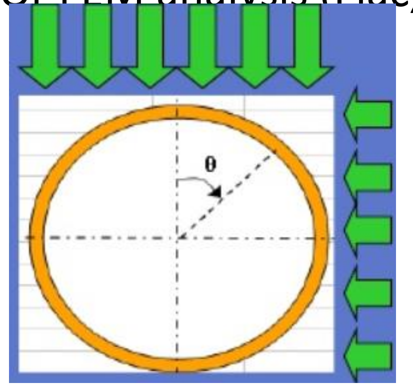
Load cases to be considered:

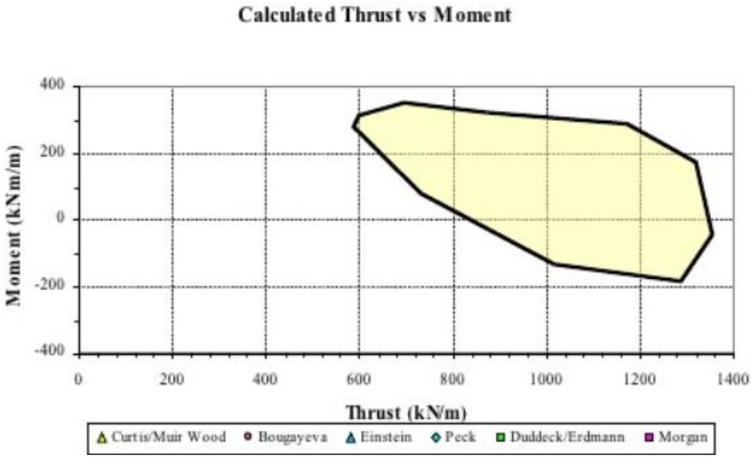
1. Ground & Groundwater loads
2. Loads produced by maximum Desirable deflection
3. TBM Propulsion jacking loads
4. Grouting loads (Annulus & secondary grouting)
5. Seismic loads
6. Handling & Stacking loads

ULS : Check for failure by Max. Bending Moment or min. thrust couple (for all loads)

SLS: Check against cracking by Max. Bending moment & Thrust couple (for Load 1,2&4)

Ground & Groundwater analysis: Elastic analysis (Curtis/Muir wood;)
Or FEM analysis (Flac, Plaxis etc.)





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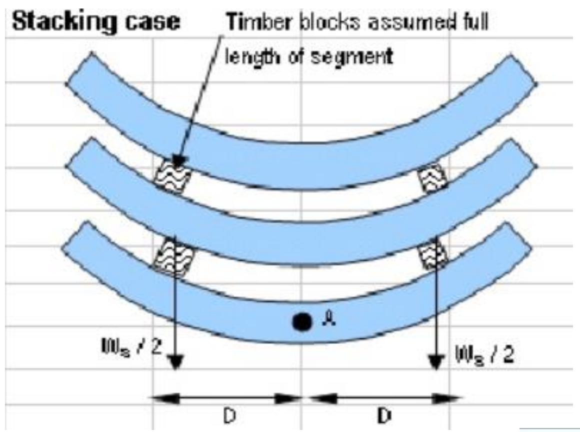
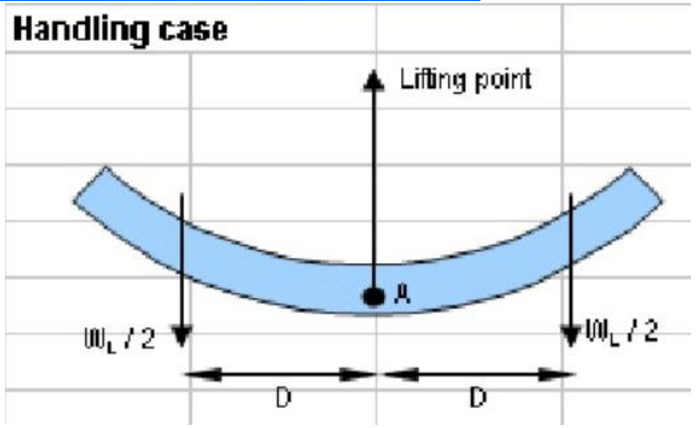
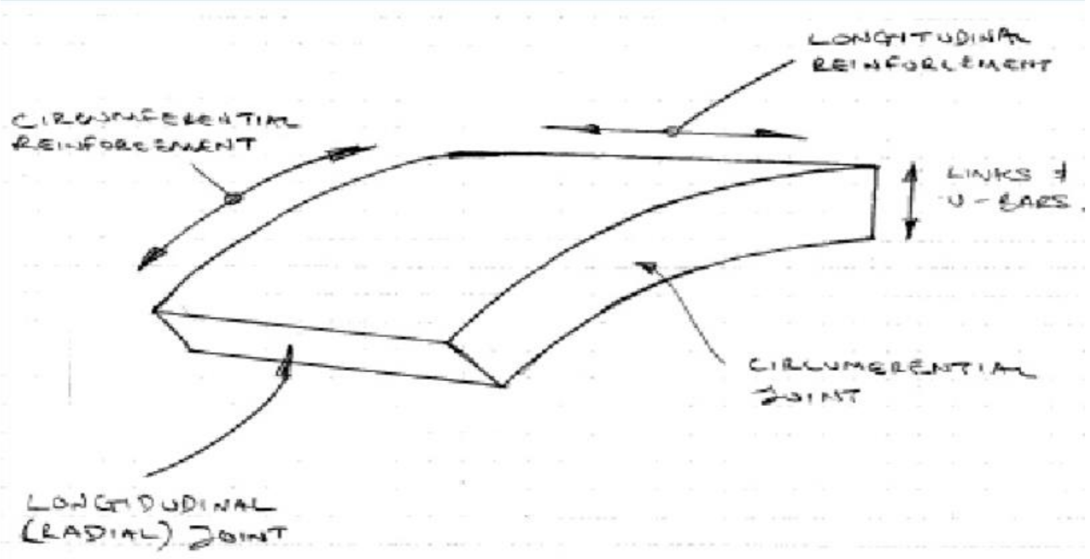




Reinforcement Design



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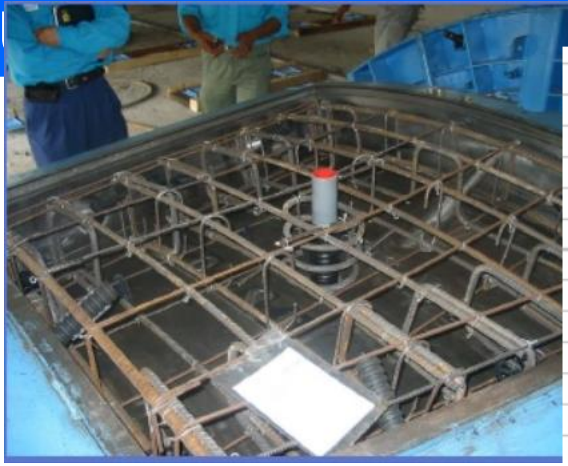
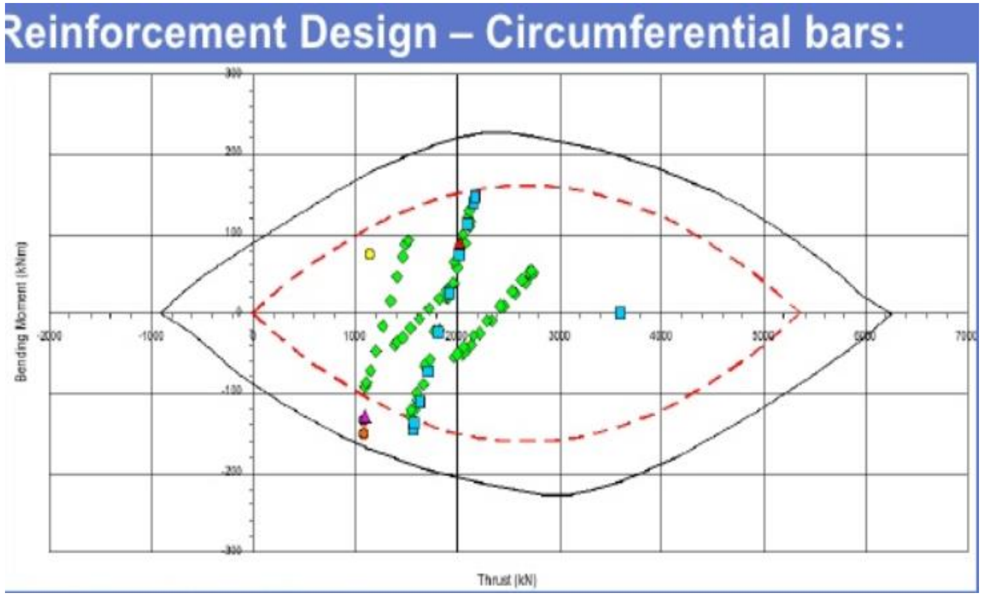


Load cases to consider are:	Reinforcement Bars		
	Circumferential	Longitudinal	Radial
Ground and groundwater loads	SC	-	Nominal
Loads induced by maximum deflection	SC	-	Nominal
TBM propulsion jacking loads	-	SC	S/T
Grouting loads	SC	-	Nominal
Effects of poor ring build	SC	SC	S/T
Seismic loads	SC	SC	S/T
Handling and stacking loads	B	-	-

SC - Design as Short Column
B - Design as Beam
S/T - Design for Shear and Tension loads



- Results from continuum analyses for ground/water loading
- Results from Plaxis analysis
- Results from analysis of grouting loads
- Results from results of birds-mouthing analysis
- Results from distortion analysis
- Results from jacking forces analysis (refer to Calc: 03-48/CG/C/S509)

Instrumentation and Monitoring in SEM/NATM

Essential component of NATM is Instrumentation and Monitoring

1. During & prior to tunnel excavation
   - Standpipe piezometers, extensometers are installed along tunnel alignment to account for sudden change in GW level and subsidence
2. During Excavation and Installation of Primary Support System

To check deformations, convergences and stresses in primary support system

- Optical Targets/ Bi reflex targets/Displacement targets
- Extensometers MPBX/Tape Extensometers, Measuring anchors
- Pressure cells, Stress meters, Load cells, inclinometers
- Piezometers

After final lining

- For long term stability monitoring of tunnel and structures on ground.

During construction, monitoring is done very frequently (fortnightly, weekly, daily). After construction monitoring frequency is reduced.

Tunnel Convergence

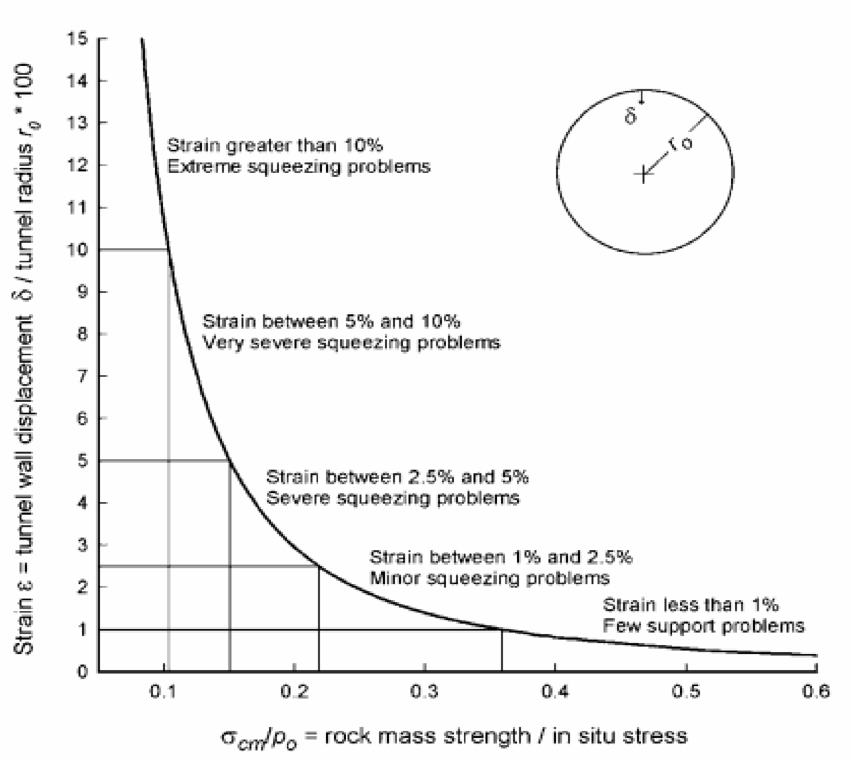
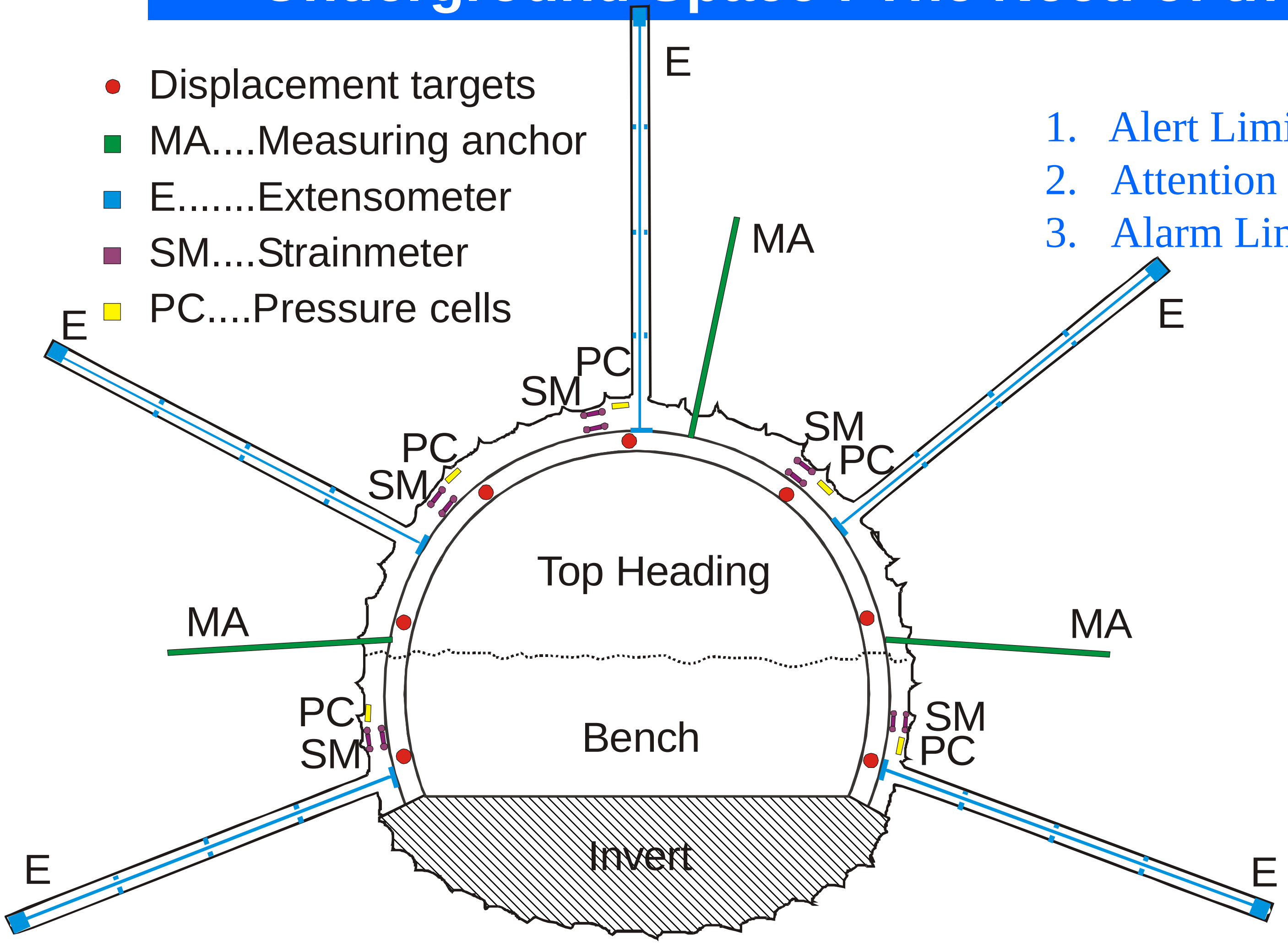
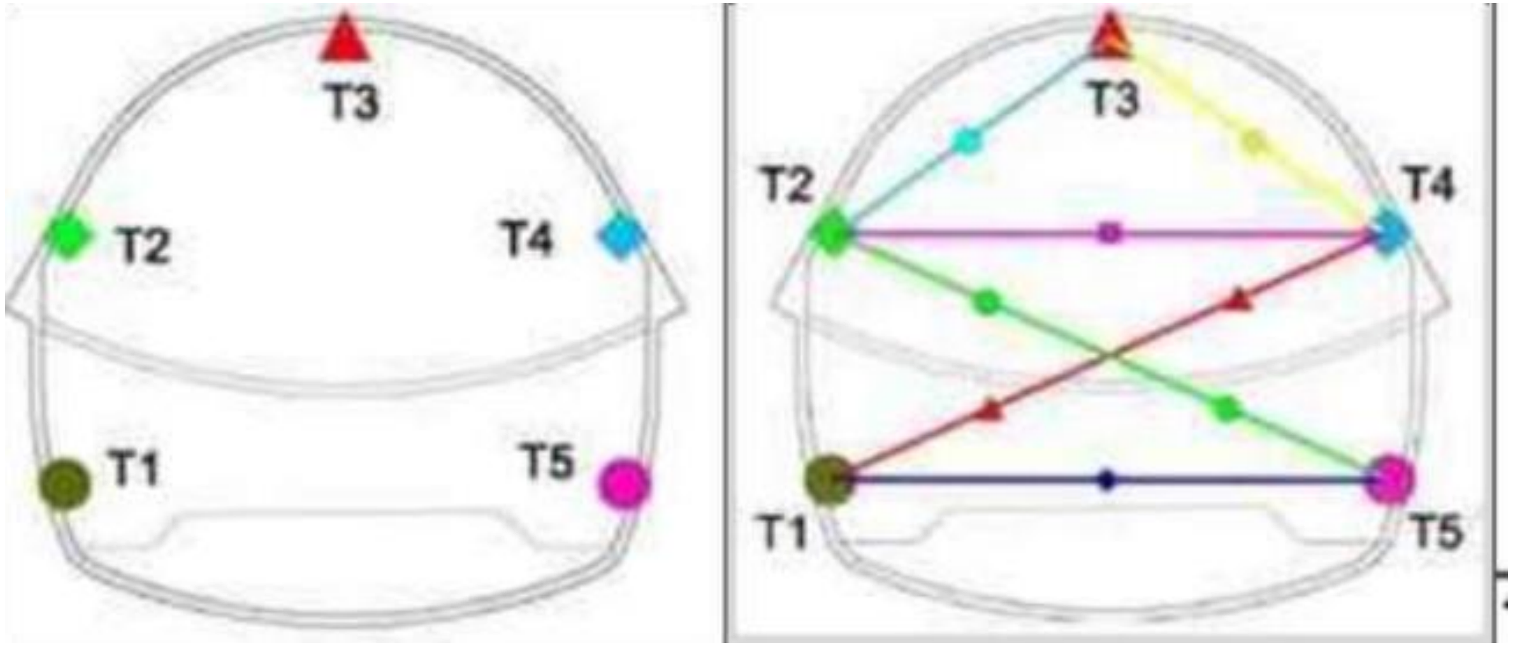


Fig. 12: Tunneling problems associated with different levels of strain.

Geotechnical Monitoring Section



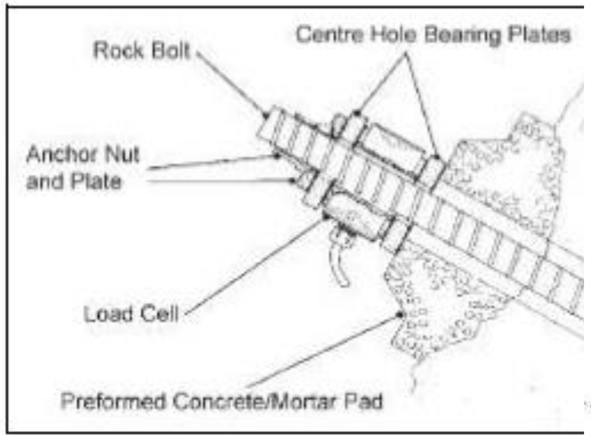
1. Alert Limit: 50-60% of predicted deformation
2. Attention Limit: 70-80% of predicted deformation
3. Alarm Limit: 95 to 100% of predicted deformation



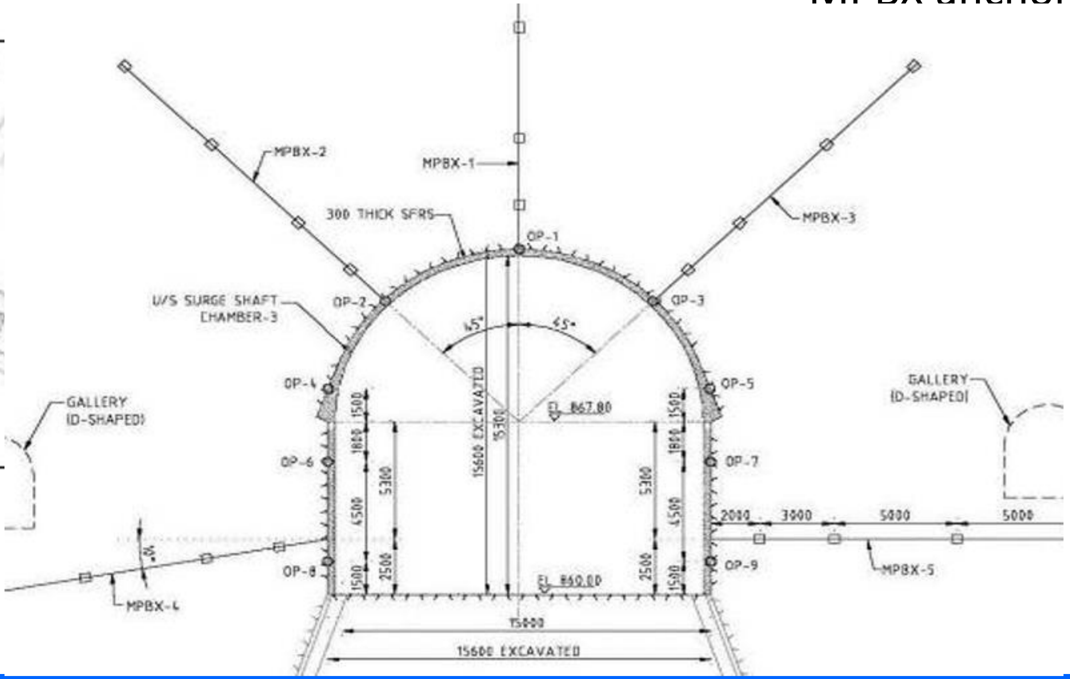
T3
T2
T4
T1
T5
T3
T2
T4
T1
T5

MPBX anchor & rods

Bi-Reflex Target



Load cell & its arrangement
With rock bolt



Some Examples

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References:

[1] E. Hoek, "Support for very weak rock associated with faults and shear zones, International Symposium on Rock Support and Reinforcement Practice in Mining, Kalgoorlie, Australia," 14-19 March 1999, pp. 20.

[2] E. Hoek, and P. Marinos, "Predicting tunnel squeezing problems in weak heterogeneous rock masses," Tunnels and Tunnelling International, in press 2000.

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Thanks for Kind Attention

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