Prepared for:

The Administration of the Union Territory of Ladakh
PWD (R&B)

सत्यमेव जयते

Project:

Detailed Project Report (DPR) for preparation of various Road/Tunnel projects of Public Works (R&B) Department, UT of Ladakh - Highway tunnel across Fotu La Pass along with its approaches on Zojila - Leh - Kargil Road

Subject:

FOTULA TUNNEL
GEOTECHNICAL DESIGN REPORT – TUNNELS
VOLUME -2A

Prepared by:

RITES
THE INFRASTRUCTURE PEOPLE

M/s RITES Ltd.

Shikhar,
Plot No. 01, Sector 29,
Gurgaon 122001
Tel: +91-124-28 18 570
Email: rcedtunneling@goolegroups.com

00	15.09.2025	Final Submission	AS	RSD	LKS
00	25.02.2025	Draft Issue	AS	RSD	LKS
Rev.	Date	Description	Originator	Checked	Approved

Document No: **RITES_00081_FOTULA_GDR_VOL-2A_R1** Revision: 01

Disclaimer

Revision History

Rev.	Date	Long Description
0	25.02.2025	1st Submission
1	15.09.2025	2nd Submission

Table of Contents

List of Tables

List of Figures

1 THE PROJECT

1.1 Objective

Major Parts of the highways in Leh-Ladakh crossing high elevation mountain passes gets blocked every year by heavy snowfall and avalanches resulting in disruption of connectivity across various places. This makes them non-motorable for some duration of the year. It is envisaged that to serve the national interest, there should be an all-weather motorable road which in turn will enable round the clock connectivity to the most important strategic locations of the country.

In order to serve the above purpose, RITES Limited, a Navratna Government of India Enterprise, has been entrusted with the assignment of preparation of Detailed Project Report (DPR) of various Road/Tunnel projects by Public Works (R&B) Department, Union territory of Ladakh vide letter No. CE/PW/R&B//Leh/97-99 dated 13.04.2022 in terms of Rule-133(3) (i) of GFR -2017.

The Project work is as given to RITES is presented below:

(i) Package-3: Highway tunnel across Fotu La Pass (1.7 Km ap-prox.) along with its approaches on Zojila - Leh - Kargil Road

This report pertains to the preparation of DPR for Package -3 “Highway tunnel across Fotu La Pass (1.7 Km ap-prox.) along with its approaches on Zojila - Leh - Kargil Road”.

The Fotu La pass having an altitude of 4108m (circa) above sea level is located between the districts of Leh and Kargil on NH-1 (Leh-Srinagar Highway). The top of Fotu La pass has the famous La-mayuru Monastry approx. 15 km to its east. See figure 1.1 below.

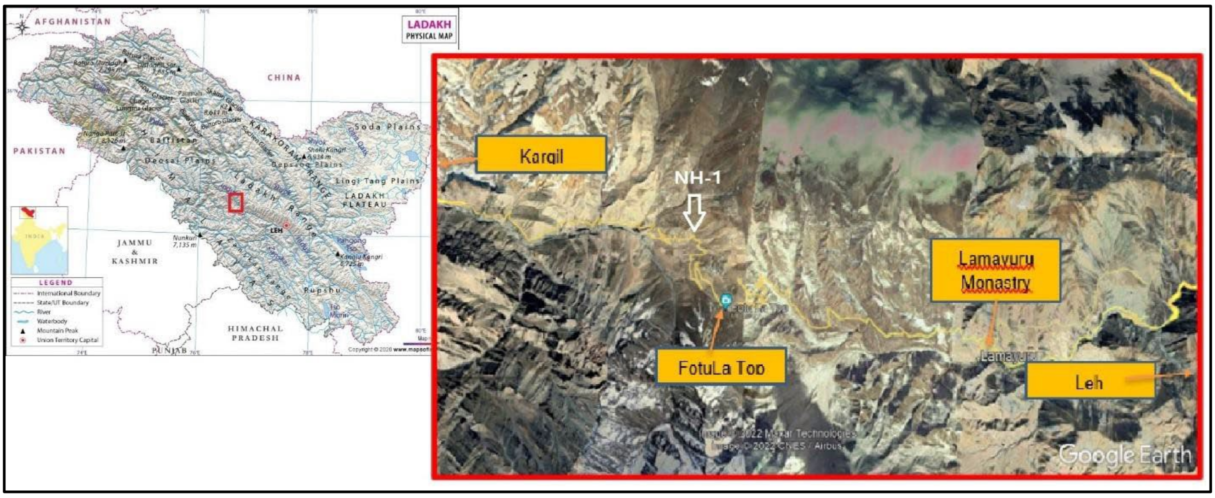


Figure 1: Project Location

The main objective of the consultancy service is to prepare detailed project report for Construction of Tunnel along with the approach roads, with the aim to construct/provide all weather road across Fotu La Pass. The approach roads would be of 4/2-lane plus paved shoulders configuration based on the approved tunnel alignment & configuration.

This report, forming part of the Detailed Project Report (DPR) aims to provide geotechnical design for main tunnel, cross passages and portal area, relevant for the design and execution of Tunnel and Appurtenant structures of the project Package-II, for Fotu La Tunnel (**Figure 1**).

2 REFERENCES / DOCUMENTS MADE AVAILABLE

2.1 Documents made available

[1] GFR of FotuLa Tunnel - RITES_FOTULA_GFR_VOL1_R0

[2] GIR of Fotula Tunnel - RITES_DPR_GIR_VOL1_R0

[3] Alignment report of Fotula Tunnel - RITES_00081_FOTULA_AR_R2

2.2 References:

[4] Austrian Society for Geomechanics, Guideline for the geotechnical design of underground structures with conventional excavation. 2001, 2008, 2009.

[5] Schubert, W., Goricki, A., Button, E., Riedmüller, G., Pölsler, P., Steindorfer, A., Vanek, R. 2001. Excavation and Support Determination for the Design and Construction of Tunnels. In P. Särkkä, P. Eloranta (eds.), EUROCK 2001; Proc. intern. symp., Espoo: 383-388. Rotterdam: Balkema.

[6] Wang, J.-A., Park, H.D.: Comprehensive prediction of rock burst based on analysis of strain energy in rocks, Tunnelling and Underground Space Technology 16, (49-57), 2001.

[7] Feder, G., Arwanitakis, M.: Zur Gebirgsmechanik ausbruchnaher Bereiche tiefliegender Hohlraumbauten, Berg- und Hüttenmännische Monatshefte, Heft 4, 1976.

[8] ONORM B 2203-1-2001: Underground works – Works contract, Part 1: Cyclic driving (conventional tunnelling)

[9] Austrian Society for Geomechanics, 2010. NATM, The Austrian Practice of Conventional Tunnelling.

3 ROCK MASS CLASSIFICATIONS AND GROUND BEHAVIOUR TYPES

The geological formations in the project areas are identified with igneous rocks. From South to North of the tunnel alignment, the rock type is expected to be granitic with occasional intrusive (dykes) having comparable strength properties. In general, massive with coarse grained rock mass could occur South as well North Portal. However varying thickness and medium to coarse grained granites with volcanic dykes could be encountered towards the South Portal with increasing frequency and leucogranite on North portal side. The rocks along the project area are also affected by tectonic deformations. Hence, along the proposed tunnel alignment, a range of rock mass types with varying mechanical properties having potential to exhibit varying behavioural patterns during tunnel excavation. The rock mass is primarily segregated based on the intensity of jointing and the resulting bock sizes. The prominence of joints in terms of their properties of persistence, spacing and aperture fillings are interpreted to be related to the intensity of deformations/ shearing underwent. Effects of large-scale weathering are likely to be restricted to low depths from surface however could extend to deeper levels around major fracture/ weak zones which also can conduct water.

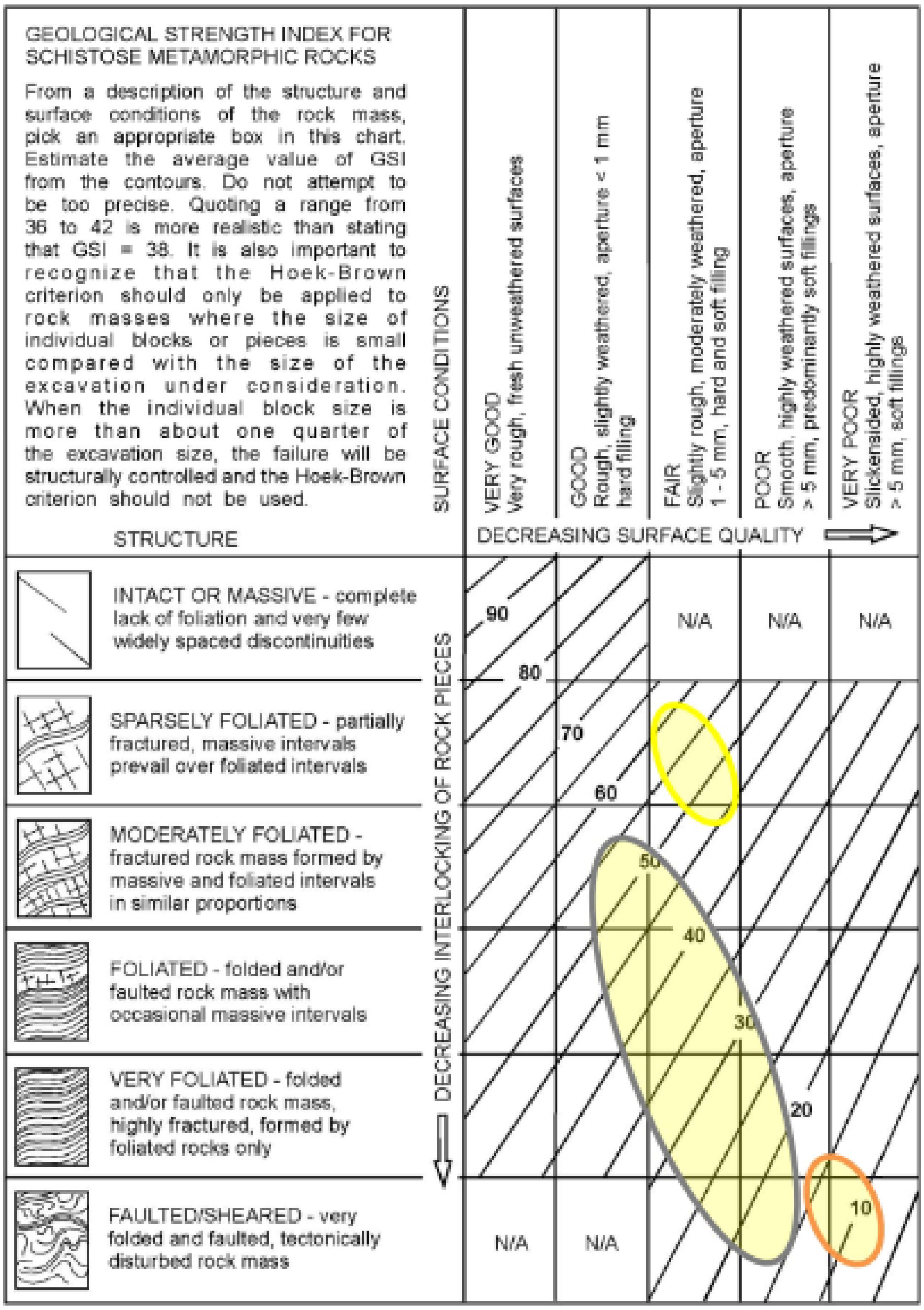


Figure 2: GSI Chart for Metamorphic Rock Mass (M.Truzman,1999)

Based on the observed exposures of bed rocks, a range of Ground/ Rock Mass Types (GTs) has been established using the chart of GSI system of evaluation (**Figure-8**). Their interpreted competencies have been estimated using software Roc Lab. Additionally, a special class of Ground Type (GT-4) has been established for the ground occurring at the portals which due to weathering and disintegration processes have its characteristics close to that of residual debris and soil conditions.

3.1 Ground Types

Four broad division of the rock mass types have been interpreted according to the combination of rock types (indicative) and their structure. The interpreted Ground/ Rock mass types and their mechanical evaluations are tabulated below in Table-5.

Ground Type	Lithology	Structure
GT1	Reddish brown coloured to dark greyish coloured phyllitic lime-stone, limestonic phyllite	Bedded and closely but tightly jointed.
GT2	Light brownish to greyish coloured, moderately jointed, moderately to closely foliated, moderately strong phyllite/quartzitic phyllite	Stratified alternations with subordinate thin-ner bands of phyllites, often warped.
GT3	Highly folded, highly fractured, closely foliated, fine grained, light brownish grey coloured, quartzitic phyllite with quartzitic bands	Stratified in alternations with subordinate thinner bands of Phyllitic Quartz-ites/Quartizitic Phyllites/Phyllites, occasion-ally folded, visibly foliated.
GT4	Slope debris at portal area consist-ing of mainly heterogeneous ma-trix (sand, silt & clay) with angular to sub angular, boulder, cobble, pebble size fragments of Quartz-ite, Phyllite, Quartzitic-Phyllite and Slate	Inhomogeneous mixture of boulders in sandy soil matrix, Colluvium/ Talus material.

Table 1: General Ground types and their description from Tunnel area.

GT- 1- Reddish brown coloured to dark greyish coloured phyllitic limestone, limestonic phyllite (**Figure-3**).

Figure 3: Reddish brown coloured to dark greyish coloured phyllitic limestone, limestonic phyllite

		Low	High
Input Rock Parameters (assumed)			
Input Rock Parameters (assumed)	[ ]	0.5	1.5
Lateral Earth pressure Coefficient, K	[kN/m^3]	26	28
Density, γ	[MPa]	30	50
Unconfined Compressive Strength, σ_{ci}	[ ]	45	60
Geological Strength Index, GSI	[ ]	10	13
Material constant, m_i	[ ]	400	600
Modulus Ratio	[ ]	0.24	0.25
Poisson's ratio, ν			
Rock Mass Parameters (estimated from RocData)*	[MPa]	1.35	3.20

Cohesion, c	[°]	29	36
Angle of Internal Friction, φ	[MPa]	2.9	4.8
Unconfined Compressive Strength, σ_c	[MPa]	0.05	0.25
Tensile Strength, σ_t	[GPa]	4.0	13.2

GT- 2- Light brownish to greyish coloured, moderately jointed, moderately to closely foliated, moderately strong phyllite/quartzitic phyllite (Figure-4).

Figure 4: Light brownish to greyish coloured, moderately jointed, moderately to closely foliated, moderately strong phyllite/quartzitic phyllite

		Low	High
Input Rock Parameters (Assumed)			
Lateral Earth pressure Coefficient, K	[ ]	0.5	1.5
Density, γ	[kN/m^3]	26	28
Unconfined Compressive Strength, σ_{ci}	[MPa]	20	25
Geological Strength Index, GSI	[ ]	25	35
Material constant, m_i	[ ]	7	9
Modulus Ratio	[ ]	400	500
Poisson's ratio, ν	[ ]	0.28	0.30
Rock Mass Parameters (estimated from RocData)*			
Cohesion, c	[MPa]	0.55	0.85
Angle of Internal Friction, φ	[°]	20	24
Unconfined Compressive Strength, σ_c	[MPa]	1.5	2.4
Tensile Strength, σ_t	[MPa]	0.02	0.03
Deformation Modulus, E_{rm}	[GPa]	1.2	1.3

GT-3- Highly folded, highly fractured, closely foliated, fine grained, light brownish grey coloured, quartzitic phyllite with quartzitic bands (Figure-5).

Figure 5: Highly folded, highly fractured, closely foliated, fine grained, light brownish grey coloured, quartzitic phyllite with quartzitic bands

		Low	High
Input Rock Parameters (Assumed)			
Lateral Earth pressure Coefficient, K	[ ]	0.5	1.5
Density, γ	[kN/m^3]	24	25
Unconfined Compressive Strength, σ_{ci}	[MPa]	10	15
Geological Strength Index, GSI	[ ]	15	25
Material constant, m_i	[ ]	6	8
Modulus Ratio	[ ]	250	260
Poisson's ratio, ν	[ ]	0.3	0.3
Rock Mass Parameters (estimated from RocData)*			
Cohesion, c	[MPa]	0.2	0.5
Angle of Internal Friction, φ	[°]	22	26
Unconfined Compressive Strength, σ_c	[MPa]	0.60	0.65
Tensile Strength, σ_t	[MPa]	0.01	0.04
Deformation Modulus, E_{rm}	[GPa]	0.75	0.90

GT-4 - Slope debris at portal area consisting of mainly heterogeneous matrix (sand, silt & clay) with angular to sub angular, boulder, cobble, pebble size fragments of Quartzite, Phyllite, Quartzitic-Phyllite and Slate (Figure-6).

Figure 6: Slope debris at portal area consisting of mainly heterogeneous matrix (sand, silt & clay) with angular to sub angular, boulder, cobble, pebble size fragments of Quartzite, Phyllite, Quartzitic-Phyllite and Slate

		Values
Input Rock Parameters (assumed)		
Lateral Earth pressure Coefficient, K	[ ]	1
Density, γ	[kN/m^3]	21
Unconfined Compressive Strength, σ_{ci}	[MPa]	20
Geological Strength Index, GSI	[ ]	15
Material constant, m_i	[ ]	8
Modulus Ratio	[ ]	125
Poisson's ratio, ν	[ ]	0.31
Rock Mass Parameters (estimated from RocData)*		
Cohesion, c	[MPa]	0.15
Angle of Internal Friction, φ	[°]	25
Unconfined Compressive Strength, σ_c	[MPa]	0.50
Tensile Strength, σ_t	[MPa]	0.00
Deformation Modulus, E_{rm}	[GPa]	0.150

The mechanical attributes of the rock mass are empirically evaluated by the essential parameters governing block size and the inter-block shear strength / joint conditions (with a representative GSI value), Intact rock properties (including σ_i, E_i etc), and Discontinuity Characteristics (Persistence, Spacing and Orientation with respect to excavation). The detrimental effects of weathering are largely restricted to near portal area and proximity of weak shear zones.

A range of these properties for each Ground Type has been assumed to encompass gradational variation for the larger spectrum of rock mass anticipated along the alignment. Towards this, the rock mass properties have been evaluated with the sub-categorization of High and Low values for each Ground Type.

3.2 Ground Behaviors

The extraneous factors like excavation of the tunnel (shape and size), ground stresses, ground water conditions influence the behaviour of individual ground types. The guidelines for geotechnical design with conventional excavation published by Austrian Society of Geomechanics identifies a set of ground behaviour types, tabulated below in Table-2:

Table 2: Ground behaviours and their description.

Basic Categories of Behaviour Types (BT)		**Description of potential failure modes/ mechanisms during excavation of the unsupported ground.**
1	Stable	Stable ground with the potential of small local gravity induced falling or sliding of blocks.
2	Potential of discontinuity controlled block fall	Voluminous discontinuity controlled, gravity induced falling and sliding of blocks, occassionall local shear failure on discontinuities.
3	Shallow failure	Shallow stress induced failure in combination with discontinuity and gravity controlled failure.
4	Voluminous stress induced failure	Stress induced failure involving large ground volumes and large deformations
5	Rock burst	Sudden and violent failure of the rock mass, caused by highly stressed brittle rocks and the rapid release of accumulated strain enenry.
6	Buckling	Buckling of rocks with a narowly spaced discontinuity set, frequently associated with shear failure.
7	Crown failure	Voluminous overbreaks in the crown with progressive shear failure.
8	Ravelling ground	Ravelling of dry or moist, intensely fractured poorly interlocked rocks or soil with low cohesion.
9	Flowing ground	Flow of intesely fractured, poorly interlocked rocks or soil with high water content
10	Swelling ground	Time dependent volume increase of the ground caused by physical-chemical reaction of the ground and water in combination with stress relief.
11	Ground with frequently changing deformation characteristics.	Combination of several behaviours with strong local variations of stresses and deformation over longer sections due to heterogeneous ground (i.e. in heterogeneous fault zones; block-in-matrix rock, tectonic melanges)

The anticipated ground types are interpreted to occur at certain locations along the proposed tunnel alignment where prevailing environment of ground stresses and ground water conditions are expected to influence typical ground behaviours patterns during tunnel excavation. The in-situ stresses are a function of the overburden and tectonic setting. The maximum overburden along the tunnel alignment is limited to 252m. Actual observations of ground's behaviour patterns upon excavation can be linked to prevailing modified ratios of the rock strength to in-situ stresses and the rock structure immediately after excavation. These behaviours can hence be influenced by the implementation of excavation and support methodologies during previous rounds of excavation.

3.2.1 GT 1- [BT-1,2,3,4]

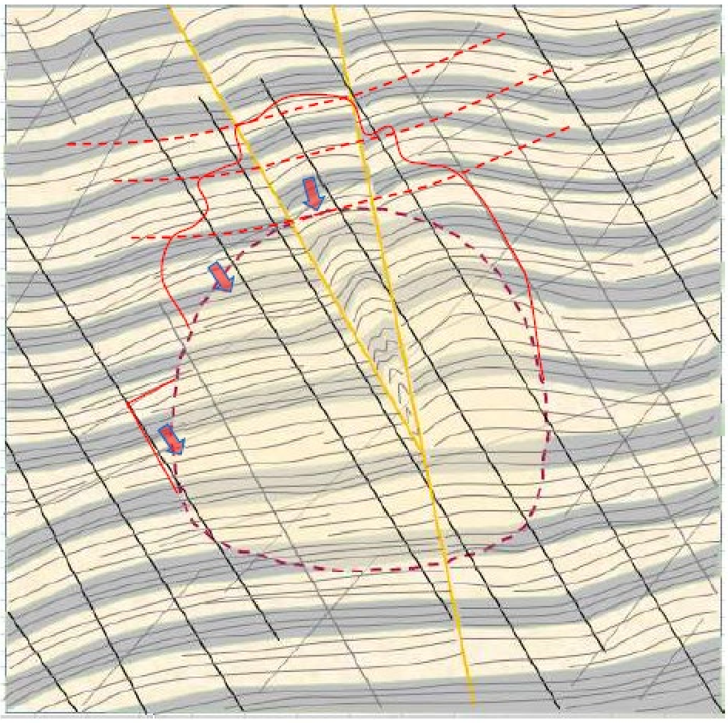


Figure 7: Symbolic Sketch 2: Ground Type-GT 1

This ground type is expected to display stress induced failure with shallow failure **(BT3)** at places where rockmass strength is better or overburden is comparatively lesser leading to low stress values at the tunnel location. The depth of plastic in such conditions shall be less than 33% in such case.

With increasing cover and reducing weathering intensity the behaviour of the rock mass passes through Shallow shear failures (**BT3**) to (voluminous) (**BT4**) shear induced failures where under relatively higher stresses could also be associated with large deformations.

At locations where GT-1 rockmass is having high overburden, voluminous stress induced failure **(BT4)** of low intensity could also be encountered. The depth of plastic zone is expected to be around 50%-60%. In both cases, radial displacement is expected to be less than 1%.

At small locations, where burden is less and the rockmass expected is good, there will be no plastic strain on the tunnel lining, and it shall possess Stable (**BT1**) behaviour. However, the rocks being generally intensely jointed the frequent release of variably sized wedges (**BT2**) is to be expected.

The occurrence of joints of high persistence are observed and can lead to combination of smaller blocks bounded by more persistent joints to forms wedges of large masses of rock mass. Mapping of persistent joints will become very important while excavation of tunnel, and the need for supplementary and specific longer bolts as per wedge geometries observed must be promptly installed.

The development of overbreak along discontinuities should be part of the learning curve during the excavation process to interpret the cohesion and frictional resistance available for stability. Under elevated ground stresses minor stress relief through popping and spalling is expected from the crown level having implications on overbreak in tunnel profile. Such phenomena, which in some cases could get accentuated when the ground comes in close vicinity of a prominent weak plane/zone. In such cases the phenomena could be localized depending on the position of the feature with respect to the tunnel profile.

Deformation monitoring is very important in this ground type to identify the trends early on and employ necessary support. This measure will help minimise, re-profiling of tunnel at a later stage.

3.2.2 GT 2- [BTs 4]

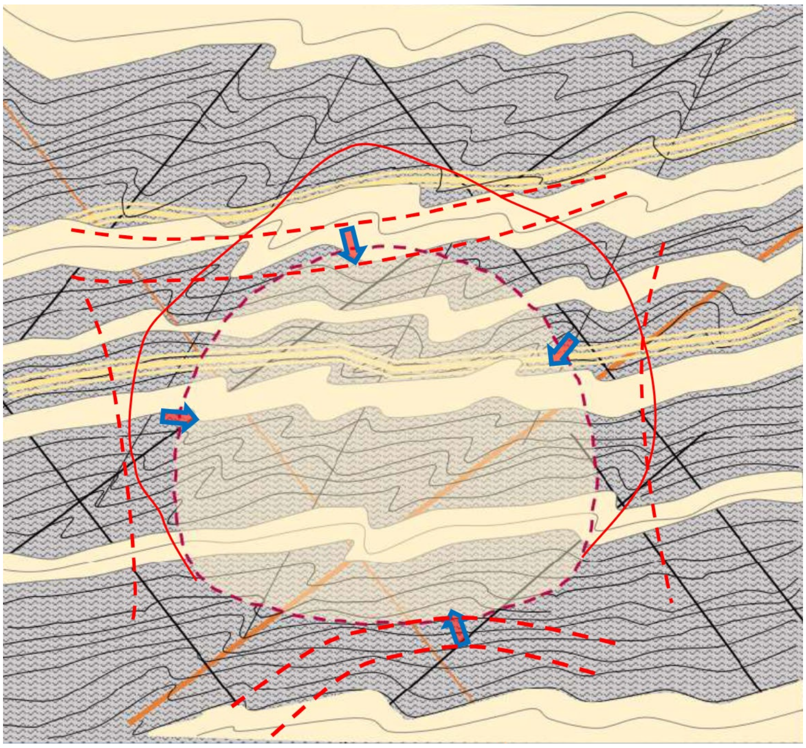


Figure 8: Symbolic Sketch 2: Ground Type-GT 2

The ground type is associated with phyllites and is characterised by their thinly foliated character and is relatively less deformed (in terms of development of other sets of discontinuities). The strength properties are highly anisotropic with respect to the orientation of its foliation. The bonding across the foliation planes is relatively high. The rock is usually frequented with minor shear seams.

Under low overburden, weathering induces weakening in the phyllo-silicate layer. Penetrative weakening along some relatively closely spaced foliation planes can be seen. In addition, similar weakening also develops along other joint sets. Together it weakens the rock mass rapidly.

The ground exhibit very low strength of rockmass and the plastic depth is expected to be more than 200% in poor geological condition exhibiting behaviour of voluminous stress induced failure (BT4) of high intensity especially where burden is high.

At lower overburden where geology of GT2 is comparatively better, voluminous stress induced failure (BT4) with low intensity shall be observed.

Deformation monitoring is very important in this ground type to identify the trends early on and employ necessary support. This measure will help minimise, re-profiling of tunnel at a later stage.

3.2.3 GT 3- [BTs 4,8]

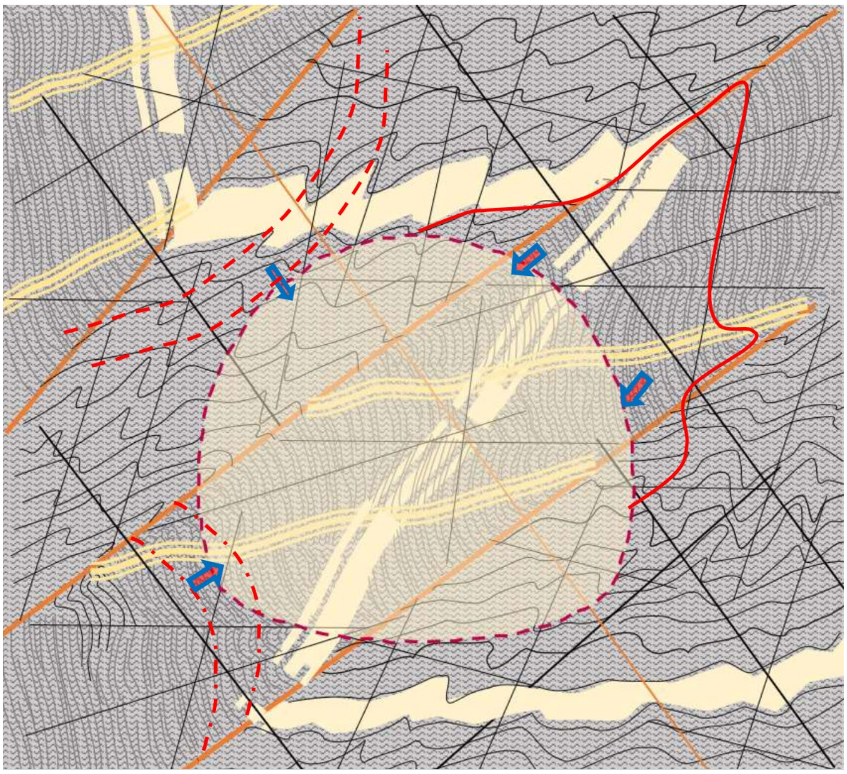


Figure 9: Symbolic Sketch 1: Ground Type -GT3

The ground exhibit very low strength of rockmass and the plastic depth is expected to be more than 200% exhibiting behaviour of voluminous stress induced failure (BT4) of high intensity where burden is high. At lower overburden, less intensity voluminous stress induced failure (BT4) shall be observed.

Also considering the nature of the Ground type, with dry or moist, intensely fractured poorly interlocked rocks having low cohesion. possibility of ravelling behaviour (BT-8) is also anticipated, especially where overburden is low.

The area is comprised of highly folded, highly fractured, closely foliated, fine grained, light brownish grey coloured, quartzitic phyllite with quartzitic bands.

The ground type is associated with wide (meter scale) shear zones/ fault zones. Studies have revealed that Shear/Fault zones usually have three subdivisions of strain distribution within them which are also most often asymmetrically distributed. These subdivisions could be defined as the Principal Slip Zone, encased within the Fault Core which in-turn is further surrounded by the Damaged (Fractured) Zone. It is understood the Damaged Zone around the Fault could vary by order of magnitude.

Faults and shear zones in the meta-sedimentary rock mass of the project area pass through multiple lithotypes. When the process of fault plane passes through the relatively ductile phyllitic rock masses, development of intense folding (crenulated) can be expected. Together with the closely spaced cleavage joints the overall mass become highly fractured. In contrast the folding may be less intense (more widely spaced) in the more quarzitic and/ or carbonate members of the lithotypes. Rapid changes in the trend of bedding/ foliation should be seen as proximity to such fault seams/ zones which may also be associated with water, for initiating probing ahead of face.

The crushed and fine to very fine core zone material, when it is like clay, has lower dispersivity and permeability than say the material between the interface between damaged and crushed zone characterised by a wider range of grain sizes in the presence of ground water. The fault core hence assists in built up of the water pressure head and good saturation of the damage zone. When the tunnel face intercepts such zone large ingress of water with erosion of the fine materials are possible. When sugar cube materials dominate, under dry conditions unravelling (**BT8**) can be expected.

Deformation monitoring is very important in this ground type to identify the trends early on and employ necessary support. This measure will help minimise, re-profiling of tunnel at a later stage.

3.2.4 GT 4- [BTs 7,8,11]

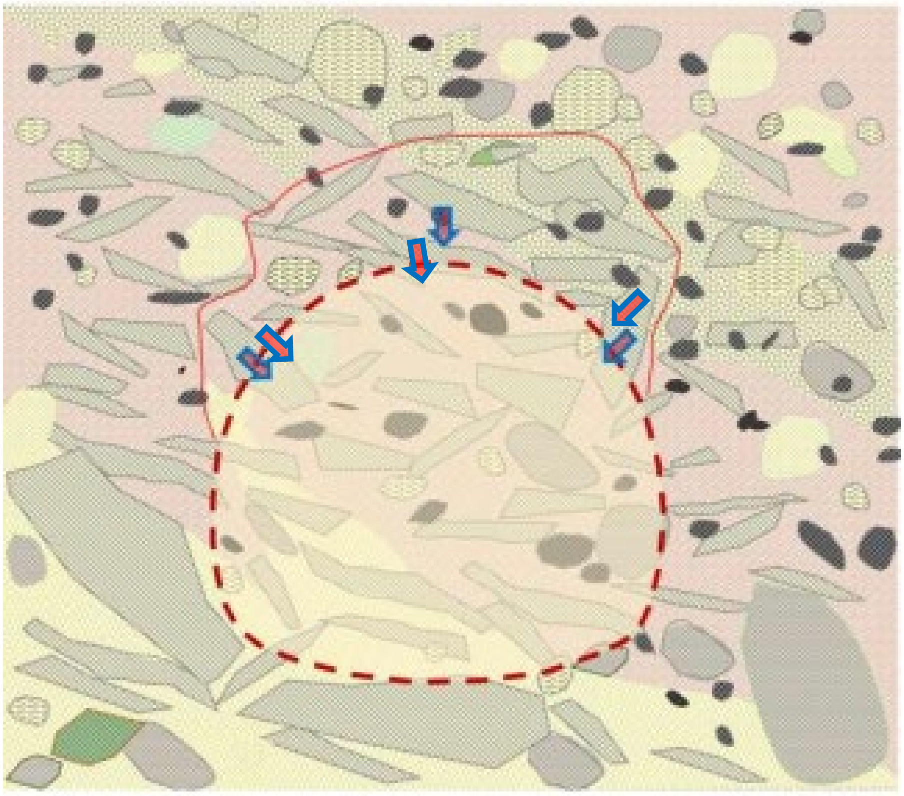


Figure 10: Symbolic Sketch 2: Ground Type- GT4

The debris materials around the portal areas are mostly derivatives of avalanches and frost wedging (mostly allochthonous). It is a mixture of soil and rock boulders (derived from the overlooking rock slopes). The carbonate material probably contributes to the cohesiveness of the soil material. The stratified/ foliated character of the bed rock has resulted in the dominance of flat tabular rock fragments. Conservative parameters are however interpreted.

The type of ground is identified at the portal areas of the tunnels and not of a deep depth, as interpreted from nearby boreholes. The material located close to the surface is unlikely to be intercepted in the tunnel and is likely to be influencing the portal slope stability alone.

However, in the event of very short stretches of tunnel coming under the influence of this material, the excavation is likely to witness variants of Crown failure (**BT7**) and Unravelling (**BT8**).

The overall strength of the rock mass is very low and may not vary significantly. When such ground conditions are extensive local variations in competency can be expected which could exhibit in multiple ground behaviour patterns (**BT11**) at the face/ in relatively short spans.

A guide to anticipated Behaviour types (BTs) correlated against the different Ground Types (GTs) under the range of overburden and in-situ stress conditions for the Fotu-La Tunnel's alignment has been shown as a matrix form in Table-7. With increasing depth and confinement, the confinement of the rock structure can be understood as cause for further improvement in competence of the rock mass. This improvement is likely to shift the behaviour types to the less adverse types.

		Overburden depth			
		0-50	50-100	100-250	250-500
Ground Types	GT1	BT-1,2	BT- 1,2,3	BT-3,4	BT-3,4
	GT2	BT-3,7,8	BT-3,4	BT-4	BT-4
	GT3	BT-4,8	BT-4,8	BT-4	BT-4
	GT4	BT-7,8,11			

Table 3: Anticipated Ground Behaviour types against overburden.

3.3 DISTRIBUTION

An interpretation of the distribution of the Rock Mass /Ground Types along the proposed tunnel alignment is made. The distribution is prepared in line with the status of GT investigations carried out. The insight into this distribution through direct observation including Field mapping and core drilling has been compiled in the report Geotechnical Factual Report. The approximated distribution of Ground water conditions, Ground types and their Behaviour types are schematically brought out in drawing Geotechnical Profile (Vol 6)

The geology in the area is influenced by the presence of highly fractured, weak, schistose phyllite and phyllite causing variation in ground condition that is anticipated to be more significant on north portal side. For cost optimization, provisions for additional investigations during construction is suggested and adequate materials for ground improvements is recommended for pre- and post-treatment of weak ground conditions.

3.3.1 Ground Types

The entire tunnel is passing through strong to very strong granite, grano-diorite, leucogranite. A range for the anticipated lengths of the tunnel set to negotiate different Ground Types is suggested below (Table-8) assuming for variations in actual geological settings and structure. This range is expressed as percentages and average lengths.

GT	GT1H	GT1L	GT2H	GT2L	GT3H	GT3L	GT4
Length (m)	300	204.1	540	410	185	149.4	154.6
Approx %	**15.4%**	**10.5%**	**27.8%**	**21.1%**	**9.5%**	**7.7%**	**8.0%**
Chainage	**0+640-0+940**	**0+435.9-0+640**	**1+350-1+890**	**0+940-1+350**	**1+890-2+075**	**2+075-2+224.4**	**0+360.9 - 0+435.9, 2+224.4 - 2+304***

Table 4: Anticipated Distribution of Ground types along Fotu La Tunnel.

*Ch taken considering average length of both tubes

The geology along the tunnel alignent is required to be estimated to asses the tunneling efforts and required support system. An interpretation for the probable conservative distribution of the rock mass types along the proposed alignment is made. The distribution shall be updated in line with the status of GT investigations.

The geology in the area is influenced by the presence of shear zones and presence of weak, fractured bands causing variation in ground condition that is anticipated to be more significant on both portal side.

For cost optimization, provisions for additional investigations during construction, for pre-treatment of weak ground conditions and materials for ground improvements is recommended.

3.3.2 Behaviour Types

It is to be noted, the Table-9 is an estimation and can vary as per actual ground conditions and their geotechnical environment. The Behaviour types are time dependent, and can degrade from one to a higher category, under governing geotechnical conditions.

BT	BT-1	BT2	BT-3	BT-4	BT-5/6	BT-7	BT-8	BT-9/10	BT-11
Length (m)	10	40	377	1211.6	0	124.60	149.90	0	30.00
Approx %	**0.5%**	**2.1%**	**19.4%**	**62.4%**	**0.0%**	**6.4%**	**7.7%**	**0.0%**	**1.5%**

Table 5: Anticipated Distribution of Behaviour Types along Fotu La Tunnel.

4 EXCAVATION DESIGN

In the following section the NATM excavation concept is described in detail for FotuLa La tunnel.

4.1 NATM Excavation Method

In general, round lengths for excavation are limited by the governing ground conditions and by limitations due to blasting vibrations, especially in the vicinity of existing structures and populated areas.

Tunnel excavation shall be performed alternating between full face and invert, and if required, alternating between top heading, bench and invert. The round length and sequence of excavation at any cross section depends on the support class assigned to that cross section which shall be decided based on the geological and geotechnical conditions.

The excavation of the Tunnel, concreting of the invert / abutments and the overt can be done simultaneously with sufficient distance in between the area of excavation and area of installation of the final lining. Over and above the excavated stretches must have stabilized, i.e. the monitored displacement rate must be below 2mm/month.

Excavation profiles shall be determined according to the rock classification & considering the temporary support system, to obtain the optimum efficiency and accuracy of the operations. The cycle time will depend on the rock classification and support system, drilling and muck evacuation equipment.

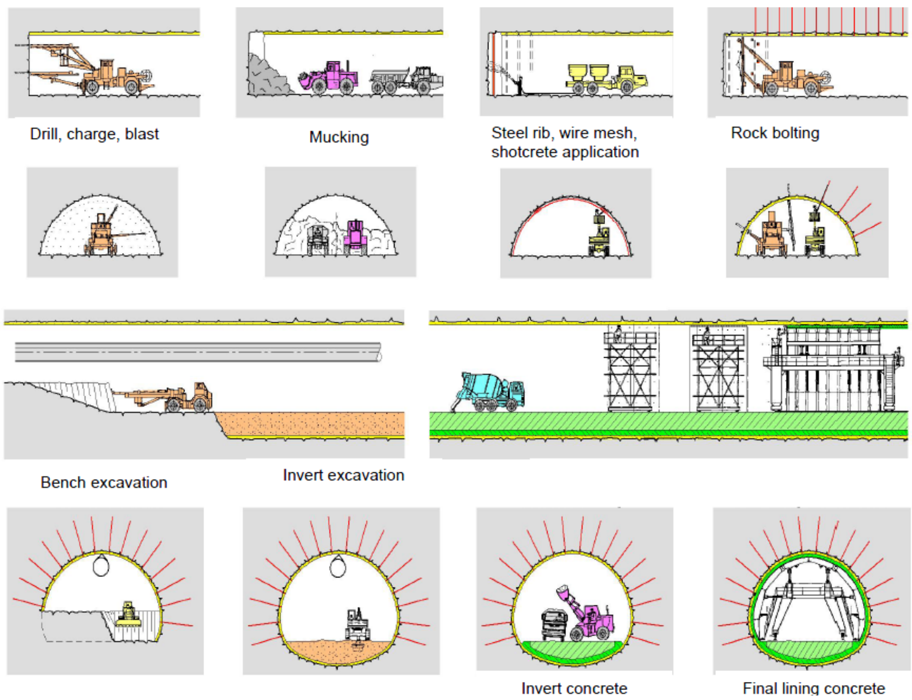


Figure 11: Typical Construction Sequence in NATM Tunnelling

5 PRIMARY SUPPORT DESIGN

The Fotu La tunnel is designed to be constructed with conventional excavation in accordance with the principles of NATM. The excavation will be carried out by drill and blast or tunnel excavator with a subdivision of the tunnel cross section into top heading, bench and invert (if required). To increase the face stability in weak ground the tunnel face excavation may be subdivided according to the actual geotechnical condition.

The tunnel support system consists of two generally independent lining systems:

- The primary (outer) support consisting of rock bolts, sprayed concrete if necessary reinforced with wire mesh or alternatively steel fibres, and lattice girders. All support measures are installed each round immediately after tunnel excavation. The primary lining is designed to provide immediate support during the change in stress state and stability of the excavation until the inner lining is installed.

- The final (inner) lining, constructed of plain or reinforced concrete, is designed to sustain all internal and external forces without considering the bearing capacity of the primary lining.

In tunnel sections with squeezing ground conditions a deformable primary tunnel lining system is designed to allow controlled deformation of the tunnel lining to limit the lining loads. The permanent concrete lining is constructed in sections of approximately 12 m and is either plain concrete or reinforced according to the structural requirements.

5.1 Excavation and Support Classes Main Tunnel

The preliminary excavation and support measures are categorised into six Excavation and Support Categories. The correlation between the Behaviour Types and the Excavation and Support Categories is given in the following table.

Table 6: Basic correlation between the Behaviour Types and the Excavation and Support Categories Main Tunnel

Behaviour Type	Support Category
BT-1 Stable	ESC I
BT-2 Potential of discontinuity-controlled block fall	ESC II
BT-3 Shallow failure	ESC III and ESC IV
BT-4 Voluminous stress induced failure	ESC V and ESC VI
BT-7 Crown failure	ESC V and ESC VI
BT-8 Ravelling ground	ESC VI

BT-11 Ground with frequently changing deformation characteristics.	ESC V and ESC VI

In the following a description of the support concept including the necessary support measures is given. This description also includes the Behaviour Types. The design of the support measures is mainly based on analytical and numerical analysis as well as experiences from comparable tunnel projects.

The Analytical design of Main tunnel is presented in Annexure-1 of this report and numerical analysis of main tunnel using Finite Element Modelling (FEM) is attached in Annexure-2 of this report.

5.1.1 Excavation and Support Class I

Designed for Behaviour Type 1 – Stable

For further details see respective drawings (Refer Annexure 6).

5.1.1.1 Excavation

The excavation is divided into top heading and bench excavation. The average round length of the top heading is 3 m. The average round length of the bench is about 6 m. The distance between the top heading and the bench face is not restricted and shall be adjusted as per the logistics requirement.

5.1.1.2 Primary Support

A 5 cm thick layer of steel fibre sprayed concrete and, if necessary, frictional bolts with immediate response, a capacity of min. 200 kN (Swellex or equivalent) and a length of 4 m provide the necessary support in the top heading and the bench.

5.1.1.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

5.1.2 Excavation and Support Class II

Designed for Behaviour Type 2 – Potential of discontinuity-controlled block fall

For further details see respective drawings (Refer Annexure 6).

5.1.2.1 Excavation

The excavation is divided into top heading and bench excavation. The average round length of the top heading is 2.5 m. The average round length of the bench is about 5 m. The distance between the top heading and the bench face is not restricted and shall be adjusted as per the logistics requirement.

5.1.2.2 Primary Support

A 10 cm thick layer of steel fibre sprayed concrete and, grouted bolts with a capacity of min. 200 kN and a length of 4 m provide the necessary support in the top heading and the bench. Every round 7-8 bolts are installed in the top heading and 3-4 bolts in bench.

5.1.2.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

5.1.3 Excavation and Support Class III

Designed for Behaviour Type 3 – Shallow stress induced failure, Behaviour Type 4 - Voluminous stress induced failure

For further details see respective drawings (Refer Annexure 6).

5.1.3.1 Excavation

The excavation is divided into top heading and bench excavation. The average round length of the top heading is 2 m. The average round length of the bench is about 4 m. The distance between the top heading and the bench face shall be more than 30 m. The maximum distance between top heading and bench excavation is not limited.

5.1.3.2 Primary Support

A 15 cm thick layer of steel fibre sprayed concrete and, grouted bolts with a capacity of min. 200 kN and a length of 4 m provide the necessary support in the top heading and the bench. Every round 13-14 bolts are installed in the top heading and 7-8 bolts in bench.

5.1.3.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

5.1.4 Excavation and Support Class IV

Designed for Behaviour Type 3 – Shallow Failure, Behaviour Type 4 – Voluminous stress induced failure

For further details see respective drawings (Refer Annexure 6).

5.1.4.1 Excavation

The excavation is divided into top heading, bench and arched invert excavation. The average round length of the top heading is 1.5 m. The average round length of the bench and arched invert is about 3 m and 6m respectively. The distance between the top heading and the bench face shall be 4 round length and the distance between the bench and the final invert face has a maximum of 6 round length of the top heading. The distance can be optimized based on field observations and instruction of EIC.

5.1.4.2 Primary Support

A 20 cm thick layer of steel fibre sprayed concrete, a lattice girder (70/20/25) and, grouted bolts with a capacity of min. 350 kN and a length of 6 m provide the necessary support in the top heading and the bench. Every round 12-13 bolts are installed in the top heading and 4-5 bolts in bench.

5.1.4.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

Forepoling with grouted steel bars with a diameter of 32 mm and a length of 3 m has to be installed to support the rock mass in the excavation roof, if necessary.

5.1.5 Excavation and Support Class V

Designed for Behaviour Type 4 – Voluminous stress induced failure, Behaviour Type 7 - Crown Failure, Type 11 - Ground with frequently changing deformation characteristics.

For further details see respective drawings (Refer Annexure 6).

5.1.5.1 Excavation

The excavation is divided into top heading, temporary invert, bench and permanent arched invert excavation. The average round length of the top heading is 1m. The average round length of the temporary invert, the bench and the permanent invert is 2m, 2m and 4m respectively. The distance between the top heading and the temporary invert face as well as the distance between the bench and the final invert face has a maximum of 6 round length of the top heading.. The maximum distance between the top heading and the bench excavation is not limited.

A face wedge of approximate height 2m is kept for additional face stability if required.

5.1.5.2 Primary Support

A 25cm thick layer of steel fibre sprayed concrete with one layer of wire mesh, a lattice girder (LG 95/20/25) and self-drilling bolts with a capacity of min. 350 kN and a length of 9m inside walls and roof provide the necessary support in the top heading and the bench. Every round, 14-15 bolts with a length of 9m are installed in the top heading and 9-10 bolts with a length of 9m in the bench. The temporary invert is supported with a 20cm thick steel fibre sprayed concrete layer, the permanent invert with a 25cm thick steel fibre sprayed concrete layer with one layer of wire mesh.

The footing of the steel fibre sprayed concrete lining in the top heading is 50cm thick (elephant foot).

5.1.5.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

Forepoling with grouted steel bars with a diameter of 32 mm and a length of 6 m at every alternate round has to be installed to support the rock mass in the excavation roof, if necessary.

As face support, 10 cm steel fibre sprayed concrete in the face with 5-6 GFRP bolts of 9m length and 3 m overlap have to be installed to support the face, if necessary.

5.1.6 Excavation and Support Class VI

Behaviour Type 4 – Voluminous stress induced failure, Behaviour Type 7 - Crown Failure, Behaviour Type 8 – Ravelling ground, Behaviour Type Type 11 – Ground with frequently changing deformation characteristics.

For further details see respective drawings (Refer Annexure 6).

5.1.6.1 Excavation

The excavation is divided into top heading, temporary invert, bench and permanent arched invert excavation. The average round length of the top heading is 0.8 m. The average round length of the temporary invert, the bench and the permanent invert is 1.6 m, 1.6 m and 3.2 m respectively. The distance between the top heading and the temporary invert face as well as the distance between the bench and the final invert face has a maximum of 6 round length of the top heading. The maximum distance between the top heading and the bench excavation is not limited.

A face wedge of approximate height 2 m is kept for additional face stability if required.

5.1.6.2 Primary Support

A 30 cm thick layer of steel fibre sprayed concrete with one layer of wire mesh, a lattice girder (LG 130/25/32) and self-drilling bolts with a capacity of min. 350 kN and a length of 12 m in side walls and 9 m in roof provide the necessary support in the top heading and the bench. Every round, 4-5 bolts with a length of 12 m and 10-11 bolts with a length of 9 m are installed in the top heading and 11-12 bolts with a length of 12 m in the bench. The temporary invert is supported with a 25 cm thick steel fibre sprayed concrete layer, the permanent invert with a 30 cm thick steel fibre sprayed concrete layer with one layer of wire mesh.

The footing of the steel fibre sprayed concrete lining in the top heading is 50 cm thick (elephant foot).

The primary lining of the top heading is divided by two horizontal gaps with a height of 50 cm each. These gaps allow large displacements of the tunnel lining. In the gaps yielding elements (lining stress controllers LSC or equivalent) shall be installed to control the stress in sprayed concrete. Additional over-excavation provides space for the displacements.

5.1.6.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

A pipe roof umbrella with 44 pieces of 76 mm steel pipes with an average distance of 30 cm, a length of 12 m and an overlap of minimum 4 m is installed to improve roof and face stability of the excavation.

As face support, 10 cm steel fibre sprayed concrete in the face with 8-9 GFRP bolts of 9m length and 3 m overlap have to be installed to support the face, if necessary.

5.2 Excavation and Support Classes Cross Passage

The preliminary excavation and support measures are categorised into four Excavation and Support Categories. The correlation between the Behaviour Types and the Excavation and Support Categories is given in the following table.

Table 7: Basic correlation between the Behaviour Types and the Excavation and Support Categories Cross Passage

Behaviour Type	Support Category
BT-1 Stable	ESC I
BT-2 Potential of discontinuity-controlled block fall	ESC I and ESC II
BT-3 Shallow failure	ESC II and ESC III
BT-4 Voluminous stress induced failure	ESC III and ESC IV
BT-7 Crown failure	ESC IV
BT-8 Ravelling ground	ESC IV
BT-11 Ground with frequently changing deformation characteristics.	ESC IV

In the following section a description of the support concept including the necessary support measures is given. This description also includes the Behaviour Types. The design of the support measures is mainly based on analytical and numerical analysis as well as experiences from comparable tunnel projects. The Analytical design of Cross Passages is presented in Annexure-3 of this report.

5.2.1 Excavation and Support Class I

Designed for Behaviour Type 1 – Stable and Behaviour Type 2 – Potential of discontinuity-controlled block fall

5.2.1.1 Excavation

The excavation is proposed as full face. The average round length is 3 m.

5.2.1.2 Primary Support

A 5 cm thick layer of steel fibre sprayed concrete and, if necessary, frictional bolts with immediate response, a capacity of min. 200 kN (Swellex or equivalent) and a length of 3 m provide the necessary support.

5.2.1.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

5.2.2 Excavation and Support Class II

Designed for Behaviour Type 2 – Potential of discontinuity-controlled block fall, Behaviour Type 3 – Shallow stress induced failure.

5.2.2.1 Excavation

The excavation is proposed as full face. The average round length is 2 m.

5.2.2.2 Primary Support

A 15 cm thick layer of steel fibre sprayed concrete and, grouted bolts with a capacity of min. 200 kN and a length of 4 m provide the necessary support in the excavation. Every round 7-8 bolts are installed.

5.2.2.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

5.2.3 Excavation and Support Class III

Designed for Behaviour Type 3 – Shallow stress induced failure, Behaviour Type 4 - Voluminous stress induced failure

5.2.3.1 Excavation

The excavation is proposed as full face. The average round length is 1.5 m.

5.2.3.2 Primary Support

A 20 cm thick layer of steel fibre sprayed concrete, a lattice girder (70/20/25) and, grouted bolts with a capacity of min. 350 kN and a length of 6 m in the side wall and roof provide the necessary support. Every round 7-8 bolts of 6 m length are installed.

5.2.3.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

Forepoling with grouted steel bars with a diameter of 32 mm and a length of 3 m has to be installed to support the rock mass in the excavation roof, if necessary.

5.2.4 Excavation and Support Class IV Voluminous stress induced failure

Designed for Behaviour Type 4, Behaviour Type 7 - Crown Failure, Behaviour Type 8 - Ravelling ground and Behaviour Type 11 - Ground with frequently changing deformation characteristics.

5.2.4.1 Excavation

The excavation is divided into top heading and invert excavation. The average round length of the top heading is 1.3 m. The average round length of the invert is about 2.6 m. The distance between the top heading face and invert shall be maximum 6 top heading rounds.

5.2.4.2 Primary Support

A 25 cm thick layer of steel fibre sprayed concrete with one layer of wire mesh, a lattice girder (95/20/25) and, grouted/self-drilling bolts with a capacity of min. 350 kN and a length of 6 m in side wall and roof provide the necessary support in the top heading. Every round 10-11 bolts of 6 m length are installed in the top heading. The invert is also supported with 25 cm thick layer of steel fibre sprayed concrete with one layer of wire mesh.

5.2.4.3 Additional Measures

Drainage drillings in case of water inflows shall be constructed.

Forepoling with grouted steel bars with a diameter of 32 mm and a length of 4 m has to be installed to support the rock mass in the excavation roof, if necessary.

As face support, 5-10 cm steel fibre sprayed concrete in the face with 6-7 GFRP bolts of 9m length and 3 m overlap have to be installed to support the face, if necessary.

6 SYSTEM BEHAVIOUR

The behaviour of the system ground-excavation-support shall be generally stable. Due to time dependency of stress redistribution in combination with construction process displacements will occur in the Excavation and Support Categories dominated by stress induced failure modes of the rock mass. For a proper evaluation of the system behaviour during and after excavation and support installation the expected system behaviour is described in the following table. It is of essential importance to observe the system behaviour also in terms of 3D displacement monitoring and to compare with the predicted values of displacements. In case of deviation, especially in case of larger displacements than predicted counter measures have to be set immediately. Otherwise, the displacements may exceed the values of over-excavation which would result in under-profile of the tunnel geometry.

In the following table the expected system behaviour of the main tunnel based on the analytical analyses are given for each support category. The analysis results are mentioned in **Annexure 1**. No voluminous overbreak shall occur during excavation. Surface settlements are not limited.

Table 8: Expected radial displacements of the tunnel primary lining in main tunnel cross sections with respect to different excavation and support categories

Excavation and Support Class	Theoretical Total Displacement (mm)
ESC I	1.7
ESC II	3.3
ESC III	7.0
ESC IV	35.2*
ESC V	26*
ESC VI	36.8*

Table 9: Expected radial displacements of the tunnel primary lining in cross passage sections with respect to different excavation and support categories

Excavation and Support Class	Theoretical Total Displacement (mm)
ESC I	2.5
ESC II	2.3
ESC III	30.0*
ESC IV	43.5*

The anticipated displacement would vary slightly from the above-mentioned theoretical displacement due to the presence of pre-support and additional measures which could not be simulated in analytical methods. Deformation allowance for support classes is defined based on such consideration. The analysis results are mentioned in **Annexure 3**.

7 DISTRIBUTION OF GROUND TYPES (GT), BEHAVIOUR TYPES (BT) AND SUPPORT CATEGORIES

7.1 Distribution

An interpretation for the distribution of the Rock Mass /Ground Types along the proposed alignment is made. The Behaviour types (**BTs**) anticipated for a given ground type under the range of overburden and in-situ stress conditions for the Fotu La Tunnel alignment considered are shown in Table below. It is to be noted, the table is an estimation and can vary as per actual ground conditions and their geotechnical environment.

Table 10 Anticipated Ground Behaviour types against overburden

		Overburden depth			
		0-50	50-100	100-250	250-500
Ground Types	GT1	BT-1,2	BT- 1,2,3	BT-3,4	BT-3,4
	GT2	BT-3,7,8	BT-3,4	BT-4	BT-4
	GT3	BT-4,8	BT-4,8	BT-4	BT-4
	GT4	BT-7,8,11			

Along the proposed twin tunnel length of approx 1943.1m each (average of both NATM tubes), the anticipated range and distribution of Ground Types is estimated. The distribution is attempted to be in line with the status of GT investigations carried out. The insight into this distribution through direct observation including Field mapping and core drilling has been compiled in the report Geotechnical Factual Report. The extent of the ground types that intercept the tunnel is expected to be controlled by proximity to and prominence of Thrust/ Fault Zones anticipated along the alignment. In case of very acute/ nearly parallel orientation of such zones to the tunnel could result in larger stretches of the tunnel coming under its influence than projected on maps.

Further, the anticpated lengths of tunnel set to negotiate different Ground Types assuming for variations in actual geological settings and structure. This range, expressed as percentage and average lengths. The anticpitated GT distribution along the tunnel length is shown in the following table, and the same can be also seen in detail in the GIR (Ref. [4])

Table 11 Anticipated Distribution of Ground types along Fotu La Tunnel

GT	GT1H	GT1L	GT2H	GT2L	GT3H	GT3L	GT4
Length (m)	300	204.1	540	410	185	149.4	154.6

Approx %	**15.4%**	**10.5%**	**27.8%**	**21.1%**	**9.5%**	**7.7%**	**8.0%**
Chainage	**0+640-0+940**	**0+435.9-0+640**	**1+350-1+890**	**0+940-1+350**	**1+890-2+075**	**2+075-2+224.4**	**0+360.9 - 0+435.9, 2+224.4 - 2+304***

The GT types are further divided into behaviour types (BT) along the tunnel length based and presented in the Table 7 below:

Table 12 Anticipated Distribution of Behaviour types along Fotu La Tunnel

BT	BT-1	BT2	BT-3	BT-4	BT-5/6	BT-7	BT-8	BT-9/10	BT-11
Length (m)	10	40	377	1211.6	0	124.60	149.90	0	30.00
Approx %	**0.5%**	**2.1%**	**19.4%**	**62.4%**	**0.0%**	**6.4%**	**7.7%**	**0.0%**	**1.5%**

Based on the anticipated behaviour (BT), Excavation and Support Class (ESC) is predicted and distributed along the tunnel length as mentioned in table 8 below:

Table 13 Anticipated Distribution of Excavation and Support types along Fotu La Tunnel

ESC	ESC-1	ESC-2	ESC-3	ESC-4	ESC-5	ESC-6
Length (m)	10	90	404.1	185	230	1024
Approx %	**0.5%**	**4.6%**	**20.8%**	**9.5%**	**11.8%**	**52.7%**

8 KINEMATIC / WEDGE ANALYSIS OF TUNNEL

Kinematic analysis is a fundamental tool in assessing structurally controlled instability in rock masses, particularly around underground excavations such as tunnels. It evaluates the geometric feasibility of potential failure modes—primarily wedge failures—based solely on the orientation of discontinuities relative to the excavation geometry, without considering the magnitude of forces.

In jointed rock masses, wedge failures occur when two or more discontinuities intersect to form a block that may slide into the excavation under gravity. The critical condition is whether the line of intersection of the planes daylights into the tunnel boundary and lies within the frictional envelope.

To perform a three-dimensional kinematic and stability assessment, UnWedge software by Rocscience is used. The software models the tunnel and joint geometry to automatically identify all feasible tetrahedral wedges around the excavation. Input parameters include tunnel orientation and shape, joint set orientations, shear strength properties, unit weight, groundwater pressure, and support conditions.

UnWedge first performs a kinematic feasibility check, identifying which wedges can form and slide. It then applies a limit equilibrium method to calculate the Factor of Safety (FoS) for each wedge, accounting for gravitational forces, water pressures, and optional support (e.g., bolts, shotcrete).

8.1 Discontinuities along the tunnel alignment:

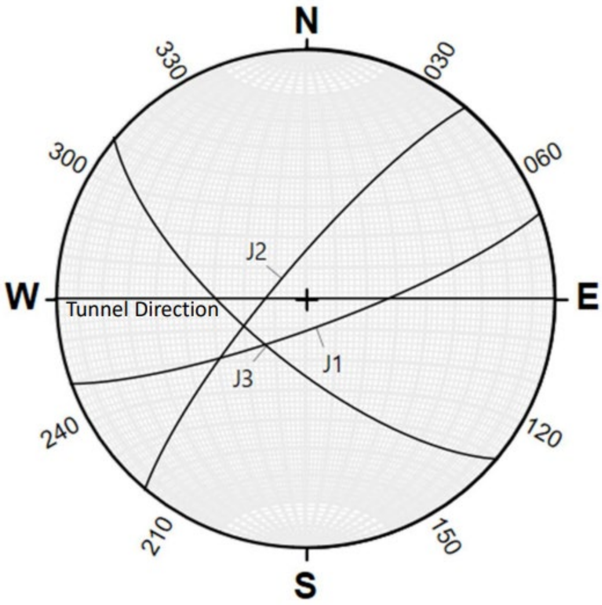
The joint orientations were collected from the East Portal, Tunnel Alignment (Along road section), offroad exposures on Left and Right side of the alignment) and West Portal and along valley) and plotted on stereo net to identify joint clusters.

The discontinuities data have been systematically collected in rock outcrops along the road alignment and also possible traverse routes in the hill slopes at/around proposed tunnel East portal. The data set has been analyzed using DIPS.

A. **Close to Eastern Portal (P1)**

Three joint sets, viz. J1: N155º/80º, J2: N310º/75º and J3: N220º/70º have been identified. The stereographic plot is given in Figure-3

Chainage- East Portal area



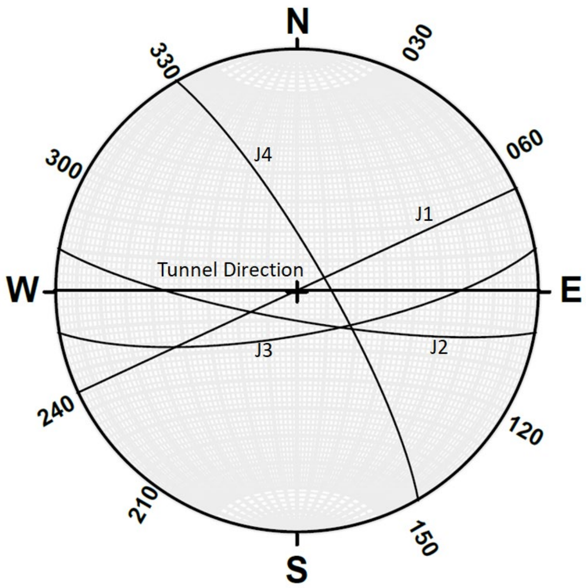
Discontinuity Sets:
Set- Dip Dir/ Dip Amt J1- 155º/80º J2- 310º/ >75º J3- 220º/ 70º

Figure 12: Showing discontinuity orientation at East Portal (P-1) area

B. **Between Eastern Portal (P1) and Western Portal (P2)**

Four joint sets, viz. J1: N150-160º/80º, J2: N190º/75º, J3: N170º/75º and J4: N60º/80º, have been identified. The stereographic plot is given in Figure-4

Chainage- P-1 to P-2



Discontinuity Sets:
Set- Dip Dir/ Dip Amt J1- 150-160º/ Vertical J2- 190º/ >75º J3- 170º/ 75º J4- 60º/ >75º

Figure 13: Showing discontinuity orientation between P-1 and P-2

C. **Close to Western Portal (P2)**

Four joint sets, viz. J1: N310º/60º, J2: N270/70º to vertical, J3: N210º/35-50º and J4: N250-260º/80º, have been identified. The stereographic plot is given in Figure-5

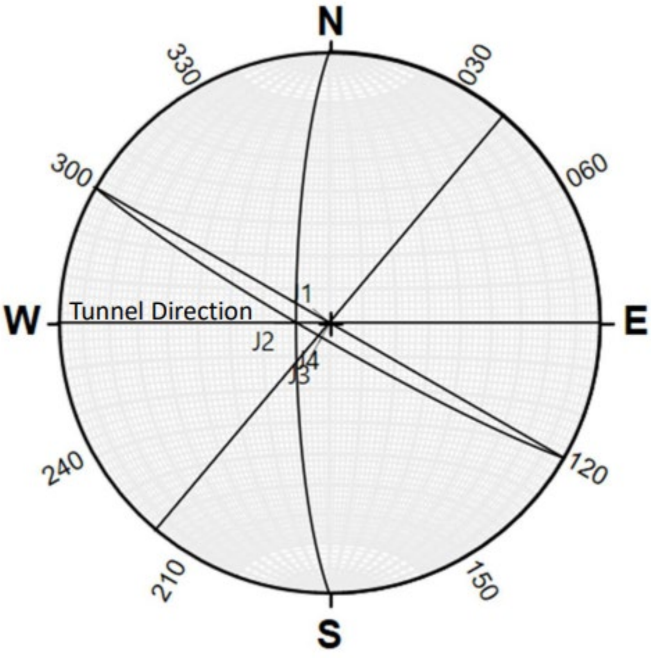
<table>
<tr><th colspan="2">Chainage- P-2</th></tr>
<tr><td rowspan="2">
</td><td>Discontinuity Sets:</td></tr>
<tr><td>Set- Dip Dir/ Dip Amt
J1- 310º/ Vertical
J2- 270º/ >70º to Vertical
J3- 210º/ Vertical
J4- 30º/ Vertical</td></tr>
</table>

Figure 14: Showing discontinuity orientation at portal P-2 and adjoining area

8.2 Orientation of the Tunnel

The tunnel is oriented broadly in the east-west direction with a curve of radius 600m in the middle.

For tunnel stretch closer to P1, Trend of the tunnel is 270º whereas Plunge is 0º

For tunnel stretch closer to P2, Trend of the tunnel is 290º whereas Plunge is 0º

Kinematic analysis is carried separately for both portals for the joint sets given in the subsequent section.

However, the kinematic analysis of tunnel stretch between P1 to P2 is further divided in two parts (as mentioned below) due to change in trend of the tunnel.

1. Closer to P1
2. Closer to P2

8.3 Kinematic Analysis

Kinematic wedge analysis was conducted using UnWedge, a three-dimensional analytical tool based on the principles of block theory and limit equilibrium analysis. The objective was to assess structurally controlled instabilities due to wedge formation around the tunnel excavation, governed by the intersection of persistent discontinuity planes.

Given the presence of four dominant joint sets, all possible combinations of three-plane intersections were systematically evaluated at each tunnel chainage to identify kinematically feasible tetrahedral wedges. A wedge is considered kinematically feasible if the line of intersection of discontinuities daylights into the excavation boundary, and the potential sliding direction lies within the envelope defined by the frictional resistance of the joint planes.

For each identified wedge-forming joint combination, the stability was assessed under no support or minimum support conditions, corresponding to Excavation Support Class (ESC-1) or ESC-2 as defined in the tunnel design framework. The analysis considers self-weight as the driving force and joint shear strength parameters (cohesion and friction angle) as resisting forces, in accordance with the principles of limit equilibrium.

It is important to note that this assessment establishes a conservative baseline, and any enhancement in support measures beyond the support checked for unwedge analysis—aligned with other Behaviour Types (BTs)—would result in increased Factors of Safety (FoS), thereby improving overall stability.

The joint set combinations contributing to wedge formations at specific tunnel locations are outlined below:

The details of joint sets which can make possible wedges with respect to the tunnel are mentioned below:

S.No.	Location	Joint set combination	Support considered for analysis	Min. FOS
1	East Portal Area (P1)	J1 J2 J3	No Support	3.169
2	Mid Alignment (Close to P1)	J1 J3 J4	ESC 2	1.515
		J2 J3 J4	ESC 2	1.232
3	Mid Alignment (Close to P2)	J1 J3 J4	ESC 2	2.746
		J2 J3 J4	ESC 2	2.008
4	West Portal Area (P2)	J1 J2 J3	No Support	3.333
		J1 J2 J4	No Support	3.333

It shall be noted that for the proposed support system for each GT, the FOS against kinematic stability will be much higher as presented in the table above.

The details of Unwedge analysis for the above combination of joint sets is presented in Annexure-4

9 PORTAL SLOPE STABILITY (FEM ANALYSIS)

9.1 Introduction

The slope stability analysis of front slope has been carried out for both East & West portals belong to the Fotu La tunnel.

The position of East portal is starting at the chainage of 0+394.6m (at right tunnel) & at chainage of 0+360.9m (at left tunnel). The slope height at the East portal is 25m with slope of 1(H) 1.5(V).

The position of West portal is starting at the chainage of 2+342.3m (at right tunnel) & at chainage of 2+299.4m (at left tunnel). The cut slope height at the West portal is 25.5m with slope of 1(H) 1.5(V).

The water table was considered as per site conditions, as recorded during sub-surface drilling of portal boreholes on both sides respectively.

Further, a surcharge load of 1m snow was also considered on the natural slopes above the portal slope cuttings, to simulate the accumulated snow during winters. It shall be noted that the snow accumulation shall not be there on the cut slopes due to steep angle.

The cuts would be stabilized with sprayed concrete and rock bolts with proper arrangement of drainage. The figures below show the portal locations.

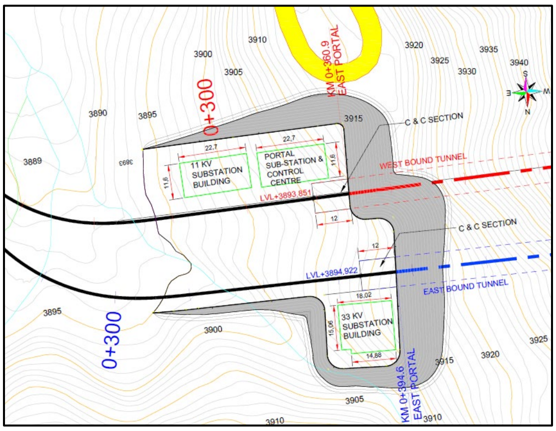


Figure 15: Layout Plan East Portal

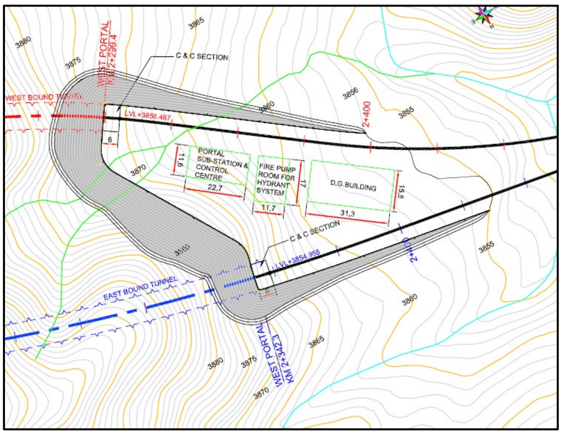


Figure 16: Layout Plan West Portal

9.2 Support Summary and Factor of Safety

The design of the support measures for portal cuts is mainly based on analytical and numerical analysis as well as experiences from comparable tunnel projects.

Front slope (FS) is analysed at both the portals (East & West) of Fotu La tunnel with and without earthquake loading. Since, at west portals, both tubes are coming out on different ridges, both are analysed separately.

The excavation and support measures for both the portals are as following.

9.2.1 East Portal

9.2.1.1 Excavation

The cut slope is 1(H) 1.5(V) and the excavation is to be carried out in steps not more than 3 m deep.

9.2.1.2 Support

The slope is to have 6 m long self-drilling bolts of minimum 350 kN capacity placed at 2 m X 2 m spacing (staggered). The bottom four rows is to have to have 9 m long self-drilling bolts of minimum 350 kN capacity placed at 2 m X 2 m spacing (staggered)

Sprayed Concrete of thickness 100mm mentioned above shall be reinforced by one layer of wire mesh of size 150/150/6mm.

9.2.1.3 Additional Measures

Drainage holes of 6 m length at 4 m X 4 m spacing to be installed (staggered)

For further details see respective drawings.

9.2.2 West Portal

9.2.2.1 Excavation

The cut slope is 1(H) 1.5(V) and the excavation is to be carried out in steps not more than 3m deep.

9.2.2.1.1 Support

The slope is to have 6 m long self-drilling bolts of minimum 350 kN capacity placed at 2 m X 2 m spacing (staggered). The Lower four rows is to have to have 9 m long self-drilling bolts of minimum 350 kN capacity placed at 2 m X 2 m spacing (staggered).

Sprayed Concrete of thickness 100mm mentioned above shall be reinforced by one layer of wire mesh of size 150/150/6mm.

9.2.2.2 Additional Measures

Drainage holes of 6 m length at 4m x 4m spacing to be installed (staggered).

For further details see respective drawings.

9.3 Factor of Safety

Portal Cuts are analyzed using the RS2 version 9 from Rocscience which is a finite element method (FEM) based, commercial software useful for geotechnical calculations. Shear Strength Reduction (SSR) technique is applied for finding the factor of safety. The analysis is done assuming the rock mass as a continuum medium.

The summary of factor of safety is tabulated here under and the FEM results are shown in the **Annexure 5**.

Table 14: Factor of safety for Portal Cuts

Slope	Support measures			Slope angle	Factor of safety	
	Rock bolt		Sprayed concrete thickness			
	Length	Pattern [m x m]			EQ	NEQ
East Portal	6m, 9m	2.0X2.0	100mm	1(H) 1.5(V)	1.46	1.86
West Portal	6m, 9m	2.0X2.0	100mm	1(H) 1.5(V)	1.18	1.54

An SSR analysis was carried out for the eastern portal under static conditions with rockbolts oriented at 10° to the horizontal. The results indicated a global Factor of Safety (FOS) of 1.85, which is slightly lower than the value obtained when the rockbolts were installed perpendicular to the slope. Accordingly, the final design adopts the configuration with rockbolts placed perpendicular to the slope. The detailed results of the analysis are presented in **Annexure-5.**

The portal cut and support drawings are given in **Annexure 8**.

10 KINEMATIC / WEDGE ANALYSIS OF SLOPES

10.1 Introduction

Slope stability is a critical consideration in rock engineering, particularly in hilly and mountainous terrains. Among the various modes of slope failure, kinematic failure—commonly manifested as wedge failure—is one of the most prevalent. Wedge failure occurs when two or more intersecting discontinuities in a rock mass form a block that is kinematically free to slide along their line of intersection. The orientation of these discontinuities relative to the slope face and the direction of excavation plays a decisive role in determining the stability of the rock slope.

In the context of the Fotula Tunnel project, the assessment of potential wedge failures forms an integral part of the slope stability evaluation. The rock mass in the project area is characterized by multiple joint sets with varying orientations, some of which intersect unfavorably with the proposed slope faces at the portals and approach roads. Such intersecting discontinuities may give rise to kinematically feasible wedges that are prone to sliding along their line of intersection under the influence of gravity and excavation-induced stresses.

Kinematic analysis has therefore been undertaken both for the portal and side slipes to systematically examine the joint orientation data, identify critical combinations likely to result in wedge failures, and evaluate their likelihood of occurrence. The findings of this assessment provide the basis for designing suitable slope reinforcement and support measures to ensure safe and stable excavation in this geologically sensitive stretch.

10.2 Discontinuities along the tunnel alignment:

The joint orientations were collected from the East Portal, Tunnel Alignment (Along road section), offroad exposures on Left and Right side of the alignment) and West Portal and along valley) and plotted on stereo net to identify joint clusters.

The discontinuities data have been systematically collected in rock outcrops along the road alignment and also possible traverse routes in the hill slopes at/around proposed tunnel East portal. The data set has been analyzed using DIPS.

A. Close to Eastern Portal (P1)

Three joint sets, viz. J1: N155º/80º, J2: N310º/75º and J3: N220º/70º have been identified. The stereographic plot is given in Figure-3

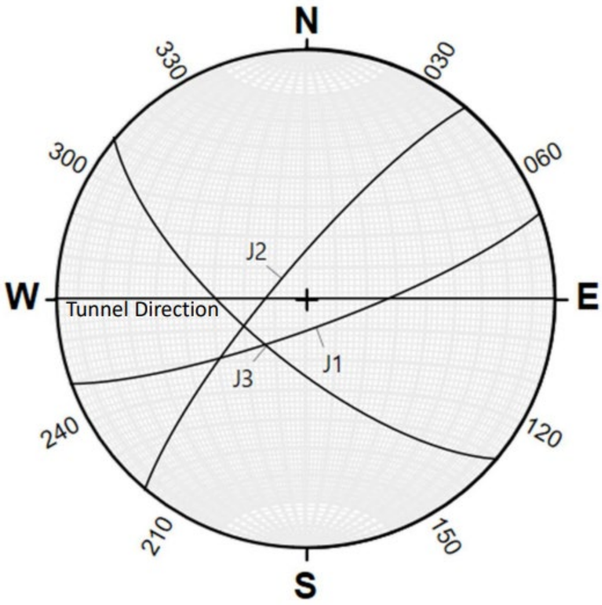
Chainage- East Portal area	
	Discontinuity Sets: Set- Dip Dir/ Dip Amt J1- 155º/80º J2- 310º/ >75º J3- 220º/ 70º

Figure 17: Showing discontinuity orientation at East Portal (P-1) area

B. Close to Western Portal (P2)

Four joint sets, viz. J1: N310º/60º, J2: N270/70º to vertical, J3: N210º/35-50º and J4: N250-260º/80º, have been identified. The stereographic plot is given in Figure-5

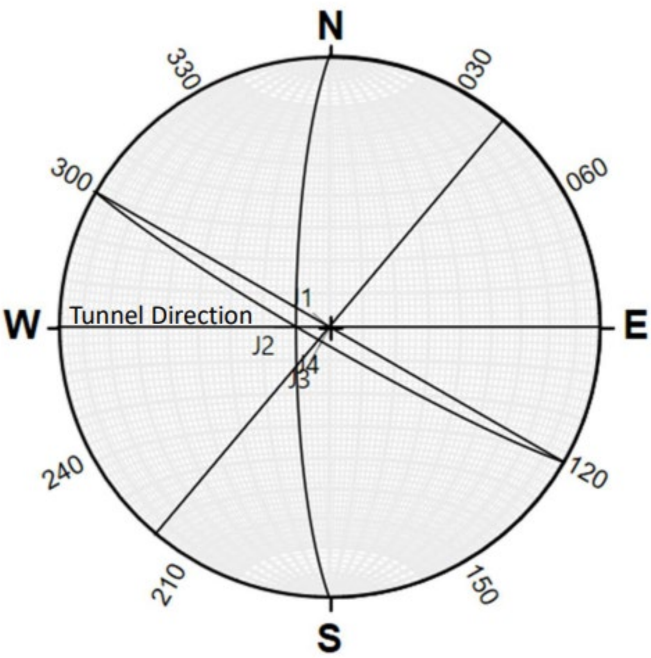
Chainage- P-2	
	Discontinuity Sets: Set- Dip Dir/ Dip Amt J1- 310º/ Vertical J2- 270º/ >70º to Vertical J3- 210º/ Vertical J4- 30º/ Vertical

Figure 18: Showing discontinuity orientation at portal P-2 and adjoining area

10.3 Orientation of Portal and Side Slopes

A. Portal P1

Parameters	Dip	Dip Direction	Height
Value	56.3	90	35

B. Portal P2

Parameters	Dip (deg.)	Dip Direction (deg.)	Height (m)
Value	56.3	290	35

C. Side Slope (North) Portal P1

Parameters	Dip	Dip Direction	Height
Value	56.3	180	35

D. Side Slope (South) Portal P1

Parameters	Dip	Dip Direction	Height
Value	56.3	0	35

E. Side Slope (North) Portal P2

Parameters	Dip	Dip Direction	Height
Value	56.3	200	35

F. Side Slope (South) Portal P2

Parameters	Dip	Dip Direction	Height
Value	56.3	20	35

Note: height of 35m is taken on conservative side, especially for side slopes whose height will be decreasing as the road moves away from the portal.

10.4 Kinematic Analysis using SWedge Software

Kinematic stability analysis of the slope at the Fotula Tunnel portals was carried out using Swedge software.

Swedge is a specialized software tool developed for evaluating the kinematic and stability conditions of rock wedges formed by the intersection of structural discontinuities. The program is based on the principles of stereographic projection and limit equilibrium analysis. It identifies potential wedge-shaped rock blocks by analyzing joint orientation data and determining whether their line of intersection daylight on the slope face, which is a prerequisite for wedge failure. Once the kinematically feasible wedges are identified, Swedge computes their stability by considering shear strength parameters along the discontinuity planes.

This analysis has provided a reliable basis for recommending appropriate slope reinforcement and support measures to ensure kinematic stability of the portal slope and side slopes.

10.5 Results of the Kinematic Analysis of Portal Slopes

The results of the Kinematic Analysis of both East (P1) and west (P2) Portal Slopes are presented in table below:

S.No.	Slope	Joint Sets Combination	Result
1	**P1**	J1-J2	No wedge Formed
2		J2-J3	No wedge Formed
3		J1-J3	No wedge Formed
4	**P2**	J1-J2	No wedge Formed
5		J1-J3	No wedge Formed
6		J1-J4	No wedge Formed
7		J2-J3	No wedge Formed
8		J2-J4	No wedge Formed
9		J3-J4	No wedge Formed

10.6 Results of the Kinematic Analysis of Side Slopes

The results of the Kinematic Analysis of all 4 side slopes are presented in table below:

S.No.	Slope	Joint Sets Combination	Result
1	**Side Slope (North) Portal P1**	J1-J2	No wedge Formed
2		J2-J3	No wedge Formed
3		J1-J3	No wedge Formed

4	**Side Slope (South) Portal P1**	J1-J2	No wedge Formed
5		J2-J3	No wedge Formed
6		J1-J3	No wedge Formed
7	**Side Slope (North) Portal P2**	J1-J2	No wedge Formed
8		J1-J3	No wedge Formed
9		J1-J4	No wedge Formed
10		J2-J3	No wedge Formed
11		J2-J4	No wedge Formed
12		J3-J4	No wedge Formed
13	**Side Slope (South) Portal P2**	J1-J2	No wedge Formed
14		J1-J3	No wedge Formed
15		J1-J4	No wedge Formed
16		J2-J3	No wedge Formed
17		J2-J4	No wedge Formed
18		J3-J4	No wedge Formed

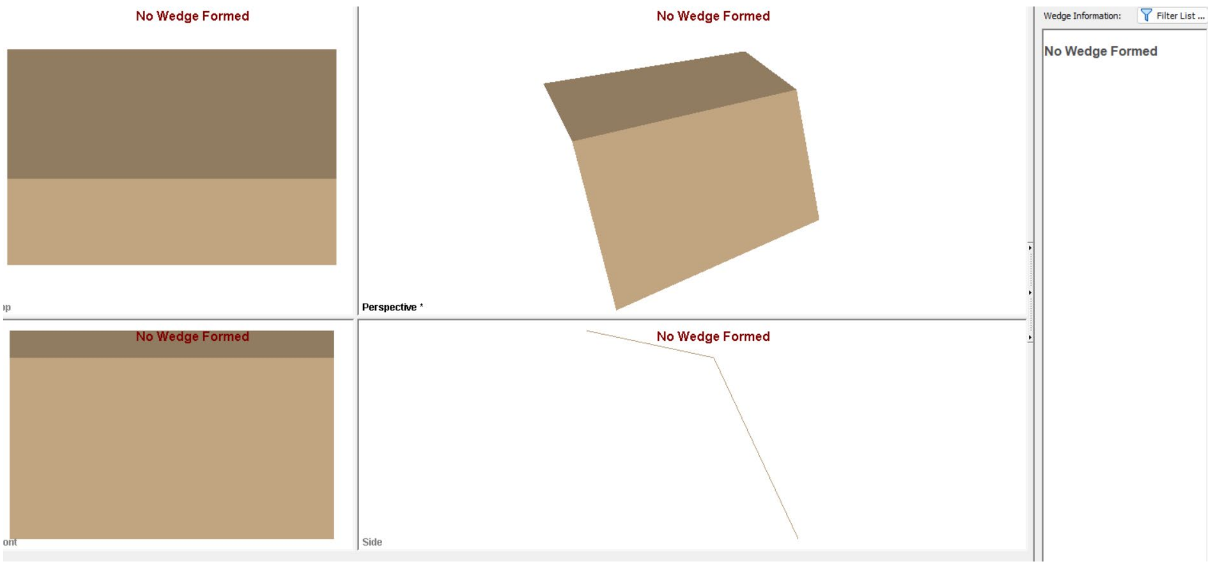


Figure 19: Results from Swedge Analysis

From the results it can be assessed that there no possibility of wedge failure on both portals and side slopes.

11 INSTRUMENTATION

The assessment of the tunnel performance, tunnel stability and proper adjustment of supporting measures and excavation sequences, is an integral part of NATM philosophy and can only be done on basis of an extensive instrumentation and monitoring program.

A tunnel with limited exploration data and significant long-lasting deformations expected requires a significant instrumentation program to

- Recognize the hazards in advance and assess protective safety measures
- Recognize the movements
- Tunnel Stability
- Adjustment, Alternative & Additional support requirement
- Changes in construction sequences
- Documentation of occurrences

In order to achieve this, standard monitoring section (SMS) to measure 3D optical displacement throughout the tunnel and Main Monitoring Section (MMS) with Multi Point Borehole Extensometer (MPBX), Radial Pressure Cell, Shotcrete Strain Gauge and Anchor/Rock Bolt Load Cell, at regular intervals are envisioned.

3D Optical Displacement Monitoring is a vital part of NATM. In general, this geotechnical monitoring system comprises the following elements:

- Reading points (3D targets/reflectors)
- Instruments to do the measurement (Sufficiently Accurate, i.e. 1” or less, Electronic Total Station)
- Specialized Software to process the data and graphical presentation

These elements should match in terms of accuracy and interfaces. The installation of highly precise Targets requires a minimum degree of accuracy from the Total Station; vice versa the use of a highly precise Total Station will be compromised by inaccurate installation of the Targets.

Getting a lot of data without employing adequate Specialized Software for data processing and organization will also compromise the motivation to do geotechnical monitoring – that is to provide information to assess the system behaviour rock mass – support system.

The principles and procedures of Geotechnical Monitoring define the requirements for data collection. It has to be stressed that especially in tunnelling a prompt and regular data collection is the basis for interpretable and reliable information.

3D optical displacement monitoring sections are installed at specified in table below according to the ground conditions or support category and with five / seven optical targets around the tunnel perimeter. These monitoring sections are used to gather and deliver most comprehensive information to support and verify design adjustment and optimization of the same during construction up to installation of primary lining on stabilized surface at later stage.

To measure the Seepage in tunnel V-notch seepage measurement system need to install one at each portal. For each portal slopes for permanent monitoring Inclinometer at top of cutting line approx. 10m away into the virgin ground need to install along with MPBX. Some 3D Targets need to install in cut slope after installation of supporting system for justification the failure of slopes, if any, along with Inclinometer or MPBX readings. Inclinometers need to reach at least 3m below the excavation level or 1m into rock.

Table 15: Distance between monitoring section

Support Category	Main Monitoring Section (MMS) in Metre(m)	Standard Monitoring Section (SMS) in Metre(m)
I	500	25
II	500	25
III	300	20
IV	300	20
V	200	10
VI	200	5

11.1 Bi-Reflex Target (3D Optical Target)

To get the position of a point at the tunnel surface in 3D, bi-reflex targets are fixed on convergence bolts. The thread of the convergence bolts is protected by a protective cap during installation and periods when the target is removed from the bolt for periodic measurements. They shall be:

- Manufacturing accuracy ± 0.1mm
- Measuring accuracy ± 1mm
- Distance Range 12-100m
- Support plastic, mounted on universal joints with foil coating both side

- Temperature -30 to 60°C
- Convergence bolts galvanized 250mm long, 20mm dia with 3/8" male thread
- Breaking points/Adaptor, protective cap

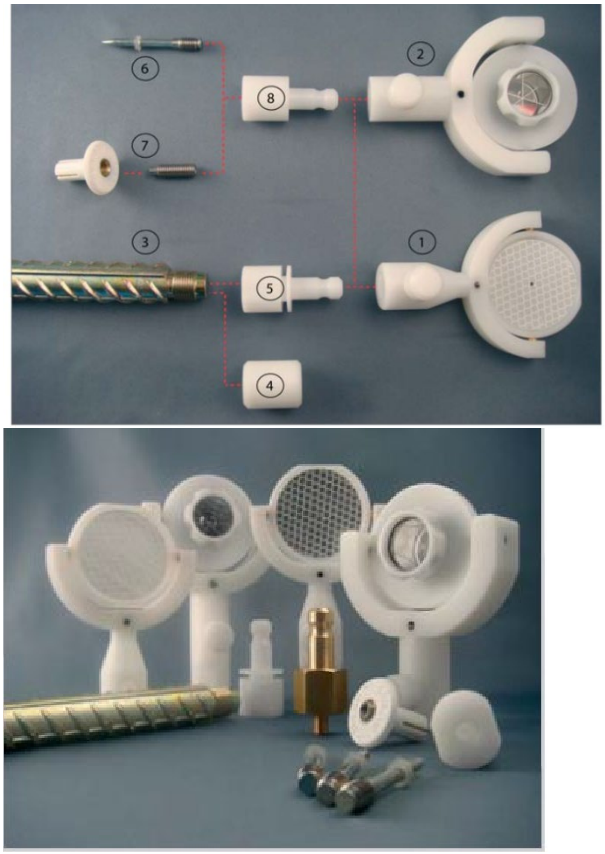


Figure 20: Bi-reflex targets with break off connections for installation

11.2 Total Station (Equipment for Measurement)

The equipment for taking the measurements is given below. The required accuracy of the total station for 3D monitoring is:

- Angular measurement accuracy Hz, V: 1” (0.3mgon)
- Distance measurement, Standard: 1mm + 1.5ppm

Guide light with reflector-less measurement for progress updating and profiling

Additional system requirement in Total Station, preferred is:

- Motorization for Speed
- Automatic target aiming with power search for target reorganization in poor visibility

11.3 Software (For data processing)

The software to be used shall be able to (minimum requirements):

- Create the design alignment and designed profile
- Create Control Points and Observed Points database, separately
- Import data from the total station
- Organize the data as per requirements, it's calculation and storage
- Free stationing calculation with standard deviation and residuals of each target position and it's acceptance after correction of errors due to wrong measurement or damaged target
- Produce diagrams/graphs (vertical/horizontal/longitudinal, convergence, vector) in relation with construction activity, suitable for geotechnical interpretation and assessment of the tunnel behaviour by the Geotechnical Engineer
- Creating tabulated data for support analysis

11.4 Extensometer

Extensometer are used for relative displacement between anchor point, installed at different depth inside rock/surface, and measuring head of instrument, around portal areas or inside the tunnel around MMS. They allow an assessment of the development of strains in the surrounding ground and stabilization of movements around the excavation. They shall be:

- Multiple (three point, 6m/9m/12m) rod type (fiber glass or stainless steel)
- 500mm fiber glass anchor, grout able
- Reference head electric version fitted with displacement transducers for remote readout
- Measuring range 150mm
- Accuracy ±0.01mm
- Resolution 0.1% Full Scale (FS)

11.5 Pressure Cell

<u>Radial Pressure Cells</u>

Radial Pressure cells are used to measure ground pressure acting on primary support. They shall be:

- Range 5Mpa
- Accuracy ± 0.1% of FS
- Over Range 150% of FS
- Temperature limit -30 to 60°C
- Pressure pad size 150mm x 250mm

11.6 Strain Gauge

Strain Gauges are used for determination of the stress developing in the sprayed concrete by measuring strains. They are always installed in pair to allow determination of sectional forces as normal thrust and bending moments. They shall be:

- Range ±15000 μ strain
- Sensitivity 1 μ strain
- Active Gauge length 166mm
- Temperature limit -30 to 60°C

11.7 Anchor/Rock Bolt Load Cell

Anchor/Rock Bolt Load Cell need to install in anchor/rock bolt at specified location/section to enable design predictions to be verified and to monitor performance. They shall be:

- Range 300KN - 600KN
- Center Hole type according to anchor/rock bolt OD
- Accuracy ±0.5% of FS
- Overload 150% of FS
- Temperature limit -30 to 60°C

11.8 Seepage Measurement System

The weir is one of the simplest and most reliable devices to monitor the quantity of flow of water. The weir normally used is the rectangular or 90° V-notch type. This system comes with Level sensor (Mechanical), measuring scale 600mm and some groutable anchors. They shall be:

- 53° V-notch, dimension 500*400*5mm
- Level Sensor (Mechanical)
- Measuring scale 75cm
- Measuring Capacity 25ltr/sec flow
- Groutable Anchor

11.9 Inclinometer

The borehole Inclinometer shall be installed to monitor lateral displacement perpendicular and parallel to the slope and approximately 5-10m away from the top face of the excavated slope. They shall be:

- ABS Casing OD 58mm, 3m long, fixed coupling with couplings and top/bottom cap
- Type – Bi-Axial digital tilt sensing probe
- Measuring Base 250mm
- Range ±20°
- Accuracy 0.002°
- Resolution 0.0005°
- Operating Temperature -30°C to 60°C
- Dist between wheel of probe 500mm
- Cable reel with 100m cable and cable guide
- Dummy Probe with 100m rope

Note: Normally separate readout unit is not required as android mobile phones can be used with app installation

11.10 Temperature Gauge

Temperature gauge to monitor temperature in concrete structures. They shall be:

- Range -40°C to 60°C
- Accuracy ±0.2°C

11.11 Readout unit

Readout unit to measure remotely the reading from sensors and they shall be:

- Storage Capacity 4500 reading from one sensor or 9sets of reading from 500sensors
- Range 450-600Hz
- Accuracy ±0.02%
- Resolution 0.1% of FS
- Temperature Range -40°C to 80°C

11.12 Switch Box

Suitable for connecting 10Nos sensors with certain core(X) cable of certain cable dia.(YZ).

11.13 Cables

Cables (additional) to connect sensors to switch box at MMS and they shall be:

- 6-Core cable, 11.5mm dia or similar, 0.14kg/m weight or similar
- 4-Core cable, 11mm dia or similar, 0.12kg/m weight or similar

12 MONITORING

Geotechnical Monitoring is most vital part of NATM Tunnelling. It is used to handle any unexpected behaviour (via analysis of 3D displacement monitoring) inside the tunnel and surrounding portal area during or immediate after the excavation. By considering of which decision can be made regarding any additional type/amount of support requirement or alteration/modification in construction approach and to alert the whole construction man-power/machinery to advance in safe manner.

The basic reference and the tunnel network is the foundation of the optical three-dimensional precision displacement monitoring. 3D measurement provides absolute, spatial displacement of individual specially marked measuring points by flexible and specialized geodetic method of measurement system with the help of highly precise state-of-art equipment. Monitoring X-section distribution depends upon the predicted geological condition of the excavated tunnel and amount of 3D targets on each X-section distributed according to that. This 3D measurement can be managed and processed for interpolation by highly capable survey, monitoring, geotechnical and visualization software.

12.1 Principles and Procedures

12.1.1 Installation of Targets

The convergence bolts are to be placed and fixed provisionally after the first layer of sprayed concrete. The following images show the general schematic as well as correct installation prior to second layer of sprayed concrete. During installation the protective cap must be installed over the threads to avoid damage.

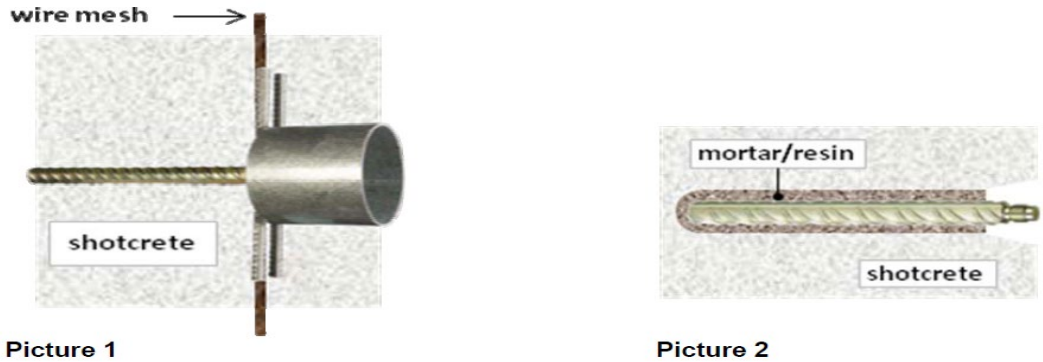


Figure 21: Schematic of a monitoring point installation

Figure 22: Dispositions of 3D targets in a tunnel profile

Figure 23: Correct Installation

The vertical position of the monitoring target in each section should be consistent to allow direct comparison of behaviour and the identification of changes in rock mass / system behaviour.

Before the Zero Reading of a newly installed monitoring target, the protective cap is replaced by the break-off point and the bi-reflex target is fixed onto the break off point. This is done after the primary support installation is finished.

During placement / replacement of the break-off points it should be observed that the break-off point is seated solidly on the convergence bolt (cleaning of the thread might be required).

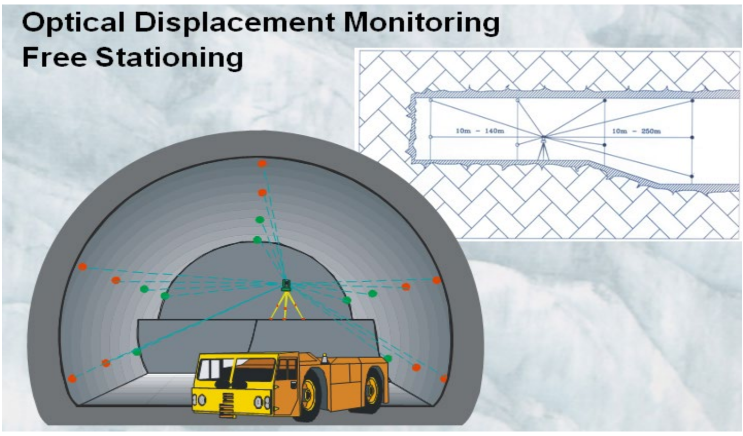


Figure 24: Schematic of Optical displacement monitoring

12.1.2 Zero Readings

After the targets have been installed completely, the Zero Reading should be taken immediately. It is good practice to do this as soon as possible and at a consistent point within the excavation cycle - optimally just prior to the excavation of the next round, since usually the major part of the deformations take place during and shortly after opening a round.

Delayed Zero Readings – be it due to late installation of the bolts or any other reason – mean a loss of information on the initial system behaviour and performance and hence an increase in risk.

12.1.3 Data Processing

Monitoring data should be processed immediately following measurement campaigns and provided as soon as possible to the Geotechnical and Tunnel Engineers. Any damage to monitoring sections/targets or irregularities during the survey which may influence the measurement accuracy should be noted on the relevant monitoring data sheets/reports.

With absolute displacement monitoring it is possible to determine 3D-coordinates of defined targets (reflectors) fixed to the tunnel wall. This information is used to track the target movements in space and allows a realistic assessment of the deformation behaviour of the tunnel.

Monitoring results are to be displayed in absolute and relative (to the last reading) movements in absolute values in respect of construction progress in the following three directions:

- Towards the tunnel axis
- Perpendicular towards the tunnel axis
- In the direction of the tunnel axis

Additionally, convergences between the different targets can be displayed. Monitoring results are to be recorded in hard and softcopy and should be transferred immediately to the Geotechnical Engineers.

12.1.4 Monitoring Section

It is obvious that the layout of monitoring section and their spacing between each other is depending on the geological conditions apart as mentioned in table 1 above.

Main Monitoring Section (MMS) with MPBX, Radial Pressure Cell, Strain Gauge and Anchor/Rock Bolt Load Cell shall be installed at regular intervals in the tunnels. MMS along with 3D Monitoring Targets allow additional assessment of the loading of the primary support and of ground movements outside the excavation for design verification purposes.

12.1.5 Monitoring Section Distribution and Frequency

Locations and distances may vary due to the actual geological conditions and monitored deformation results. This should be decided by the concerned Geotechnical Engineer or Engineer in Charge.

The locations of instrumented monitoring sections shown in the drawings shall be considered as adjustable and shall be modified according to the encountered ground conditions.

Data acquisition shall be performed with a data logger.

Monitoring frequencies shall be as given below respectively and should be adjusted according to the encountered ground behaviour.

Table 16: Monitoring Frequency

Frequency	Area of Monitoring
Daily	Up to 100m from excavation zone
Twice per week	From 100m to 250m from excavation zone
Once per week	Above 250m from excavation zone

All monitoring devices shall be installed with utmost care by experienced personnel according to the manufacturer’s recommendations and as shown on the relevant design drawings, if any.

For all monitoring devices installed, installation protocols shall be prepared, giving all information relevant to the installed monitoring devices such as detailed location in cross section, installation chainage, time and date of installation and of zero reading, zero reading values, etc.

Calibration Certificate for each instrument, Pre-installation check and Post Installation report should be available at site as a QA guideline and for audit purpose.

12.2 Evaluation And Interpretation of Monitoring Results

12.2.1 General Procedure

In general, the data handling and information flow of monitoring results shall be as follows:

Upon completion of daily monitoring activities and pre-processing of monitoring raw data a preliminary evaluation of the monitoring results shall be performed. Only after the results must be found reasonable and eventual errors have been excluded and corrected, an update of the database shall be performed. Preliminary evaluation shall be performed by the responsible Surveyor together with the Geotechnical Expert.

When the database has been updated with the actual monitoring results, the Geotechnical Expert shall proceed with the evaluation and interpretation of the monitoring results. To guarantee a quick decision regarding support requirements and working procedures the database must be updated with the daily measurements latest until midday.

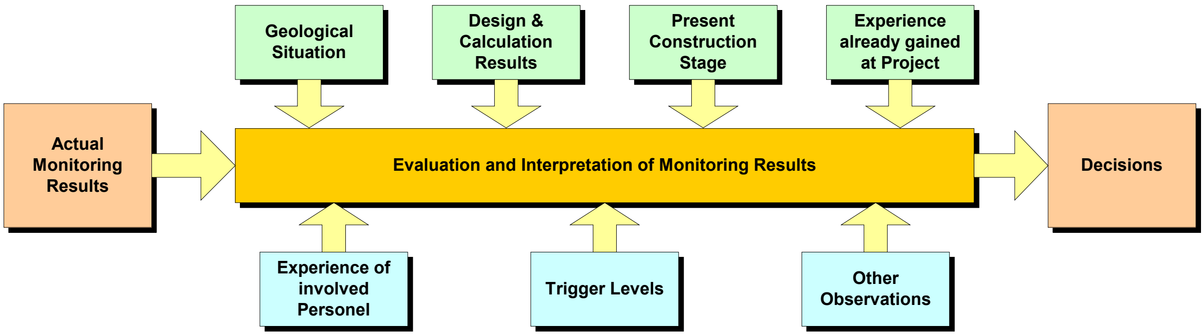


Figure 25: Chain of Interpretation

12.2.2 Method of Data Evaluation and Interpretation

Main monitoring parameters for tunnelling are as follows:

Table 17: Method of Data Evaluation

Parameter	Geomechanical Relevance
Trend of Time Histories	Useful for assessment of time dependent components of displacement and stabilisation of construction steps
Distribution of Displacement Vectors in Cross Section	Reflects the effects of geological structures sub parallel to the tunnel axis
Influence Lines (General)	Reflects the geomechanical conditions of the ground along the tunnel and the effect of

	individual excavation steps on the already excavated section
Trend Lines	Useful for determination of changes in ground conditions and as indicator for critical developments
Development of longitudinal Displacements close to the excavation face	Indicates changes in ground stiffness ahead of the face
Trend of advancing settlement due to bench excavation	Reflects the influence on individual bench excavation steps on the already excavated tunnel sections
Development of differential settlements between crown and top heading footings	Reflects the bearing behaviour of the primary lining and the quality of the primary lining foundations

12.2.3 Control Limits

Comparison of monitoring data with control limits will give a first indication for the identification of potential areas which are close to or exceeding design limits.

For the judgement of ground mass behaviour and performance of the primary support, control limits are established in terms of primary lining displacements, displacement velocities, shotcrete strains, settlements etc.

Under expected construction conditions the monitored displacements and other monitored data will be below the established threshold values, called control limits, which define certain design limitations.

Alert Level

The alert level relates to threshold values representing the assessed behaviour (predicted values), on exceeding of which, certain routines will be started to impose an increased attention and surveillance to these specific areas.

The alert values indicate that the specific area is approaching a level where additional actions and / or contingency measures may be necessary. The need for adjustment of excavation and support procedures and / or monitoring shall be considered.

This is normally 0.5times of serviceability limit.

Action Level

The Alarm level relates to threshold values, on exceeding of which the element of work may be approaching a critical state. The Geotechnical Expert shall convene for judgement of the specific case and the overall support and rock mass performance. Implementation of additional support and / or contingency measures to avoid the exceeding of the Action Level shall be considered.

This is normally 0.8times of serviceability limit.

Alarm Level

This level relates to threshold values, on exceeding of which the element of work is considered to be outside the expected range of assessed behaviour and may be close to its ultimate limit capacity.

The overall performance shall be rechecked together with a related risk assessment. A design review shall be performed together with an assessment of the need for a redesign. Additional support and / or contingency measures to guarantee the safety of the works shall be implemented.

For the case of identification of an unacceptable safety risk, the works shall be stopped and remedial measures shall be implemented immediately.

This is normally set as serviceability limit.

12.2.4 Presentation

12.2.4.1 Time Displacement Diagrams, Magnitude of Displacements

Time-Displacement diagrams show the development of the displacement of one point versus time. Time-displacement diagrams can be generated for all three components of the displacement vector (vertical, horizontal and longitudinal displacement). Construction phases (top heading, bench, and invert) are to be shown on the same diagram to allow for an easy correlation between displacement behaviour and construction activities

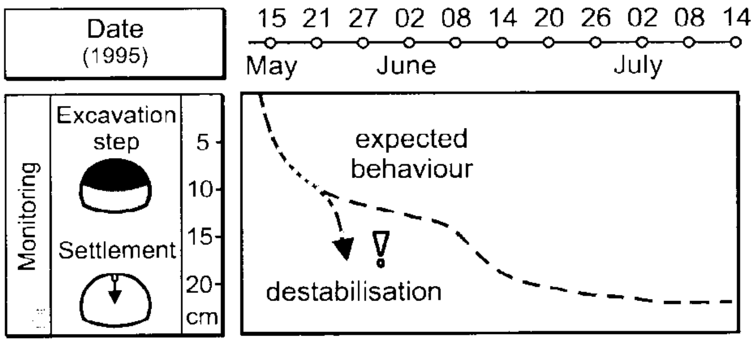


Figure 26: Example of Time- Displacement Diagram

12.2.4.2 Distribution of Displacements in Vector Diagrams

Displacement Vector plots allow the representation of the cross-sectional displacements and their development with time.

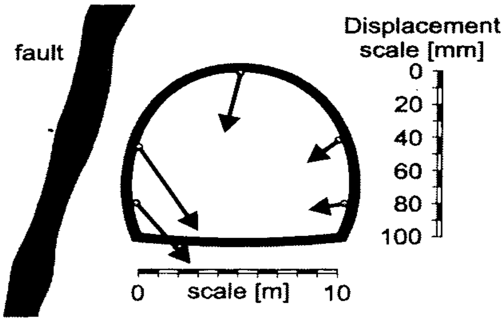


Figure 27: Example of Vector Diagram Presentation

Displacement vector plots allow the detection of weak zones and / or faults/ shear zones outside the excavation area. They provide additional information about the rock mass structure and deformation phenomena close to the tunnel. In general, the displacement vector orientation in cross section reflects the influence of geological structures on the deformation behaviour sub parallel to the tunnel.

-------- End of main document --------

13 TABLE OF ANNEXURES

Sr No.	Topic	Pages
1	Primary support analyses and results (Main tunnel) (Analytical)	44
2	Primary support analyses and results (Main tunnel) (FEM)	15
3	Primary support analyses and results (Cross Passage)	16
4	Kinematic / Wedge Analysis of tunnel and results (Unwedge)	21
5	Slope stability analysis and results (FEM – SSR Analysis)	4
6	Primary support drawings for Main tunnel	9
7	Primary support drawings for Cross Passage	4
8	Portal cut and support drawings	4

ANNEXURE 1 - Primary support analysis and results (Main tunnel) - Analytical

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **5.61**
Mobilized Support Pressure : **0.05** MPa

With support installed :
Radius of Plastic Zone r_p : **6.37** m
Wall Displacement u_p : **3.69** mm
Tunnel Convergence : **0.06** %

With no support installed :
Radius of Plastic Zone r_p : **6.47** m
Wall Displacement u_p : **3.83** mm
Tunnel Convergence : **0.06** %

Deformation at the tunnel face :
Wall displacement : **1.09** mm
Tunnel Convergence : **0.02** %

Critical Pressure p_{cr} : **0.24** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **1.91** MPa

Young's Modulus of Rock Mass E : **4000** MPa
Poisson Ratio ν : **0.3**

rocscience ROCSUPPORT 5.003	*Project* FotuLa Tunnel	
	Analysis Description ESC I - GT1L	
	Drawn By	*Company*
	Date 12-02-2025, 13:13:54	*File Name* GT1l High overburden ESC 1.rsp

Cohesion of Rock Mass C_{rm} : **0.854115** MPa

Compressive Strength of Rock Mass σ_{rm} : **2.9** MPa

Friction Angle ϕ : **29°**

Support Parameters:

Total combined :

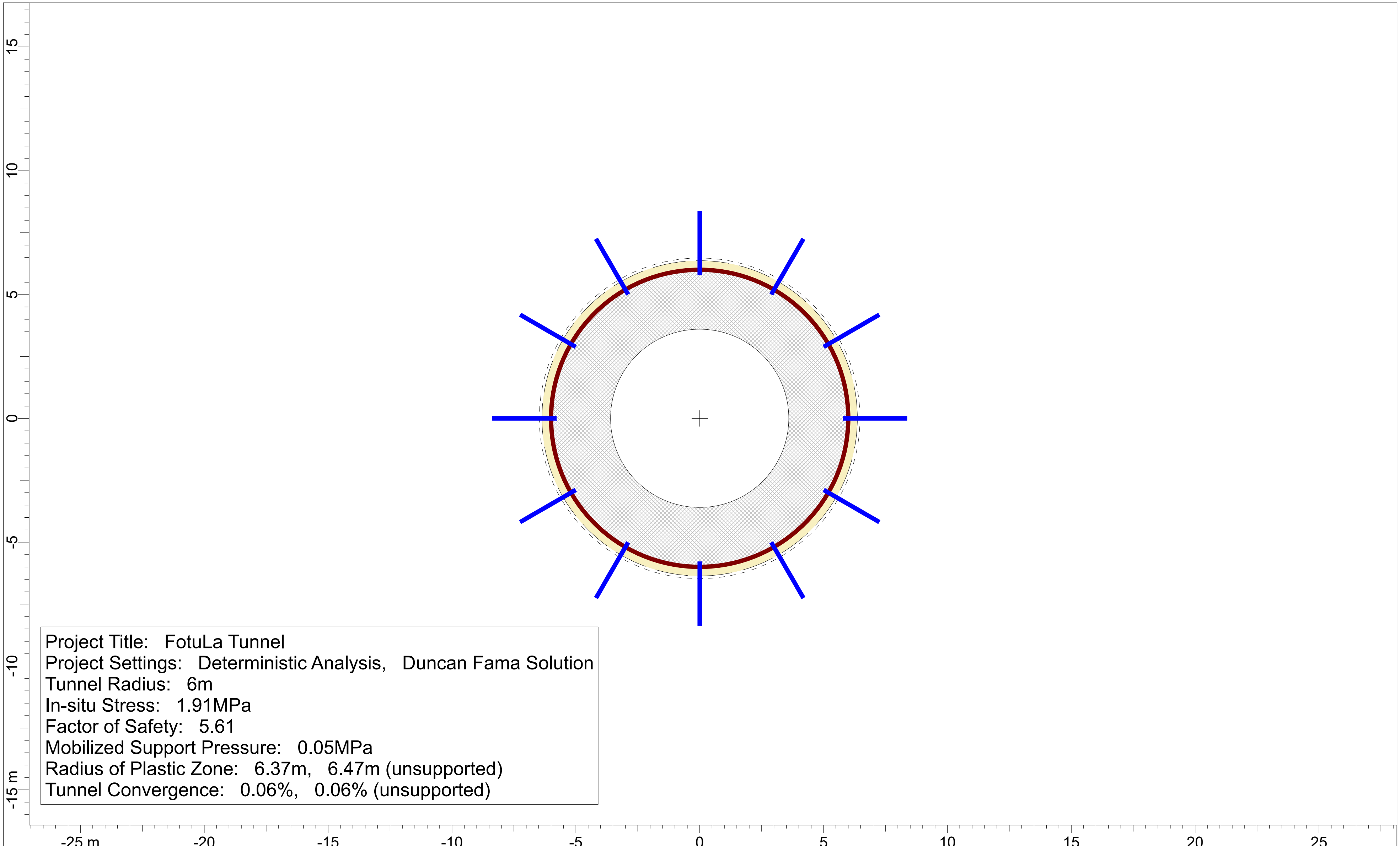
Maximum support pressure : **0.271** MPa
Maximum support strain : **0.131** %
Installed at distance from tunnel face : **2.5** m
Initial Tunnel Convergence : **0.04** %
Initial Wall Displacement : **2.29** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :

Type : **Custom**
Properties : **Diameter = 25 mm, Capacity = 0.2 MN, Young's Modulus = 207000 MPa, Free Length = 4 m**
Maximum support pressure : **0.022** MPa
Maximum support strain : **0.131** %
Rockbolt Circumferential Spacing : **3** m
Rockbolt Longitudinal Spacing : **3** m

Shotcrete :

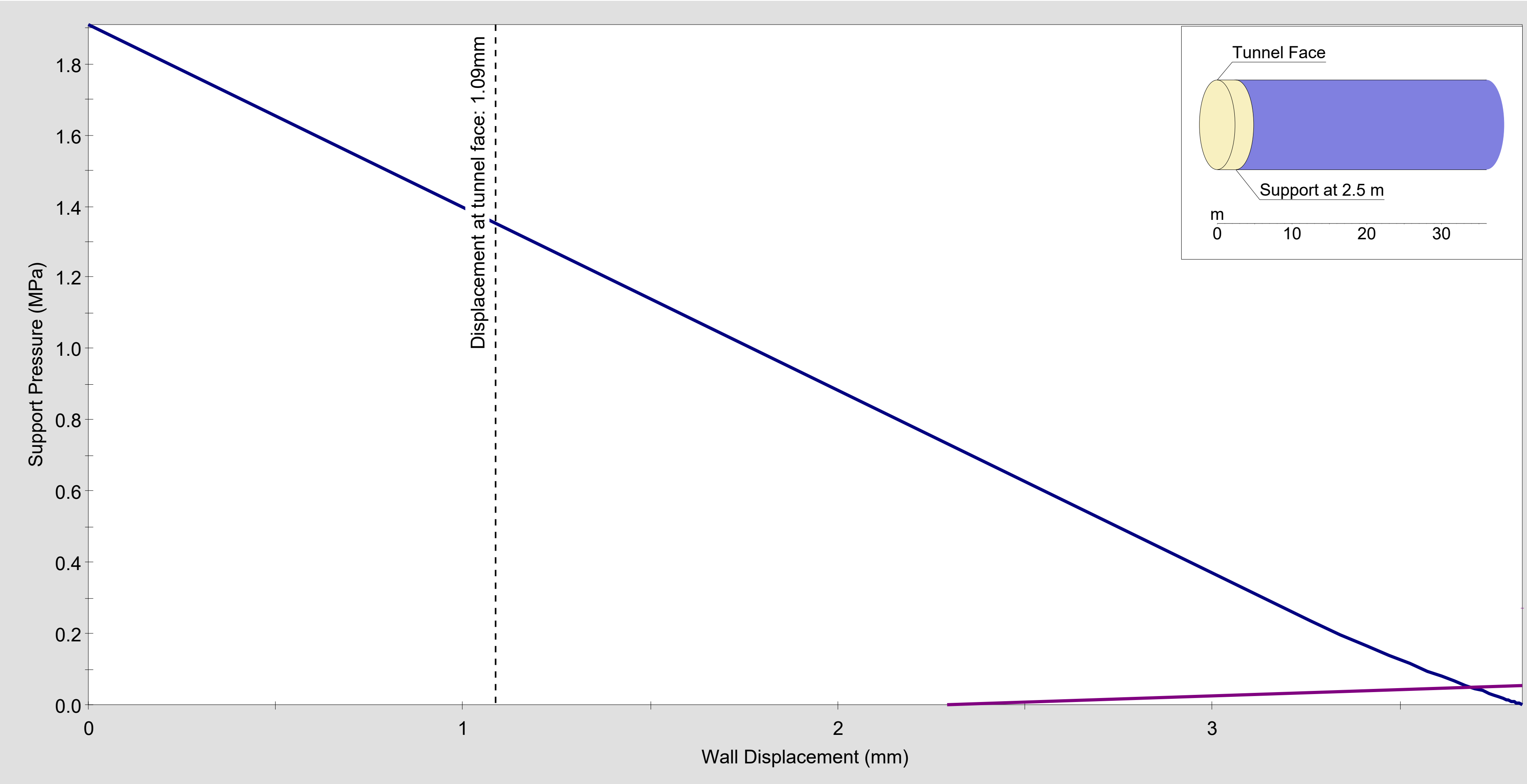
Type : **Custom**
Properties : **Thickness = 50 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **0.249** MPa
Maximum support strain : **0.106** %



Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 1.91MPa
Factor of Safety: 5.61
Mobilized Support Pressure: 0.05MPa
Radius of Plastic Zone: 6.37m, 6.47m (unsupported)
Tunnel Convergence: 0.06%, 0.06% (unsupported)

rocscience	*Project*	FotuLa Tunnel	
	Analysis Description	ESC I - GT1L	
	Drawn By		*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54		*File Name* GT1l High overburden ESC 1.rsp

Ground Reaction and Support Reaction



Final wall displacement: 3.69mm, FS: 5.61
Displacement at tunnel face: 1.09mm, Displacement at support: 2.29mm

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESC I - GT1L		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT1l High overburden ESC 1.rsp	

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **4.5**
Mobilized Support Pressure : **0.12** MPa

With support installed :
Radius of Plastic Zone r_p : **6.71** m
Wall Displacement u_p : **4.77** mm
Tunnel Convergence : **0.08** %

With no support installed :
Radius of Plastic Zone r_p : **6.98** m
Wall Displacement u_p : **5.21** mm
Tunnel Convergence : **0.09** %

Deformation at the tunnel face :
Wall displacement : **1.46** mm
Tunnel Convergence : **0.02** %

Critical Pressure p_{cr} : **0.5** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **2.43** MPa

Young's Modulus of Rock Mass E : **4000** MPa
Poisson Ratio ν : **0.3**

Cohesion of Rock Mass C_{rm} : **0.854115** MPa
Compressive Strength of Rock Mass σ_{rm} : **2.9** MPa

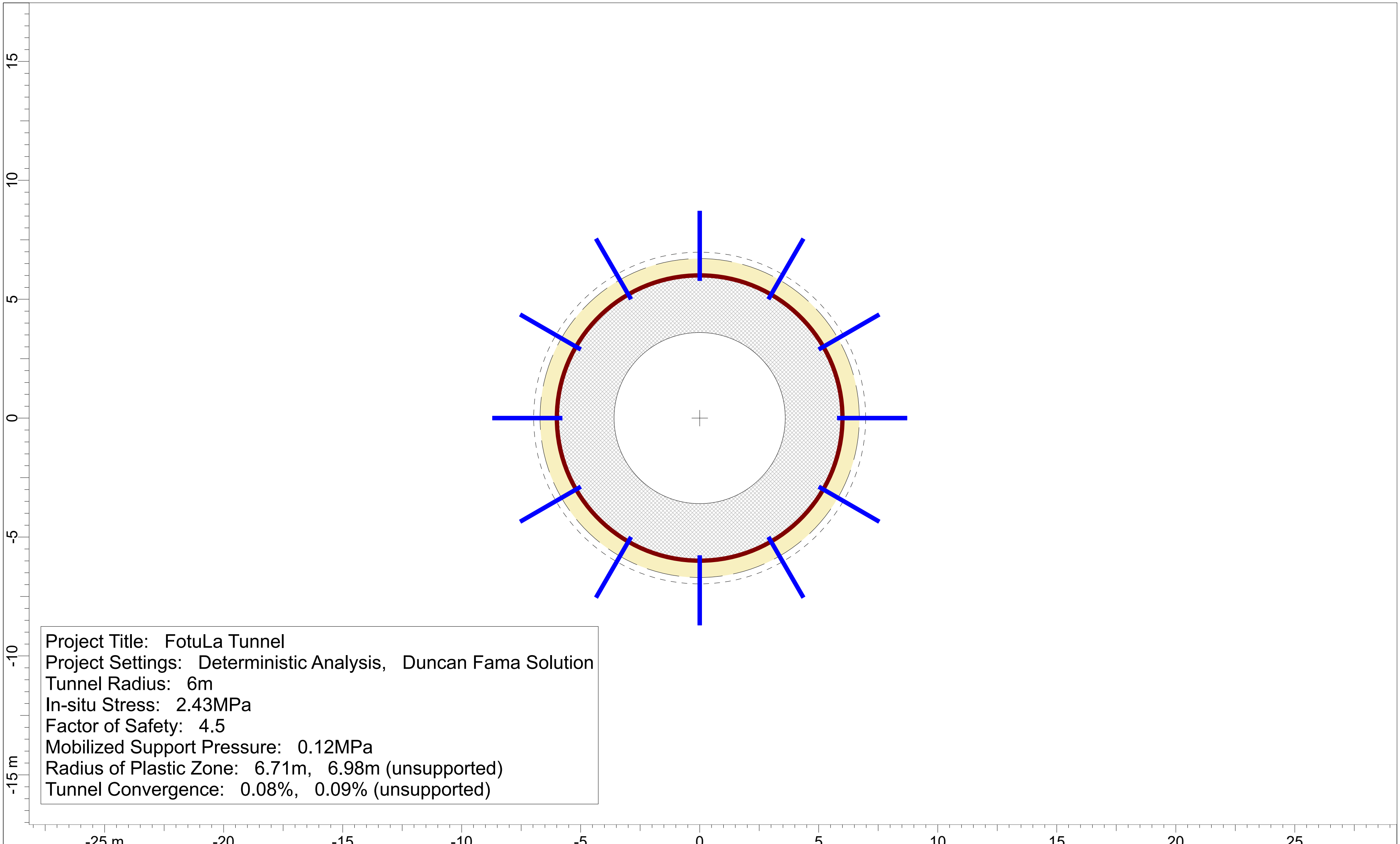
Friction Angle ϕ : **29°**

Support Parameters:

Total combined :
Maximum support pressure : **0.528** MPa
Maximum support strain : **0.131** %
Installed at distance from tunnel face : **2.5** m
Initial Tunnel Convergence : **0.05** %
Initial Wall Displacement : **3.02** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 25 mm, Capacity = 0.2 MN, Young's Modulus = 207000 MPa, Free Length = 4 m**
Maximum support pressure : **0.032** MPa
Maximum support strain : **0.131** %
Rockbolt Circumferential Spacing : **2.5** m
Rockbolt Longitudinal Spacing : **2.5** m

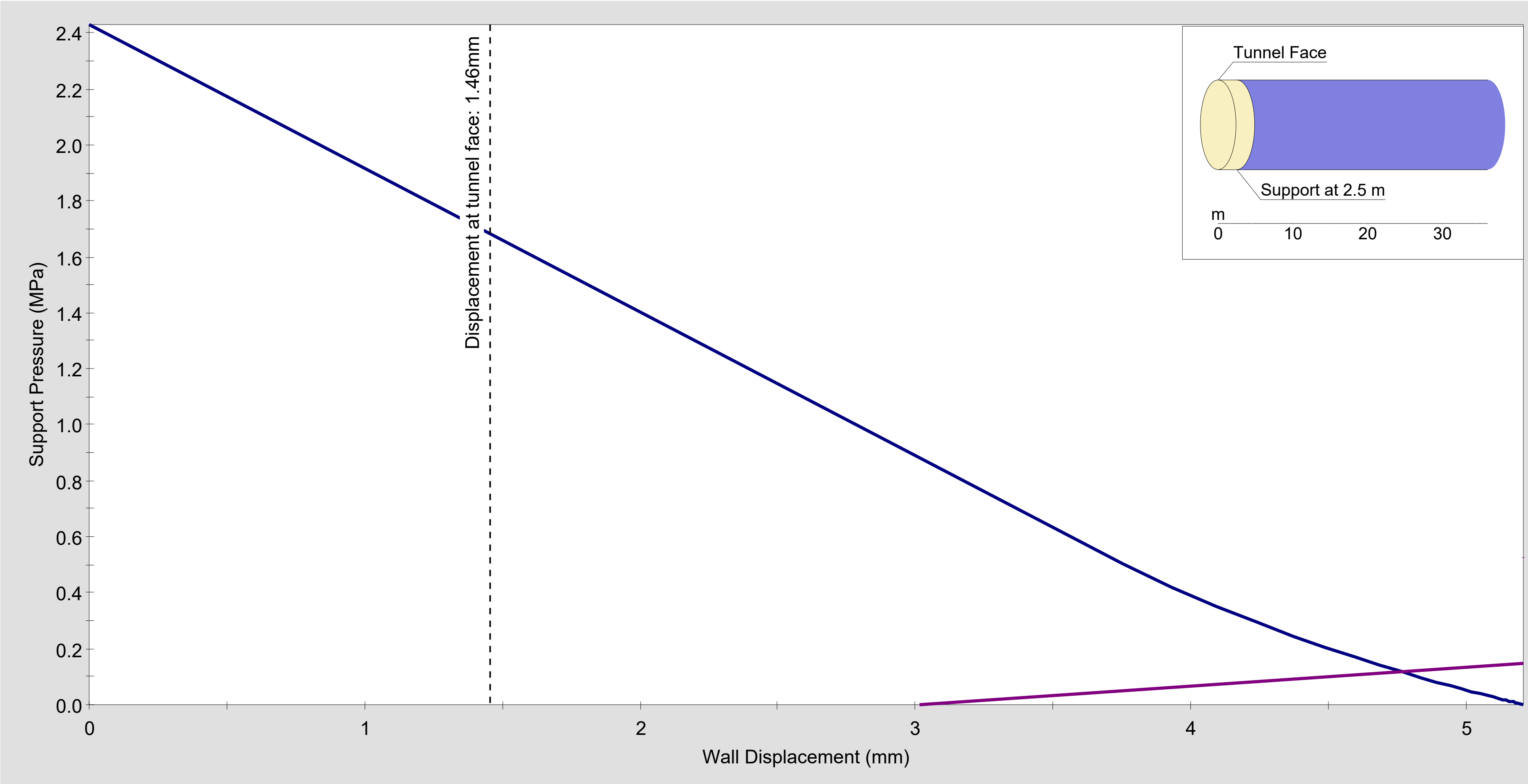
Shotcrete :
Type : **Custom**
Properties : **Thickness = 100 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **0.496** MPa
Maximum support strain : **0.105** %



Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 2.43MPa
Factor of Safety: 4.5
Mobilized Support Pressure: 0.12MPa
Radius of Plastic Zone: 6.71m, 6.98m (unsupported)
Tunnel Convergence: 0.08%, 0.09% (unsupported)

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESC II - GT1L		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT1L High overburden ESC 2.rsp	

Ground Reaction and Support Reaction



Final wall displacement: 4.77mm, FS: 4.5
Displacement at tunnel face: 1.46mm, Displacement at support: 3.02mm

rocscience	*Project*	FotuLa Tunnel	
	Analysis Description	ESC II - GT1L	
	Drawn By		*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54		*File Name* GT1L High overburden ESC 2.rsp

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **5.12**
Mobilized Support Pressure : **0.1** MPa

With support installed :
Radius of Plastic Zone r_p : **7.2** m
Wall Displacement u_p : **3.8** mm
Tunnel Convergence : **0.06** %

With no support installed :
Radius of Plastic Zone r_p : **7.35** m
Wall Displacement u_p : **3.99** mm
Tunnel Convergence : **0.07** %

Deformation at the tunnel face :
Wall displacement : **1.11** mm
Tunnel Convergence : **0.02** %

Critical Pressure p_{cr} : **1.32** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **5.6** MPa

Young's Modulus of Rock Mass E : **13200** MPa
Poisson Ratio ν : **0.3**

rocscience ROCSUPPORT 5.003	*Project* FotuLa Tunnel		
	Analysis Description ESC II - GT1H		
	Drawn By	*Company*	
	Date 12-02-2025, 13:13:54	*File Name* GT1H High overburden ESC 2.rsp	

Cohesion of Rock Mass C_{rm} : **1.22286** MPa
Compressive Strength of Rock Mass σ_{rm} : **4.8** MPa

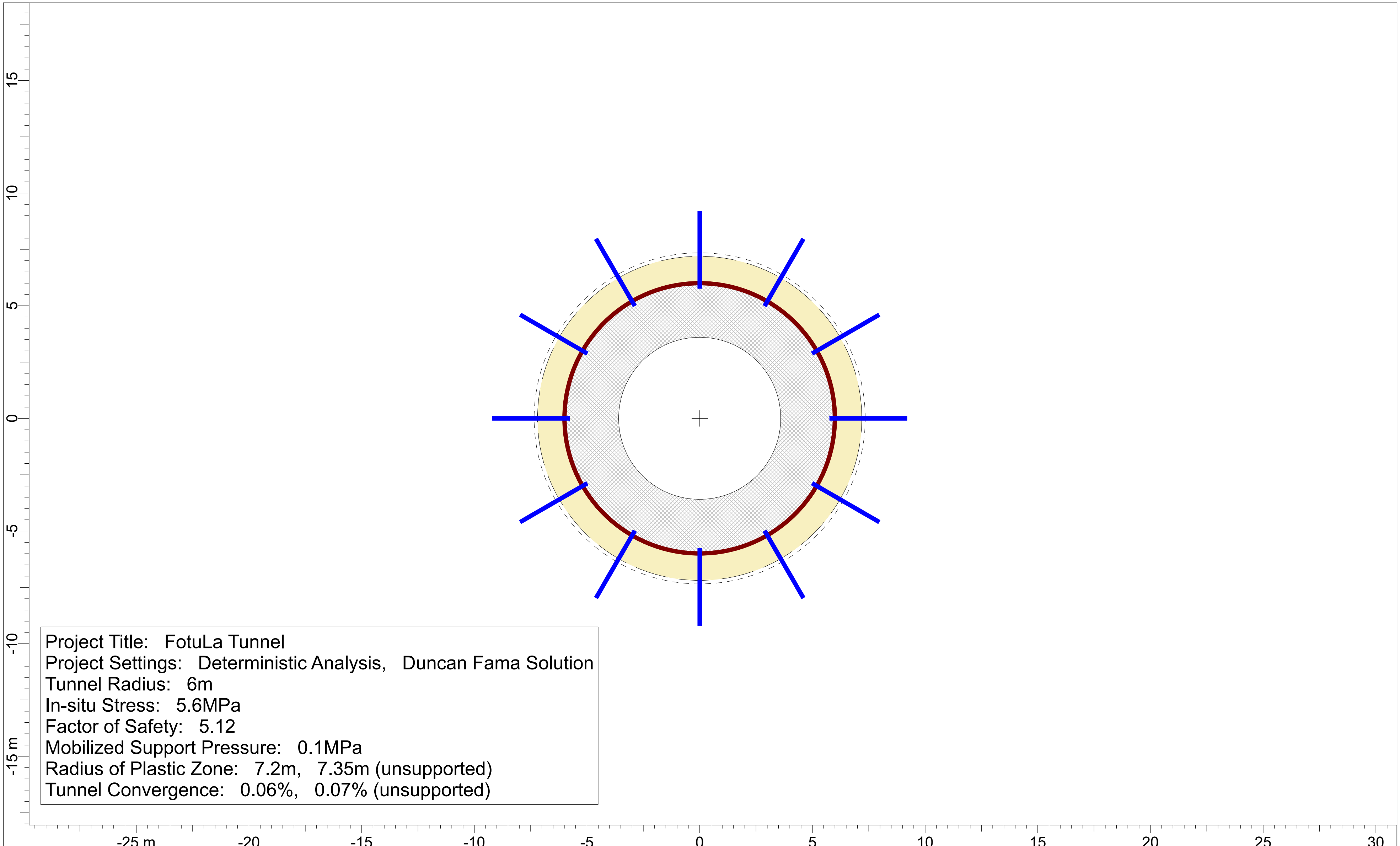
Friction Angle ϕ : **36°**

Support Parameters:

Total combined :
Maximum support pressure : **0.528** MPa
Maximum support strain : **0.131** %
Installed at distance from tunnel face : **2.5** m
Initial Tunnel Convergence : **0.04** %
Initial Wall Displacement : **2.26** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 25 mm, Capacity = 0.2 MN, Young's Modulus = 207000 MPa, Free Length = 4 m**
Maximum support pressure : **0.032** MPa
Maximum support strain : **0.131** %
Rockbolt Circumferential Spacing : **2.5** m
Rockbolt Longitudinal Spacing : **2.5** m

Shotcrete :
Type : **Custom**
Properties : **Thickness = 100 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **0.496** MPa
Maximum support strain : **0.105** %



rocscience

ROCSUPPORT 5.003

Project
FotuLa Tunnel

Analysis Description
ESC II - GT1H

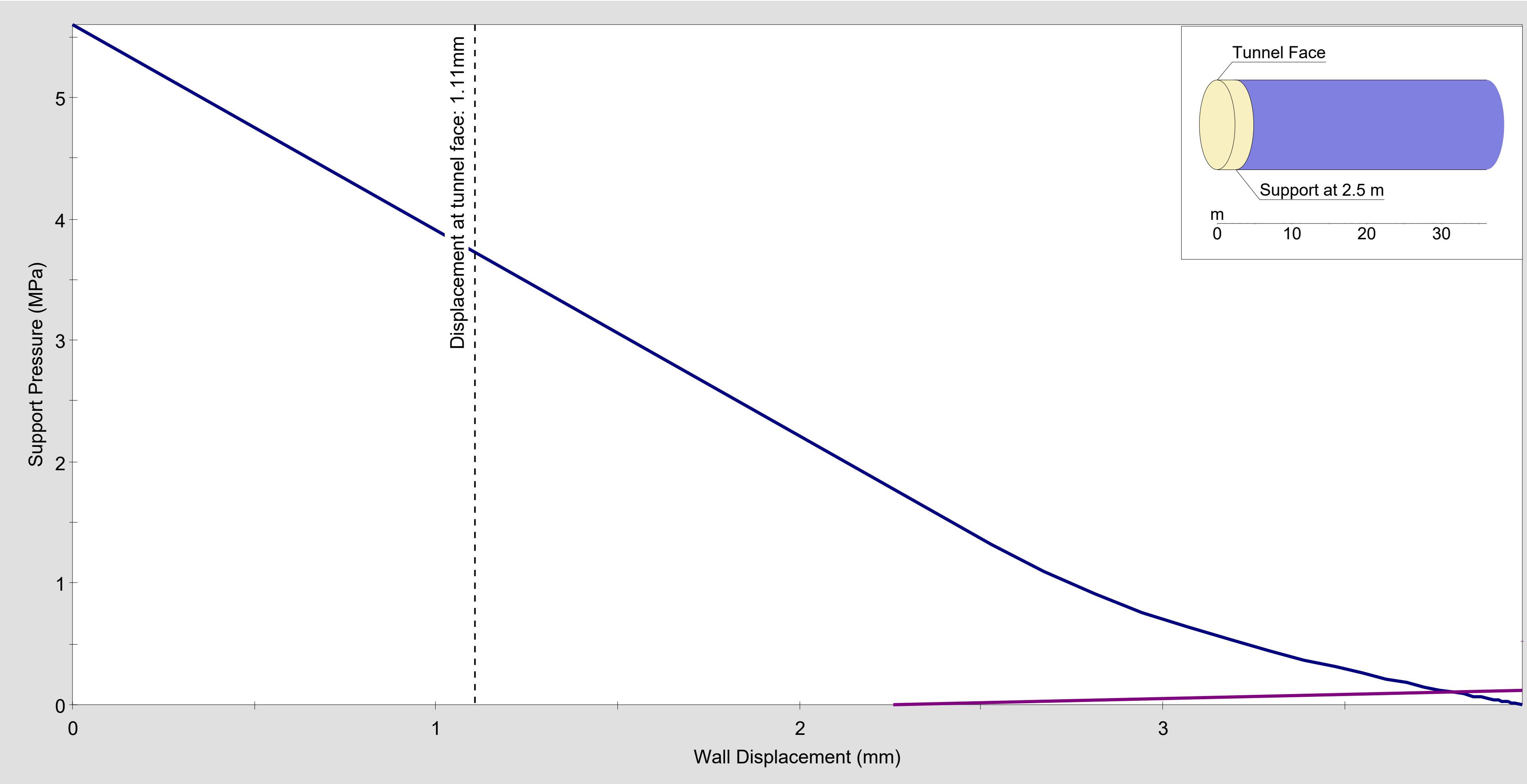
Drawn By

Company

Date
12-02-2025, 13:13:54

File Name
GT1H High overburden ESC 2.rsp

Ground Reaction
and Support Reaction



Final wall displacement: 3.8mm, FS: 5.12
Displacement at tunnel face: 1.11mm, Displacement at support: 2.26mm

rocscience	*Project*	FotuLa Tunnel	
	Analysis Description	ESC II - GT1H	
	Drawn By		*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name*	GT1H High overburden ESC 2.rsp

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **2.02**
Mobilized Support Pressure : **0.4** MPa

With support installed :
Radius of Plastic Zone r_p : **7.97** m
Wall Displacement u_p : **10.97** mm
Tunnel Convergence : **0.18** %

With no support installed :
Radius of Plastic Zone r_p : **9** m
Wall Displacement u_p : **14.92** mm
Tunnel Convergence : **0.25** %

Deformation at the tunnel face :
Wall displacement : **3.97** mm
Tunnel Convergence : **0.07** %

Critical Pressure p_{cr} : **1.77** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **4.88** MPa

Young's Modulus of Rock Mass E : **4000** MPa
Poisson Ratio ν : **0.2**

rocscience	Project: FotuLa Tunnel	
	Analysis Description: ESc III - GT1L	
	Drawn By:	Company:
ROCSUPPORT 5.003	Date: 12-02-2025, 13:13:54	File Name: GT1L High overburden ESC 3.rsp

Cohesion of Rock Mass C_{rm} : **0.854115** MPa
Compressive Strength of Rock Mass σ_{rm} : **2.9** MPa

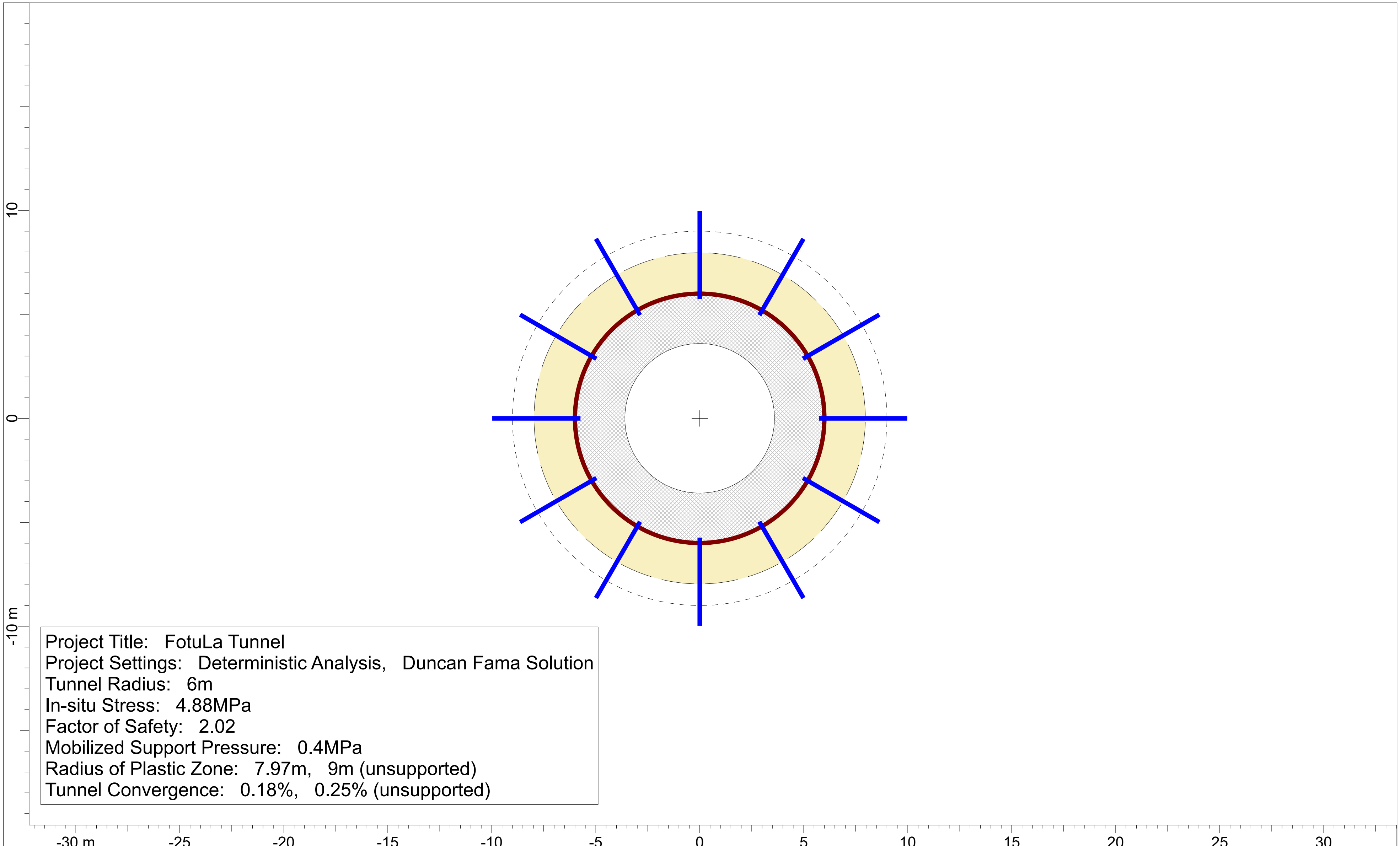
Friction Angle ϕ : **29°**

Support Parameters:

Total combined :
Maximum support pressure : **0.807** MPa
Maximum support strain : **0.131** %
Installed at distance from tunnel face : **2** m
Initial Tunnel Convergence : **0.12** %
Initial Wall Displacement : **7.07** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 25 mm, Capacity = 0.2 MN, Young's Modulus = 207000 MPa, Free Length = 4 m**
Maximum support pressure : **0.067** MPa
Maximum support strain : **0.131** %
Rockbolt Circumferential Spacing : **1.5** m
Rockbolt Longitudinal Spacing : **2** m

Shotcrete :
Type : **Custom**
Properties : **Thickness = 150 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **0.741** MPa
Maximum support strain : **0.104** %



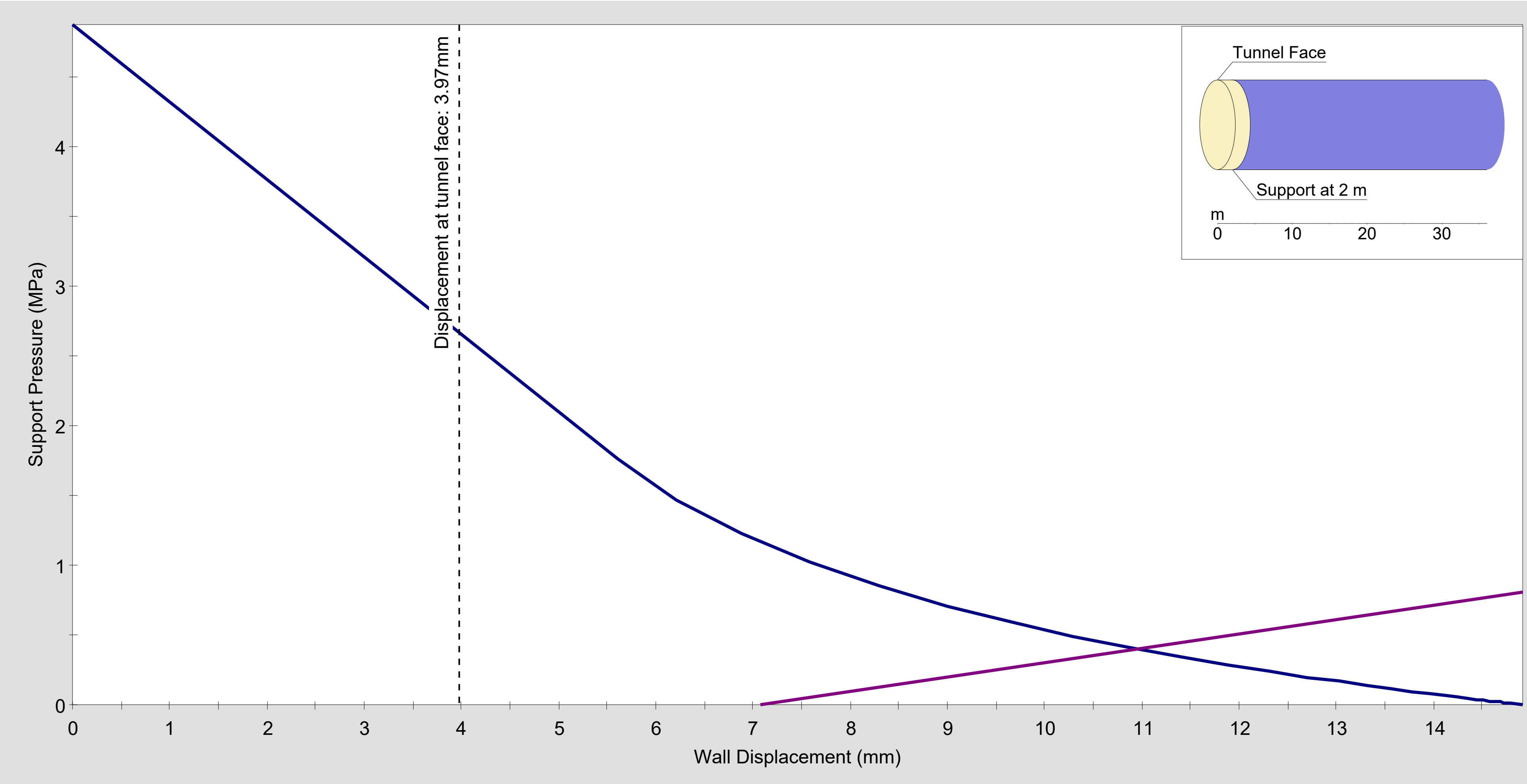
Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 4.88MPa
Factor of Safety: 2.02
Mobilized Support Pressure: 0.4MPa
Radius of Plastic Zone: 7.97m, 9m (unsupported)
Tunnel Convergence: 0.18%, 0.25% (unsupported)

rocscience

ROCSUPPORT 5.003

Project	FotuLa Tunnel
Analysis Description	ESc III - GT1L
Drawn By	*Company*
Date 12-02-2025, 13:13:54	*File Name* GT1L High overburden ESC 3.rsp

Ground Reaction and Support Reaction



Final wall displacement: 10.97mm, FS: 2.02
Displacement at tunnel face: 3.97mm, Displacement at support: 7.07mm

rocscience	*Project* FotuLa Tunnel	
	Analysis Description ESc III - GT1L	
	Drawn By	*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT1L High overburden ESC 3.rsp

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **3.96**
Mobilized Support Pressure : **0.2** MPa

With support installed :
Radius of Plastic Zone r_p : **7.45** m
Wall Displacement u_p : **4.55** mm
Tunnel Convergence : **0.08** %

With no support installed :
Radius of Plastic Zone r_p : **7.75** m
Wall Displacement u_p : **5.04** mm
Tunnel Convergence : **0.08** %

Deformation at the tunnel face :
Wall displacement : **1.38** mm
Tunnel Convergence : **0.02** %

Critical Pressure p_{cr} : **1.81** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **6.8** MPa

Young's Modulus of Rock Mass E : **13200** MPa
Poisson Ratio ν : **0.2**

rocscience	Project	FotuLa Tunnel		
	Analysis Description	ESC III - GT-1H		
	Drawn By		Company	
ROCSUPPORT 5.003	Date	12-02-2025, 13:13:54	File Name	GT1H High overburden ESC 3.rsp

Cohesion of Rock Mass C_{rm} : **1.22286** MPa
Compressive Strength of Rock Mass σ_{rm} : **4.8** MPa

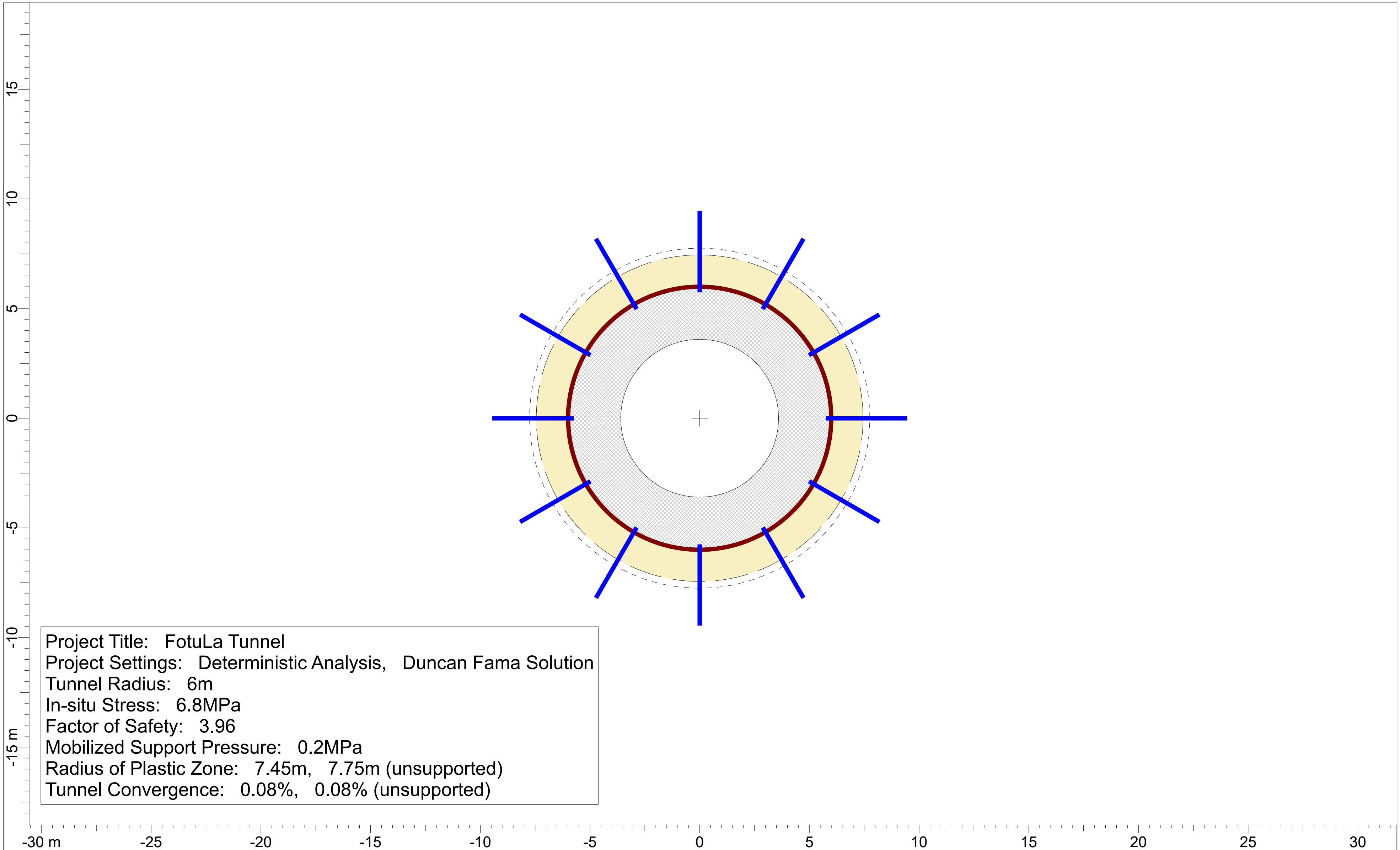
Friction Angle ϕ : **36°**

Support Parameters:

Total combined :
Maximum support pressure : **0.807** MPa
Maximum support strain : **0.131** %
Installed at distance from tunnel face : **2** m
Initial Tunnel Convergence : **0.04** %
Initial Wall Displacement : **2.56** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 25 mm, Capacity = 0.2 MN, Young's Modulus = 207000 MPa, Free Length = 4 m**
Maximum support pressure : **0.067** MPa
Maximum support strain : **0.131** %
Rockbolt Circumferential Spacing : **1.5** m
Rockbolt Longitudinal Spacing : **2** m

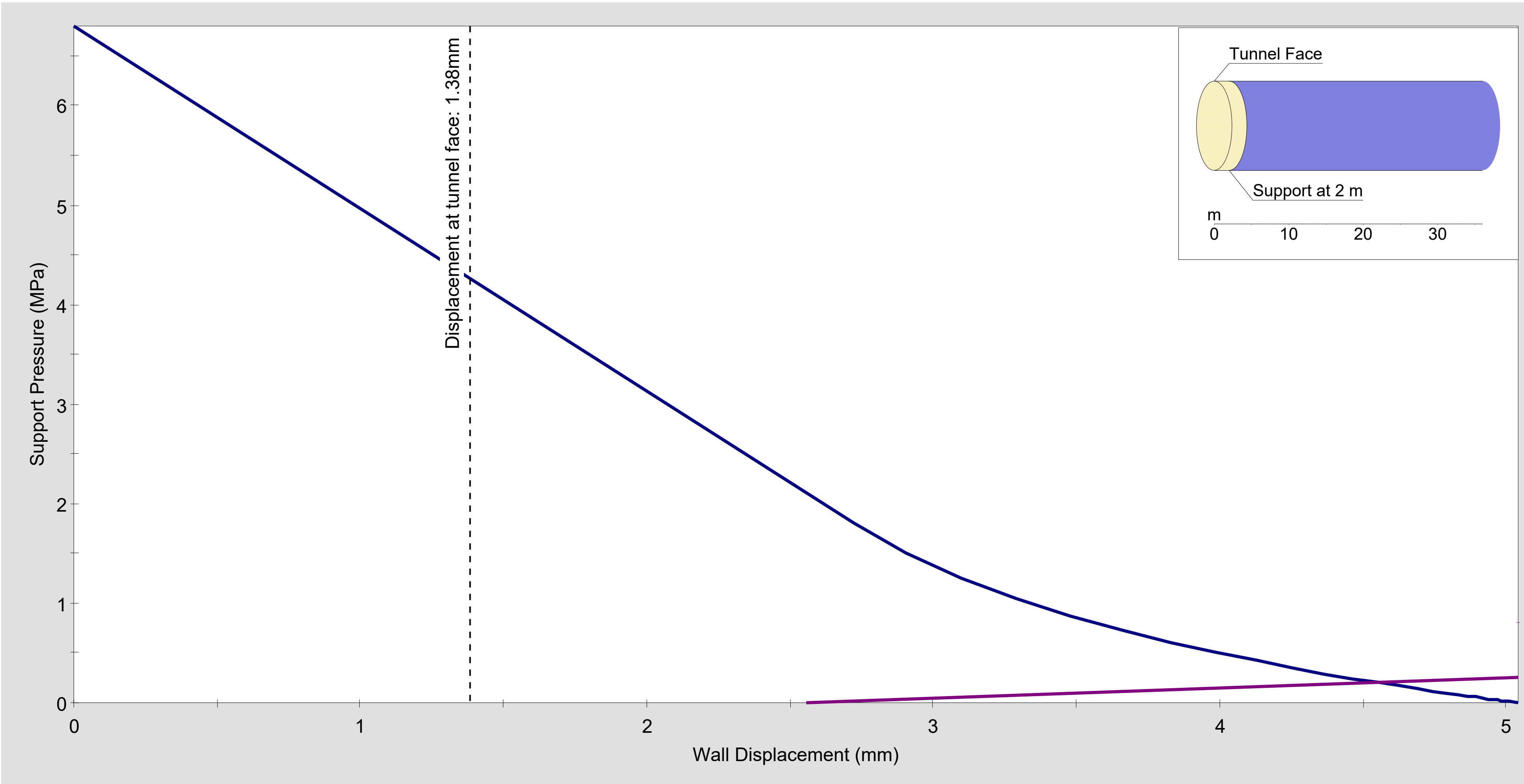
Shotcrete :
Type : **Custom**
Properties : **Thickness = 150 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **0.741** MPa
Maximum support strain : **0.104** %



Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 6.8MPa
Factor of Safety: 3.96
Mobilized Support Pressure: 0.2MPa
Radius of Plastic Zone: 7.45m, 7.75m (unsupported)
Tunnel Convergence: 0.08%, 0.08% (unsupported)

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESC III - GT-1H		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT1H High overburden ESC 3.rsp	

Ground Reaction and Support Reaction



Final wall displacement: 4.55mm, FS: 3.96
Displacement at tunnel face: 1.38mm, Displacement at support: 2.56mm

rocscience	*Project*	FotuLa Tunnel	
	Analysis Description	ESC III - GT-1H	
	Drawn By		*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54		*File Name* GT1H High overburden ESC 3.rsp

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **1.97**
Mobilized Support Pressure : **0.6** MPa

With support installed :
Radius of Plastic Zone r_p : **12.21** m
Wall Displacement u_p : **105.37** mm
Tunnel Convergence : **1.76** %

With no support installed :
Radius of Plastic Zone r_p : **21.63** m
Wall Displacement u_p : **361.53** mm
Tunnel Convergence : **6.03** %

Deformation at the tunnel face :
Wall displacement : **70.18** mm
Tunnel Convergence : **1.17** %

Critical Pressure p_{cr} : **2.66** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **5.07** MPa

Young's Modulus of Rock Mass E : **900** MPa
Poisson Ratio ν : **0.3**

rocscience	Project: FotuLa Tunnel		
	Analysis Description: ESc IV - GT3H		
	Drawn By:	Company:	
ROCSUPPORT 5.003	Date: 12-02-2025, 13:13:54	File Name: GT3H High overburden ESC 4.rsp	

Cohesion of Rock Mass C_{rm} : **0.203083** MPa
Compressive Strength of Rock Mass σ_{rm} : **0.65** MPa

Friction Angle ϕ : **26°**

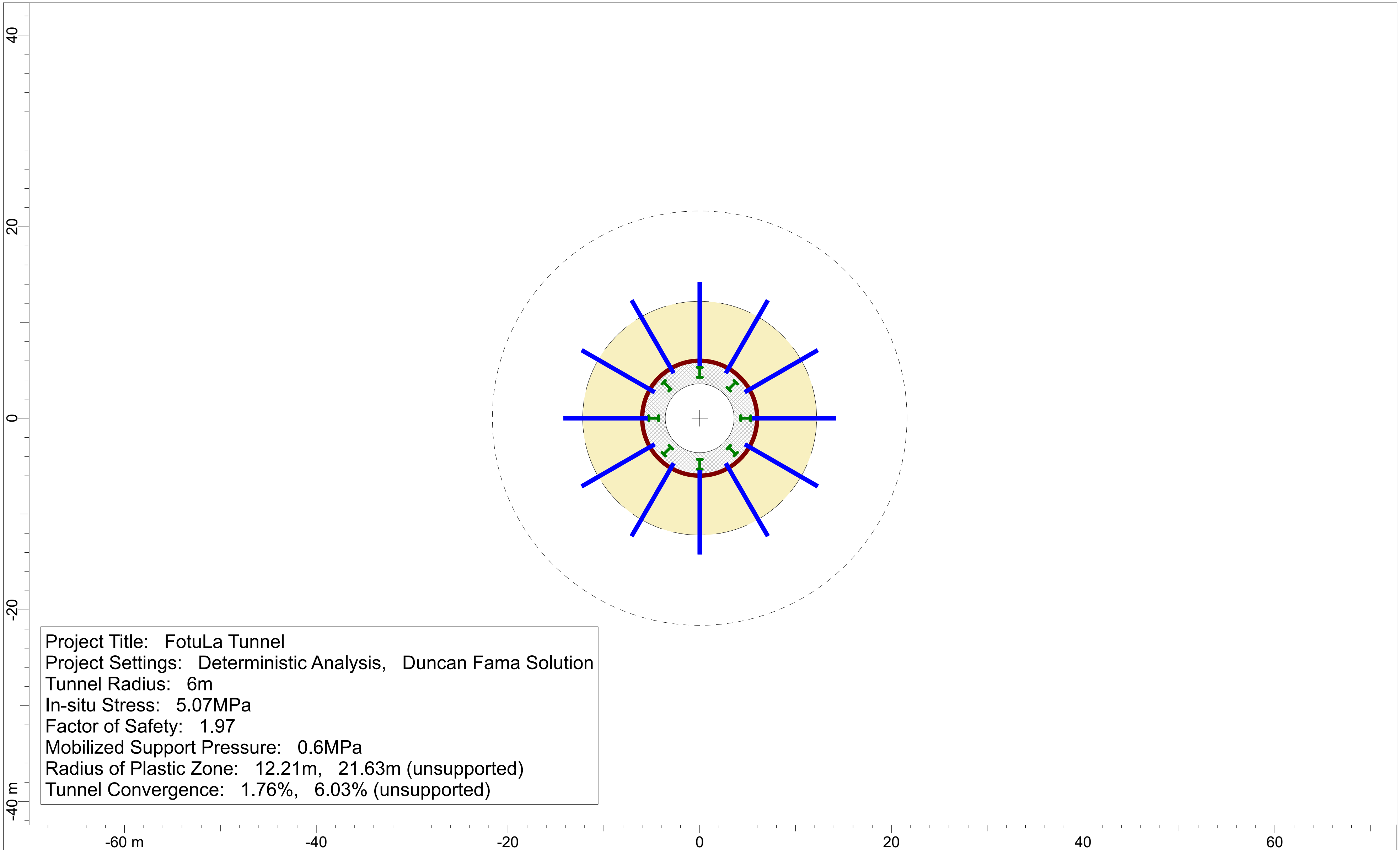
Support Parameters:

Total combined :
Maximum support pressure : **1.181** MPa
Maximum support strain : **0.21** %
Installed at distance from tunnel face : **1.5** m
Initial Tunnel Convergence : **1.65** %
Initial Wall Displacement : **98.97** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 6 m**
Maximum support pressure : **0.156** MPa
Maximum support strain : **0.21** %
Rockbolt Circumferential Spacing : **1.5** m
Rockbolt Longitudinal Spacing : **1.5** m

Steelset :
Type : **Custom**
Properties : **Area = 1040 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.042** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **1** m

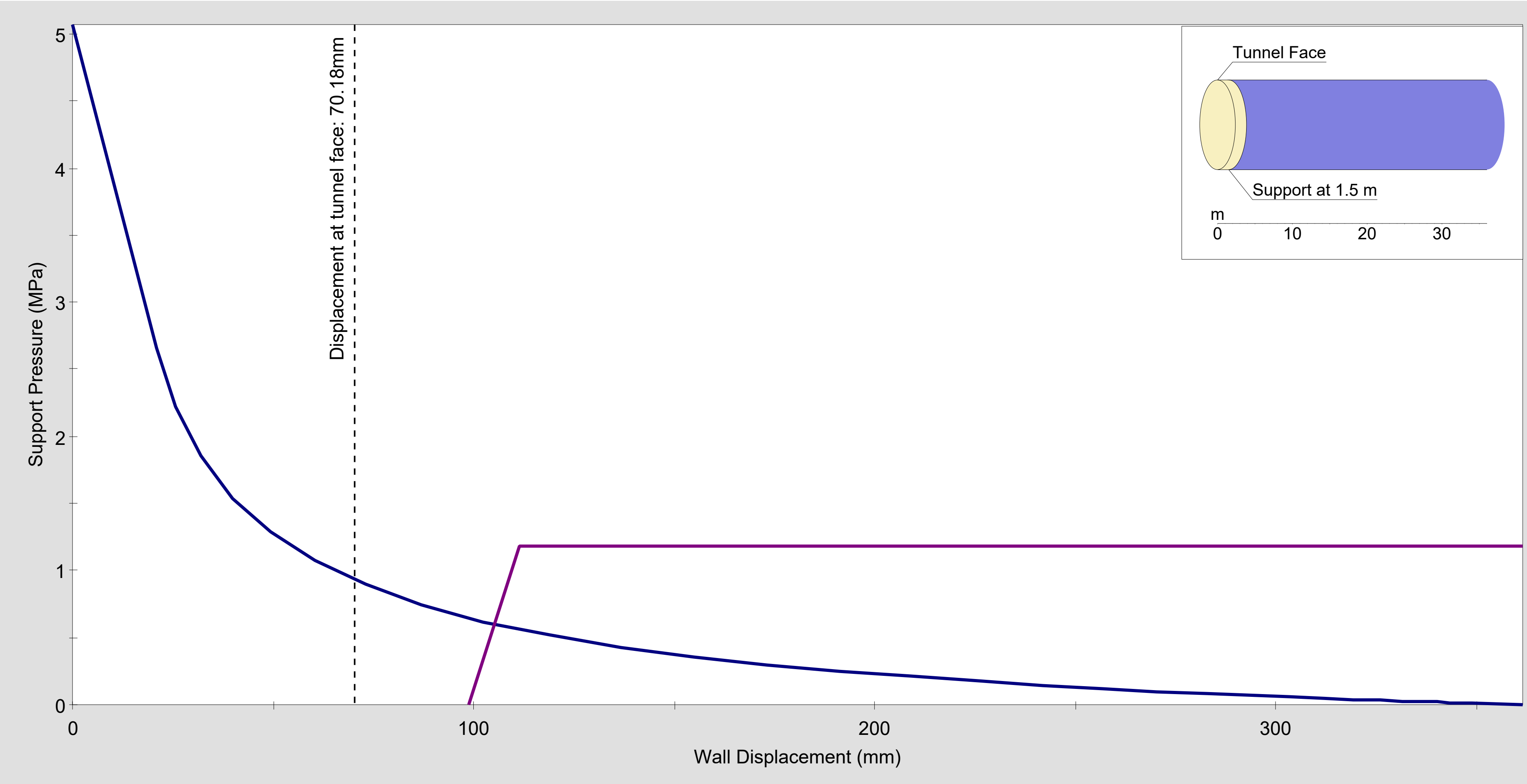
Shotcrete :
Type : **Custom**
Properties : **Thickness = 200 mm, UCS = 30 MPa, Young's Modulus = 27300 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **0.983** MPa
Maximum support strain : **0.102** %



Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 5.07MPa
Factor of Safety: 1.97
Mobilized Support Pressure: 0.6MPa
Radius of Plastic Zone: 12.21m, 21.63m (unsupported)
Tunnel Convergence: 1.76%, 6.03% (unsupported)

rocscience ROCSUPPORT 5.003	*Project* FotuLa Tunnel		
	Analysis Description ESc IV - GT3H		
	Drawn By	*Company*	
	Date 12-02-2025, 13:13:54	*File Name* GT3H High overburden ESC 4.rsp	

Ground Reaction and Support Reaction



Final wall displacement: 105.37mm, FS: 1.97
Displacement at tunnel face: 70.18mm, Displacement at support: 98.97mm

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESc IV - GT3H		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT3H High overburden ESC 4.rsp	

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **1.31**
Mobilized Support Pressure : **1.24** MPa

With support installed :
Radius of Plastic Zone r_p : **9.32** m
Wall Displacement u_p : **61.06** mm
Tunnel Convergence : **1.02** %

With no support installed :
Radius of Plastic Zone r_p : **13.77** m
Wall Displacement u_p : **148.09** mm
Tunnel Convergence : **2.47** %

Deformation at the tunnel face :
Wall displacement : **34.98** mm
Tunnel Convergence : **0.58** %

Critical Pressure p_{cr} : **3.72** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **7.47** MPa

Young's Modulus of Rock Mass E : **1300** MPa
Poisson Ratio ν : **0.3**

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESC V - GT2H		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT2H high overburden ESC 5.rsp	

Cohesion of Rock Mass C_{rm} : **0.779289** MPa

Compressive Strength of Rock Mass σ_{rm} : **2.4** MPa

Friction Angle ϕ : **24°**

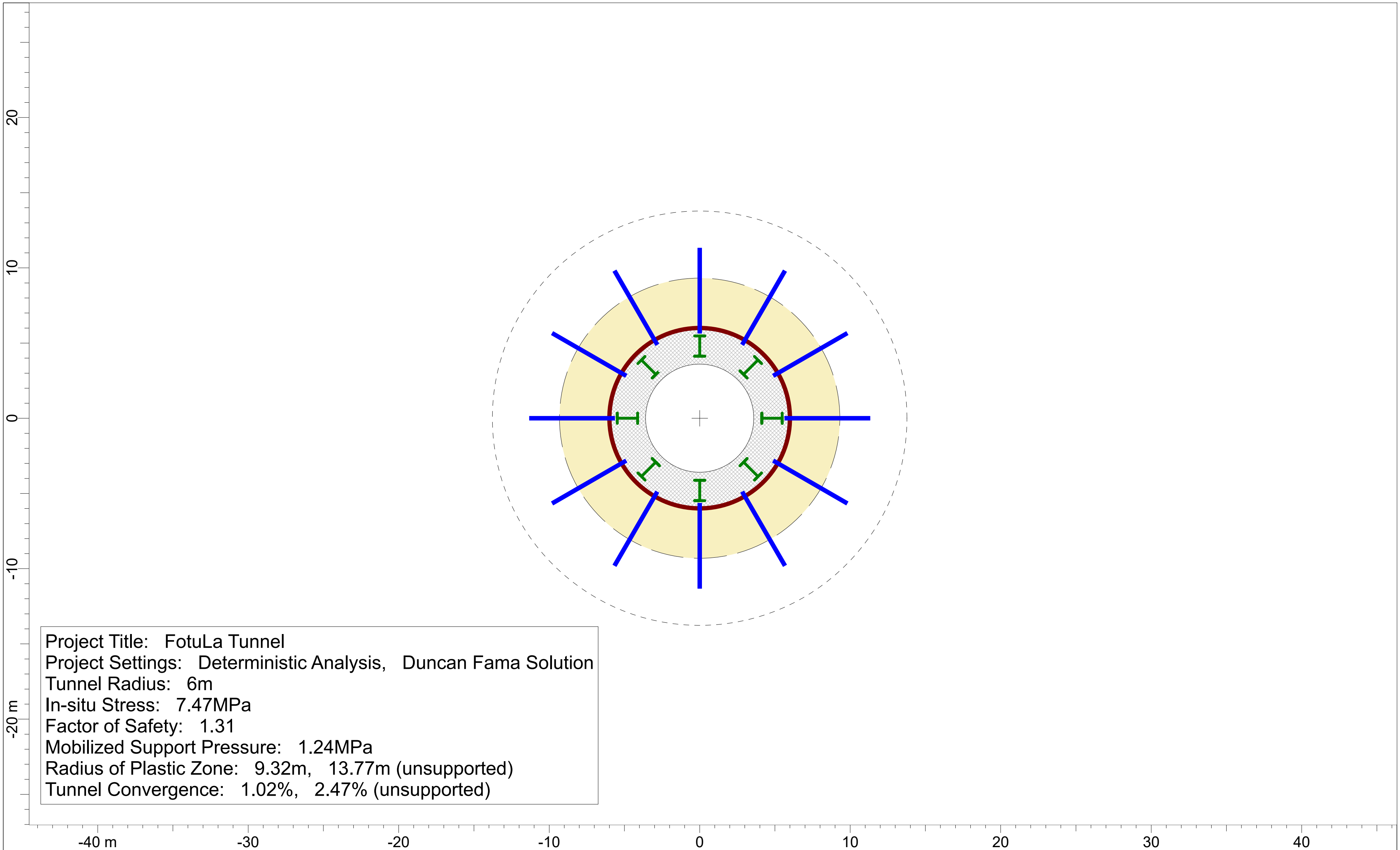
Support Parameters:

Total combined :
Maximum support pressure : **1.629** MPa
Maximum support strain : **0.315** %
Installed at distance from tunnel face : **1** m
Initial Tunnel Convergence : **0.78** %
Initial Wall Displacement : **46.65** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 9 m**
Maximum support pressure : **0.337** MPa
Maximum support strain : **0.315** %
Rockbolt Circumferential Spacing : **1.3** m
Rockbolt Longitudinal Spacing : **0.8** m

Steelset :
Type : **Custom**
Properties : **Area = 1335 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.068** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **0.8** m

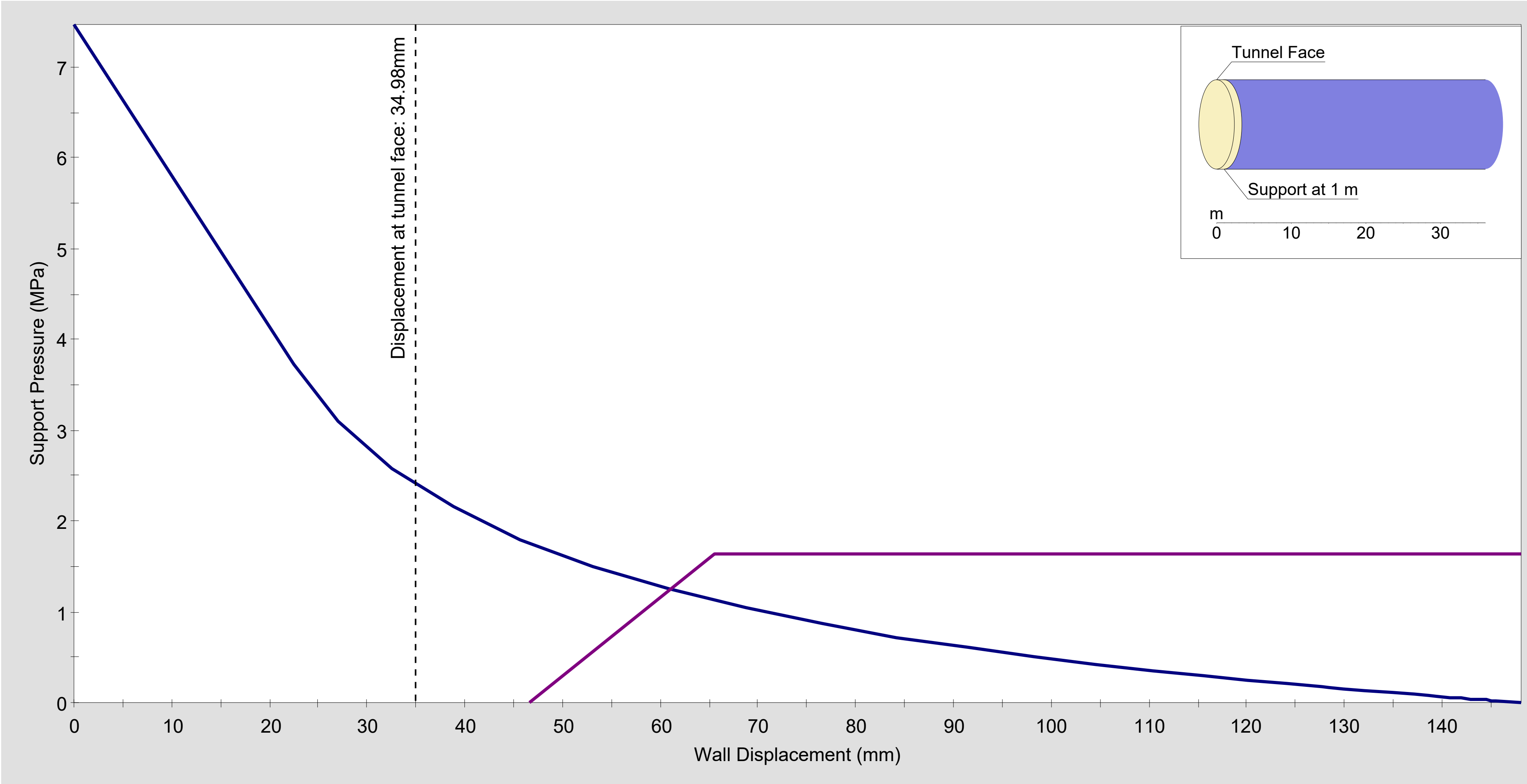
Shotcrete :
Type : **Custom**
Properties : **Thickness = 250 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.224** MPa
Maximum support strain : **0.102** %



Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 7.47MPa
Factor of Safety: 1.31
Mobilized Support Pressure: 1.24MPa
Radius of Plastic Zone: 9.32m, 13.77m (unsupported)
Tunnel Convergence: 1.02%, 2.47% (unsupported)

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESC V - GT2H		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT2H high overburden ESC 5.rsp	

Ground Reaction and Support Reaction



Final wall displacement: 61.06mm, FS: 1.31
Displacement at tunnel face: 34.98mm, Displacement at support: 46.65mm

rocscience ROCSUPPORT 5.003	Project: FotuLa Tunnel		
	Analysis Description: ESC V - GT2H		
	Drawn By:	Company:	
	Date: 12-02-2025, 13:13:54	File Name: GT2H high overburden ESC 5.rsp	

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **1.18**
Mobilized Support Pressure : **1.58** MPa

With support installed :
Radius of Plastic Zone r_p : **9.81** m
Wall Displacement u_p : **82.21** mm
Tunnel Convergence : **1.37** %

With no support installed :
Radius of Plastic Zone r_p : **15.68** m
Wall Displacement u_p : **234.58** mm
Tunnel Convergence : **3.91** %

Deformation at the tunnel face :
Wall displacement : **52.84** mm
Tunnel Convergence : **0.88** %

Critical Pressure p_{cr} : **4.78** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **9.26** MPa

Young's Modulus of Rock Mass E : **1300** MPa
Poisson Ratio ν : **0.3**

Cohesion of Rock Mass C_{rm} : **0.779289** MPa
Compressive Strength of Rock Mass σ_{rm} : **2.4** MPa

Friction Angle ϕ : **24°**

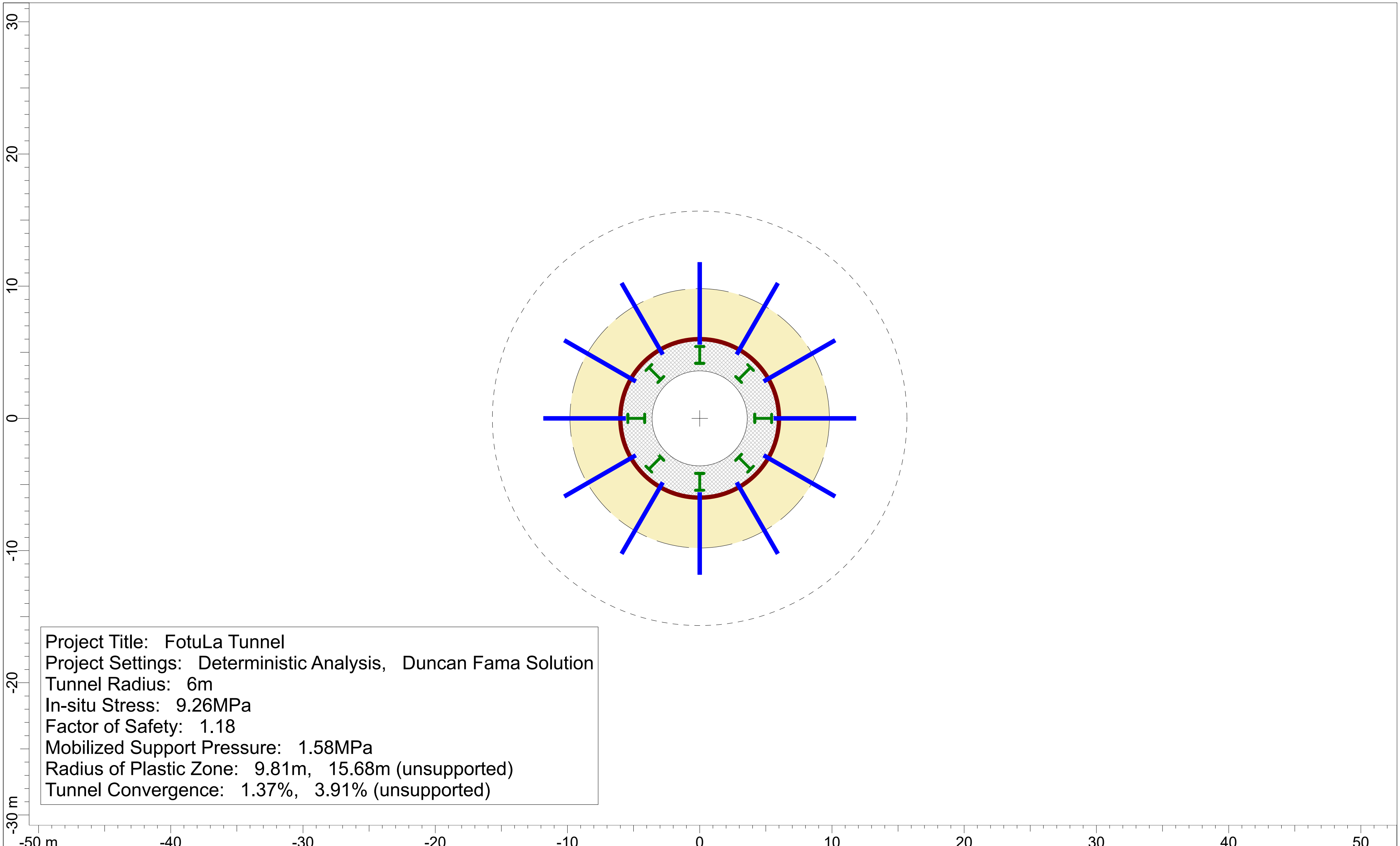
Support Parameters:

Total combined :
Maximum support pressure : **1.867** MPa
Maximum support strain : **0.315** %
Installed at distance from tunnel face : **0.8** m
Initial Tunnel Convergence : **1.1** %
Initial Wall Displacement : **66.23** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 9 m**
Maximum support pressure : **0.337** MPa
Maximum support strain : **0.315** %
Rockbolt Circumferential Spacing : **1.3** m
Rockbolt Longitudinal Spacing : **0.8** m

Steelset :
Type : **Custom**
Properties : **Area = 1335 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.068** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **0.8** m

Shotcrete :
Type : **Custom**
Properties : **Thickness = 300 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.462** MPa
Maximum support strain : **0.101** %



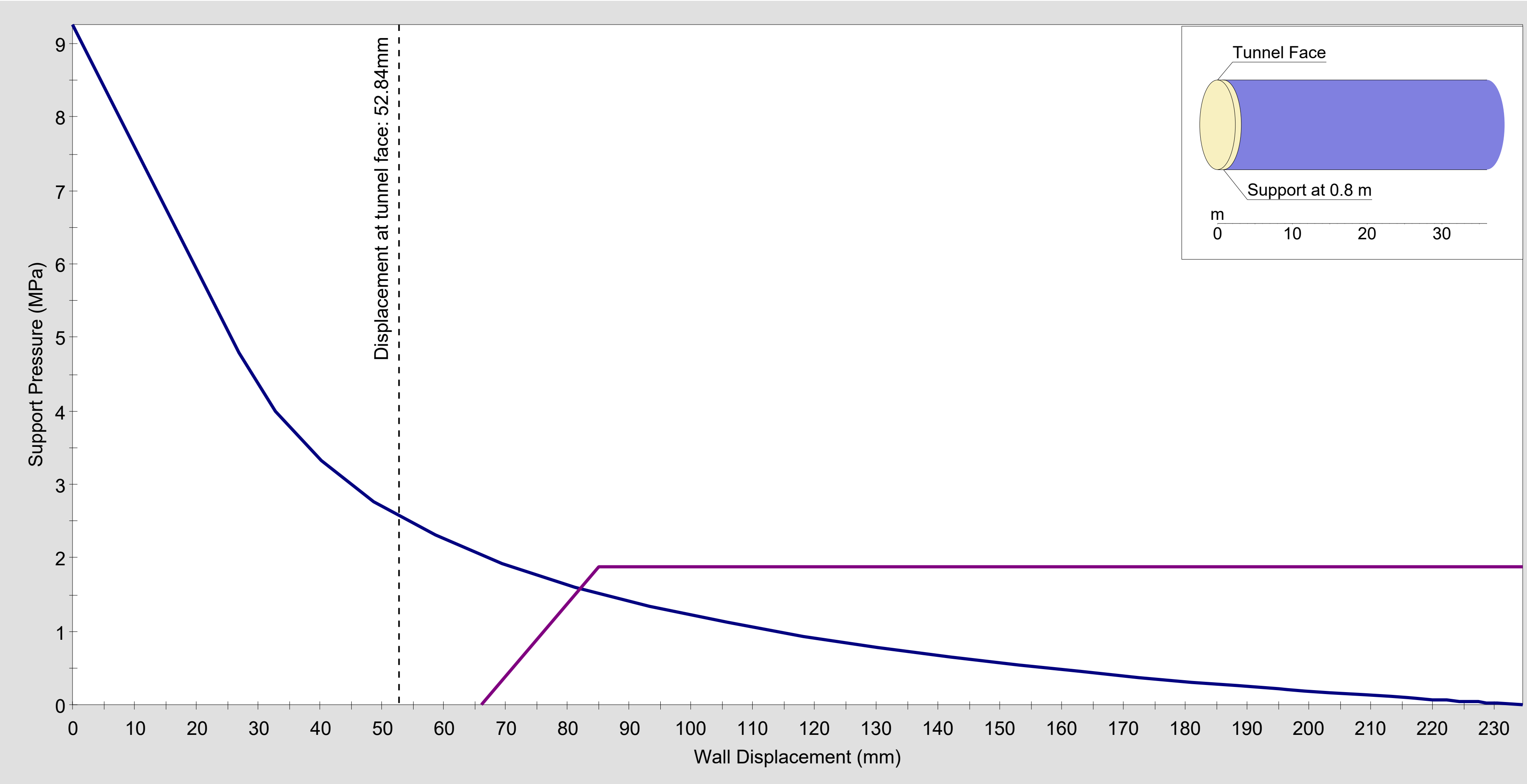
Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 9.26MPa
Factor of Safety: 1.18
Mobilized Support Pressure: 1.58MPa
Radius of Plastic Zone: 9.81m, 15.68m (unsupported)
Tunnel Convergence: 1.37%, 3.91% (unsupported)

rocscience

ROCSUPPORT 5.003

Project	FotuLa Tunnel
Analysis Description	ESc VI - GT2H
Drawn By	
Company	
Date	12-02-2025, 13:13:54
File Name	GT2H high overburden ESC 6.rsp

Ground Reaction
and Support Reaction



Final wall displacement: 82.21mm, FS: 1.18
Displacement at tunnel face: 52.84mm, Displacement at support: 66.23mm

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESc VI - GT2H		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT2H high overburden ESC 6.rsp	

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **1.27**
Mobilized Support Pressure : **1.47** MPa

With support installed :
Radius of Plastic Zone r_p : **13.38** m
Wall Displacement u_p : **139.17** mm
Tunnel Convergence : **2.32** %

With no support installed :
Radius of Plastic Zone r_p : **26.3** m
Wall Displacement u_p : **592.83** mm
Tunnel Convergence : **9.88** %

Deformation at the tunnel face :
Wall displacement : **102.38** mm
Tunnel Convergence : **1.71** %

Critical Pressure p_{cr} : **5.26** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **8.75** MPa

Young's Modulus of Rock Mass E : **1200** MPa
Poisson Ratio ν : **0.28**

Cohesion of Rock Mass C_{rm} : **0.525156** MPa
Compressive Strength of Rock Mass σ_{rm} : **1.5** MPa

Friction Angle ϕ : **20°**

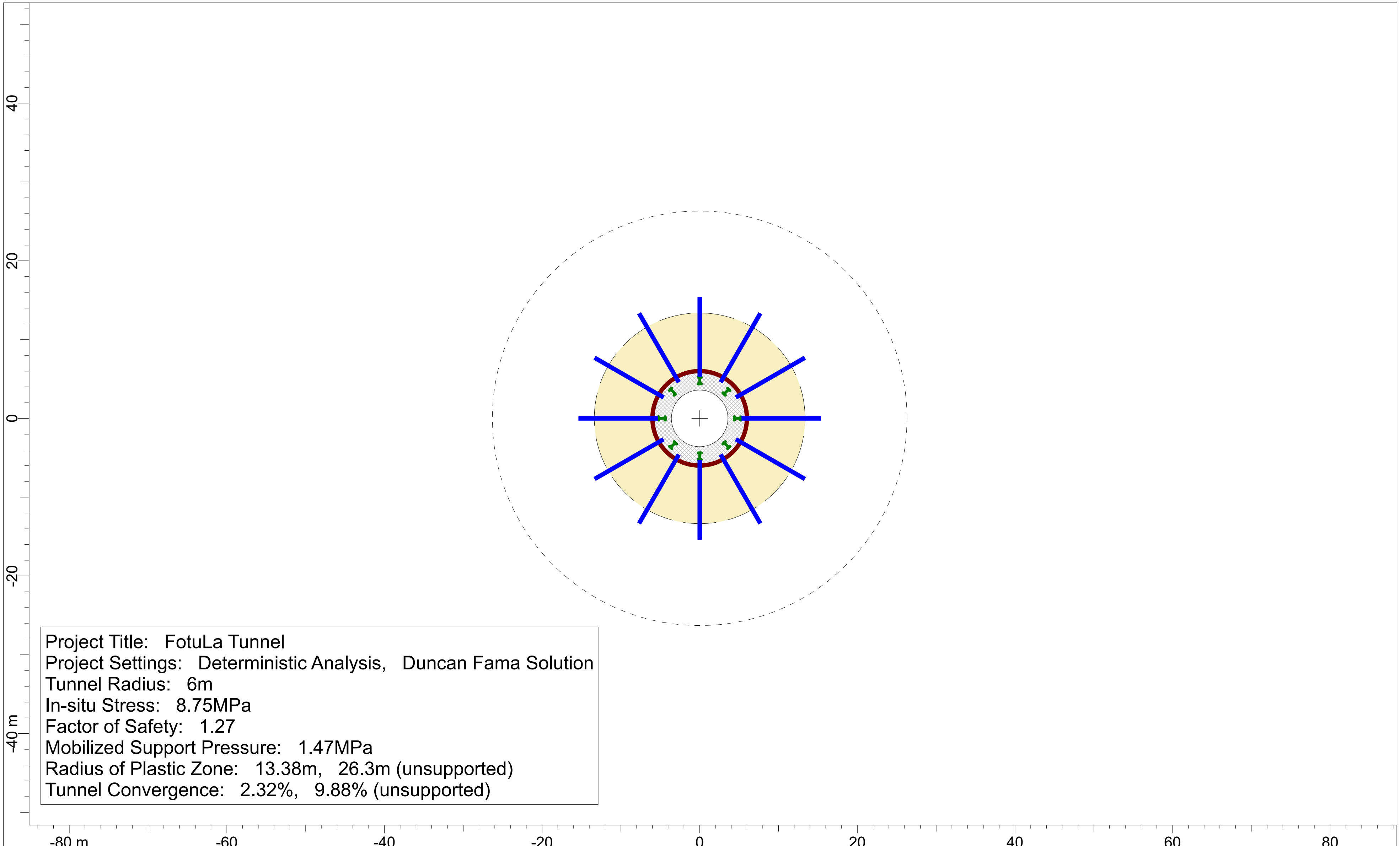
Support Parameters:

Total combined :
Maximum support pressure : **1.867** MPa
Maximum support strain : **0.315** %
Installed at distance from tunnel face : **0.8** m
Initial Tunnel Convergence : **2.07** %
Initial Wall Displacement : **124.25** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 9 m**
Maximum support pressure : **0.337** MPa
Maximum support strain : **0.315** %
Rockbolt Circumferential Spacing : **1.3** m
Rockbolt Longitudinal Spacing : **0.8** m

Steelset :
Type : **Custom**
Properties : **Area = 1335 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.068** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **0.8** m

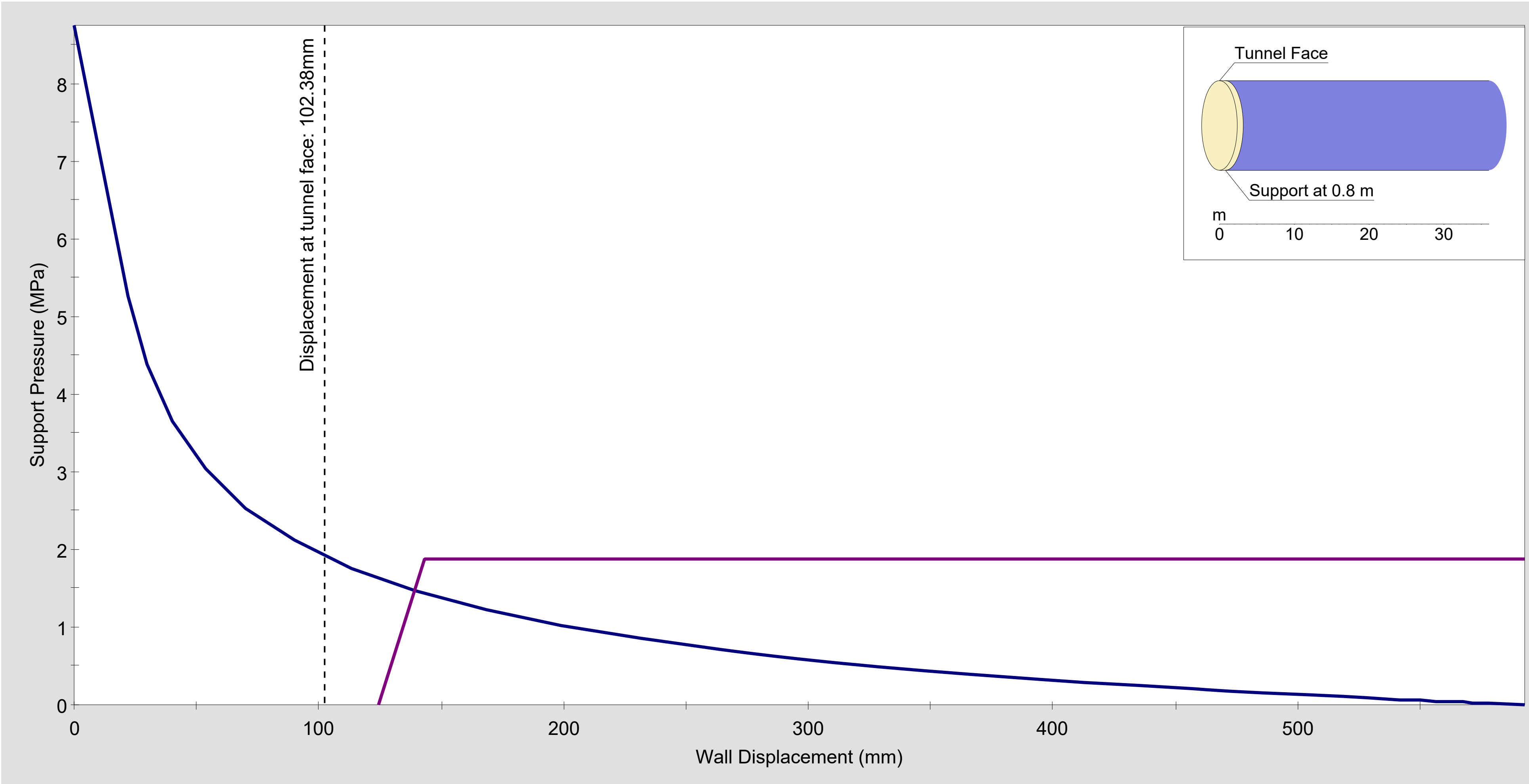
Shotcrete :
Type : **Custom**
Properties : **Thickness = 300 mm, UCS = 30 MPa, Young's Modulus = 27300 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.462** MPa
Maximum support strain : **0.1** %



Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 8.75MPa
Factor of Safety: 1.27
Mobilized Support Pressure: 1.47MPa
Radius of Plastic Zone: 13.38m, 26.3m (unsupported)
Tunnel Convergence: 2.32%, 9.88% (unsupported)

rocscience ROCSUPPORT 5.003	*Project* FotuLa Tunnel		
	Analysis Description ESC VI - GT2L		
	Drawn By	*Company*	
	Date 12-02-2025, 13:13:54	*File Name* GT2L High overburden ESC 6.rsp	

Ground Reaction
and Support Reaction



Final wall displacement: 139.17mm, FS: 1.27
Displacement at tunnel face: 102.38mm, Displacement at support: 124.25mm

rocscience ROCSUPPORT 5.003	*Project* FotuLa Tunnel		
	Analysis Description ESC VI - GT2L		
	Drawn By	*Company*	
	Date 12-02-2025, 13:13:54	*File Name* GT2L High overburden ESC 6.rsp	

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **3.68**
Mobilized Support Pressure : **0.51** MPa

With support installed :
Radius of Plastic Zone r_p : **13.33** m
Wall Displacement u_p : **87.61** mm
Tunnel Convergence : **1.46** %

With no support installed :
Radius of Plastic Zone r_p : **27.22** m
Wall Displacement u_p : **402.94** mm
Tunnel Convergence : **6.72** %

Deformation at the tunnel face :
Wall displacement : **68.02** mm
Tunnel Convergence : **1.13** %

Critical Pressure p_{cr} : **1.92** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **3.3** MPa

Young's Modulus of Rock Mass E : **750** MPa
Poisson Ratio ν : **0.28**

rocscience		
	Project: FotuLa Tunnel	
	Analysis Description: ESC VI - GT3L	
	Drawn By:	Company:
ROCSUPPORT 5.003	Date: 12-02-2025, 13:13:54	File Name: GT3L High overburden ESC 6.rsp

Cohesion of Rock Mass C_{rm} : **0.151764** MPa

Compressive Strength of Rock Mass σ_{rm} : **0.45** MPa

Friction Angle ϕ : **22°**

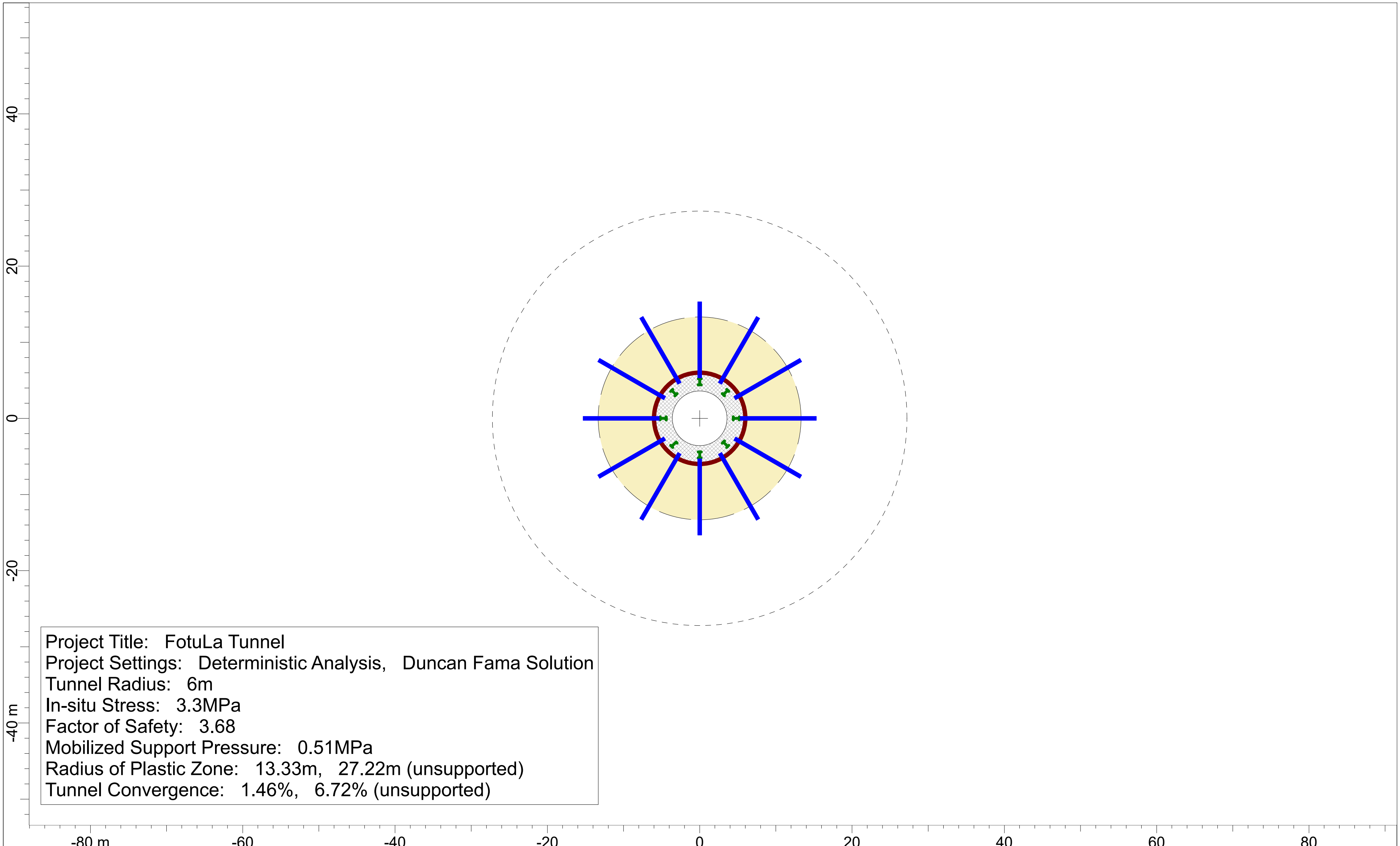
Support Parameters:

Total combined :
Maximum support pressure : **1.867** MPa
Maximum support strain : **0.315** %
Installed at distance from tunnel face : **0.8** m
Initial Tunnel Convergence : **1.37** %
Initial Wall Displacement : **82.46** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 9 m**
Maximum support pressure : **0.337** MPa
Maximum support strain : **0.315** %
Rockbolt Circumferential Spacing : **1.3** m
Rockbolt Longitudinal Spacing : **0.8** m

Steelset :
Type : **Custom**
Properties : **Area = 1335 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.068** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **0.8** m

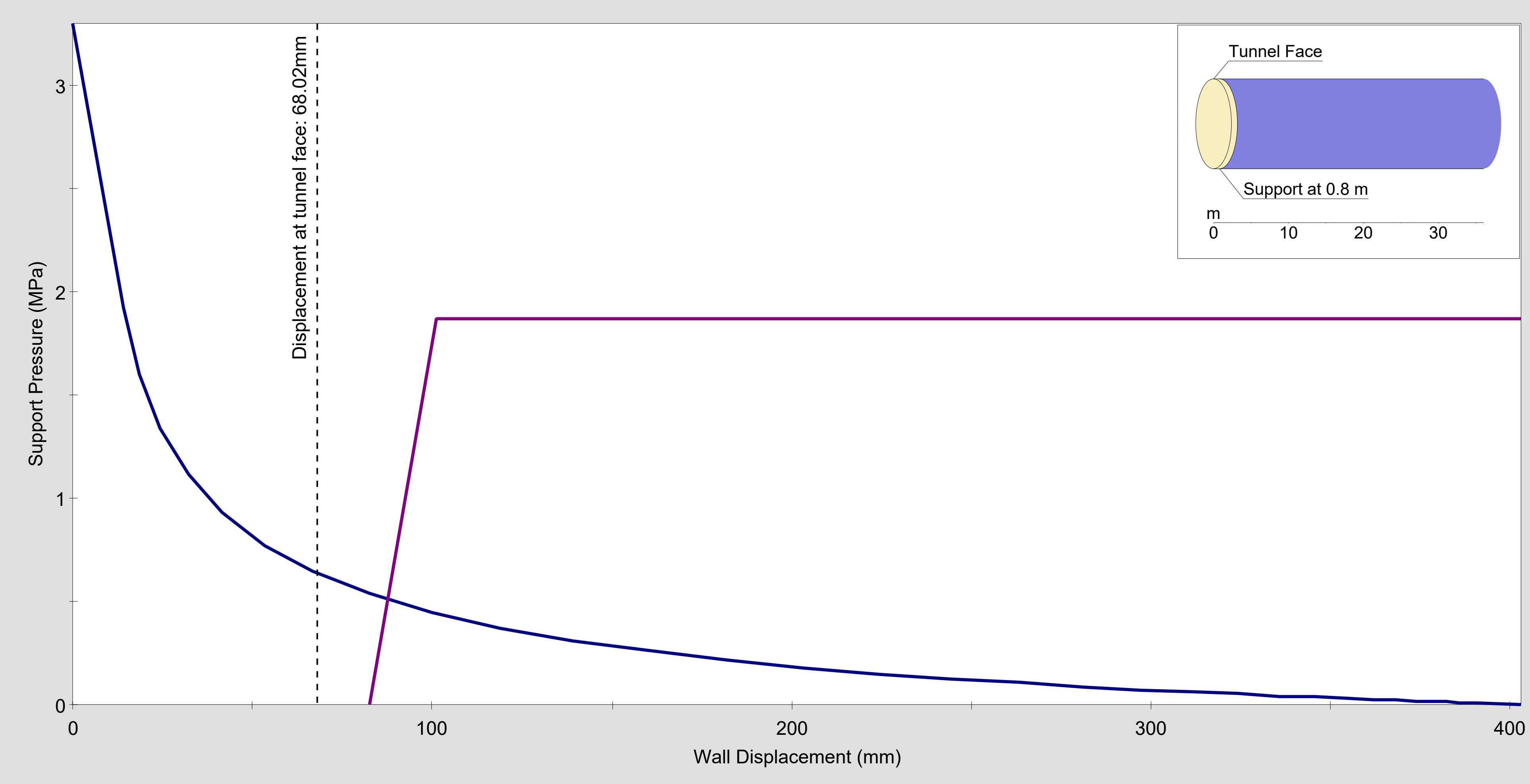
Shotcrete :
Type : **Custom**
Properties : **Thickness = 300 mm, UCS = 30 MPa, Young's Modulus = 27300 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.462** MPa
Maximum support strain : **0.1** %



Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 3.3MPa
Factor of Safety: 3.68
Mobilized Support Pressure: 0.51MPa
Radius of Plastic Zone: 13.33m, 27.22m (unsupported)
Tunnel Convergence: 1.46%, 6.72% (unsupported)

rocscience	*Project*	FotuLa Tunnel	
	Analysis Description	ESC VI - GT3L	
	Drawn By		*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54		*File Name* GT3L High overburden ESC 6.rsp

Ground Reaction
and Support Reaction



Final wall displacement: 87.61mm, FS: 3.68
Displacement at tunnel face: 68.02mm, Displacement at support: 82.46mm

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESC VI - GT3L		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT3L High overburden ESC 6.rsp	

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **6.19**
Mobilized Support Pressure : **0.3** MPa

With support installed :
Radius of Plastic Zone r_p : **7.62** m
Wall Displacement u_p : **55.28** mm
Tunnel Convergence : **0.92** %

With no support installed :
Radius of Plastic Zone r_p : **12.16** m
Wall Displacement u_p : **164.83** mm
Tunnel Convergence : **2.75** %

Deformation at the tunnel face :
Wall displacement : **40.54** mm
Tunnel Convergence : **0.68** %

Critical Pressure p_{cr} : **0.56** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **6** m
In-Situ Stress p_o : **1.19** MPa

Young's Modulus of Rock Mass E : **150** MPa
Poisson Ratio ν : **0.28**

rocscience ROCSUPPORT 5.003	Project: FotuLa Tunnel	
	Analysis Description: ESC VI - GT4	
	Drawn By:	Company:
	Date: 12-02-2025, 13:13:54	File Name: GT4 High overburden ESC 6.rsp

Cohesion of Rock Mass C_{rm} : **0.143341** MPa

Compressive Strength of Rock Mass σ_{rm} : **0.45** MPa

Friction Angle ϕ : **25°**

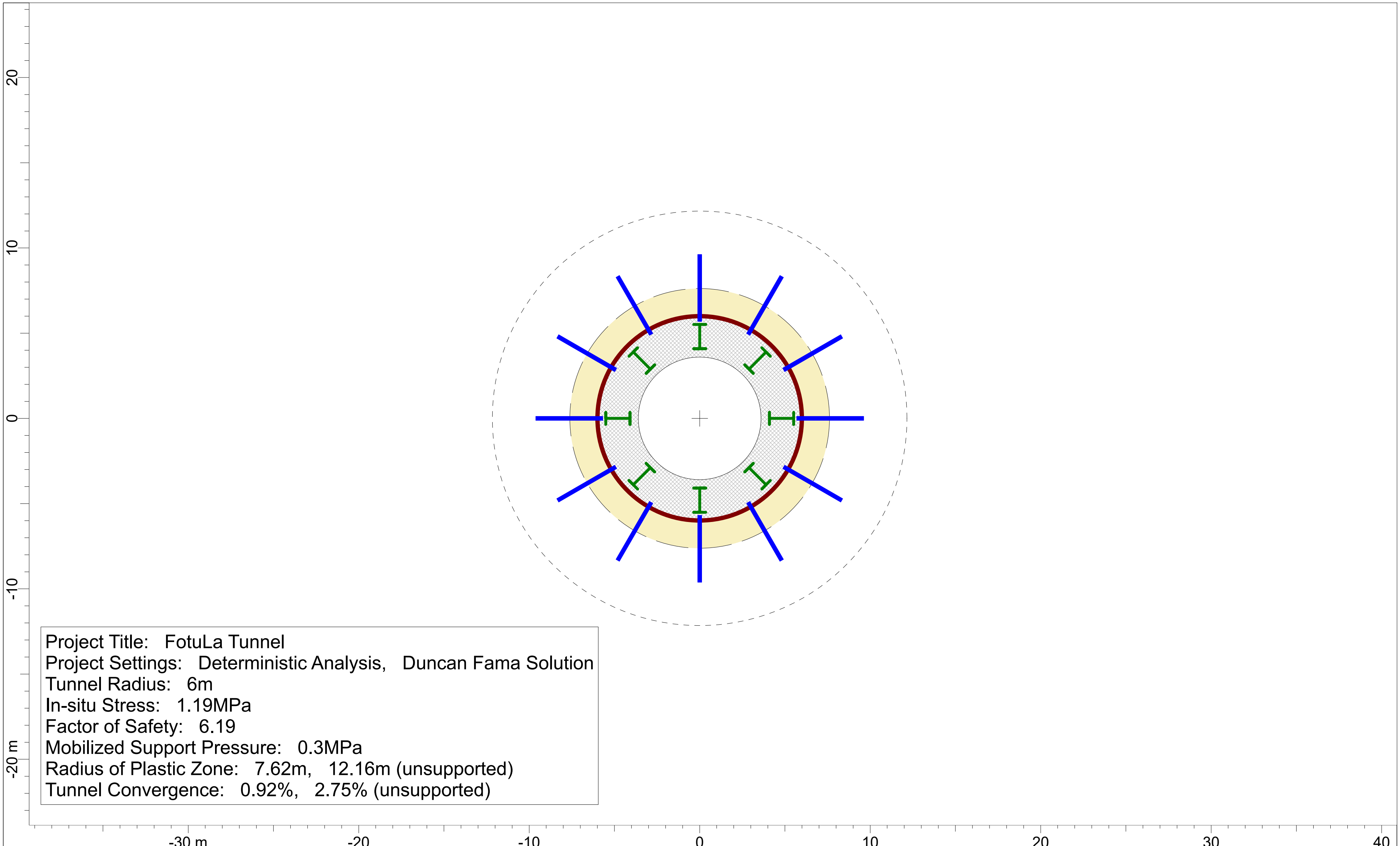
Support Parameters:

Total combined :
Maximum support pressure : **1.867** MPa
Maximum support strain : **0.315** %
Installed at distance from tunnel face : **0.8** m
Initial Tunnel Convergence : **0.87** %
Initial Wall Displacement : **52.22** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 9 m**
Maximum support pressure : **0.337** MPa
Maximum support strain : **0.315** %
Rockbolt Circumferential Spacing : **1.3** m
Rockbolt Longitudinal Spacing : **0.8** m

Steelset :
Type : **Custom**
Properties : **Area = 1335 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.068** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **0.8** m

Shotcrete :
Type : **Custom**
Properties : **Thickness = 300 mm, UCS = 30 MPa, Young's Modulus = 27300 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.462** MPa
Maximum support strain : **0.1** %



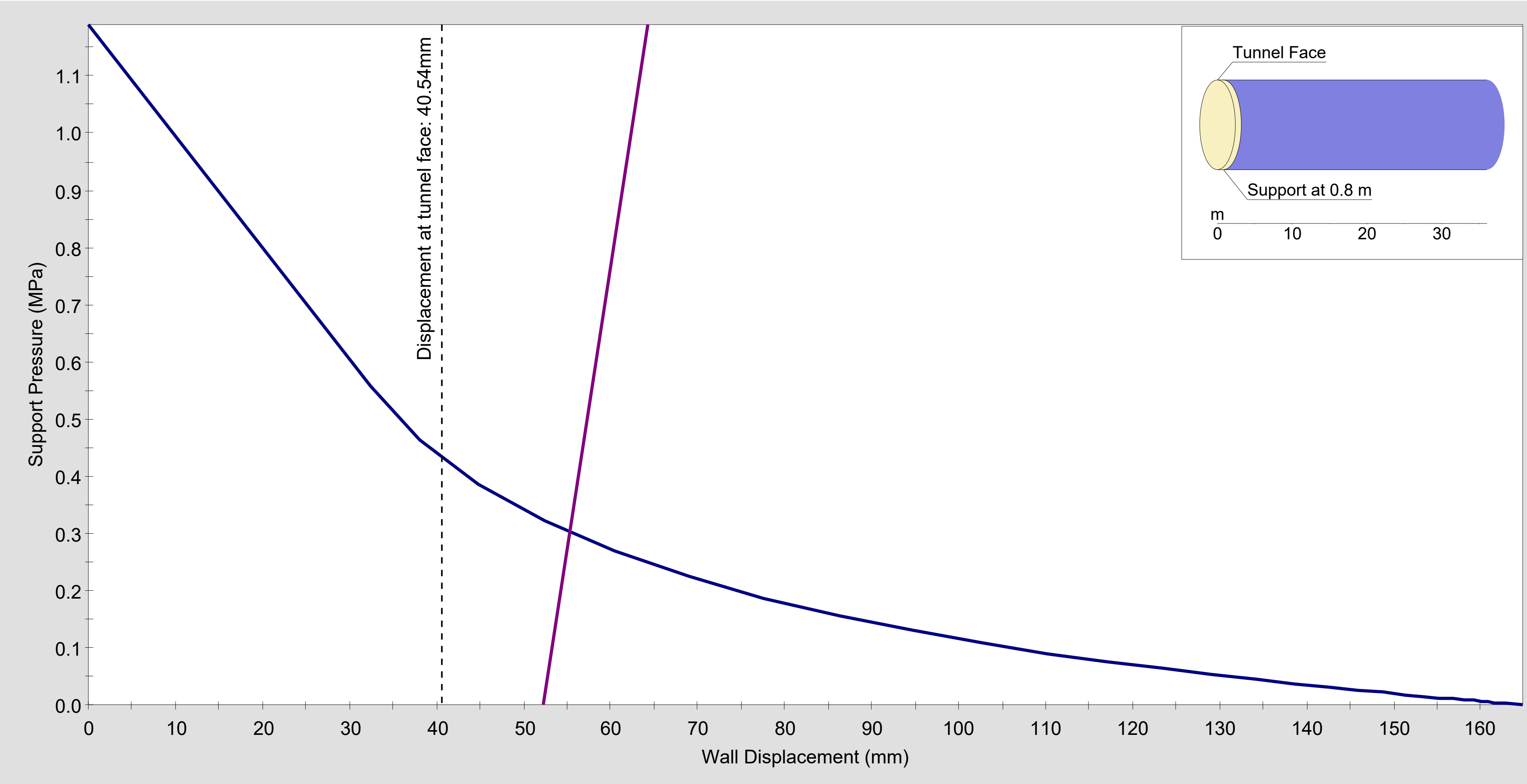
Project Title: FotuLa Tunnel
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 6m
In-situ Stress: 1.19MPa
Factor of Safety: 6.19
Mobilized Support Pressure: 0.3MPa
Radius of Plastic Zone: 7.62m, 12.16m (unsupported)
Tunnel Convergence: 0.92%, 2.75% (unsupported)

rocscience

ROCSUPPORT 5.003

Project	FotuLa Tunnel		
Analysis Description	ESC VI - GT4		
Drawn By		*Company*	
Date	12-02-2025, 13:13:54	*File Name*	GT4 High overburden ESC 6.rsp

Ground Reaction
and Support Reaction



Final wall displacement: 55.28mm, FS: 6.19
Displacement at tunnel face: 40.54mm, Displacement at support: 52.22mm

rocscience	*Project* FotuLa Tunnel		
	Analysis Description ESC VI - GT4		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* GT4 High overburden ESC 6.rsp	

ANNEXURE 2 - Primary support analysis and results (Main tunnel) - FEM

Finite Element analysis (FEM) for Main tunnel

1. **GT 1H – Max overburden – Excavation and Support Class (ESC) - 3**

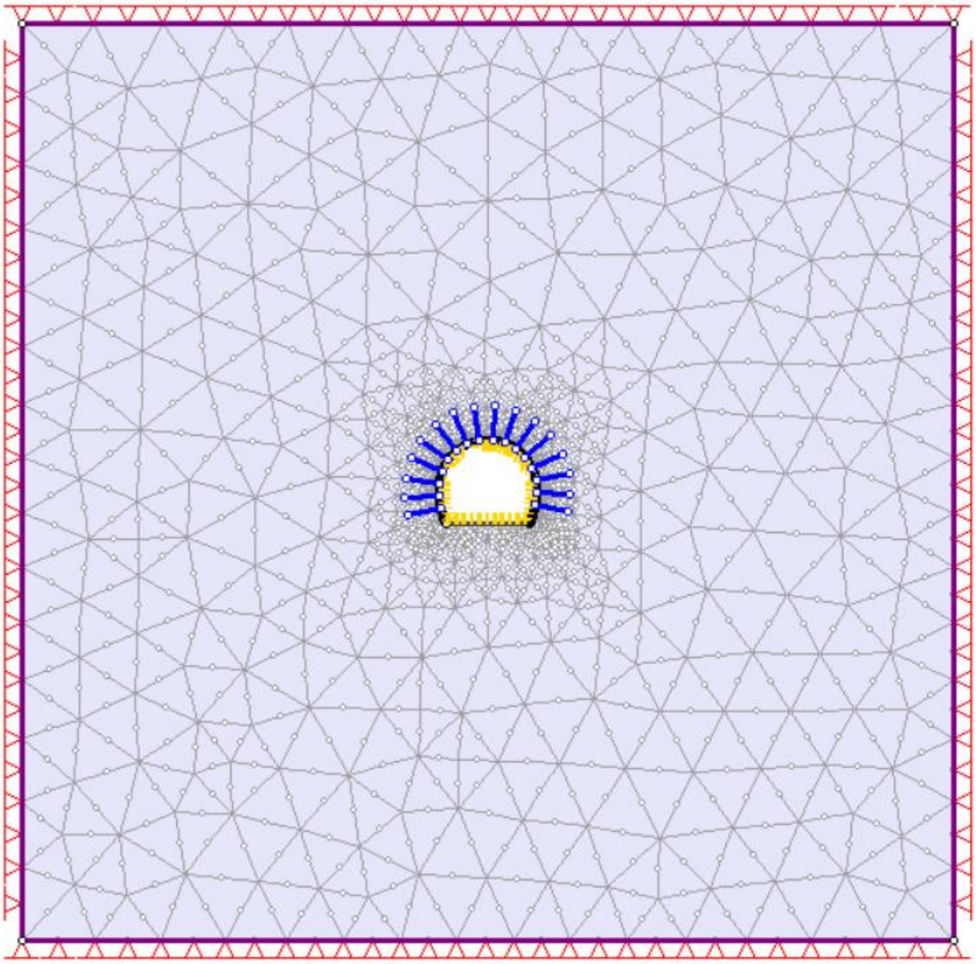


Fig-1 RS2 Model of GT1H with support ESC 3

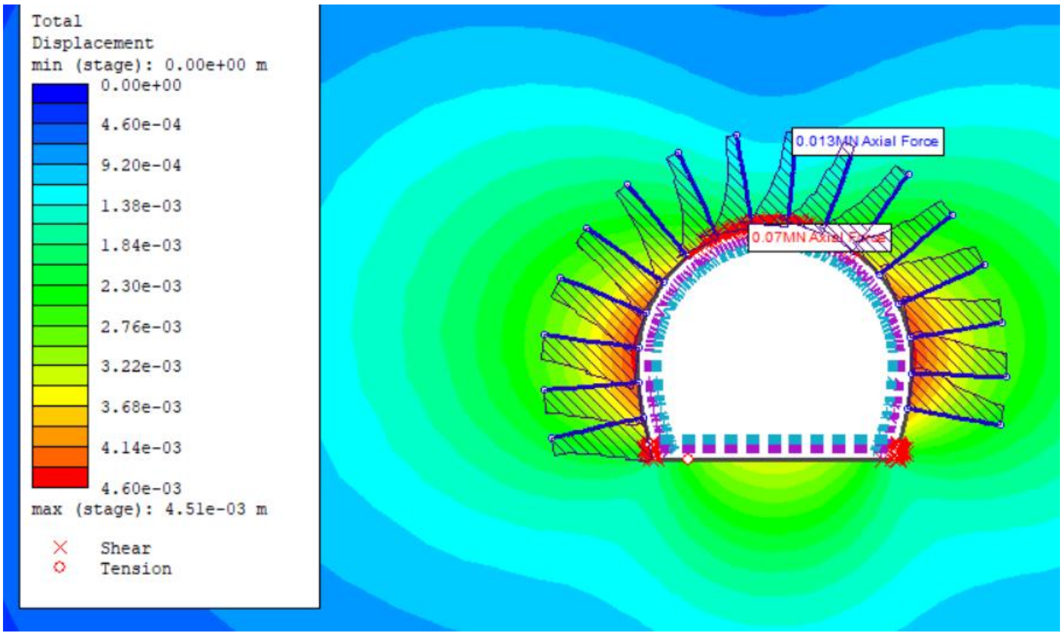


Fig-2 Max Displacement = 4.51mm

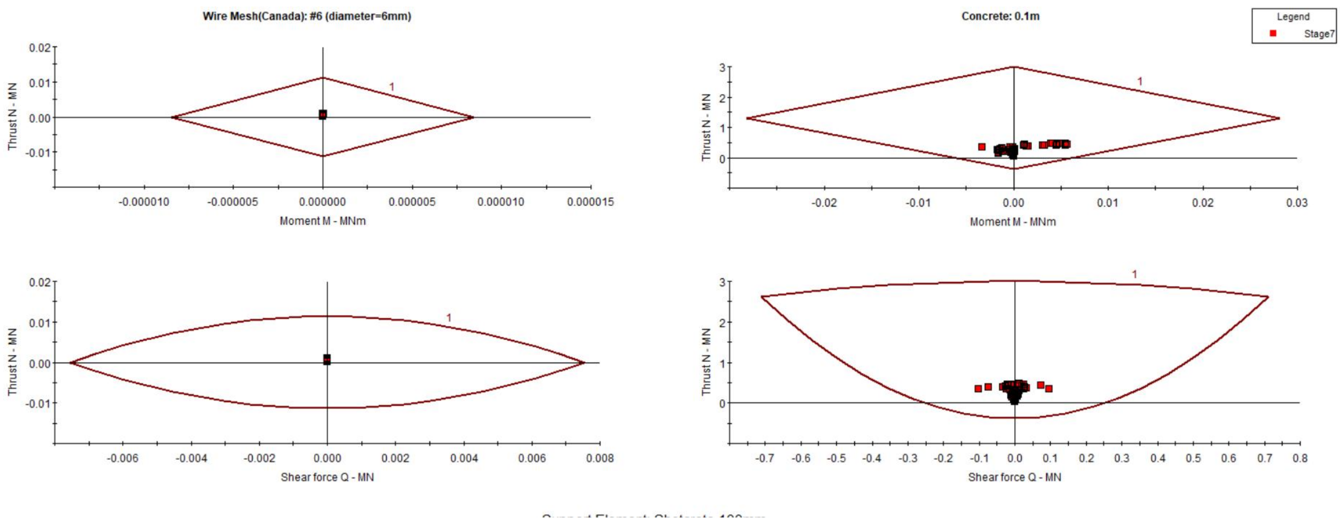


Fig-3 Support capacity curve for Shotcrete and wiremesh (ESC-3)

2. GT 1L – Max overburden – Excavation and Support Class (ESC) – 3

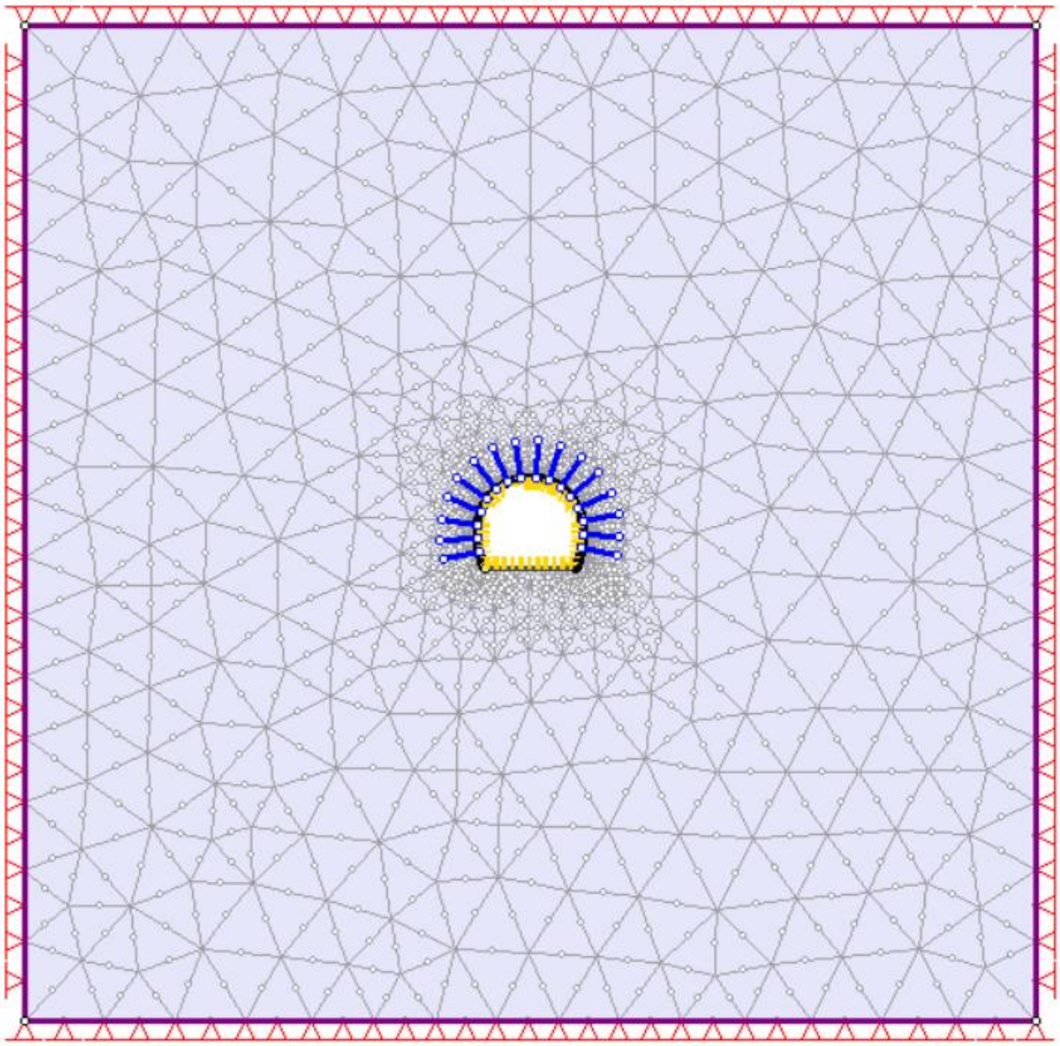


Fig-4 RS2 Model of GT1L with support ESC 3

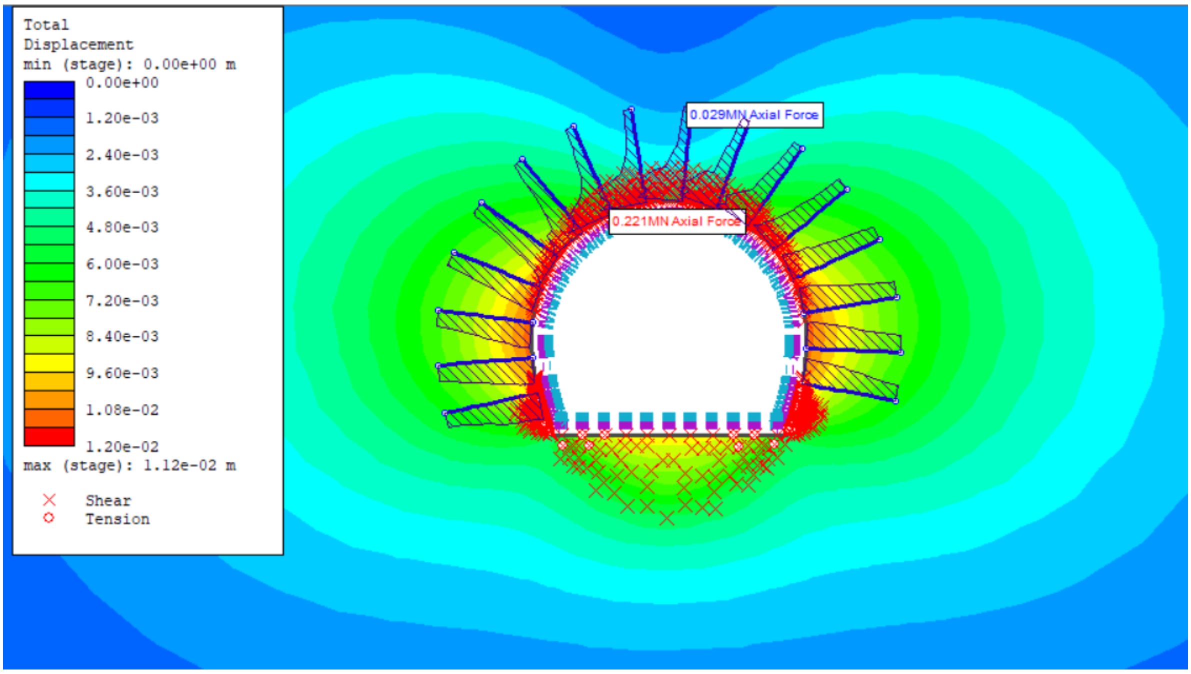


Fig-5 Max Displacement = 11.2 mm

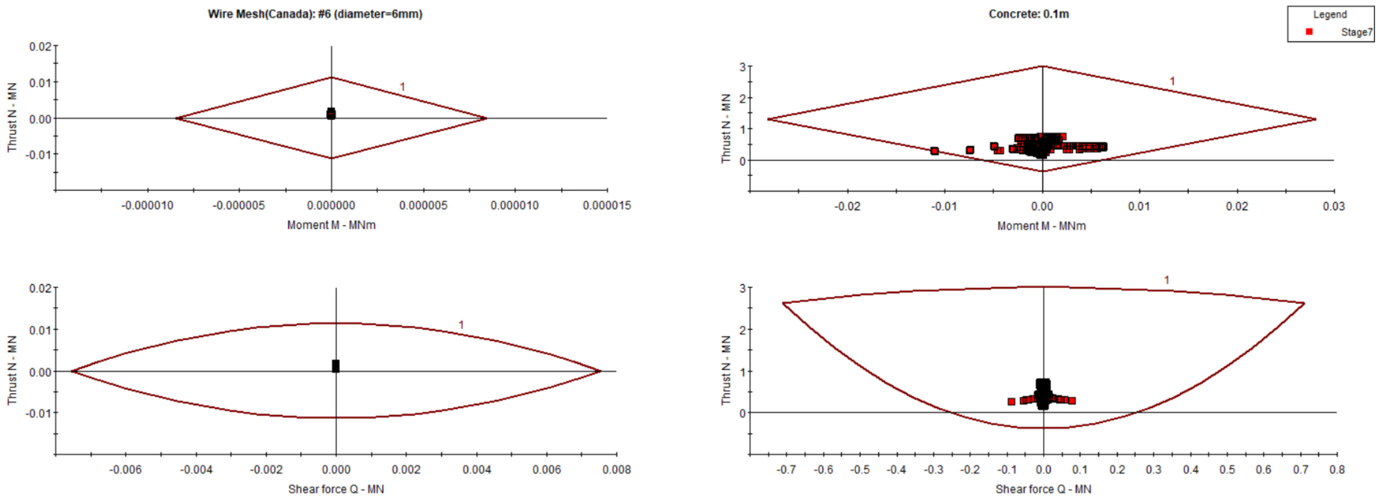


Fig-6 Support capacity curve for Shotcrete and wiremesh (ESC-3)

3. **GT 2H – 200m overburden – Excavation and Support Class (ESC) – 5**

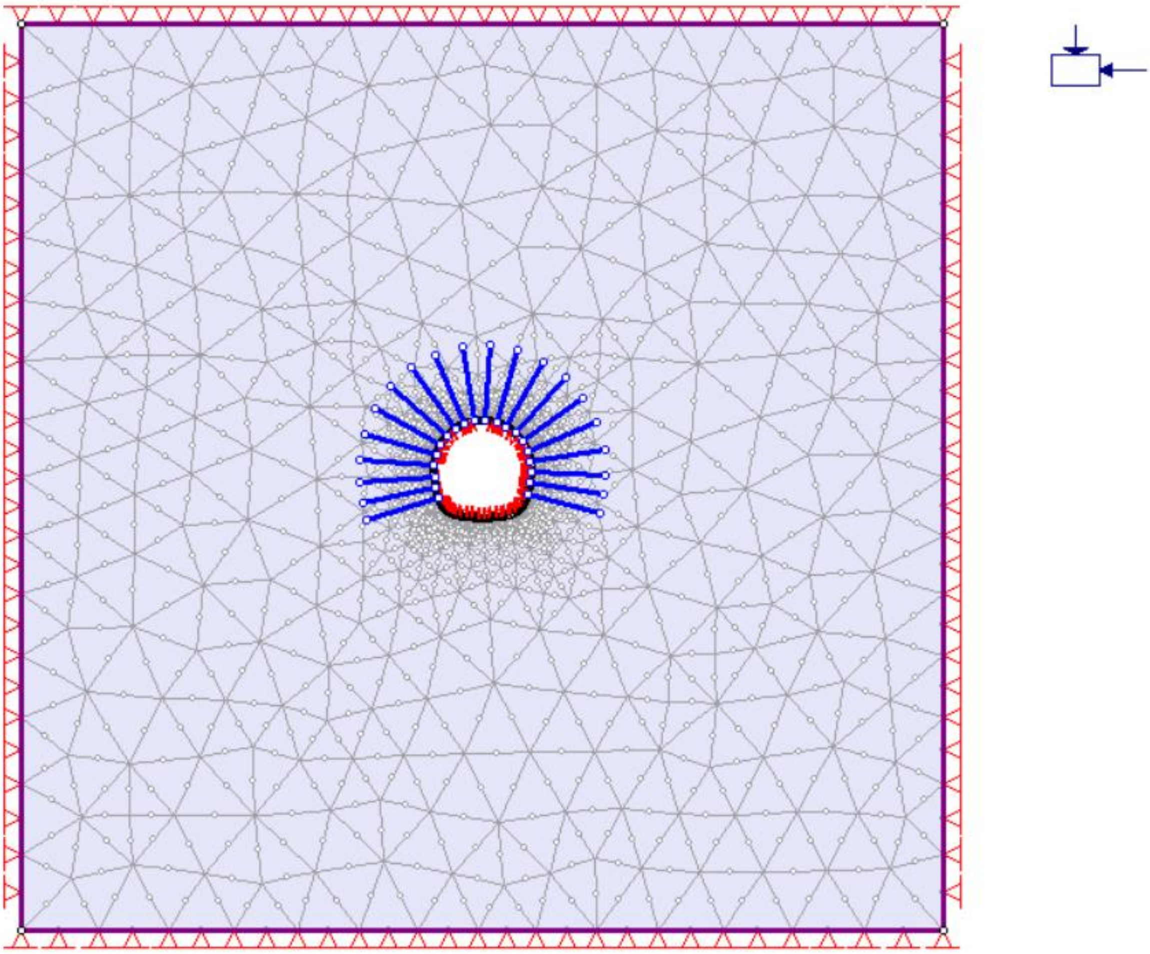


Fig-7 RS2 Model of GT2H (200m burden) with support ESC 5

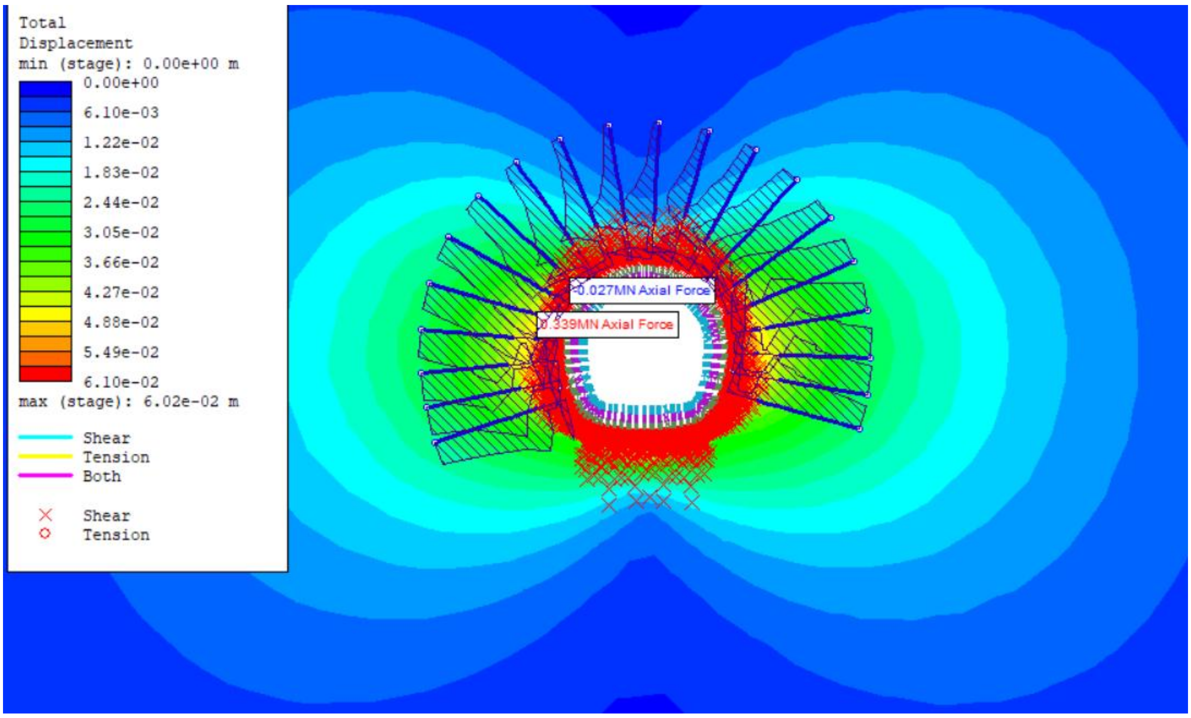


Fig-8 Max Displacement = 60.2 mm

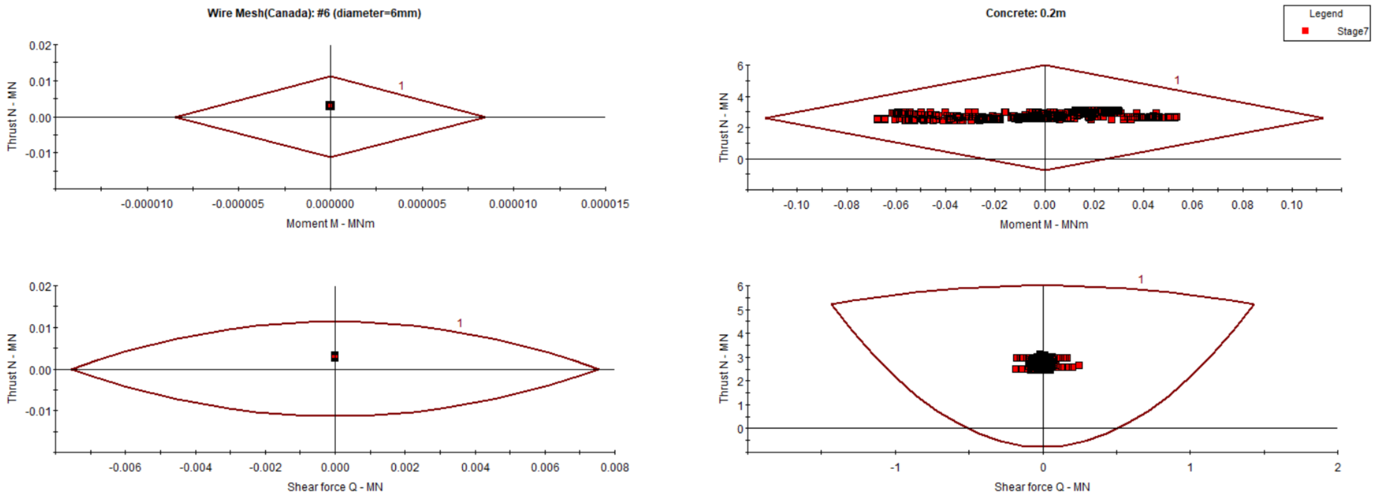


Fig-9 Support capacity curve for Shotcrete and wiremesh (ESC-5)

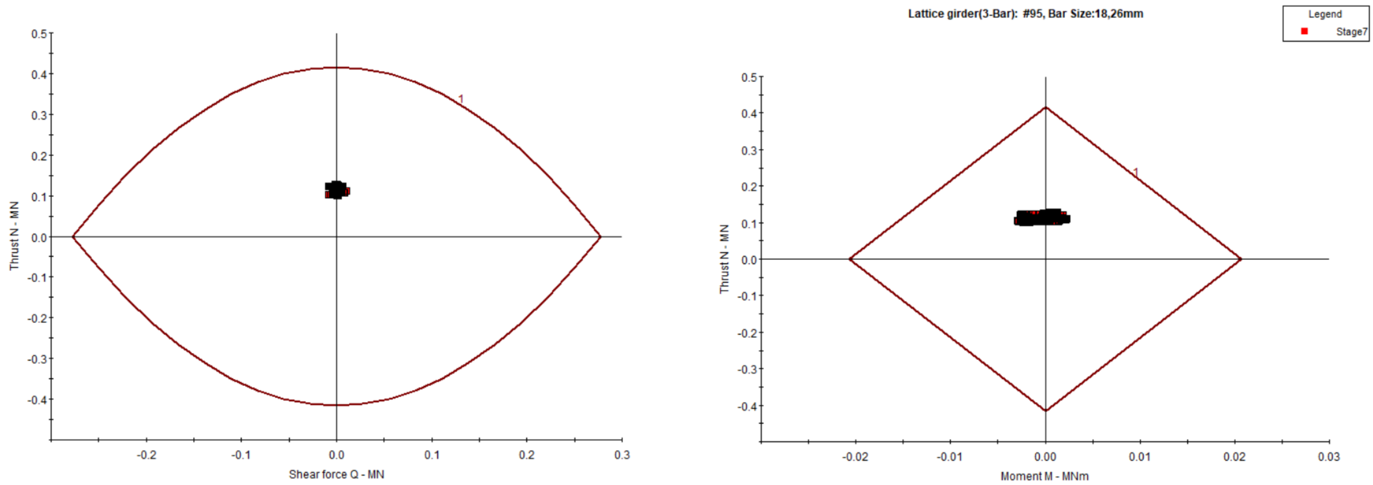


Fig-10 Support capacity curve for Lattice Girder (ESC-5)

4. **GT 2H – Maximum overburden – Excavation and Support Class (ESC) – 6**

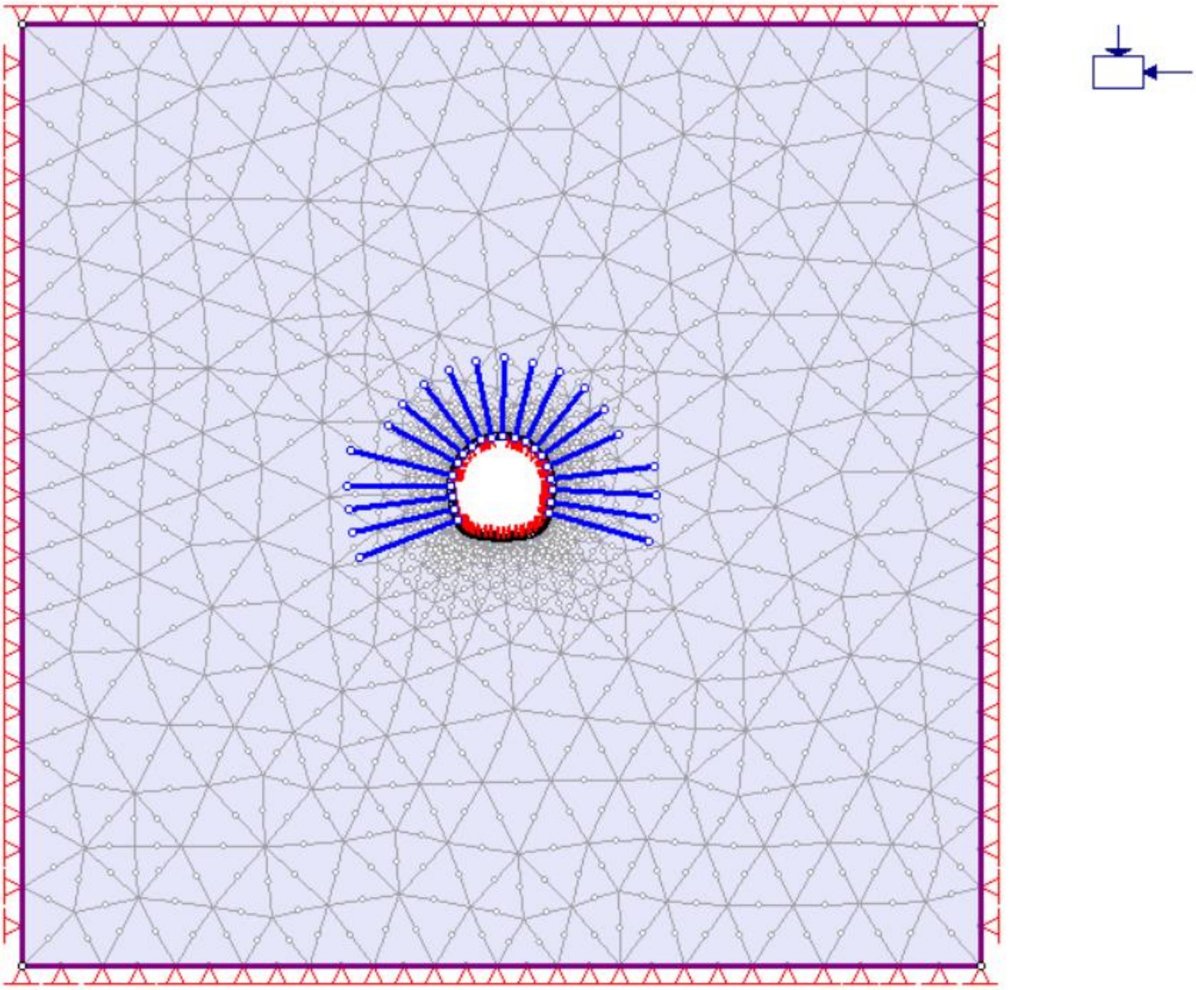


Fig-11 RS2 Model of GT2H max burden with support ESC 6

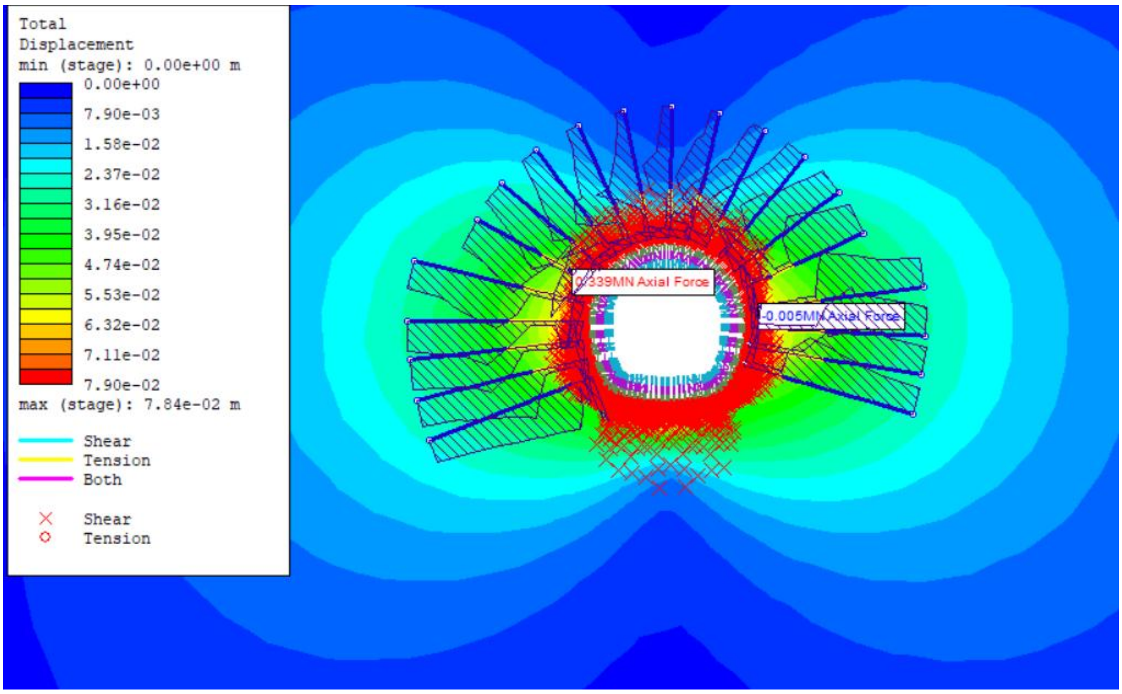


Fig-12 Max Displacement = 78.4 mm

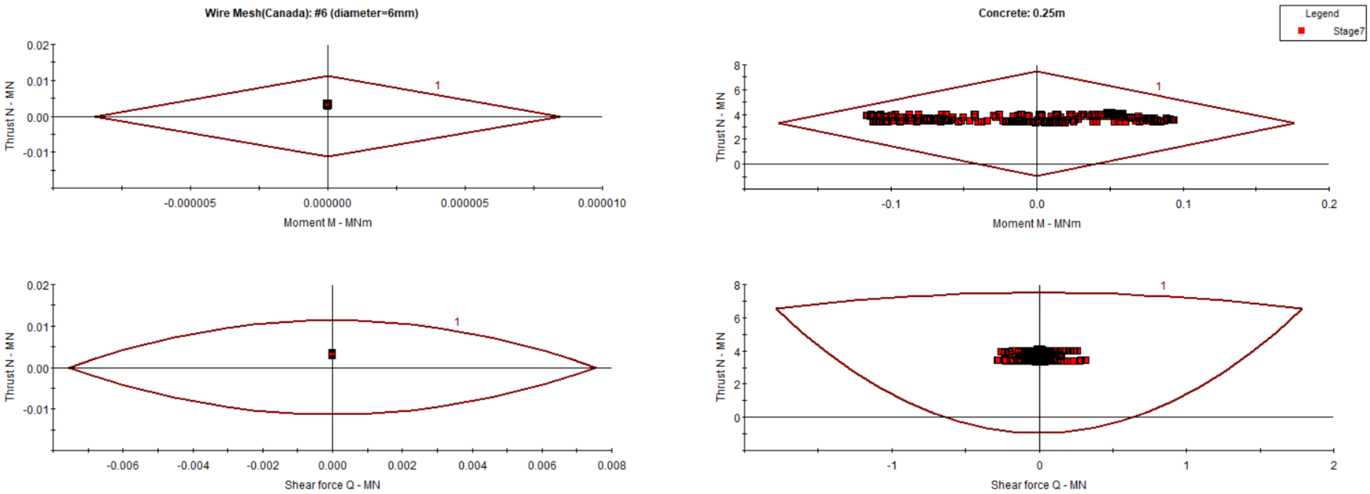


Fig-13 Support capacity curve for Shotcrete and wiremesh (ESC-6)

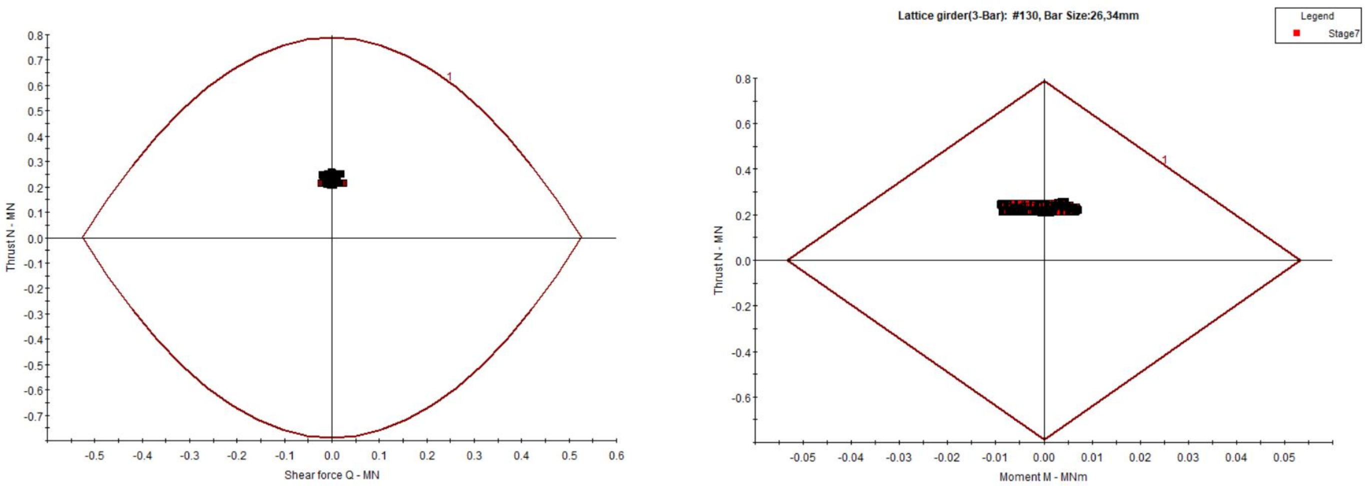


Fig-14 Support capacity curve for Lattice Girder (ESC-6)

5. **GT 2L – Maximum overburden – Excavation and Support Class (ESC) – 6**

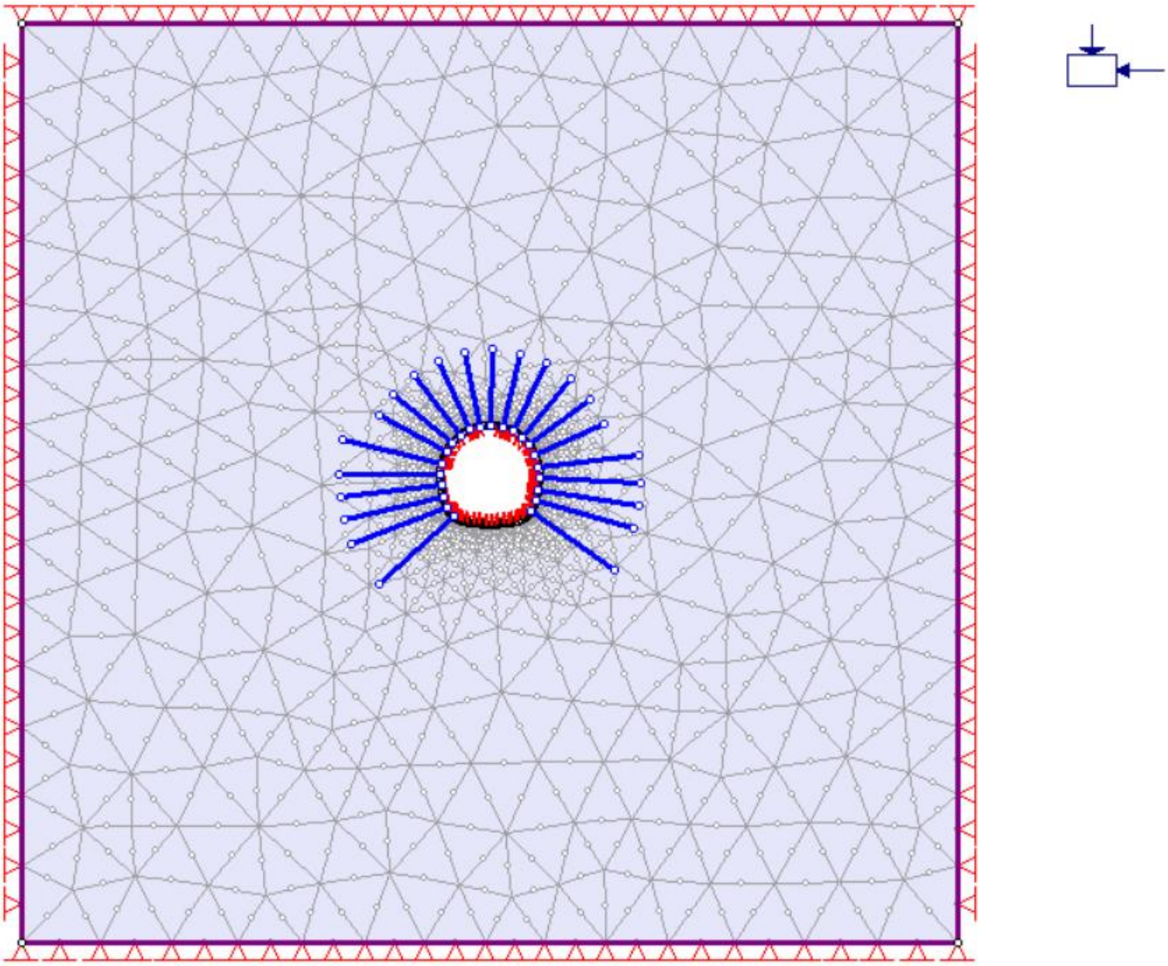


Fig-15 RS2 Model of GT2L max burden with support ESC 6

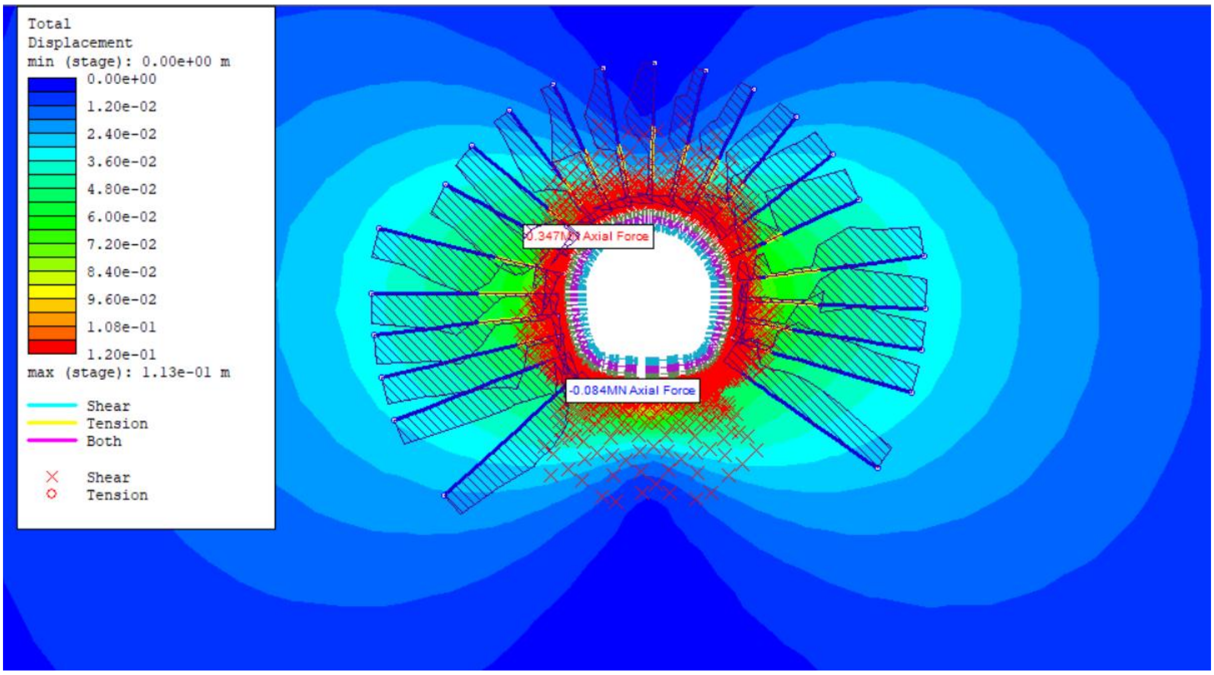


Fig-16 Max Displacement = 113 mm

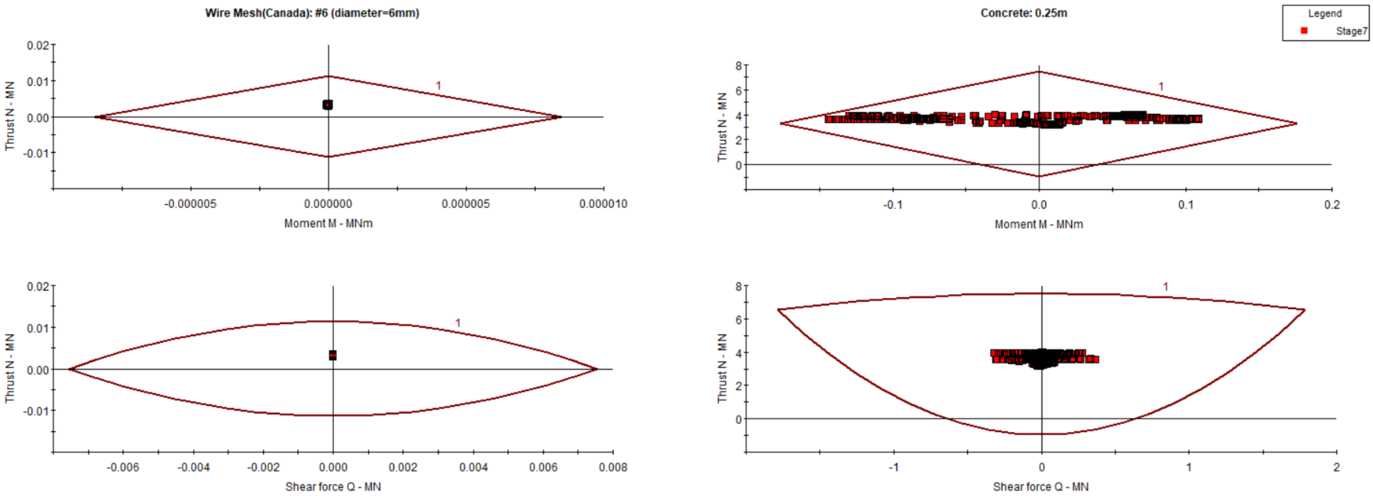


Fig-17 Support capacity curve for Shotcrete and wiremesh (ESC-6)

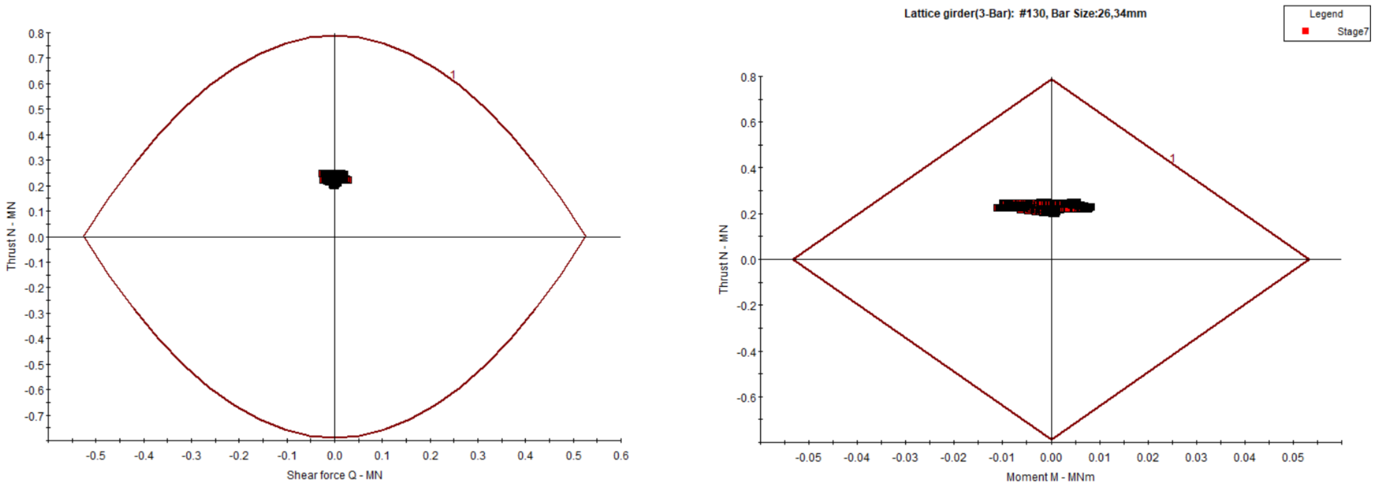


Fig-18 Support capacity curve for Lattice Girder (ESC-6)

6. **GT 3H – Maximum overburden – Excavation and Support Class (ESC) – 4**

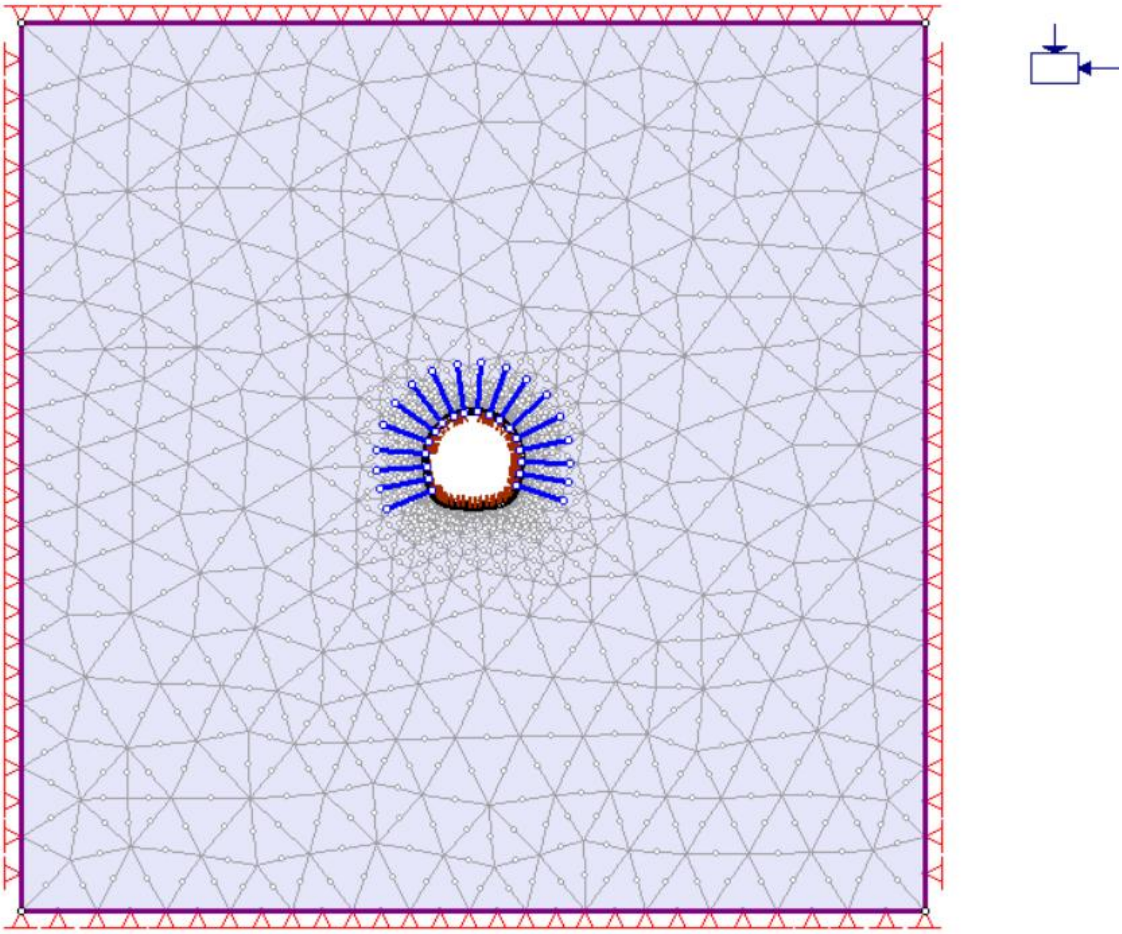


Fig-19 RS2 Model of GT3H max burden with support ESC 4

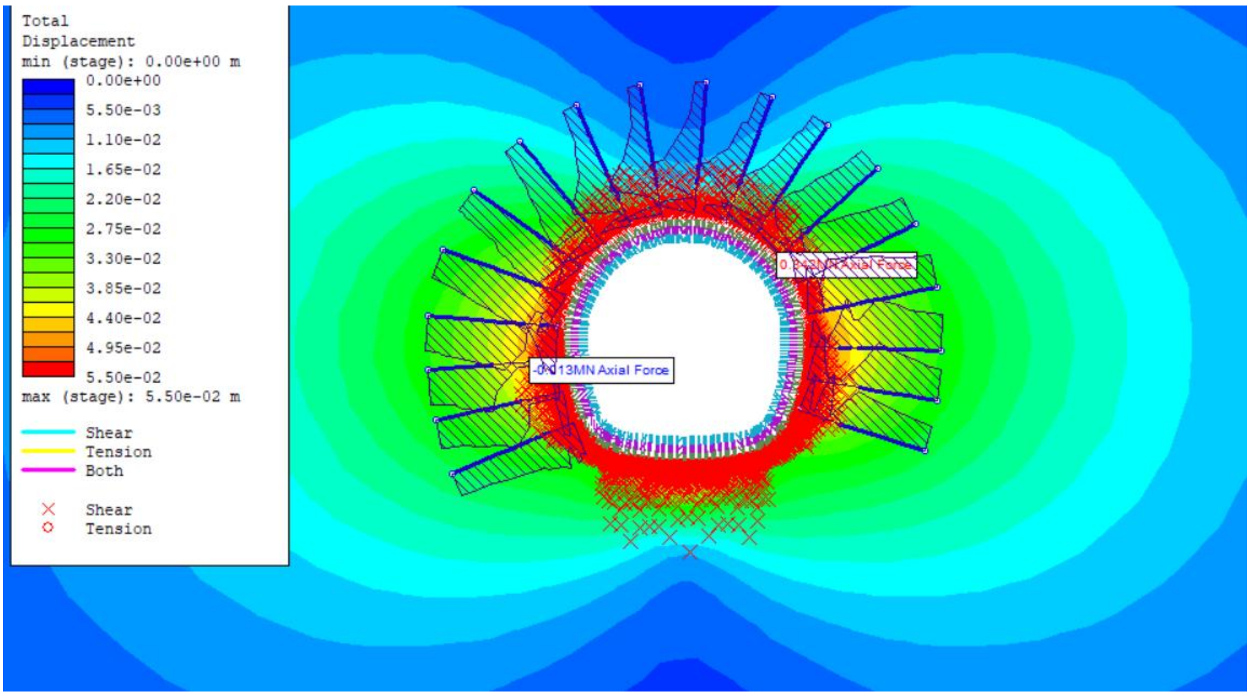


Fig-20 Max Displacement = 55 mm

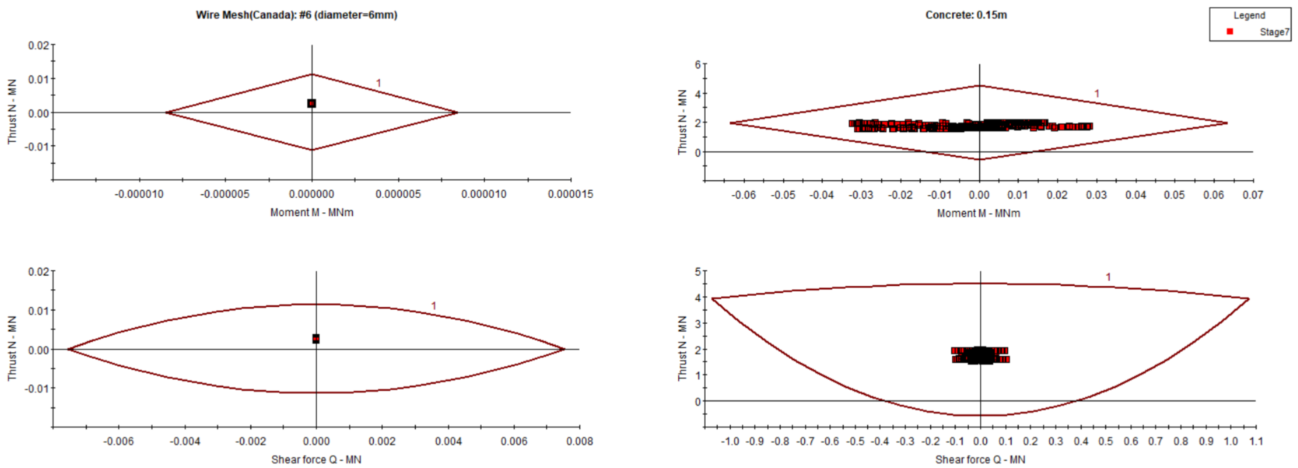


Fig-21 Support capacity curve for Shotcrete and wiremesh (ESC-4)

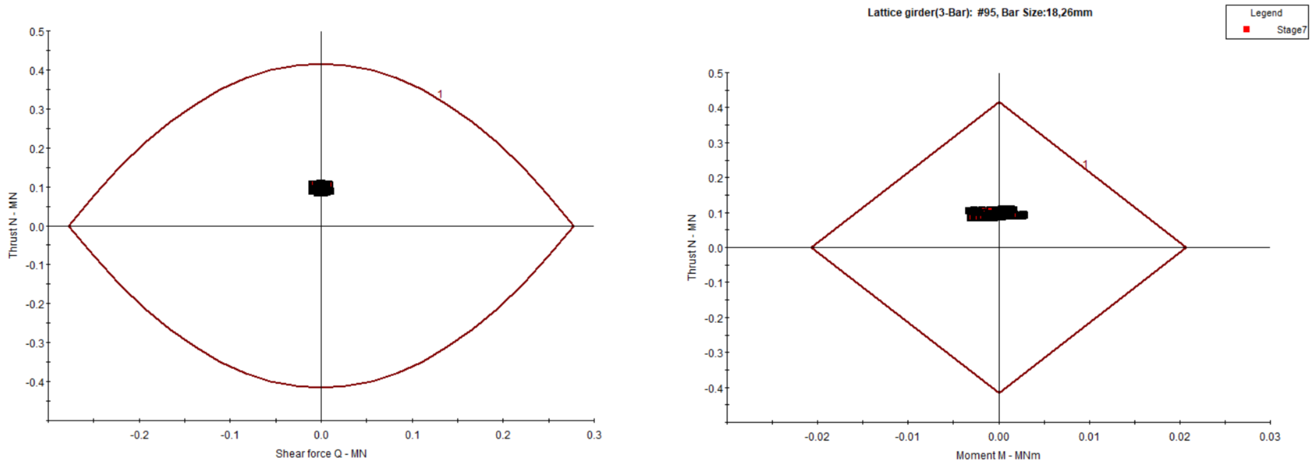


Fig-22 Support capacity curve for Lattice Girder (ESC-4)

7. **GT 3L – Maximum overburden – Excavation and Support Class (ESC) – 6**

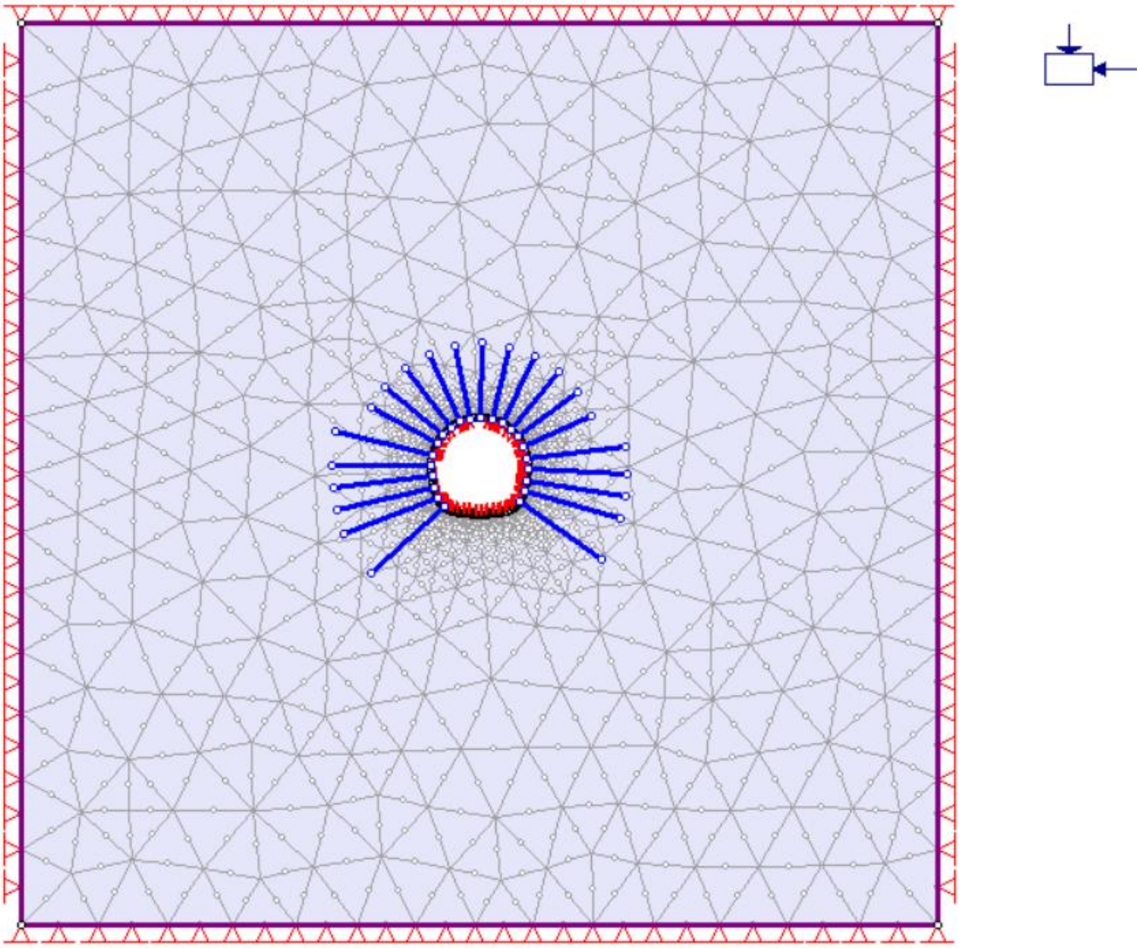


Fig-23 RS2 Model of GT3H max burden with support ESC 6

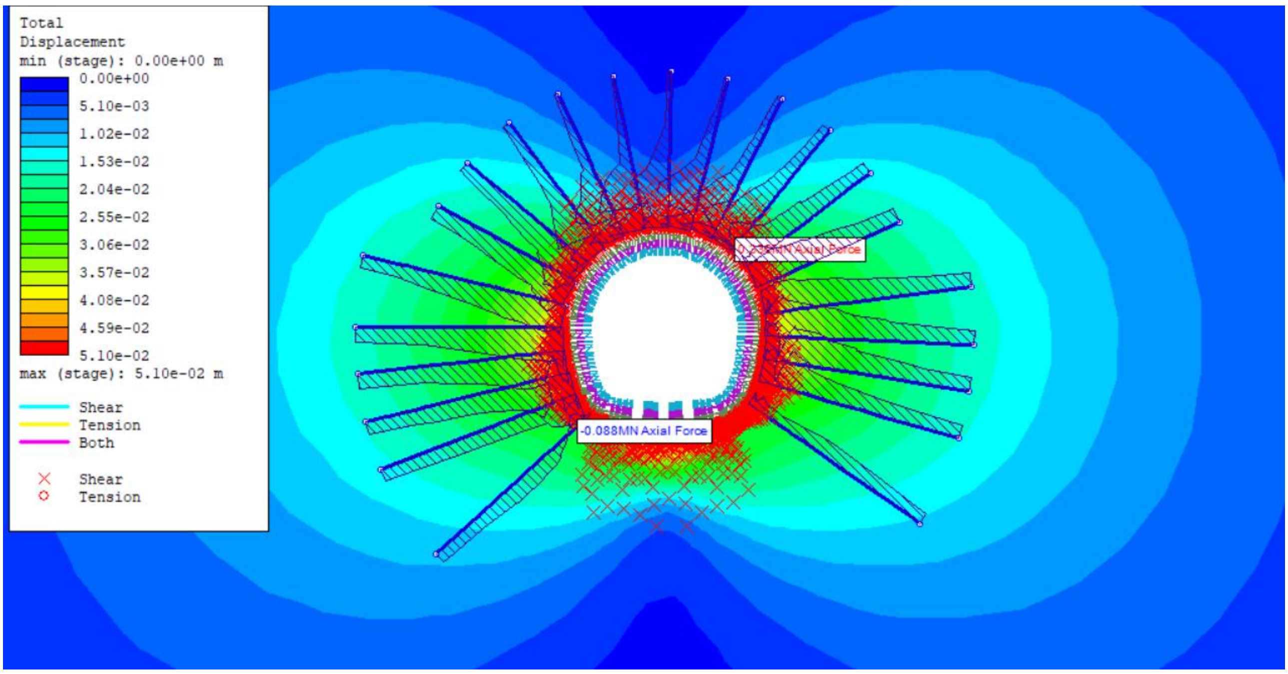


Fig-24 Max Displacement = 51 mm

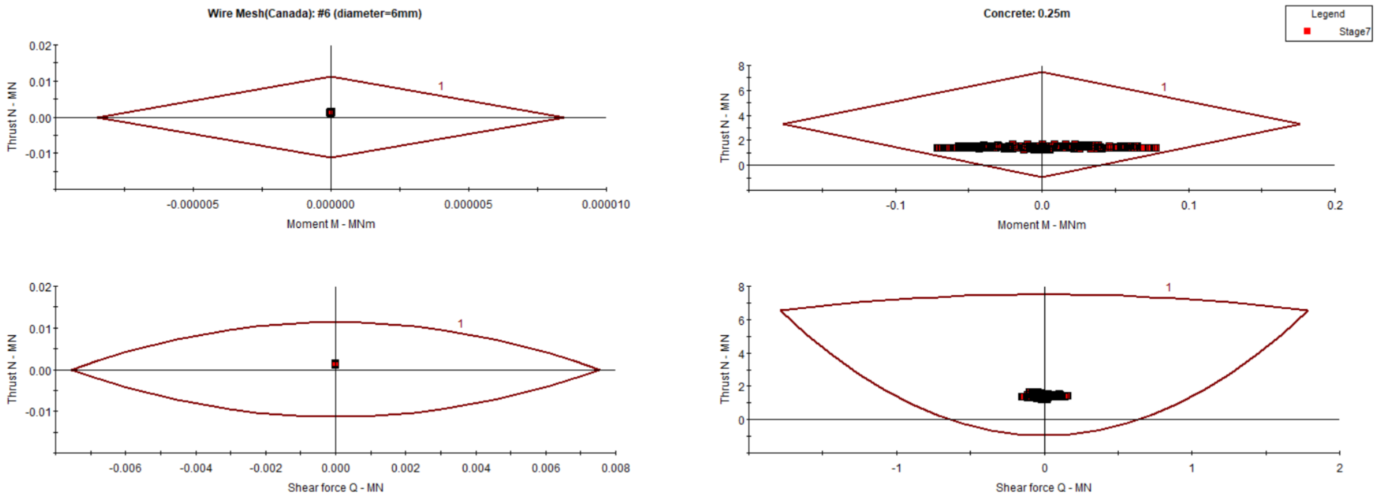


Fig-25 Support capacity curve for Shotcrete and wiremesh (ESC-6)

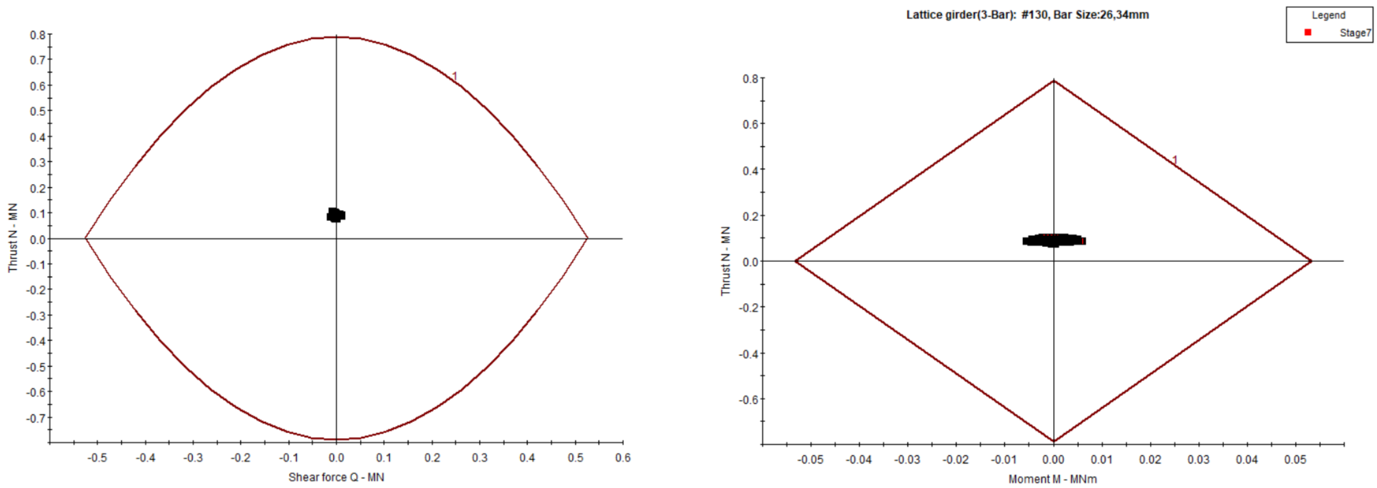


Fig-26 Support capacity curve for Lattice Girder (ESC-6)

8. GT 4 – Maximum overburden – Excavation and Support Class (ESC) – 6

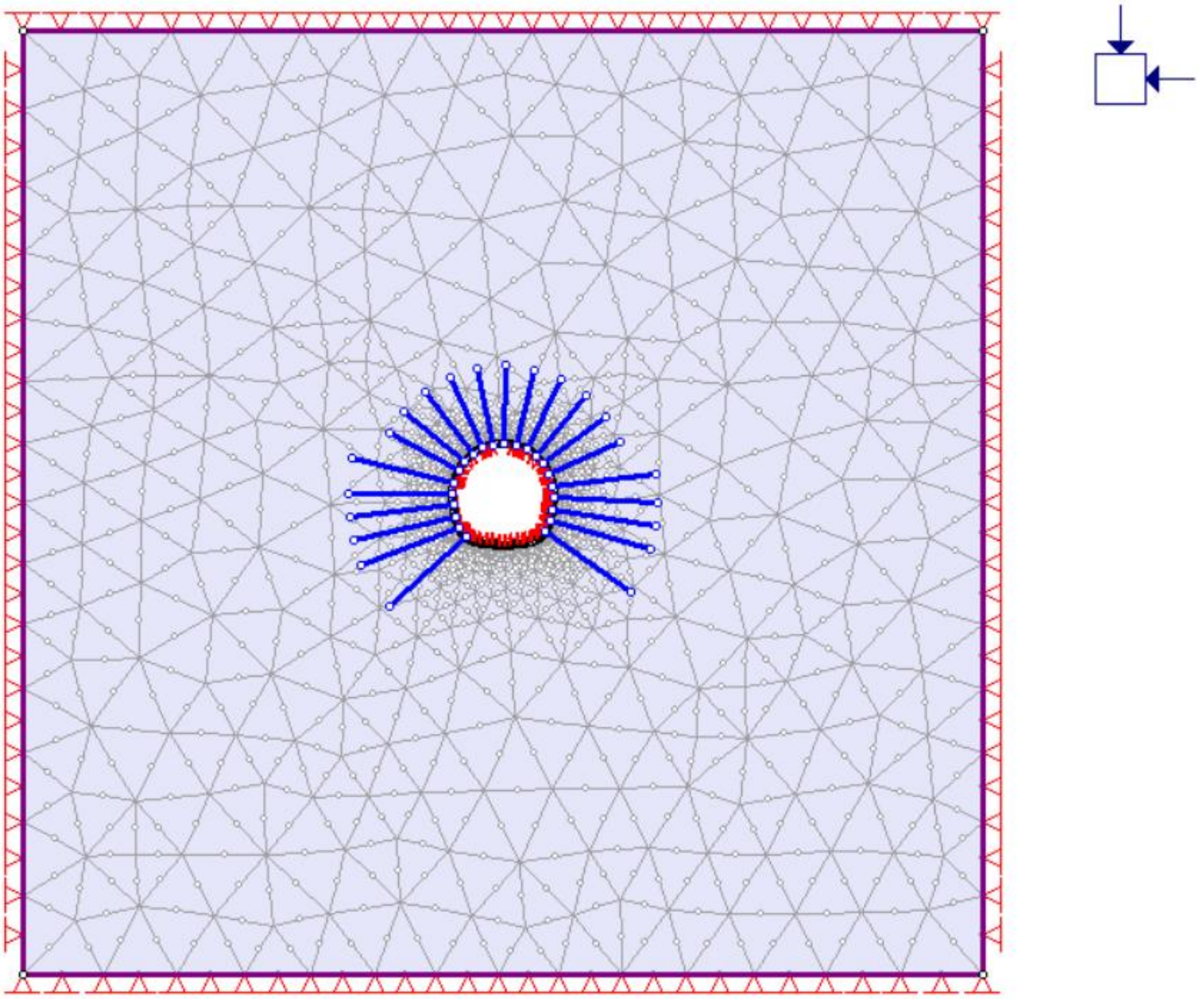


Fig-27 RS2 Model of GT4 max burden with support ESC 6

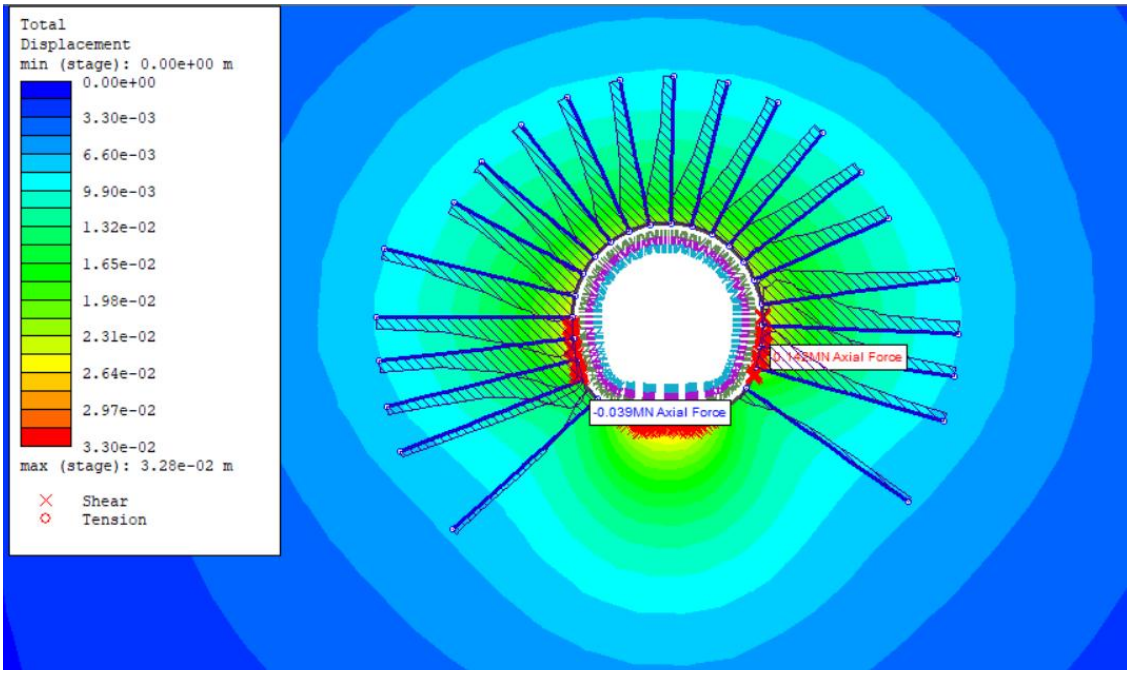


Fig-28 Max Displacement = 32.8 mm

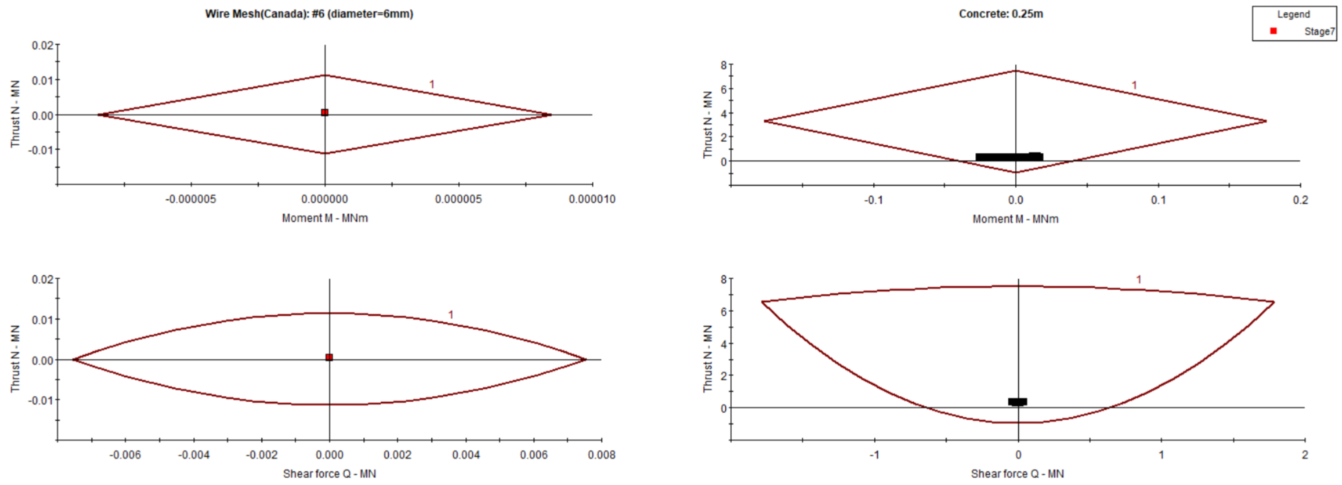


Fig-29 Support capacity curve for Shotcrete and wiremesh (ESC-6)

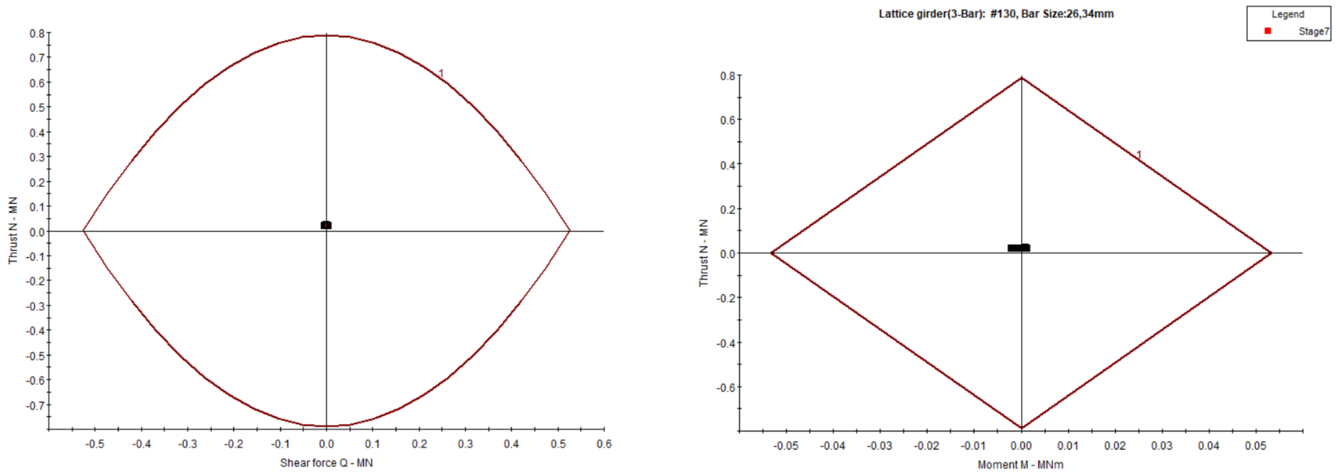


Fig-30 Support capacity curve for Lattice Girder (ESC-6)

ANNEXURE 3 (Primary support analyses and results for cross passage)

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel CP1**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **6.71**
Mobilized Support Pressure : **0.17** MPa

With support installed :
Radius of Plastic Zone r_p : **5.01** m
Wall Displacement u_p : **3.29** mm
Tunnel Convergence : **0.08** %

With no support installed :
Radius of Plastic Zone r_p : **5.18** m
Wall Displacement u_p : **3.57** mm
Tunnel Convergence : **0.09** %

Deformation at the tunnel face :
Wall displacement : **0.98** mm
Tunnel Convergence : **0.02** %

Critical Pressure p_{cr} : **1.84** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **4** m
In-Situ Stress p_o : **6.87** MPa

Young's Modulus of Rock Mass E : **13200** MPa
Poisson Ratio ν : **0.3**

rocscience			
	Project FotuLa Tunnel CP1		
	Analysis Description ESC2 - GT1H		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* CP-1 GT1H ESC 2.rsp	

Cohesion of Rock Mass C_{rm} : **1.22286** MPa
Compressive Strength of Rock Mass σ_{rm} : **4.8** MPa

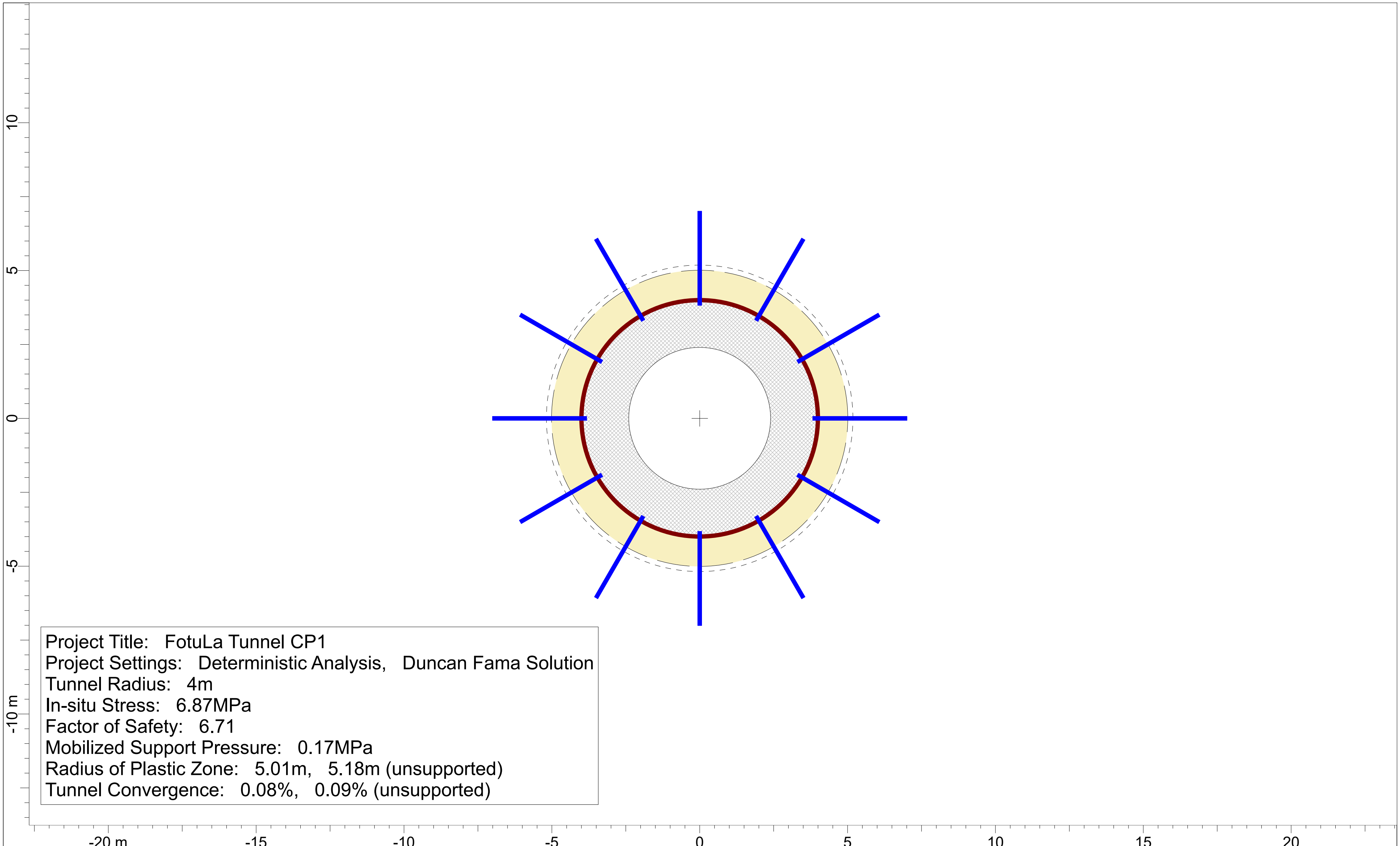
Friction Angle ϕ : **36°**

Support Parameters:

Total combined :
Maximum support pressure : **1.154** MPa
Maximum support strain : **0.197** %
Installed at distance from tunnel face : **2** m
Initial Tunnel Convergence : **0.05** %
Initial Wall Displacement : **2.12** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 25 mm, Capacity = 0.2 MN, Young's Modulus = 207000 MPa, Free Length = 4 m**
Maximum support pressure : **0.05** MPa
Maximum support strain : **0.197** %
Rockbolt Circumferential Spacing : **2** m
Rockbolt Longitudinal Spacing : **2** m

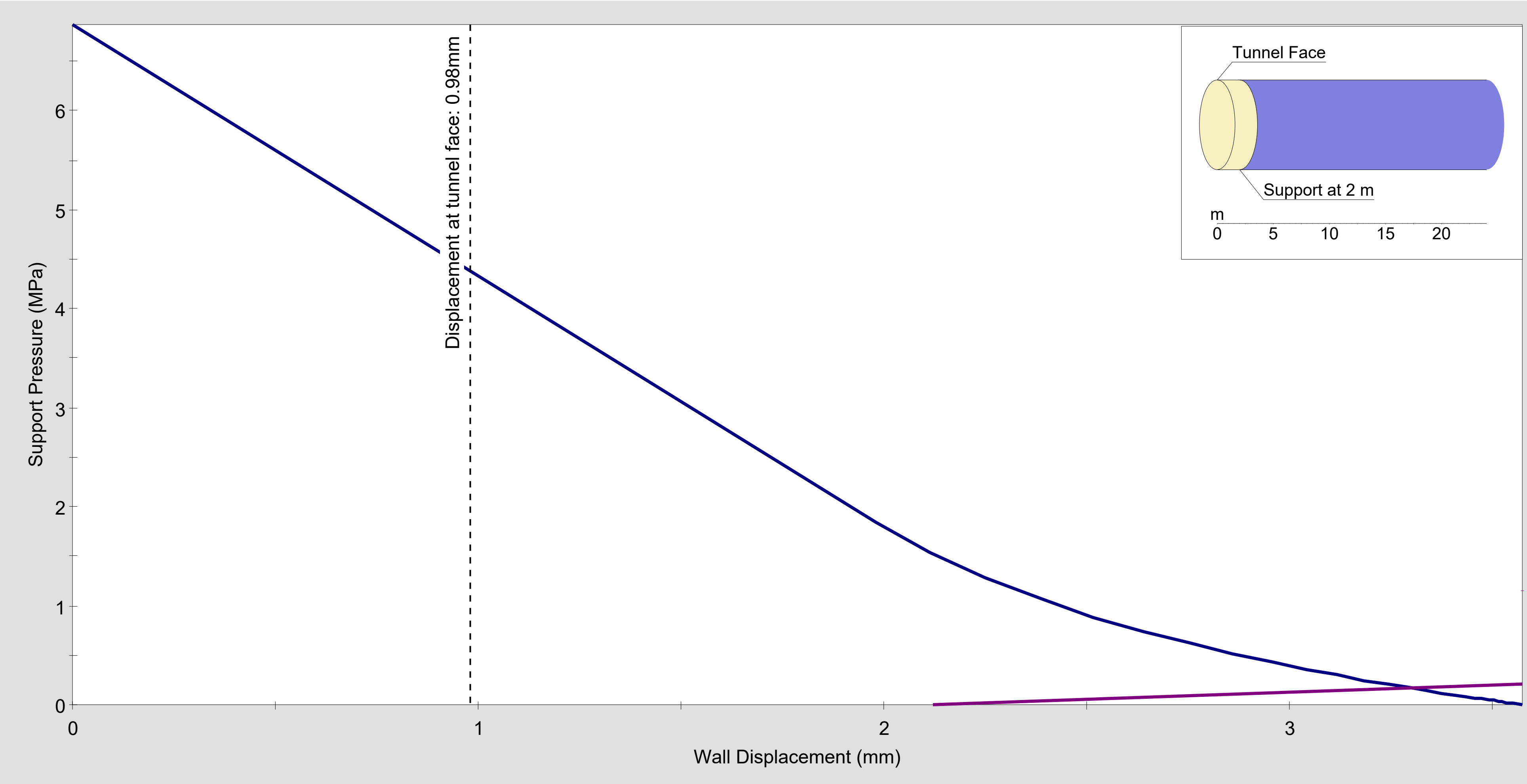
Shotcrete :
Type : **Custom**
Properties : **Thickness = 150 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.104** MPa
Maximum support strain : **0.103** %



Project Title: FotuLa Tunnel CP1
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 4m
In-situ Stress: 6.87MPa
Factor of Safety: 6.71
Mobilized Support Pressure: 0.17MPa
Radius of Plastic Zone: 5.01m, 5.18m (unsupported)
Tunnel Convergence: 0.08%, 0.09% (unsupported)

rocscience	*Project*	FotuLa Tunnel CP1	
	Analysis Description	ESC2 - GT1H	
	Drawn By		*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54		*File Name* CP-1 GT1H ESC 2.rsp

Ground Reaction
and Support Reaction



Final wall displacement: 3.29mm, FS: 6.71
Displacement at tunnel face: 0.98mm, Displacement at support: 2.12mm

rocscience	Project	FotuLa Tunnel CP1	
	Analysis Description	ESC2 - GT1H	
	Drawn By		Company
ROCSUPPORT 5.003	Date	12-02-2025, 13:13:54	File Name: CP-1 GT1H ESC 2.rsp

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel - CP2**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **1.56**
Mobilized Support Pressure : **1.33** MPa

With support installed :
Radius of Plastic Zone r_p : **7.08** m
Wall Displacement u_p : **67.63** mm
Tunnel Convergence : **1.69** %

With no support installed :
Radius of Plastic Zone r_p : **10.68** m
Wall Displacement u_p : **168.75** mm
Tunnel Convergence : **4.22** %

Deformation at the tunnel face :
Wall displacement : **37.69** mm
Tunnel Convergence : **0.94** %

Critical Pressure p_{cr} : **4.98** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **4** m
In-Situ Stress p_o : **9.59** MPa

Young's Modulus of Rock Mass E : **1300** MPa
Poisson Ratio ν : **0.3**

rocscience	Project	FotuLa Tunnel - CP2	
	Analysis Description	ESC 4 - GT2H	
	Drawn By		Company
ROCSUPPORT 5.003	Date	12-02-2025, 13:13:54	File Name: CP-2 GT2H ESC 4.rsp

Cohesion of Rock Mass C_{rm} : **0.779289** MPa
Compressive Strength of Rock Mass σ_{rm} : **2.4** MPa

Friction Angle ϕ : **24°**

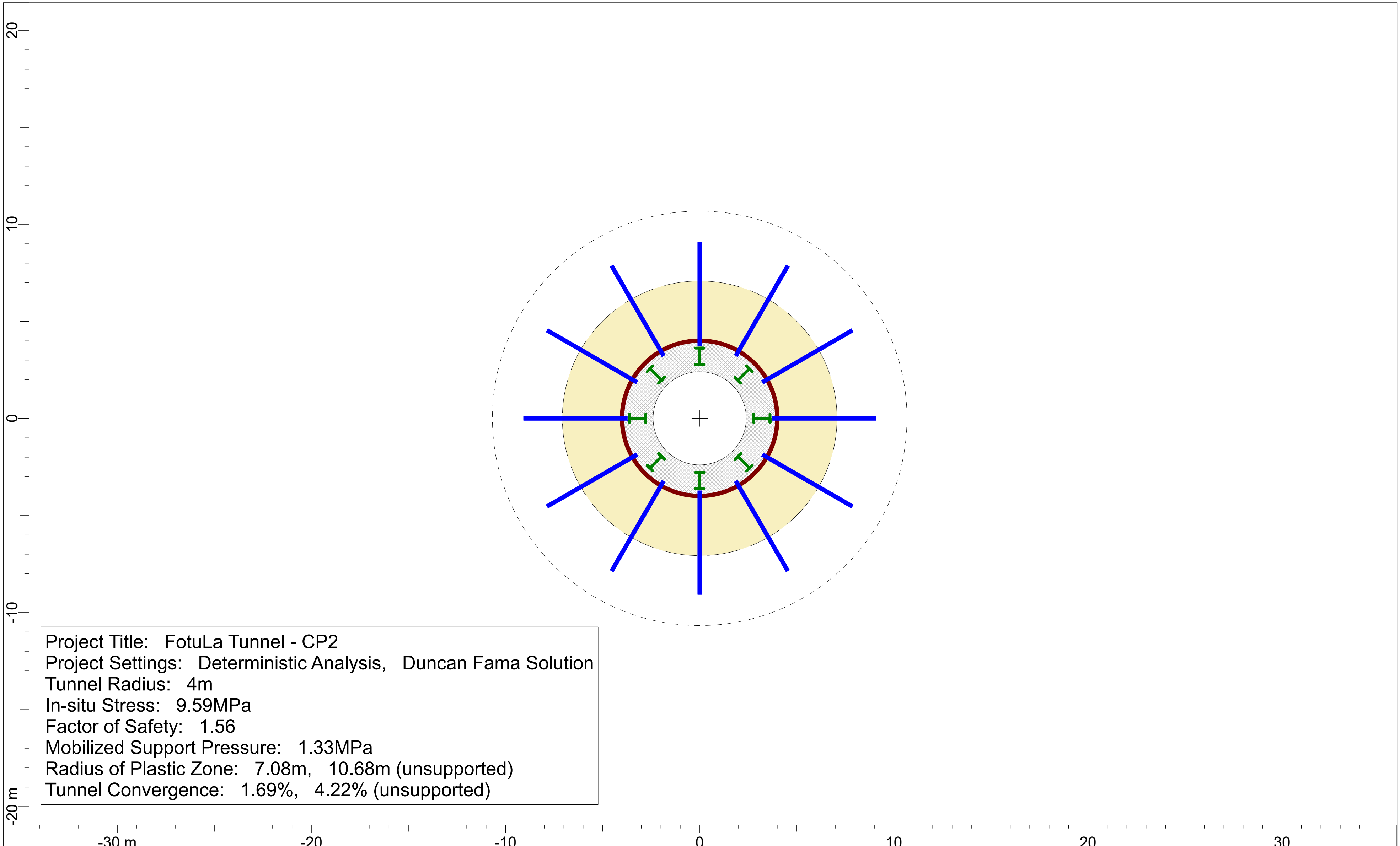
Support Parameters:

Total combined :
Maximum support pressure : **2.076** MPa
Maximum support strain : **0.315** %
Installed at distance from tunnel face : **1.3** m
Initial Tunnel Convergence : **1.49** %
Initial Wall Displacement : **59.56** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 6 m**
Maximum support pressure : **0.179** MPa
Maximum support strain : **0.315** %
Rockbolt Circumferential Spacing : **1.5** m
Rockbolt Longitudinal Spacing : **1.3** m

Steelset :
Type : **Custom**
Properties : **Area = 1040 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.08** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **0.8** m

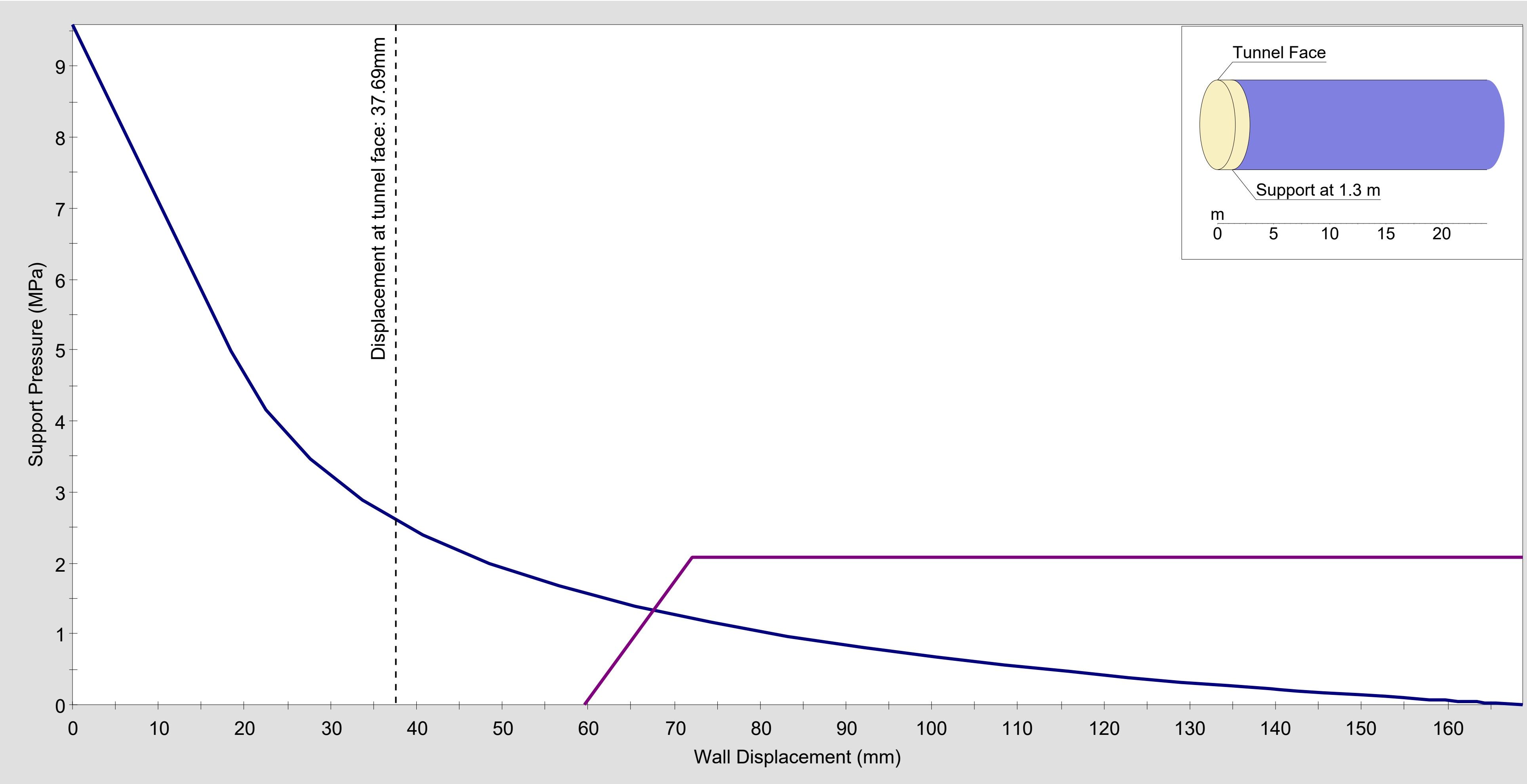
Shotcrete :
Type : **Custom**
Properties : **Thickness = 250 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.816** MPa
Maximum support strain : **0.1** %



Project Title: FotuLa Tunnel - CP2
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 4m
In-situ Stress: 9.59MPa
Factor of Safety: 1.56
Mobilized Support Pressure: 1.33MPa
Radius of Plastic Zone: 7.08m, 10.68m (unsupported)
Tunnel Convergence: 1.69%, 4.22% (unsupported)

rocscience ROCSUPPORT 5.003	*Project* FotuLa Tunnel - CP2		
	Analysis Description ESC 4 - GT2H		
	Drawn By	*Company*	
	Date 12-02-2025, 13:13:54	*File Name* CP-2 GT2H ESC 4.rsp	

Ground Reaction and Support Reaction



Final wall displacement: 67.63mm, FS: 1.56
Displacement at tunnel face: 37.69mm, Displacement at support: 59.56mm

rocscience	Project	FotuLa Tunnel - CP2		
	Analysis Description	ESC 4 - GT2H		
	Drawn By		Company	
ROCSUPPORT 5.003	Date	12-02-2025, 13:13:54	File Name	CP-2 GT2H ESC 4.rsp

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel CP1**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **7.86**
Mobilized Support Pressure : **0.05** MPa

With support installed :
Radius of Plastic Zone r_p : **5.13** m
Wall Displacement u_p : **3.49** mm
Tunnel Convergence : **0.09** %

With no support installed :
Radius of Plastic Zone r_p : **5.18** m
Wall Displacement u_p : **3.57** mm
Tunnel Convergence : **0.09** %

Deformation at the tunnel face :
Wall displacement : **0.98** mm
Tunnel Convergence : **0.02** %

Critical Pressure p_{cr} : **1.84** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **4** m
In-Situ Stress p_o : **6.87** MPa

Young's Modulus of Rock Mass E : **13200** MPa
Poisson Ratio ν : **0.3**

rocscience			
	Project	FotuLa Tunnel CP1	
	Analysis Description	ESC1 - GT1H	
	Drawn By	Company	
ROCSUPPORT 5.003	Date: 12-02-2025, 13:13:54	File Name	CP-1 GT1H ESC 1.rsp

Cohesion of Rock Mass C_{rm} : **1.22286** MPa

Compressive Strength of Rock Mass σ_{rm} : **4.8** MPa

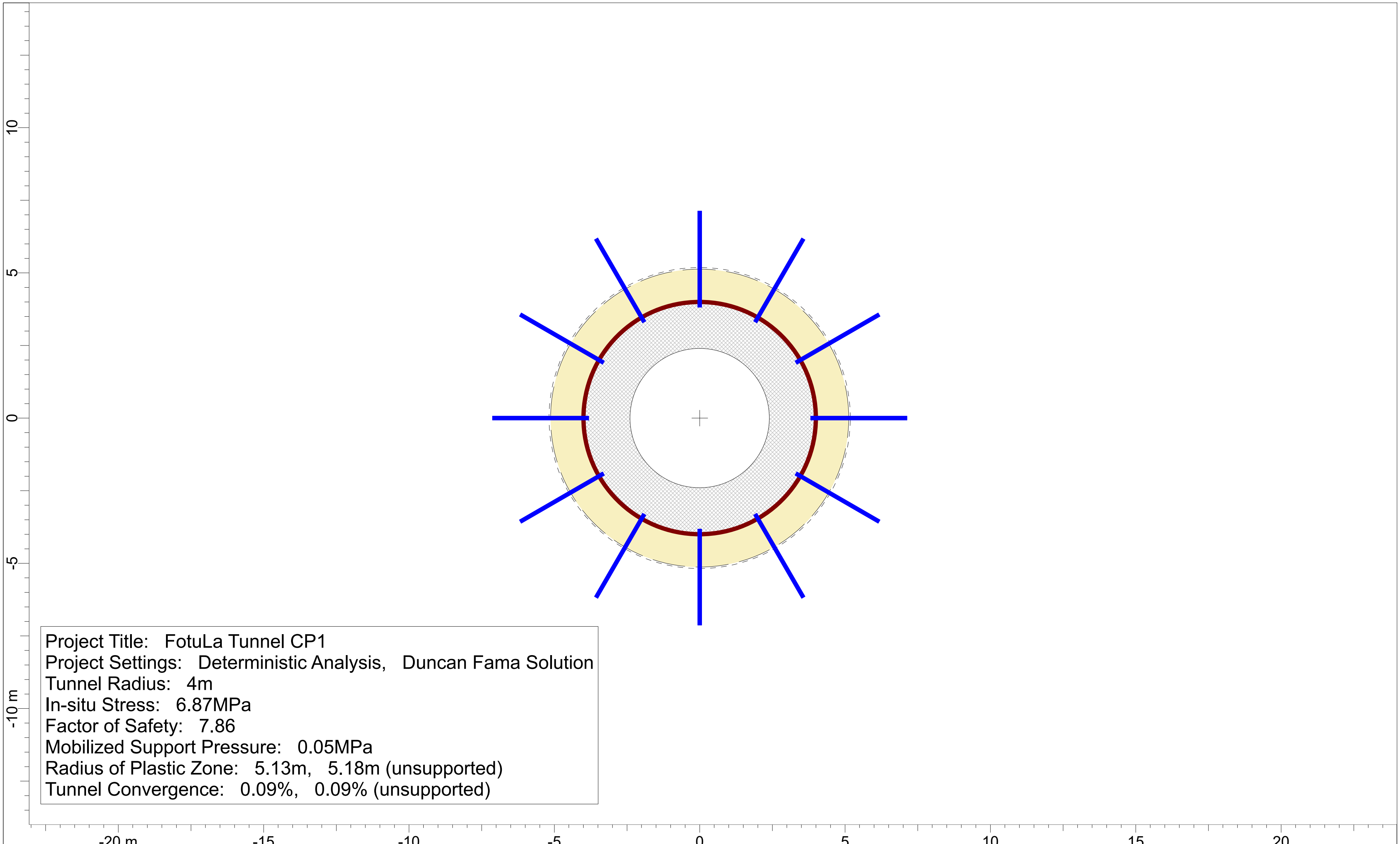
Friction Angle ϕ : **36°**

Support Parameters:

Total combined :
Maximum support pressure : **0.395** MPa
Maximum support strain : **0.197** %
Installed at distance from tunnel face : **3** m
Initial Tunnel Convergence : **0.06** %
Initial Wall Displacement : **2.49** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 25 mm, Capacity = 0.2 MN, Young's Modulus = 207000 MPa, Free Length = 4 m**
Maximum support pressure : **0.022** MPa
Maximum support strain : **0.197** %
Rockbolt Circumferential Spacing : **3** m
Rockbolt Longitudinal Spacing : **3** m

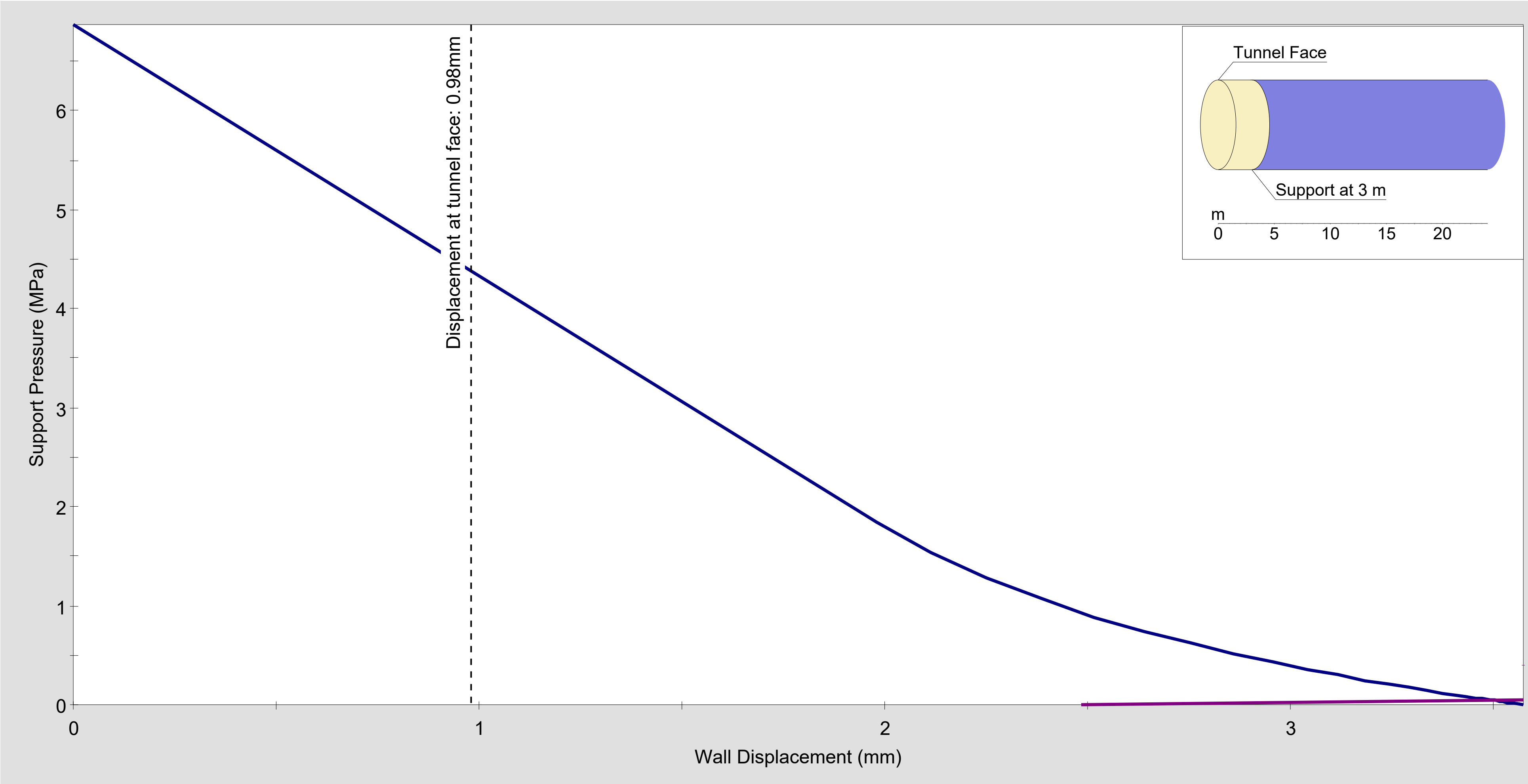
Shotcrete :
Type : **Custom**
Properties : **Thickness = 50 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **0.373** MPa
Maximum support strain : **0.105** %



Project Title: FotuLa Tunnel CP1
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 4m
In-situ Stress: 6.87MPa
Factor of Safety: 7.86
Mobilized Support Pressure: 0.05MPa
Radius of Plastic Zone: 5.13m, 5.18m (unsupported)
Tunnel Convergence: 0.09%, 0.09% (unsupported)

rocscience ROCSUPPORT 5.003	*Project* FotuLa Tunnel CP1		
	Analysis Description ESC1 - GT1H		
	Drawn By	*Company*	
	Date 12-02-2025, 13:13:54	*File Name* CP-1 GT1H ESC 1.rsp	

Ground Reaction and Support Reaction



Final wall displacement: 3.49mm, FS: 7.86
Displacement at tunnel face: 0.98mm, Displacement at support: 2.49mm

rocscience	*Project*	FotuLa Tunnel CP1	
	Analysis Description	ESC1 - GT1H	
	Drawn By		*Company*
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54		*File Name* CP-1 GT1H ESC 1.rsp

RocSupport Project Information

Project Settings:

Project Title: **FotuLa Tunnel CP3**
Solution Method: Duncan Fama solution
Analysis Type: Deterministic
Modulus Method: Hoek, Carranza-Torres, Corkum (2002)

Analysis Results:

Factor of Safety : **2.89**
Mobilized Support Pressure : **0.57** MPa

With support installed :
Radius of Plastic Zone r_p : **10.45** m
Wall Displacement u_p : **122.06** mm
Tunnel Convergence : **3.05** %

With no support installed :
Radius of Plastic Zone r_p : **19.68** m
Wall Displacement u_p : **461.7** mm
Tunnel Convergence : **11.54** %

Deformation at the tunnel face :
Wall displacement : **73.58** mm
Tunnel Convergence : **1.84** %

Critical Pressure p_{cr} : **2.88** MPa

Tunnel and Rock Parameters:

Tunnel Radius r_o : **4** m
In-Situ Stress p_o : **4.9** MPa

Young's Modulus of Rock Mass E : **750** MPa
Poisson Ratio ν : **0.3**

rocscience	Project	FotuLa Tunnel CP3	
	Analysis Description	ESC III - GT3L	
	Drawn By		Company
ROCSUPPORT 5.003	Date	12-02-2025, 13:13:54	File Name: CP-3 GT3L ESC 3.rsp

Cohesion of Rock Mass C_{rm} : **0.202353** MPa
Compressive Strength of Rock Mass σ_{rm} : **0.6** MPa

Friction Angle ϕ : **22°**

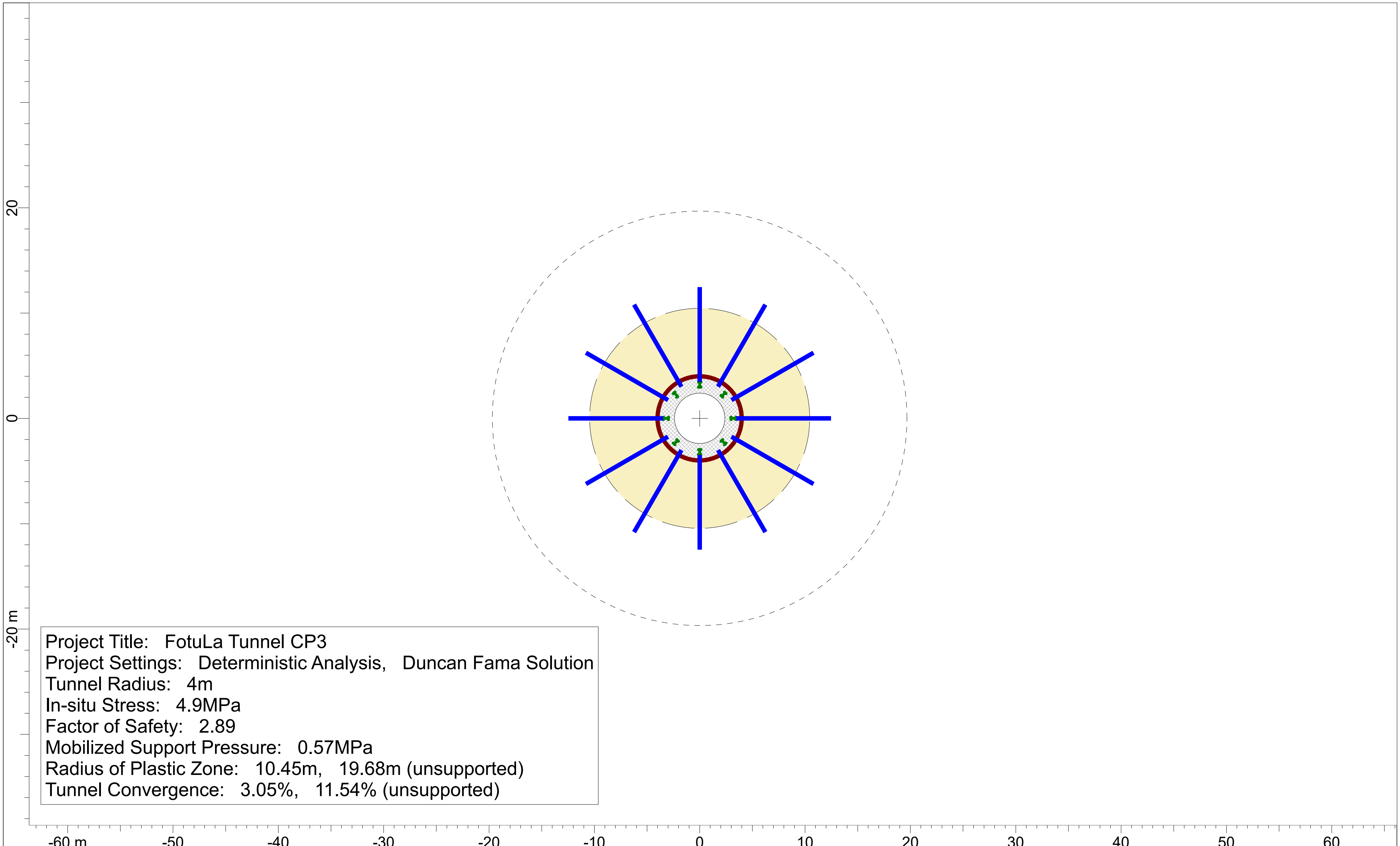
Support Parameters:

Total combined :
Maximum support pressure : **1.643** MPa
Maximum support strain : **0.473** %
Installed at distance from tunnel face : **1.5** m
Initial Tunnel Convergence : **2.89** %
Initial Wall Displacement : **115.51** mm
Longitudinal Deformation Profile : **Vlachopoulos and Diederichs (2009)**

Rockbolts :
Type : **Custom**
Properties : **Diameter = 32 mm, Capacity = 0.35 MN, Young's Modulus = 207000 MPa, Free Length = 9 m**
Maximum support pressure : **0.117** MPa
Maximum support strain : **0.473** %
Rockbolt Circumferential Spacing : **2** m
Rockbolt Longitudinal Spacing : **1.5** m

Steelset :
Type : **Custom**
Properties : **Area = 1040 mm2, Yield Strength = 245 MPa, Young's Modulus = 207000 MPa**
Maximum support pressure : **0.064** MPa
Maximum support strain : **0.118** %
Steelset out-of-plane spacing : **1** m

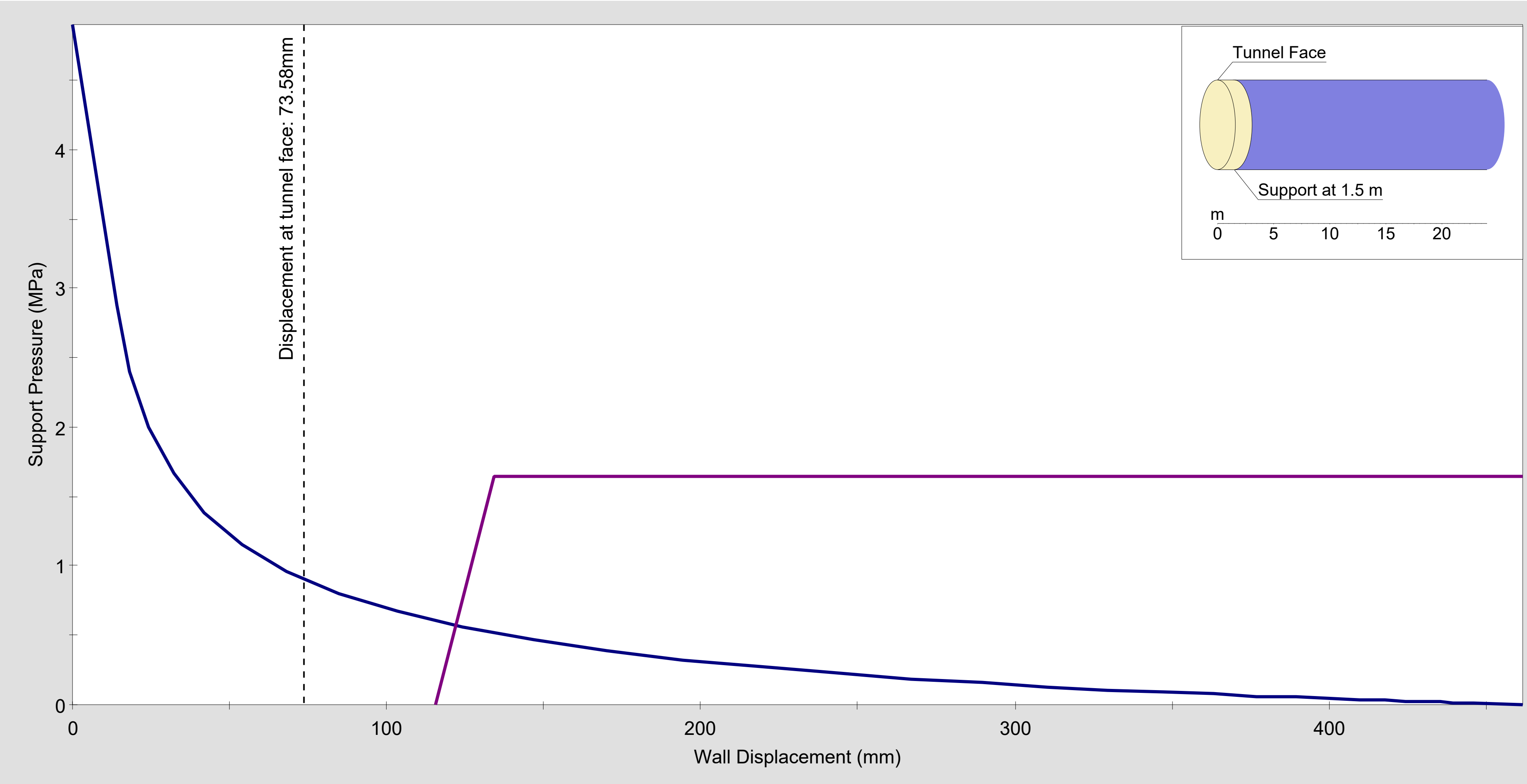
Shotcrete :
Type : **Custom**
Properties : **Thickness = 200 mm, UCS = 30 MPa, Young's Modulus = 27000 MPa, Poisson Ratio = 0.2**
Maximum support pressure : **1.463** MPa
Maximum support strain : **0.101** %



Project Title: FotuLa Tunnel CP3
Project Settings: Deterministic Analysis, Duncan Fama Solution
Tunnel Radius: 4m
In-situ Stress: 4.9MPa
Factor of Safety: 2.89
Mobilized Support Pressure: 0.57MPa
Radius of Plastic Zone: 10.45m, 19.68m (unsupported)
Tunnel Convergence: 3.05%, 11.54% (unsupported)

rocscience	*Project* FotuLa Tunnel CP3		
	Analysis Description ESC III - GT3L		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* CP-3 GT3L ESC 3.rsp	

Ground Reaction
and Support Reaction



Final wall displacement: 122.06mm, FS: 2.89
Displacement at tunnel face: 73.58mm, Displacement at support: 115.51mm

rocscience	*Project* FotuLa Tunnel CP3		
	Analysis Description ESC III - GT3L		
	Drawn By	*Company*	
ROCSUPPORT 5.003	*Date* 12-02-2025, 13:13:54	*File Name* CP-3 GT3L ESC 3.rsp	

ANNEXURE 4 Kinematic / Wedge Analysis of tunnel and results (Unwedge)

UnWedge Analysis Information

Project Summary

File Name:	Unwedge1
Project Title:	FotuLa Tunnel
Analysis:	East Portal Area (P1)
Wedges Computed:	Perimeter and End Wedges
Prismatic Wedges Computed:	No
Units:	Metric, stress as MPa

General Input Data

Tunnel Axis Orientation	
Trend:	270°
Plunge:	0°

Design Factor of Safety:	1.000
Unit Weight of Rock:	0.027 MN/m3
Unit Weight of Water:	0.010 MN/m3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1	
Dip:	80°
Dip Direction:	160°
Joint 2	
Dip:	75°
Dip Direction:	310°
Joint 3	
Dip:	70°
Dip Direction:	220°

Joint Properties

Joint Properties 1	
Water Pressure Type:	Constant
Pressure:	0 MPa
Waviness:	0°
Continuity Type:	Infinite
Shear Strength Model:	Mohr-Coulomb
Phi:	20°
Cohesion:	0.1 MPa
Tensile Strength:	0 MPa

Bolt Properties

Bolt Property 1	
Color	
Bolt Type:	Mechanically Anchored
Tensile Capacity:	0.1 MN
Plate Capacity:	0.1 MN
Anchor Capacity:	0.1 MN
Shear Strength:	Unused
Bolt Orientation Efficiency:	Used
Method:	Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1	
Color:	
Shear Strength:	1.000 MPa
Unit Weight:	0.026 MN/m3
Thickness:	10.00 cm

Support Summary

Summary of Perimeter Shotcrete

No Shotcrete on Perimeter

Summary of Perimeter Support Pressure

No Support Pressure on Perimeter

Summary of Perimeter Bolt Patterns

No Bolt Patterns on Perimeter

Summary of End Bolt Patterns

No Bolt Pattern on Ends

Summary of End Support Pressure

No Support Pressure on Ends

Summary of End Shotcrete

No Shotcrete on Ends

Wedge Information

	Floor wedge [2]	Roof wedge [7]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	stable	3.169	12.409	stable
Wedge Weight [MN]	15.043	10.992	0.311	0.311

UnWedge Analysis Information

Project Summary

File Name:	J1 J3 J4 - P1 (with ESC 2)
Project Title:	FotuLa Tunnel
Analysis:	J1 J3 J4 - P1 (with ESC 2)
Wedges Computed:	Perimeter and End Wedges
Prismatic Wedges Computed:	No
Units:	Metric, stress as MPa

General Input Data

Tunnel Axis Orientation	
Trend:	270°
Plunge:	0°

Design Factor of Safety:	1.000
Unit Weight of Rock:	0.027 MN/m3
Unit Weight of Water:	0.010 MN/m3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1	
Dip:	90°
Dip Direction:	160°
Joint 2	
Dip:	75°
Dip Direction:	185°
Joint 3	
Dip:	75°
Dip Direction:	060°

Joint Properties

Joint Properties 1	
Water Pressure Type:	Constant
Pressure:	0 MPa
Waviness:	0°
Continuity Type:	Infinite
Shear Strength Model:	Mohr-Coulomb
Phi:	20°
Cohesion:	0.1 MPa
Tensile Strength:	0 MPa

Bolt Properties

Bolt Property 1	
Color	
Bolt Type:	Grouted Dowel
Tensile Capacity:	0.2 MN
Plate Capacity:	0.2 MN
Bond Strength:	0.2 MN/m
Bond Length:	100% of Bolt Length
Shear Strength:	Unused
Bolt Orientation Efficiency:	Used
Method:	Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1	
Color:	
Shear Strength:	1.000 MPa
Unit Weight:	0.026 MN/m3
Thickness:	10.00 cm

Support Summary

Summary of Perimeter Shotcrete

Number of Shotcrete Layers on Perimeter: 1

Perimeter Shotcrete Layer 1	
Shotcrete Property:	Shotcrete Property 1

Summary of Perimeter Support Pressure

No Support Pressure on Perimeter

Summary of Perimeter Bolt Patterns

Number of Bolt Patterns on Perimeter: 1

Perimeter Bolt Pattern 1	
Property:	Bolt Property 1
Strength type:	Grouted Dowel
Bolt Length:	4.00 m
Orientation:	normal to boundary
Pattern Spacing - In Plane:	2.50 m
Pattern Spacing - Out of Plane:	2.50 m
Pattern Spacing - Out of Plane Offset:	0.00 m

Summary of End Bolt Patterns

No Bolt Pattern on Ends

Summary of End Support Pressure

No Support Pressure on Ends

Summary of End Shotcrete

No Shotcrete on Ends

Wedge Information

	Lower Right wedge [2]	Roof wedge [4]	Floor wedge [5]	Lower Left wedge [7]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	39.775	1.515	stable	23.065	13.797	11.410
Wedge Weight [MN]	0.012	16.742	28.290	0.014	0.144	0.144

UnWedge Analysis Information

Project Summary

File Name:	J2 J3 J4 - P1
Project Title:	FotuLa Tunnel
Analysis:	J2 J3 J4 - P1 (ESC 2)
Wedges Computed:	Perimeter and End Wedges
Prismatic Wedges Computed:	No
Units:	Metric, stress as MPa

General Input Data

Tunnel Axis Orientation	
Trend:	270°
Plunge:	0°

Design Factor of Safety:	1.000
Unit Weight of Rock:	0.027 MN/m3
Unit Weight of Water:	0.010 MN/m3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1	
Dip:	75°
Dip Direction:	160°
Joint 2	
Dip:	75°
Dip Direction:	185°
Joint 3	
Dip:	75°
Dip Direction:	060°

Joint Properties

Joint Properties 1	
Water Pressure Type:	Constant
Pressure:	0 MPa
Waviness:	0°
Continuity Type:	Infinite
Shear Strength Model:	Mohr-Coulomb
Phi:	20°
Cohesion:	0.1 MPa
Tensile Strength:	0 MPa

Bolt Properties

Bolt Property 1	
Color	
Bolt Type:	Mechanically Anchored
Tensile Capacity:	0.1 MN
Plate Capacity:	0.1 MN
Anchor Capacity:	0.1 MN
Shear Strength:	Unused
Bolt Orientation Efficiency:	Used
Method:	Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1	
Color:	
Shear Strength:	1.000 MPa
Unit Weight:	0.026 MN/m3
Thickness:	10.00 cm

Support Summary

Summary of Perimeter Shotcrete

Number of Shotcrete Layers on Perimeter: 1

Perimeter Shotcrete Layer 1	
Shotcrete Property:	Shotcrete Property 1

Summary of Perimeter Support Pressure

No Support Pressure on Perimeter

Summary of Perimeter Bolt Patterns

Number of Bolt Patterns on Perimeter: 1

Perimeter Bolt Pattern 1	
Property:	Bolt Property 1
Strength type:	Mechanically Anchored
Bolt Length:	4.00 m
Orientation:	normal to boundary
Pattern Spacing - In Plane:	2.50 m
Pattern Spacing - Out of Plane:	2.50 m
Pattern Spacing - Out of Plane Offset:	0.00 m

Summary of End Bolt Patterns

No Bolt Pattern on Ends

Summary of End Support Pressure

No Support Pressure on Ends

Summary of End Shotcrete

No Shotcrete on Ends

Wedge Information

	Roof wedge [4]	Floor wedge [5]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	1.232	stable	stable	78.463
Wedge Weight [MN]	71.851	84.429	0.003	0.003

UnWedge Analysis Information

Project Summary

File Name:	J1 J3 J4 - P2 (ESC 2)
Project Title:	FotuLa Tunnel
Analysis:	J1 J3 J4 - P2 (ESC 2)
Wedges Computed:	Perimeter and End Wedges
Prismatic Wedges Computed:	No
Units:	Metric, stress as MPa

General Input Data

Tunnel Axis Orientation	
Trend:	290°
Plunge:	0°

Design Factor of Safety:	1.000
Unit Weight of Rock:	0.027 MN/m3
Unit Weight of Water:	0.010 MN/m3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1	
Dip:	90°
Dip Direction:	160°
Joint 2	
Dip:	75°
Dip Direction:	185°
Joint 3	
Dip:	75°
Dip Direction:	060°

Joint Properties

Joint Properties 1	
Water Pressure Type:	Constant
Pressure:	0 MPa
Waviness:	0°
Continuity Type:	Infinite
Shear Strength Model:	Mohr-Coulomb
Phi:	20°
Cohesion:	0.1 MPa
Tensile Strength:	0 MPa

Bolt Properties

Bolt Property 1	
Color	
Bolt Type:	Mechanically Anchored
Tensile Capacity:	0.1 MN
Plate Capacity:	0.1 MN
Anchor Capacity:	0.1 MN
Shear Strength:	Unused
Bolt Orientation Efficiency:	Used
Method:	Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1	
Color:	
Shear Strength:	1.000 MPa
Unit Weight:	0.026 MN/m3
Thickness:	10.00 cm

Support Summary

Summary of Perimeter Shotcrete

Number of Shotcrete Layers on Perimeter: 1

Perimeter Shotcrete Layer 1	
Shotcrete Property:	Shotcrete Property 1

Summary of Perimeter Support Pressure

No Support Pressure on Perimeter

Summary of Perimeter Bolt Patterns

Number of Bolt Patterns on Perimeter: 1

Perimeter Bolt Pattern 1	
Property:	Bolt Property 1
Strength type:	Mechanically Anchored
Bolt Length:	4.00 m
Orientation:	normal to boundary
Pattern Spacing - In Plane:	2.50 m
Pattern Spacing - Out of Plane:	2.50 m
Pattern Spacing - Out of Plane Offset:	0.00 m

Summary of End Bolt Patterns

No Bolt Pattern on Ends

Summary of End Support Pressure

No Support Pressure on Ends

Summary of End Shotcrete

No Shotcrete on Ends

Wedge Information

	Lower Right wedge [2]	Upper Left wedge [3]	Roof wedge [4]	Floor wedge [5]	Lower Left wedge [7]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	44.080	771.459	2.746	stable	38.565	17.081	14.283
Wedge Weight [MN]	0.013	0.000	4.419	9.501	0.012	0.102	0.102

UnWedge Analysis Information

Project Summary

File Name:	J2 J3 J4 - P2 (ESC 2)
Project Title:	FotuLa Tunnel
Analysis:	J2 J3 J4 - P2 (ESC 2)
Wedges Computed:	Perimeter and End Wedges
Prismatic Wedges Computed:	No
Units:	Metric, stress as MPa

General Input Data

Tunnel Axis Orientation	
Trend:	290°
Plunge:	0°

Design Factor of Safety:	1.000
Unit Weight of Rock:	0.027 MN/m3
Unit Weight of Water:	0.010 MN/m3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1	
Dip:	75°
Dip Direction:	160°
Joint 2	
Dip:	75°
Dip Direction:	185°
Joint 3	
Dip:	75°
Dip Direction:	060°

Joint Properties

Joint Properties 1	
Water Pressure Type:	Constant
Pressure:	0 MPa
Waviness:	0°
Continuity Type:	Infinite
Shear Strength Model:	Mohr-Coulomb
Phi:	20°
Cohesion:	0.1 MPa
Tensile Strength:	0 MPa

Bolt Properties

Bolt Property 1	
Color	
Bolt Type:	Mechanically Anchored
Tensile Capacity:	0.1 MN
Plate Capacity:	0.1 MN
Anchor Capacity:	0.1 MN
Shear Strength:	Unused
Bolt Orientation Efficiency:	Used
Method:	Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1	
Color:	
Shear Strength:	1.000 MPa
Unit Weight:	0.026 MN/m3
Thickness:	10.00 cm

Support Summary

Summary of Perimeter Shotcrete

Number of Shotcrete Layers on Perimeter: 1

Perimeter Shotcrete Layer 1	
Shotcrete Property:	Shotcrete Property 1

Summary of Perimeter Support Pressure

No Support Pressure on Perimeter

Summary of Perimeter Bolt Patterns

Number of Bolt Patterns on Perimeter: 1

Perimeter Bolt Pattern 1	
Property:	Bolt Property 1
Strength type:	Mechanically Anchored
Bolt Length:	4.00 m
Orientation:	normal to boundary
Pattern Spacing - In Plane:	2.50 m
Pattern Spacing - Out of Plane:	2.50 m
Pattern Spacing - Out of Plane Offset:	0.00 m

Summary of End Bolt Patterns

No Bolt Pattern on Ends

Summary of End Support Pressure

No Support Pressure on Ends

Summary of End Shotcrete

No Shotcrete on Ends

Wedge Information

	Roof wedge [4]	Floor wedge [5]	Near End wedge [9]	Far End wedge [10]
Factor of Safety	2.008	stable	stable	21.576
Wedge Weight [MN]	16.744	22.731	0.048	0.048

UnWedge Analysis Information

Project Summary

File Name:	J1 J2 J3 - P2
Project Title:	FotuLa Tunnel
Analysis:	J1 J2 J3 - P2
Wedges Computed:	Perimeter and End Wedges
Prismatic Wedges Computed:	No
Units:	Metric, stress as MPa

General Input Data

Tunnel Axis Orientation	
Trend:	290°
Plunge:	0°

Design Factor of Safety:	1.000
Unit Weight of Rock:	0.027 MN/m3
Unit Weight of Water:	0.010 MN/m3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1	
Dip:	90°
Dip Direction:	310°
Joint 2	
Dip:	80°
Dip Direction:	270°
Joint 3	
Dip:	90°
Dip Direction:	210°

Joint Properties

Joint Properties 1	
Water Pressure Type:	Constant
Pressure:	0 MPa
Waviness:	0°
Continuity Type:	Infinite
Shear Strength Model:	Mohr-Coulomb
Phi:	20°
Cohesion:	0.1 MPa
Tensile Strength:	0 MPa

Bolt Properties

Bolt Property 1	
Color	
Bolt Type:	Mechanically Anchored
Tensile Capacity:	0.1 MN
Plate Capacity:	0.1 MN
Anchor Capacity:	0.1 MN
Shear Strength:	Unused
Bolt Orientation Efficiency:	Used
Method:	Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1	
Color:	
Shear Strength:	1.000 MPa
Unit Weight:	0.026 MN/m3
Thickness:	10.00 cm

Support Summary

Summary of Perimeter Shotcrete

No Shotcrete on Perimeter

Summary of Perimeter Support Pressure

No Support Pressure on Perimeter

Summary of Perimeter Bolt Patterns

No Bolt Patterns on Perimeter

Summary of End Bolt Patterns

No Bolt Pattern on Ends

Summary of End Support Pressure

No Support Pressure on Ends

Summary of End Shotcrete

No Shotcrete on Ends

Wedge Information

	Roof wedge [3]	Upper Left wedge [4]	Floor wedge [6]
Factor of Safety	3.333	414.247	stable
Wedge Weight [MN]	6.977	0.000	9.827

UnWedge Analysis Information

Project Summary

File Name:	J1 J2 J4 - P2
Project Title:	FotuLa Tunnel
Analysis:	J1 J2 J4 - P2
Wedges Computed:	Perimeter and End Wedges
Prismatic Wedges Computed:	No
Units:	Metric, stress as MPa

General Input Data

Tunnel Axis Orientation	
Trend:	290°
Plunge:	0°

Design Factor of Safety:	1.000
Unit Weight of Rock:	0.027 MN/m3
Unit Weight of Water:	0.010 MN/m3

Seismic Forces

Not Used

Scale Wedges Settings

Not Used

Joint Orientations

Joint 1	
Dip:	90°
Dip Direction:	310°
Joint 2	
Dip:	80°
Dip Direction:	270°
Joint 3	
Dip:	90°
Dip Direction:	030°

Joint Properties

Joint Properties 1	
Water Pressure Type:	Constant
Pressure:	0 MPa
Waviness:	0°
Continuity Type:	Infinite
Shear Strength Model:	Mohr-Coulomb
Phi:	20°
Cohesion:	0.1 MPa
Tensile Strength:	0 MPa

Bolt Properties

Bolt Property 1	
Color	
Bolt Type:	Mechanically Anchored
Tensile Capacity:	0.1 MN
Plate Capacity:	0.1 MN
Anchor Capacity:	0.1 MN
Shear Strength:	Unused
Bolt Orientation Efficiency:	Used
Method:	Cosine Tension/Shear

Shotcrete Properties

Shotcrete Property 1	
Color:	
Shear Strength:	1.000 MPa
Unit Weight:	0.026 MN/m3
Thickness:	10.00 cm

Support Summary

Summary of Perimeter Shotcrete

No Shotcrete on Perimeter

Summary of Perimeter Support Pressure

No Support Pressure on Perimeter

Summary of Perimeter Bolt Patterns

No Bolt Patterns on Perimeter

Summary of End Bolt Patterns

No Bolt Pattern on Ends

Summary of End Support Pressure

No Support Pressure on Ends

Summary of End Shotcrete

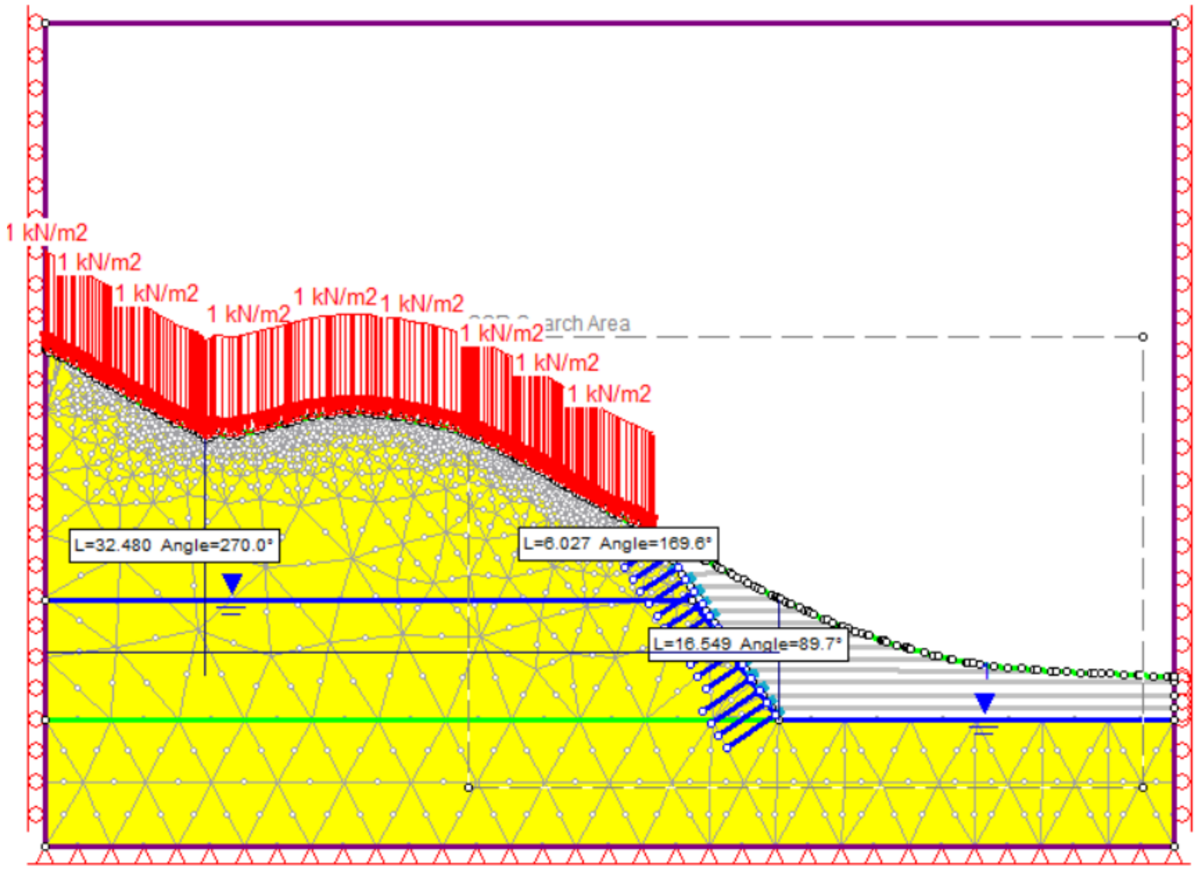
No Shotcrete on Ends

Wedge Information

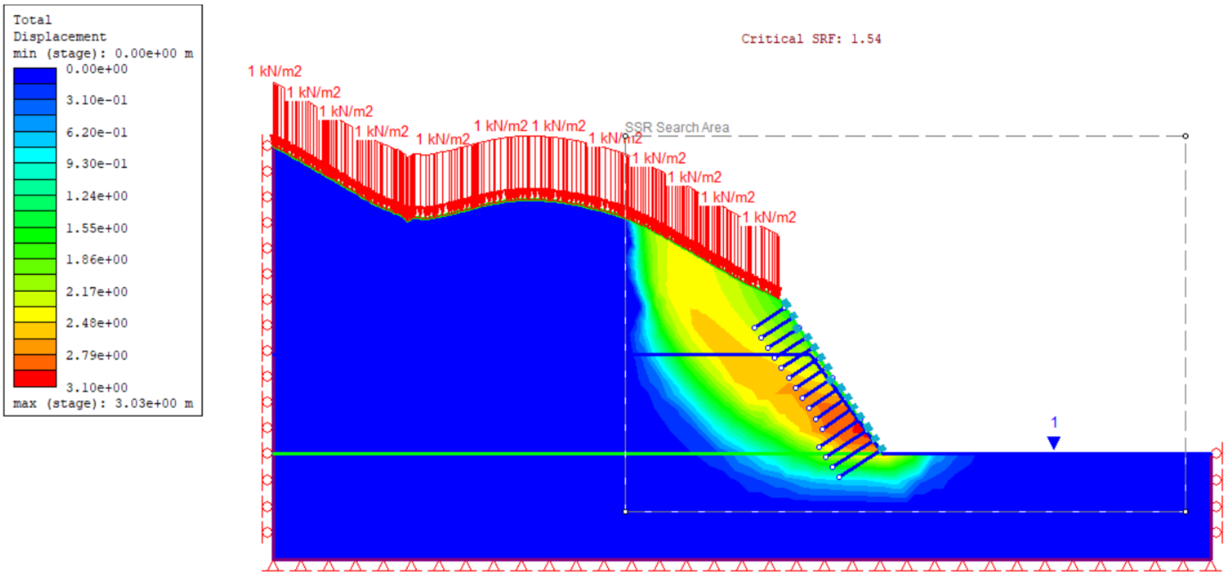
	Upper Left wedge [3]	Roof wedge [4]	Floor wedge [5]
Factor of Safety	414.247	3.333	stable
Wedge Weight [MN]	0.000	6.977	9.827

ANNEXURE 5 Slope stability analysis and results (FEM – SSR Analysis)

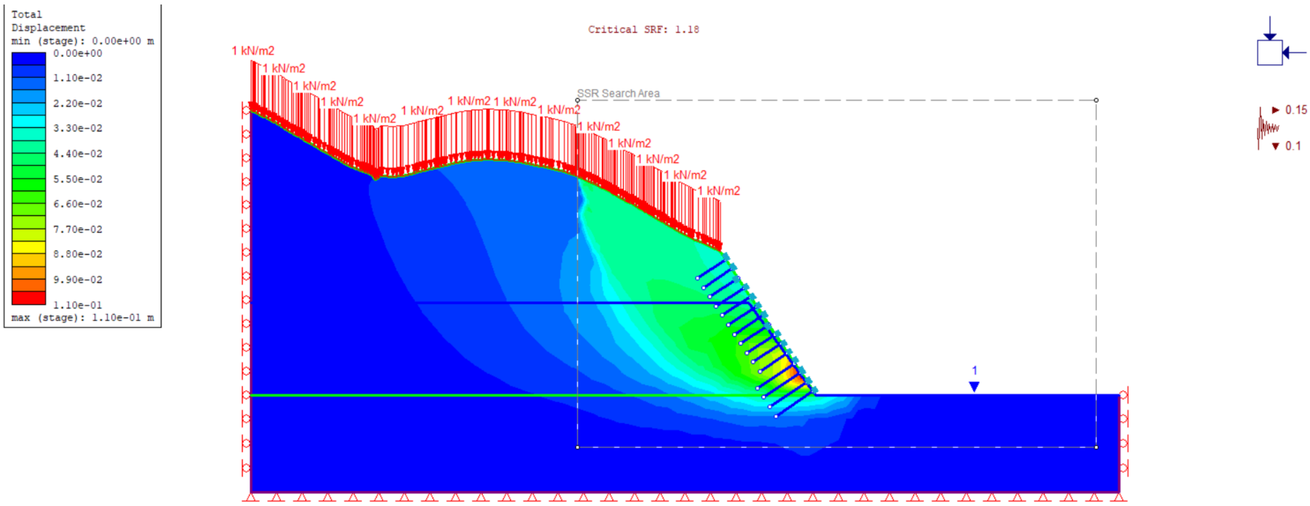
1. SSR Analysis for West Portal – RS2



Geological Model West Portal



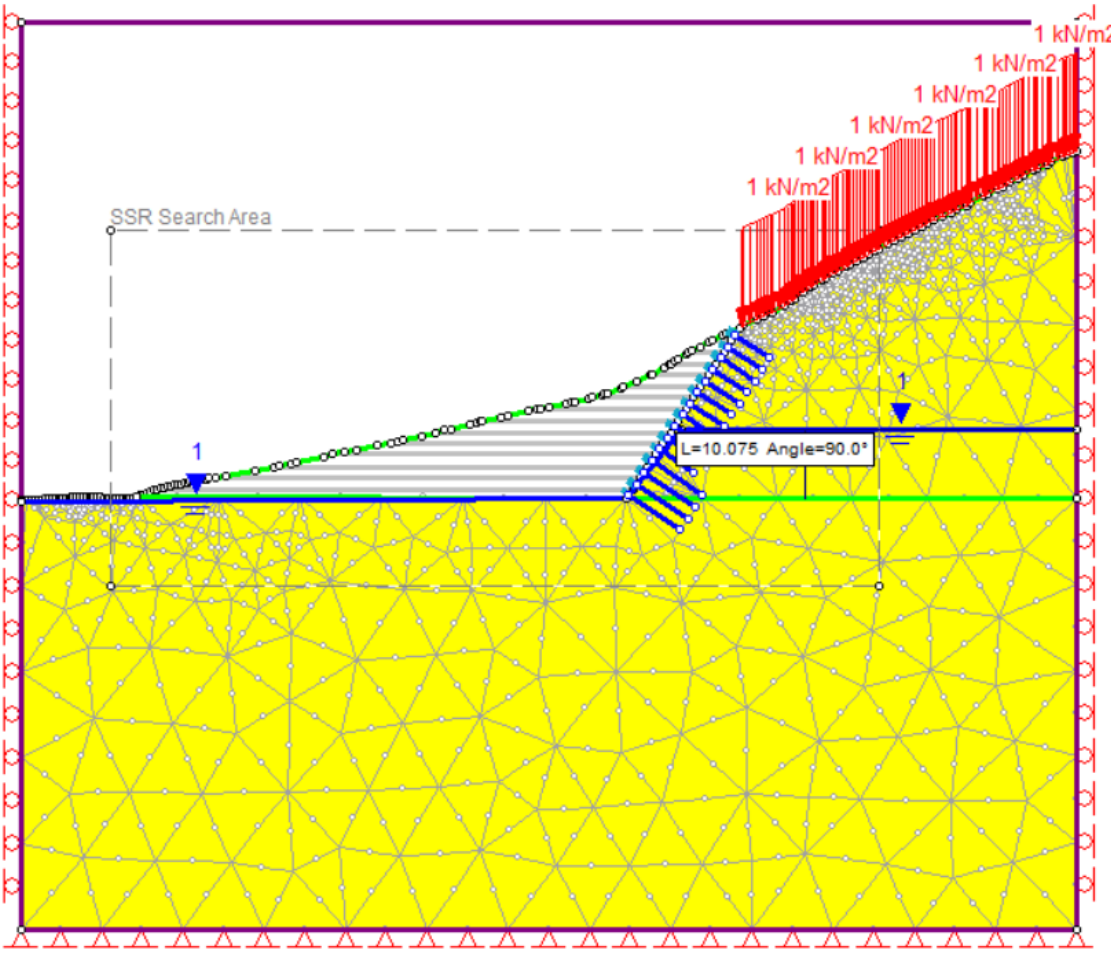
West Portal SSR Analysis results - Without EQ



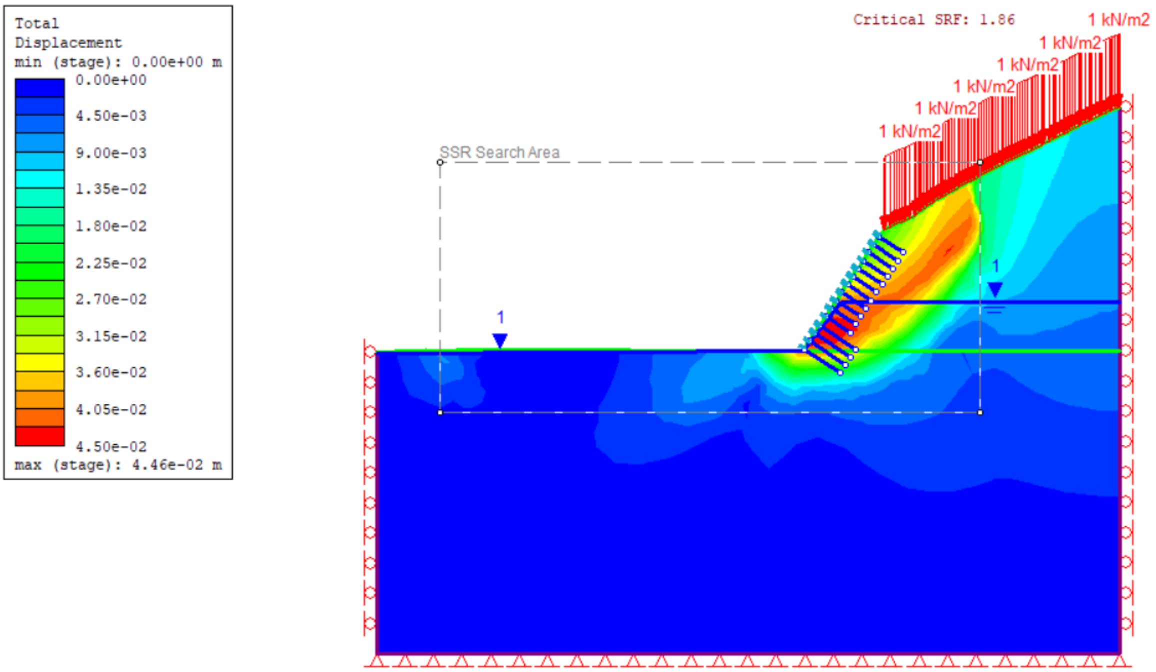
West Portal SSR Analysis results - With EQ

2. SSR Analysis for East Portal – RS2

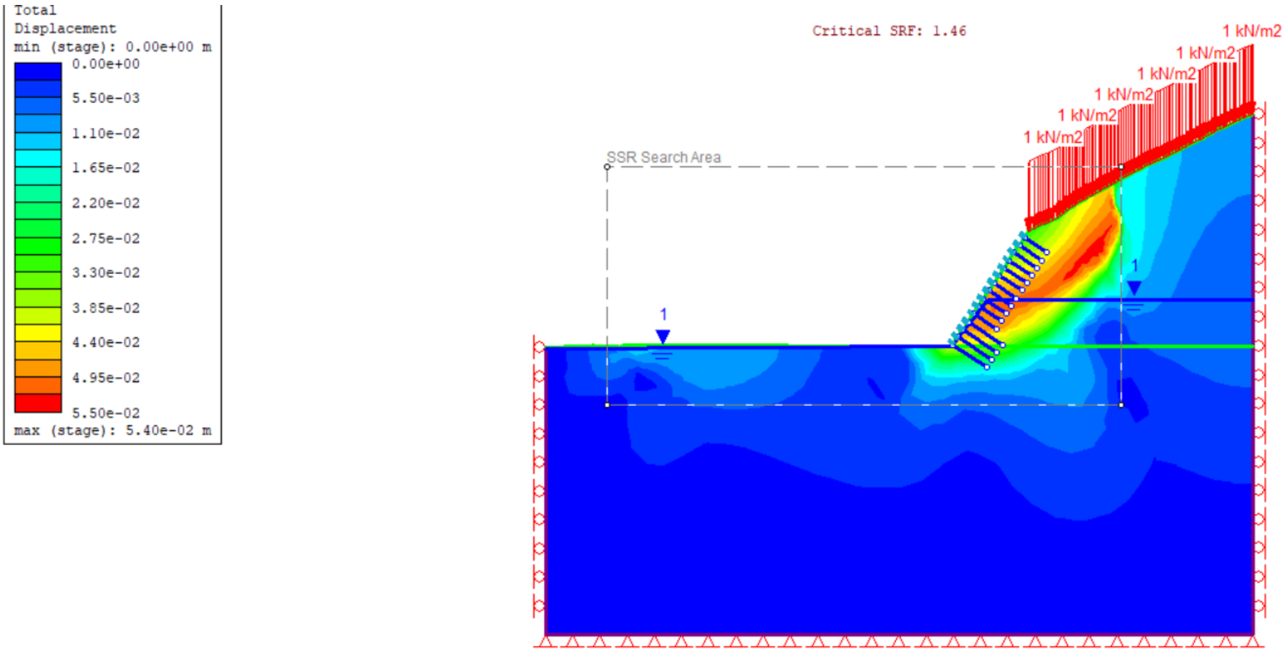
Case-1 – Rockbolts placed perpendicular to the slope



Geological Model East Portal

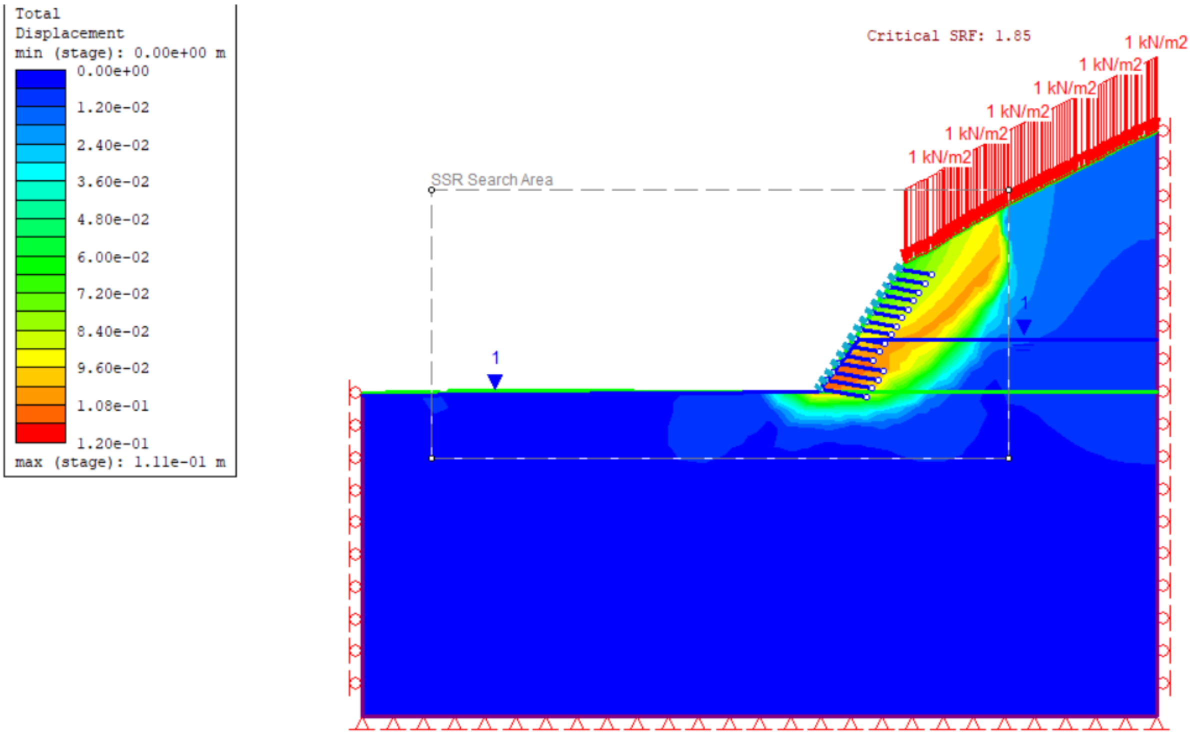


East Portal SSR Analysis results - Without EQ



East Portal SSR Analysis results - With EQ

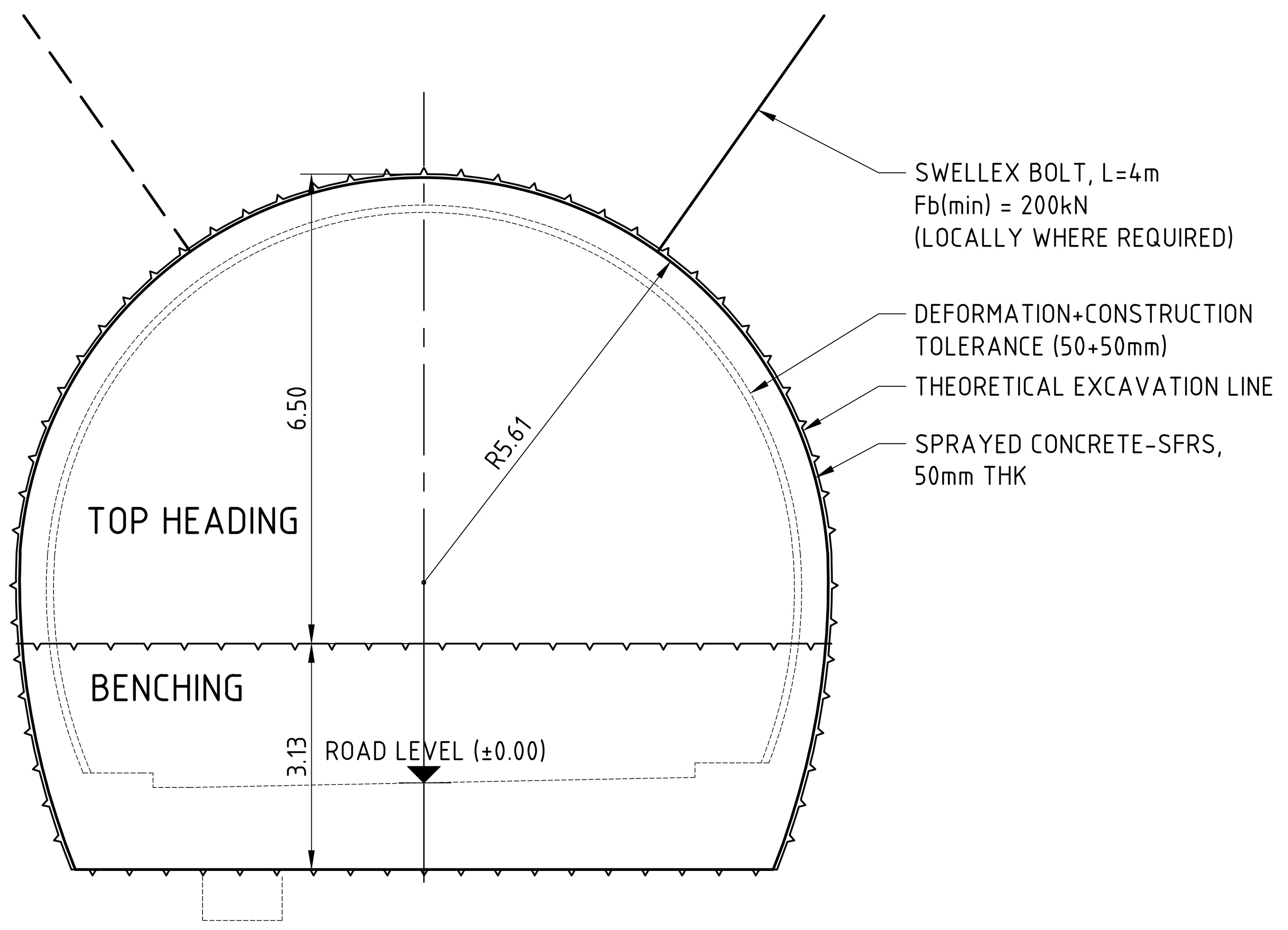
Case-2 – Rockbolts placed 10^0 to the horizontal (For Comparison)



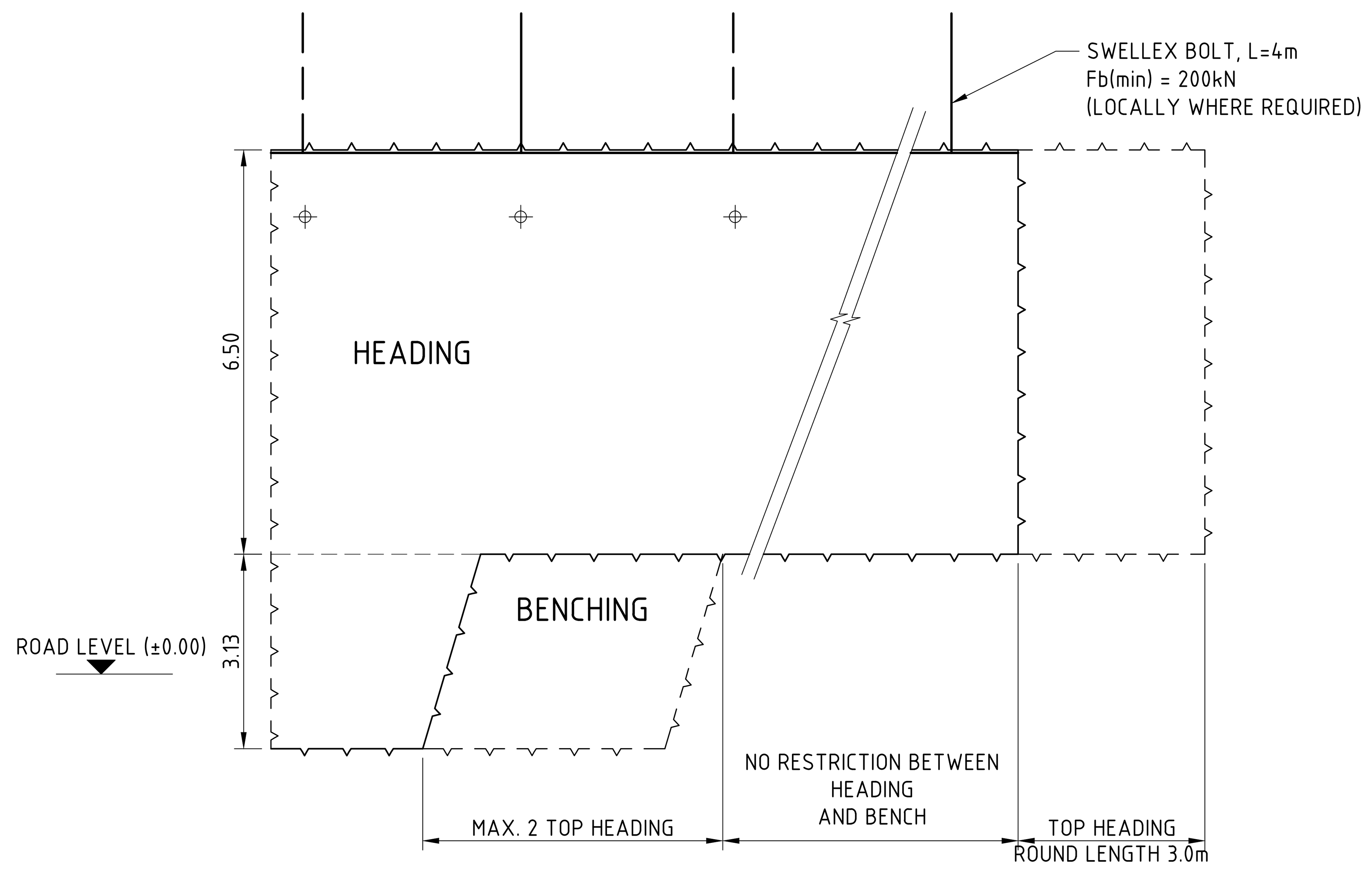
East Portal SSR Analysis results - Without EQ

ANNEXURE 6 (Primary support drawings for Main tunnel)

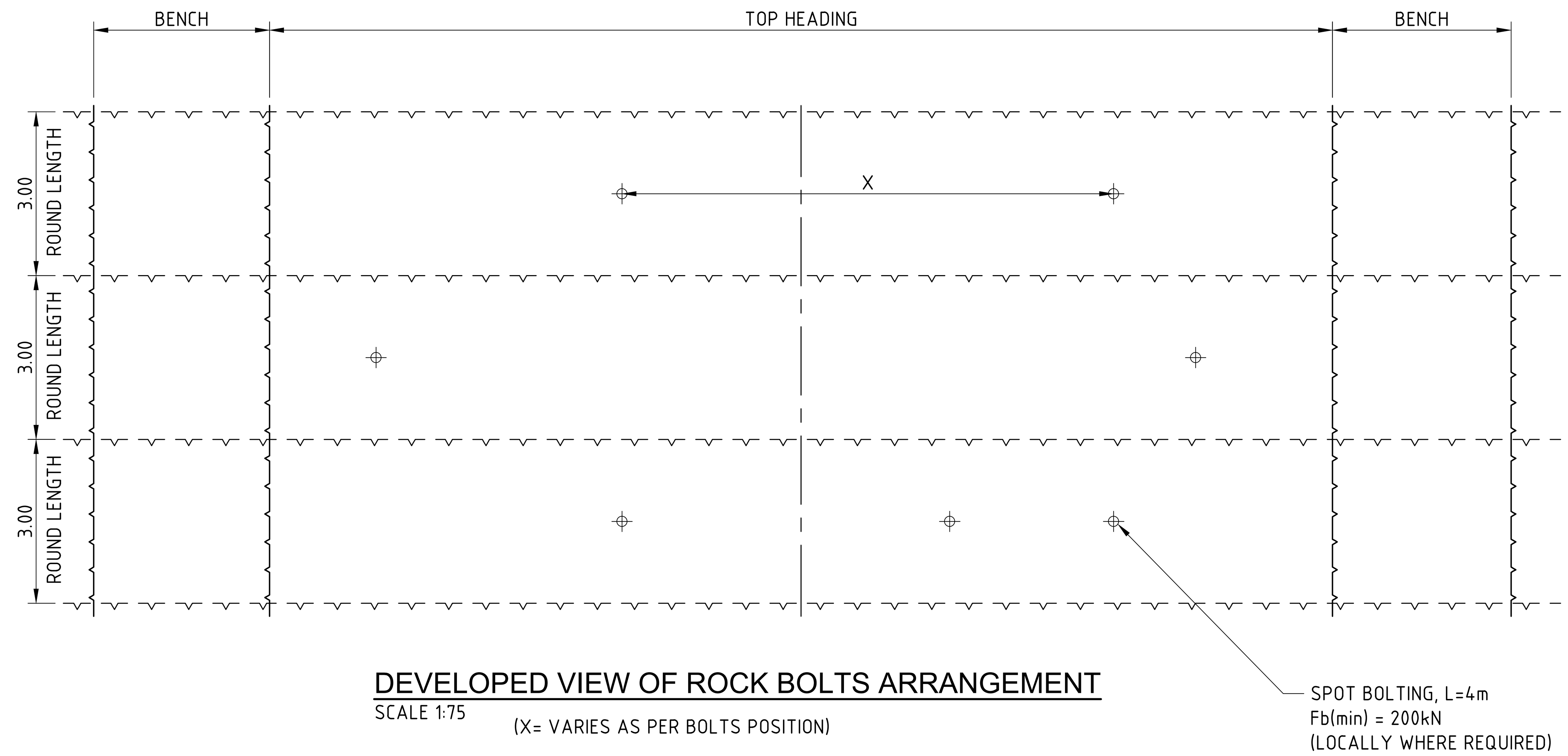
Original Drawing Size A1



SUPPORT CLASS I
CROSS SECTION
SCALE 1:75



LONGITUDINAL SECTION
SCALE 1:75



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT
SCALE 1:75
(X= VARIES AS PER BOLTS POSITION)

EXCAVATION AND SUPPORT QUANTITIES/m

TOP HEADING	Excavation	Round Length	Avg. 3.0m
		Theoretical Excavation Volume	59.75 m^3
		Theoretical Excavation Circumference(excluding invert)	19.46 m
	Support	Sprayed Concrete-SFRS	19.30 m^2
		Swellex Bolts, L=4m	as reqd.
BENCH	Excavation	Round Length	Avg. 6.0m
		Theoretical Excavation Volume	33.32 m^3
		Theoretical Excavation Circumference(excluding invert)	6.44 m
	Support	Sprayed Concrete-SFRS	6.44 m^2

NOTES :
1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3.. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).
4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.

SCALE 1 : 75
2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:
4m BOLT -SWELLEX- Fb(min.) 200 kN

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE
The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commisioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commisioned.

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORT CLASS-I

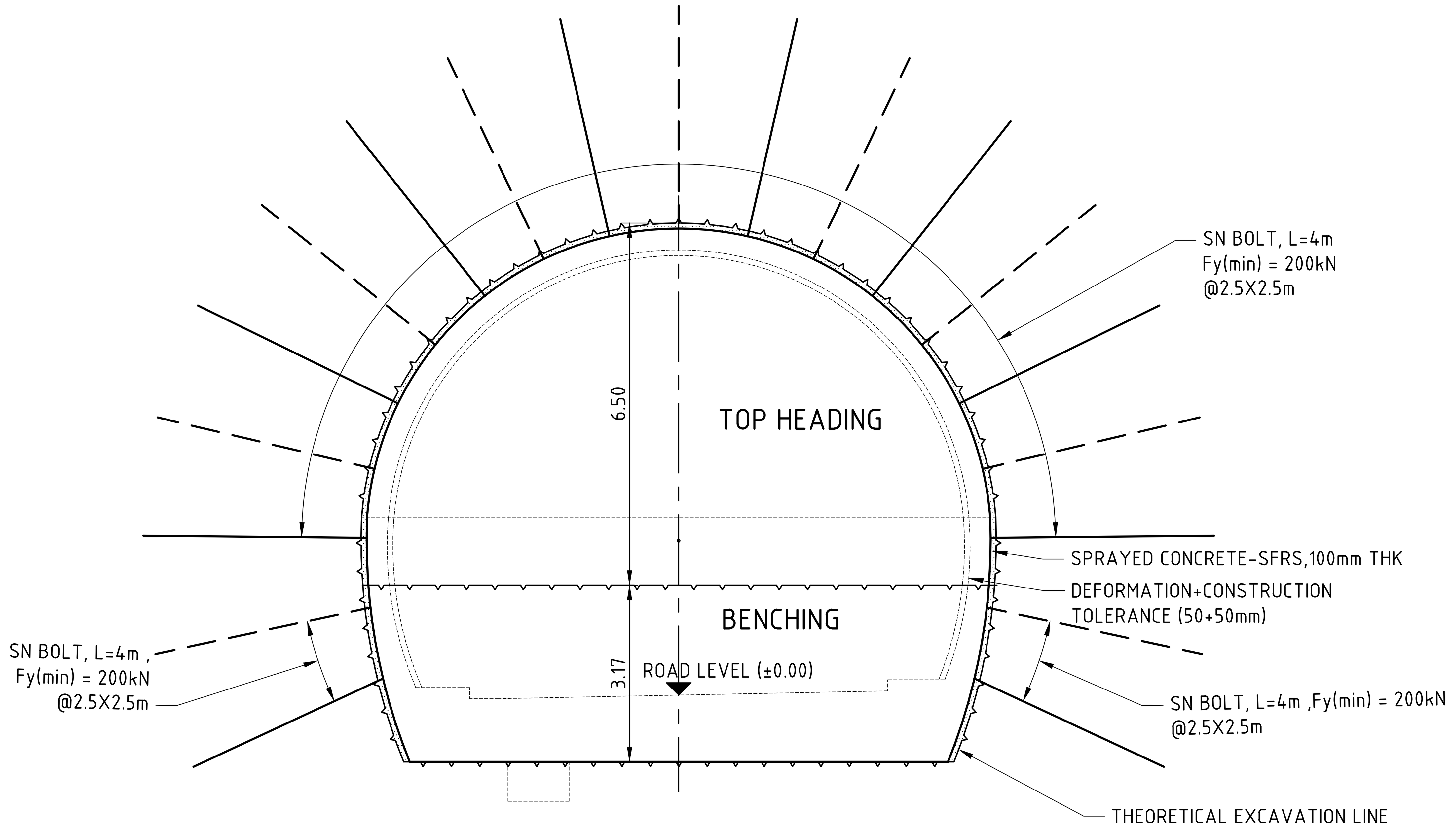
DRAWING NUMBER
FOLA-SUP-MT-1106

REV
A

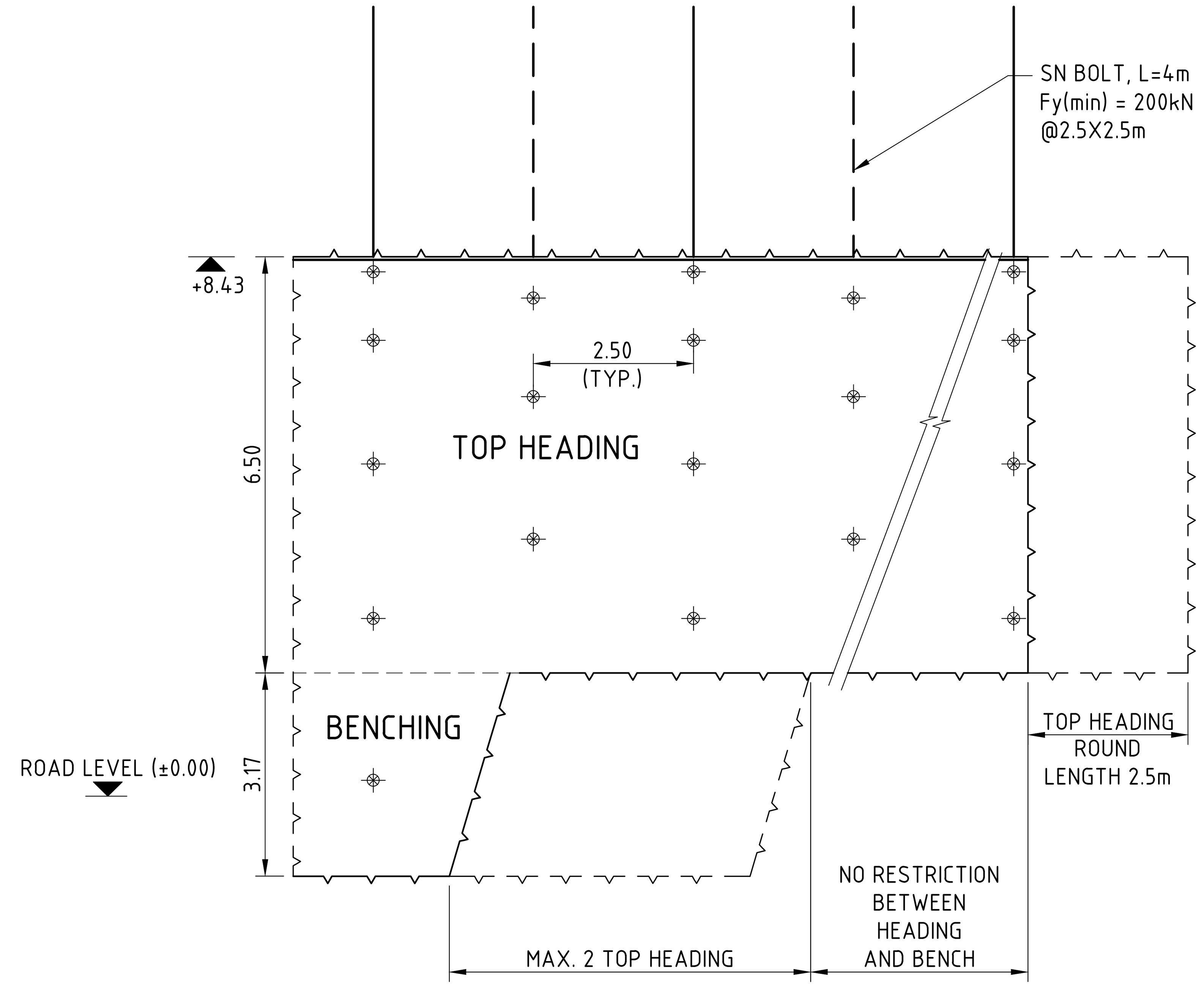
SCALE

MONTH (Current Issue)
FEB 2025

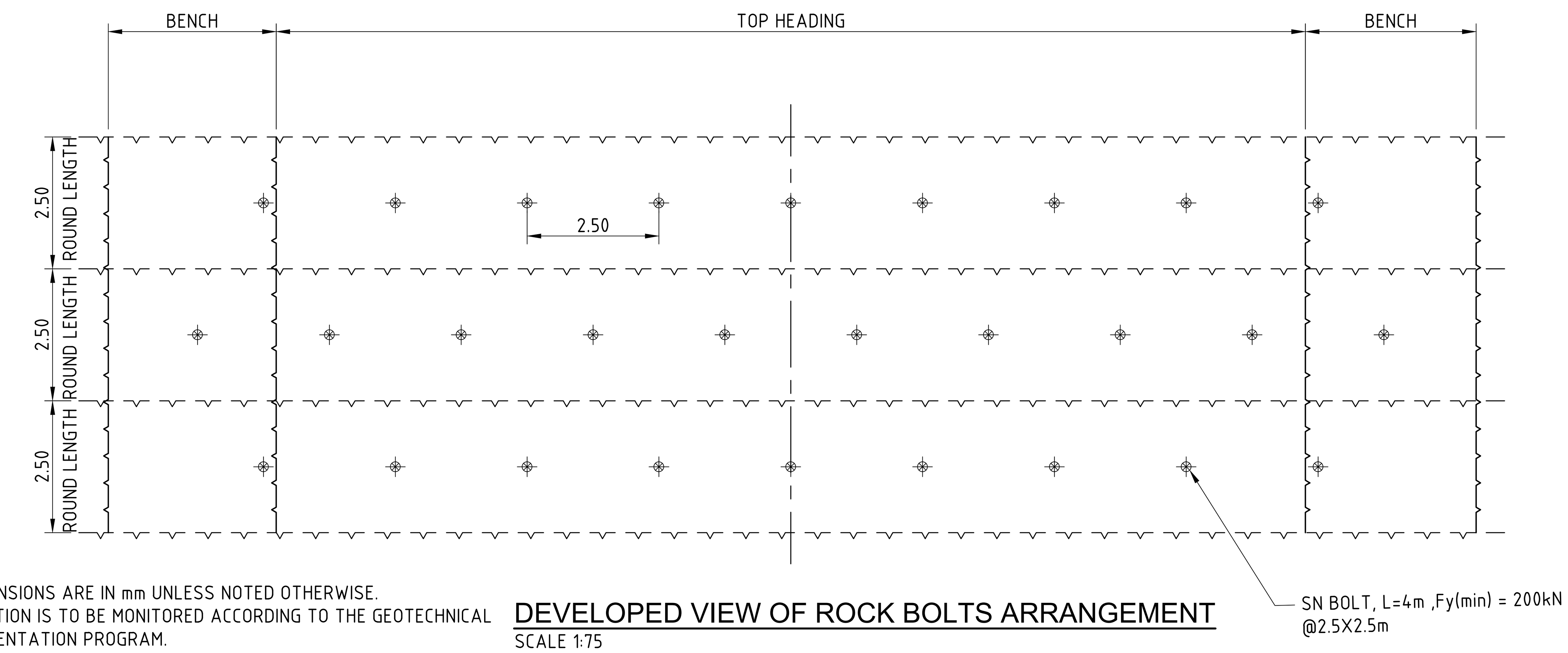
Original Drawing Size A1



SUPPORT CLASS II
CROSS SECTION
SCALE 1:75



LONGITUDINAL SECTION
SCALE 1:75



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT
SCALE 1:75

EXCAVATION AND SUPPORT QUANTITIES/m			
TOP HEADING	Excavation	Round Length	Avg. 2.5m
		Theoretical Excavation Volume	60.18 m^3
		Theoretical Excavation Circumference(excluding invert)	19.52 m
	Support	Sprayed Concrete 100mm Thk.-SFRS	19.36 m^2
		SN Bolts, L=4m	3 no.
BENCH	Excavation	Round Length	Avg. 5 m
		Theoretical Excavation Volume	34.19 m^3
		Theoretical Excavation Circumference (excluding invert)	6.54 m
	Support	Sprayed Concrete-SFRS	6.54 m^2
		SN Bolts, L=4m	0.8 no.

SCALE 1 : 75

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3.. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).
4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

.T Fy(min) 200 kN

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commissioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commissioned.

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORTCLASS-II

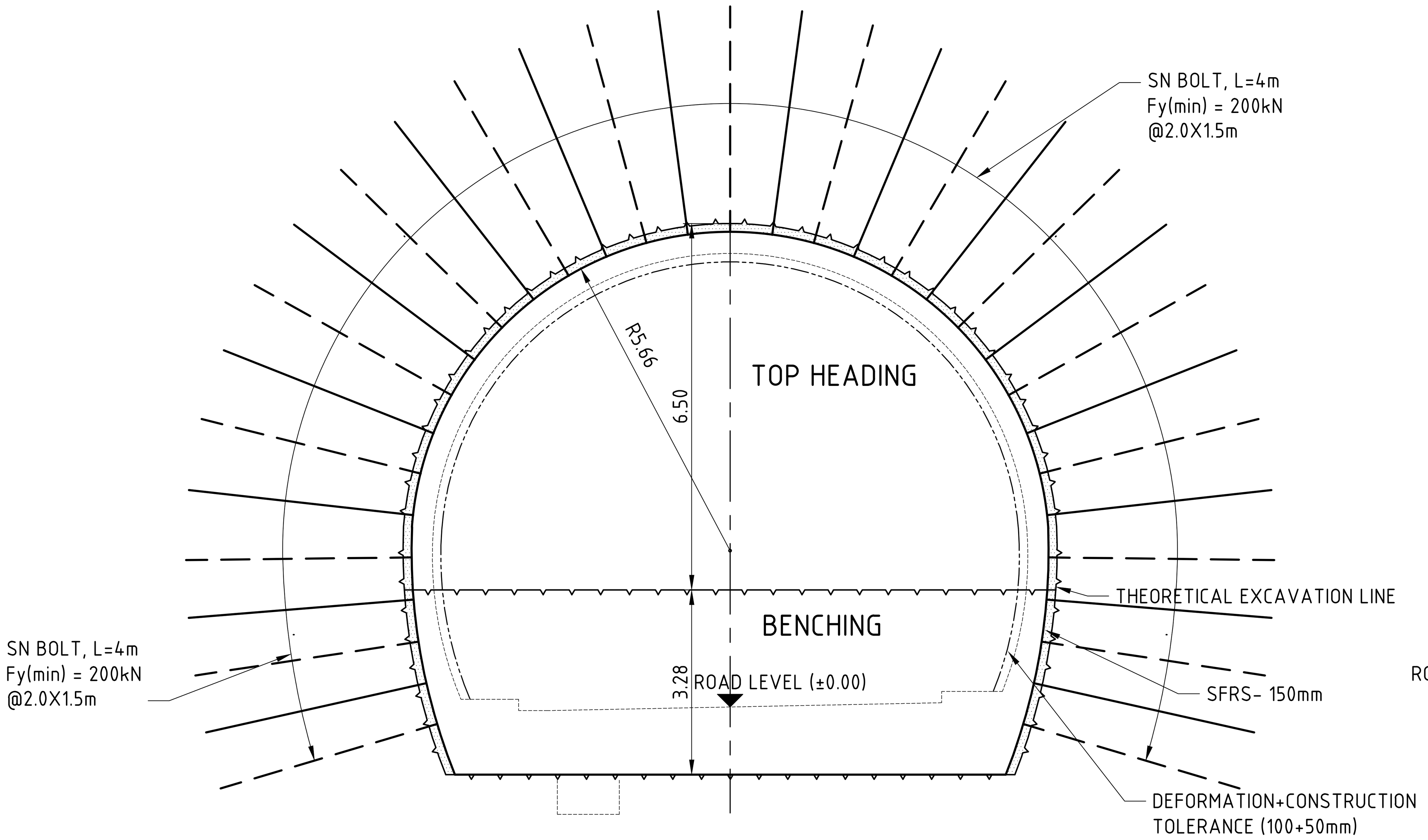
DRAWING NUMBER
FOLA-SUP-MT-1107

REV
A

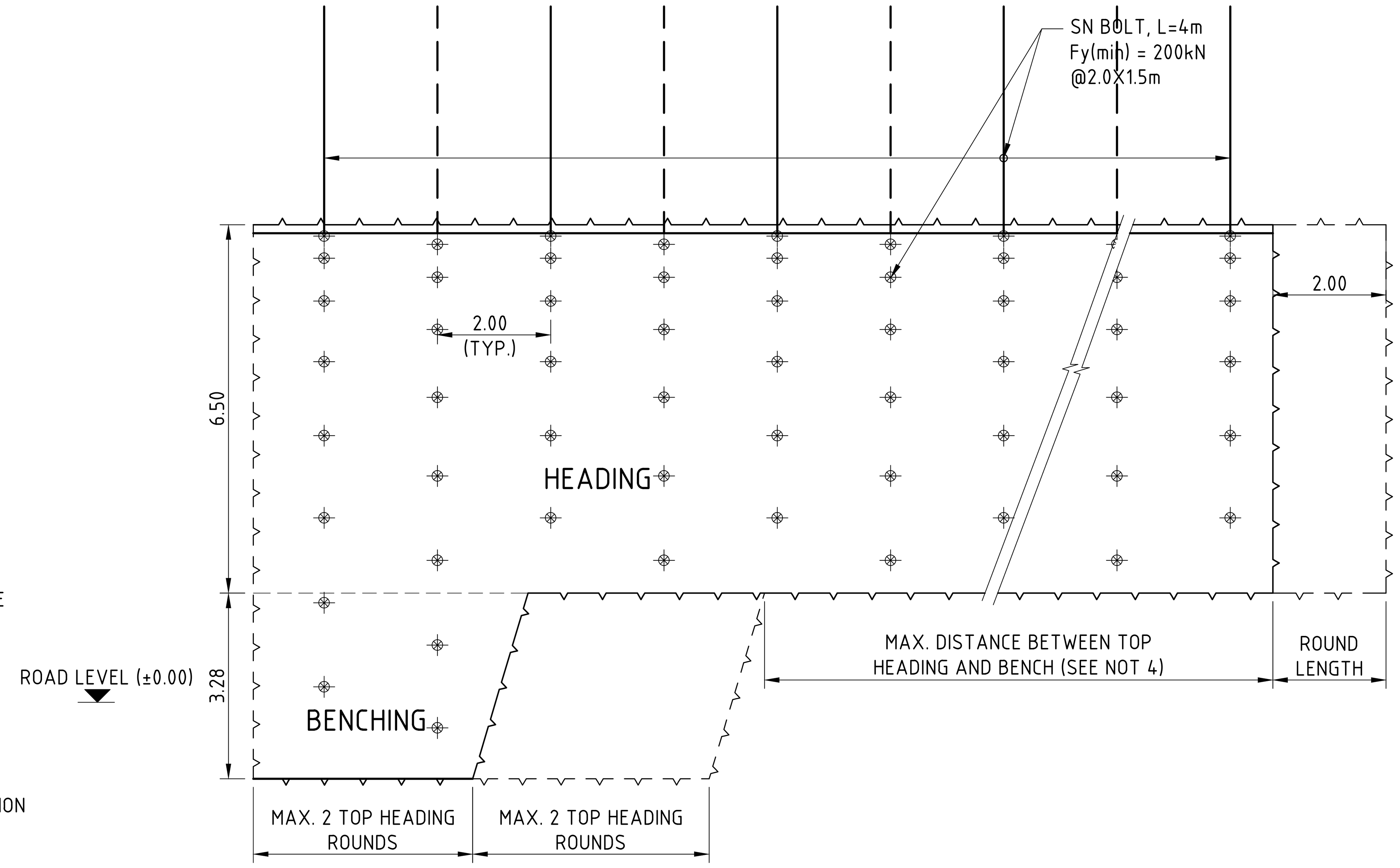
SCALE

MONTH (Current Issue)
FEB 2025

Original Drawing Size A1

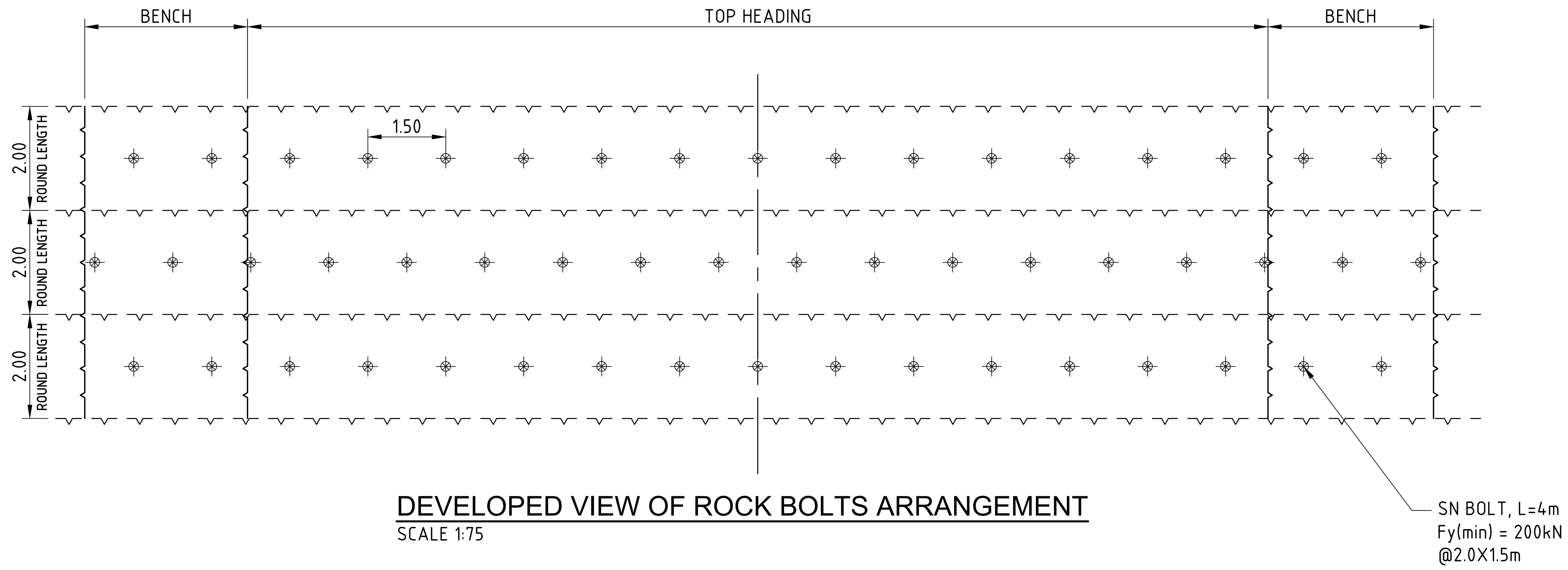


SUPPORT CLASS III
CROSS SECTION
SCALE 1:75



LONGITUDINAL SECTION

SCALE 1:75



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT
SCALE 1:75

EXCAVATION AND SUPPORT QUANTITIES/m

TOP HEADING	Excavation	Round Length	Avg. 2m
		Theoretical Excavation Volume	60.98 m^3
		Theoretical Excavation Circumference(excluding invert)	19.63 m
	Support	Shotcrete-SFRS	19.40 m^2
		SN Bolts, L=4m	6.25 no.
BENCH	Excavation	Round Length	Avg. 4 m
		Theoretical Excavation Volume	36.02 m^3
		Theoretical Excavation Circumference (excluding invert)	6.74 m
	Support	Shotcrete-SFRS	6.74 m^2
		SN Bolts, L=4m	2.0 no.

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3.. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).
4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.

SCALE 1 : 75
2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

⌖ 4m SN BOLT , Fy(min) 200 kN

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORT CLASS-III

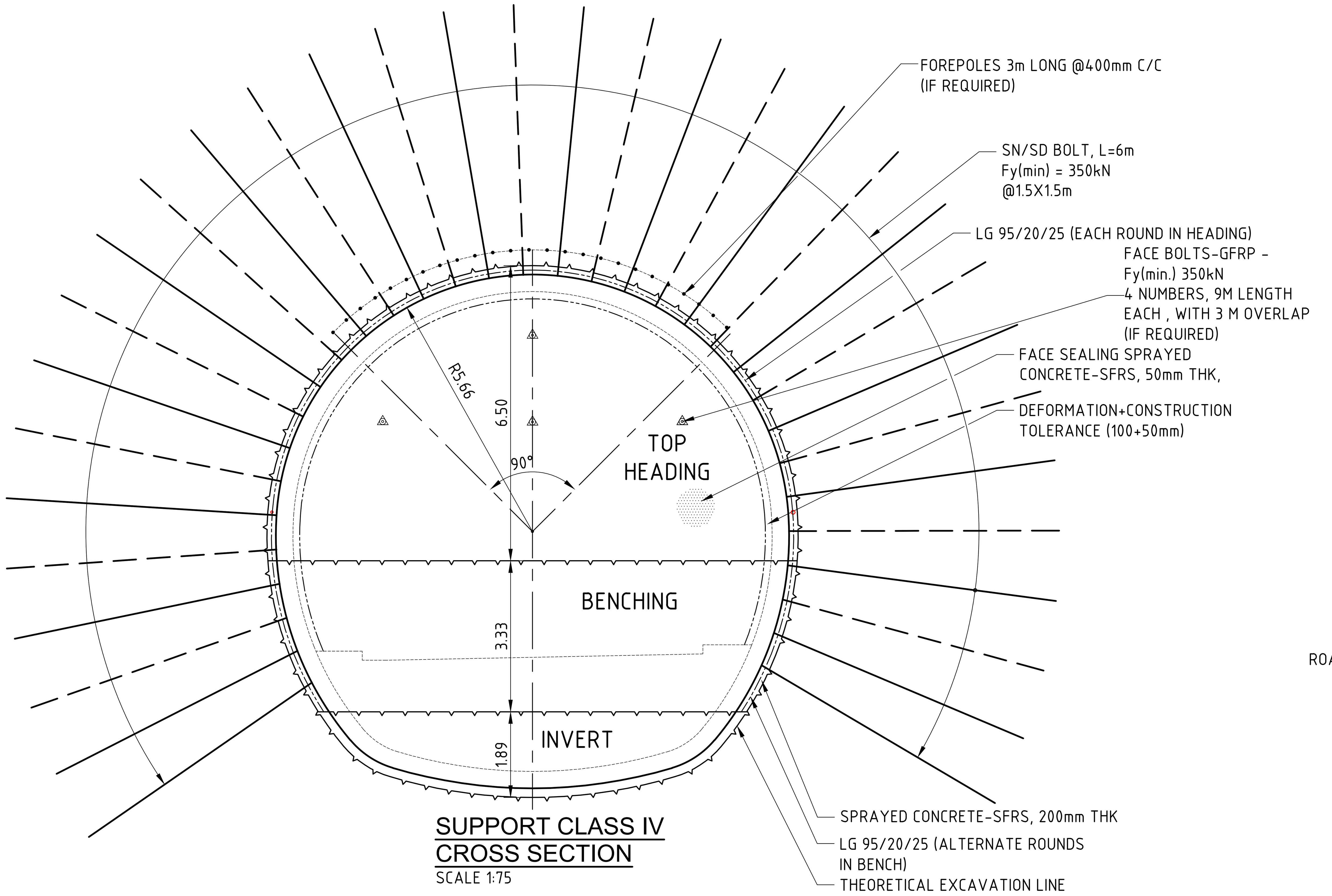
DRAWING NUMBER: FOLA-SUP-MT-1108

REV: A

SCALE

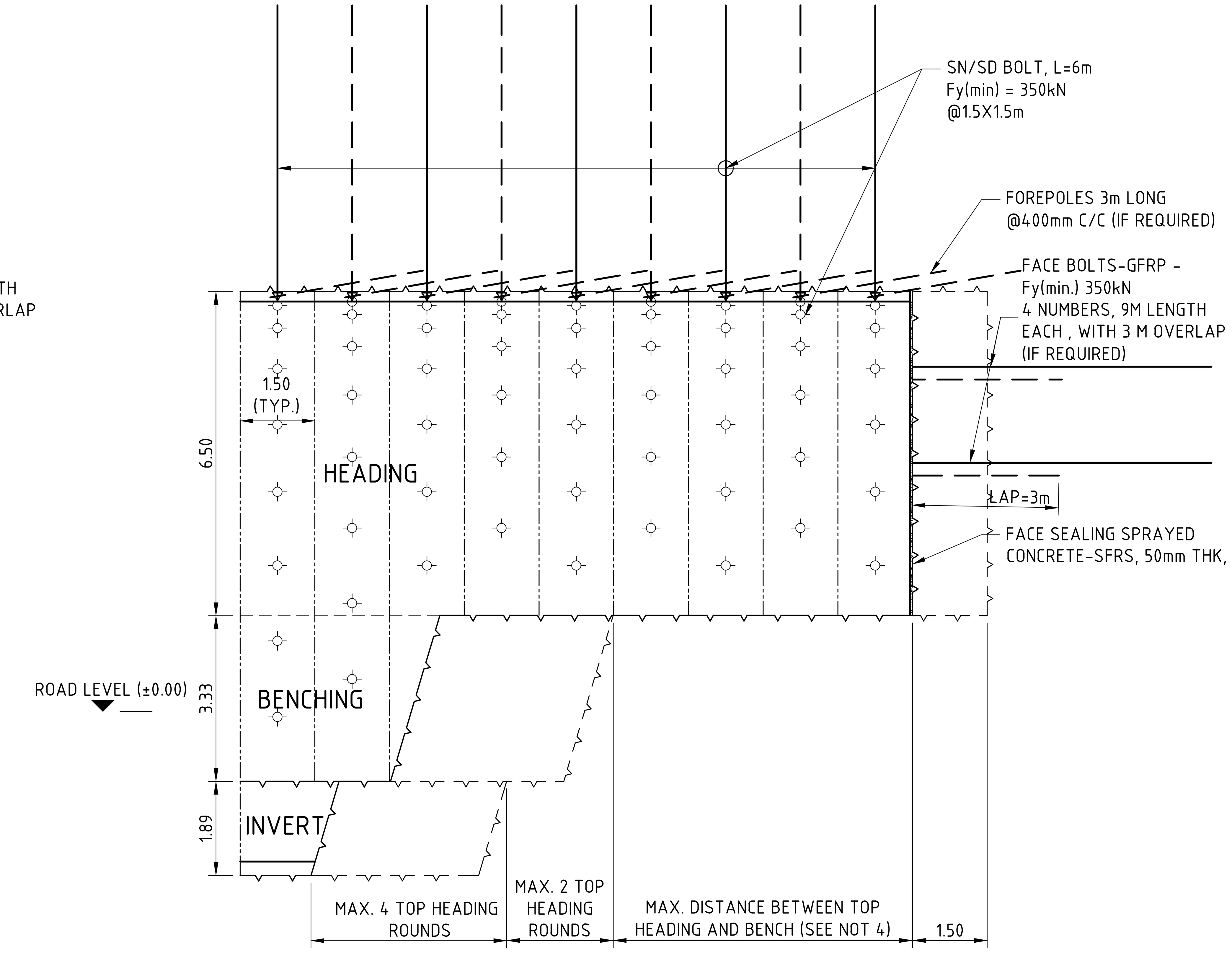
MONTH (Current Issue): FEB 2025

Original Drawing Size A1



SUPPORT CLASS IV CROSS SECTION

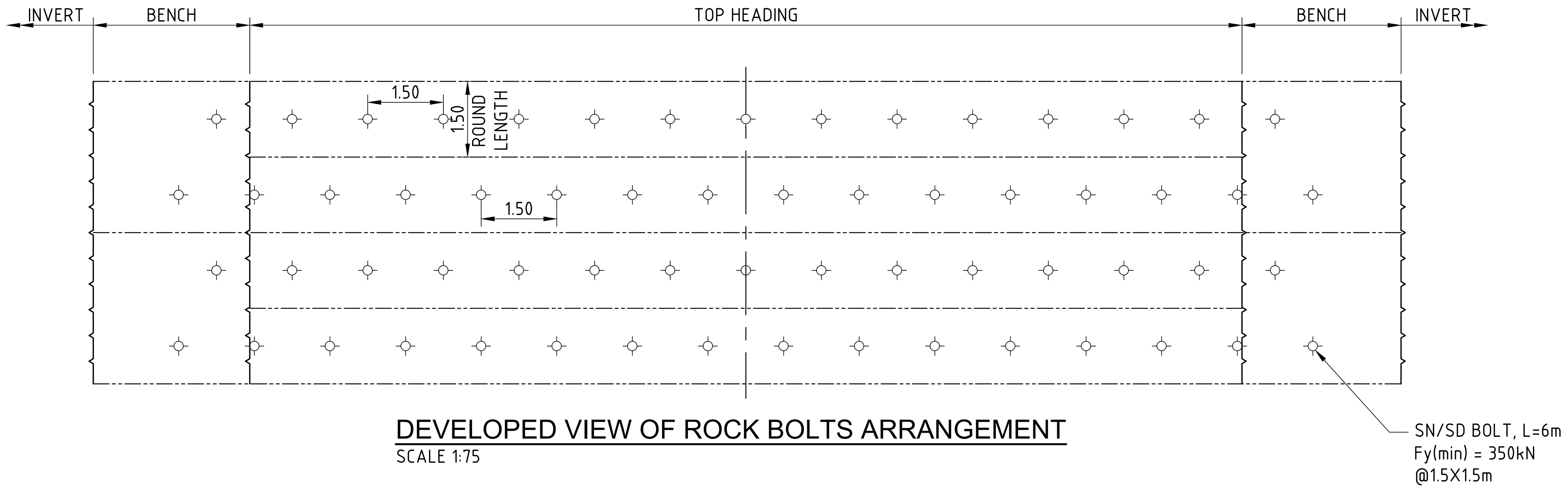
SCALE 1:75



LONGITUDINAL SECTION

SCALE 1:75

FOR EXCAVATION AND SUPPORT QUANTITIES/m, REFER SHEET-2



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT

SCALE 1:75

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).
4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.

SCALE 1 : 75

2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

- ⌖ 6m BOLT- SN/SD-Fy(min.) 350kN
- • FOREPOLES-3m LONG

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS Including Approaches in U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commisioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commisioned.

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORT CLASS-IV

DRAWING NUMBER: FOLA-SUP-MT-1109-01

REV: A

SCALE

MONTH (Current Issue): FEB 2025

Original Drawing Size A1

EXCAVATION AND SUPPORT QUANTITIES/m

TOP HEADING	Excavation	Round Length	Avg. 1.5m
		Theoretical Excavation Volume	61.30 m^3
		Theoretical Excavation Circumference(excluding invert)	19.68 m
	Support	Sprayed Concrete-SFRS, 200mm THK	19.35 m^2
		SN/SD Bolts, L=6m	8.33no.
		Lattice Girder 95/20/25	19.35 m
		Forepoles, 3m Long	16.66 no.
		Face Sealing Sprayed Concrete-SFRS, 50mm THK	61.30 m^3
		Face Bolt	0.67 Nos
BENCH	Excavation	Round Length	Avg. 3 m
		Theoretical Excavation Volume	36.09m^3
		Theoretical Excavation Circumference (excluding invert)	7.08 m
	Support	Sprayed Concrete-SFRS, 200mm THK	7.08 m^2
		SN/SD Bolts, L=6m	2.66 no.
		Lattice Girder 95/20/25(alternate round)	7.8 m
INVERT	Excavation	Round Length	Avg. 6 m
		Theoretical Excavation Volume	13.71 m^3
		Theoretical Excavation Circumference (Invert only)	10.73 m
		Sprayed Concrete-SFRS, 200mm THK	10.40 m^2

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved
Originators					

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORT CLASS-IV

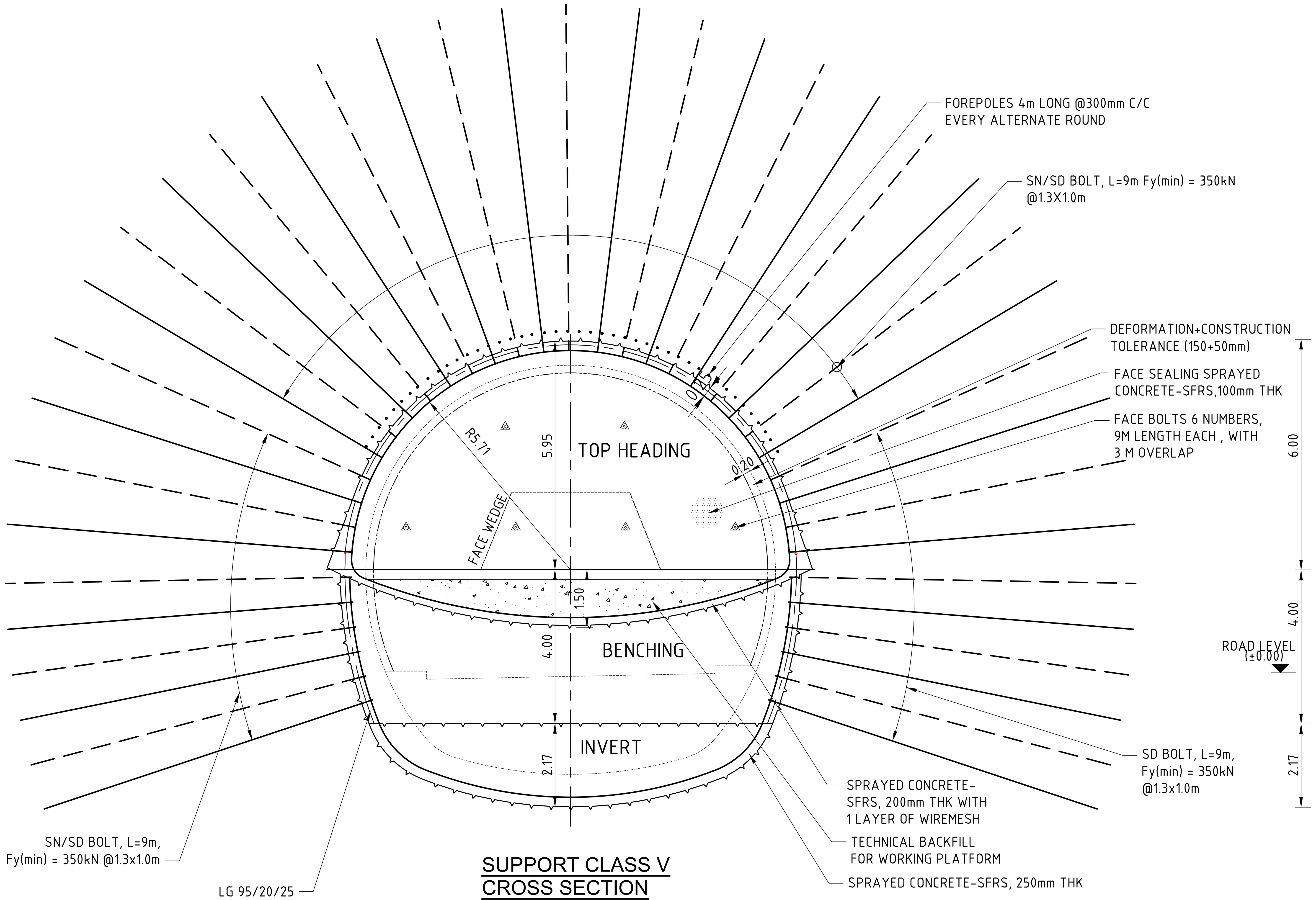
DRAWING NUMBER FOLA-SUP-MT-1109-02

REV A

SCALE

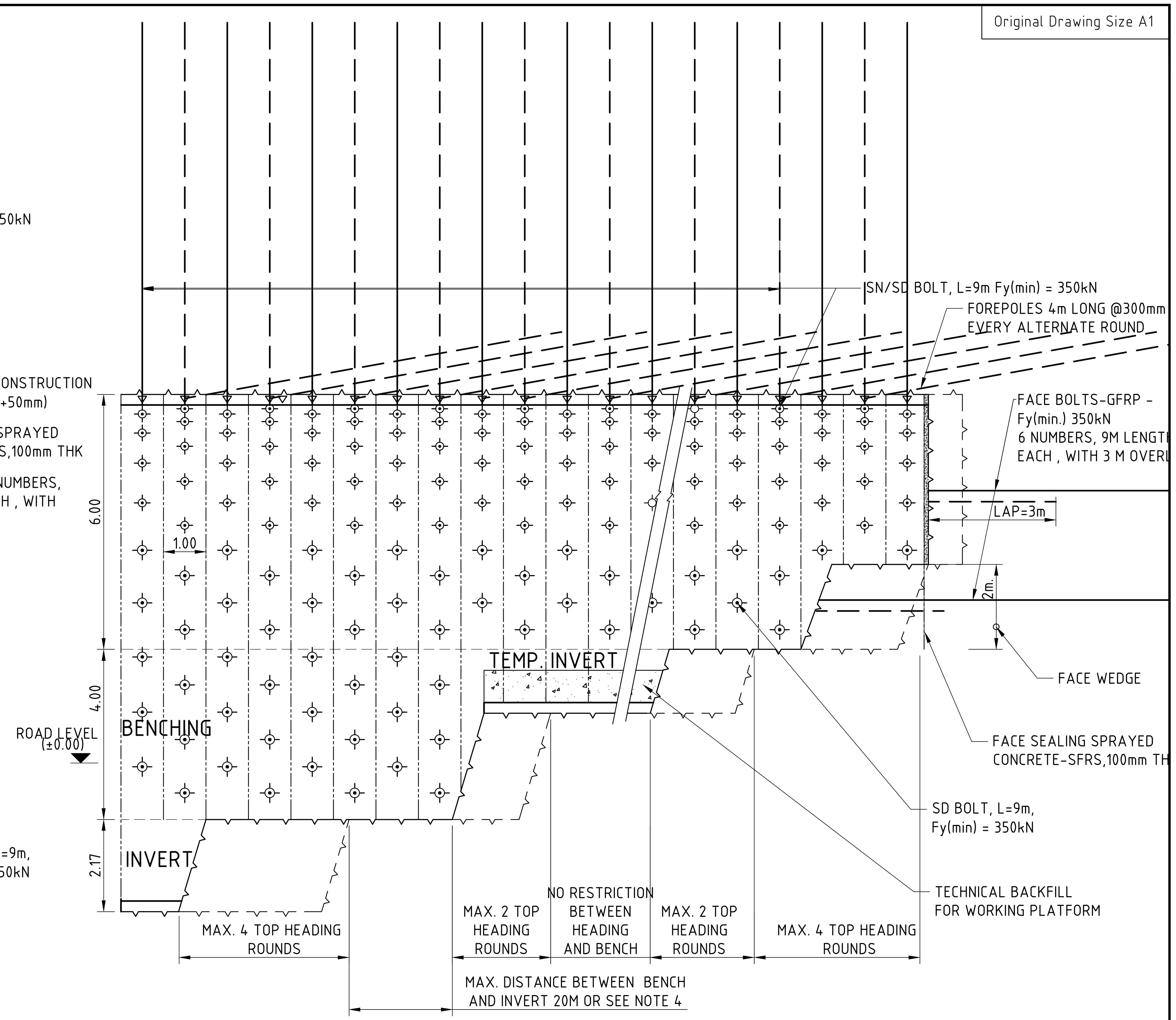
MONTH (Current Issue) FEB 2025

Original Drawing Size A1



SUPPORT CLASS V CROSS SECTION

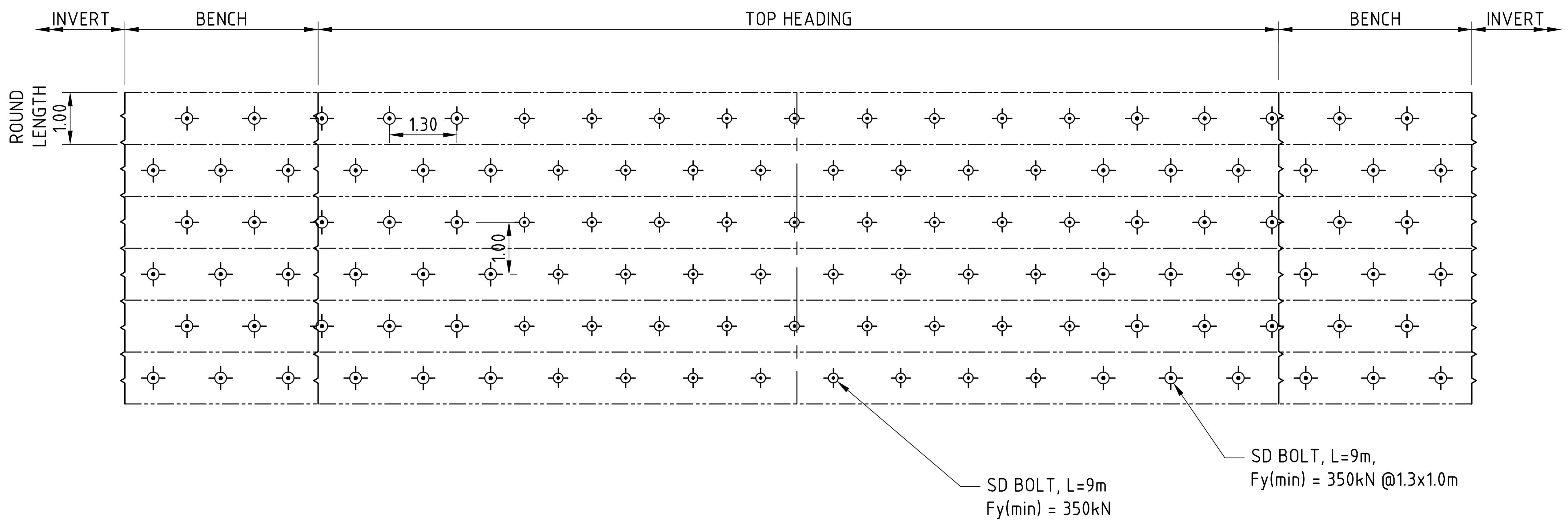
SCALE 1:75



LONGITUDINAL SECTION

SCALE 1:75

FOR EXCAVATION AND SUPPORT QUANTITIES/m,
REFER SHEET-2



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT

SCALE 1:75

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3.. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).
4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.

SCALE 1 : 75
2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:
- 9m SN/SD BOLT- SN-Fy(min.) 350kN
- FACE BOLTS-9M LONG Fy(min.) 350kN
- FOREPOLES-4m LONG

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commisioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commisioned.

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORT CLASS-V

DRAWING NUMBER FOLA-SUP-MT-1110-01
REV A

SCALE

MONTH (Current Issue) FEB 2025

Original Drawing Size A1

EXCAVATION AND SUPPORT QUANTITIES/m

TOP HEADING	Excavation	Round Length	Avg. 1 m
		Theoretical Excavation volume (Including temp invert)	69.87 m^3
		Theoretical Excavation Circumference(Including temp invert)	32.17 m
		Sprayed Concrete-SFRS, 250mm THK	18.86 m^2
	Support	Sprayed Concrete-SFRS, 200mm THK (temp inv)	13.86 m^2
		SN/SD Bolts, L=9m	14.5 no.
		Lattice Girder 95/20/25	18.86 m
		Forepoles, 4 m Long	22 no.
		Face Sealing Sprayed Concrete-SFRS, 100mm THK	69.87 m^2
		Face bolts	1 no.
		Wire mesh 150X150X6	18.86 m^2
BENCH	Excavation	Round Length	Avg. 2 m
		Theoretical Excavation Volume	33.23 m^3
		Theoretical Excavation Circumference (excluding invert)	7.84 m
	Support	Sprayed Concrete-SFRS, 250mm	7.8 m^2
		SN/SD Bolts, L=9m	5 no.
		Lattice Girder 95/20/25	7.7 m
		Wire mesh 150X150X6	7.7 m^2
INVERT	Excavation	Round Length	Avg. 4 m
		Theoretical Excavation Volume	17.51 m^3
		Theoretical Excavation Circumference (Invert only)	12.01 m
	Support	Sprayed Concrete-SFRS, 250mm THK	11.56 m^2
		Wire mesh 150X150X6	11.53 m^2

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

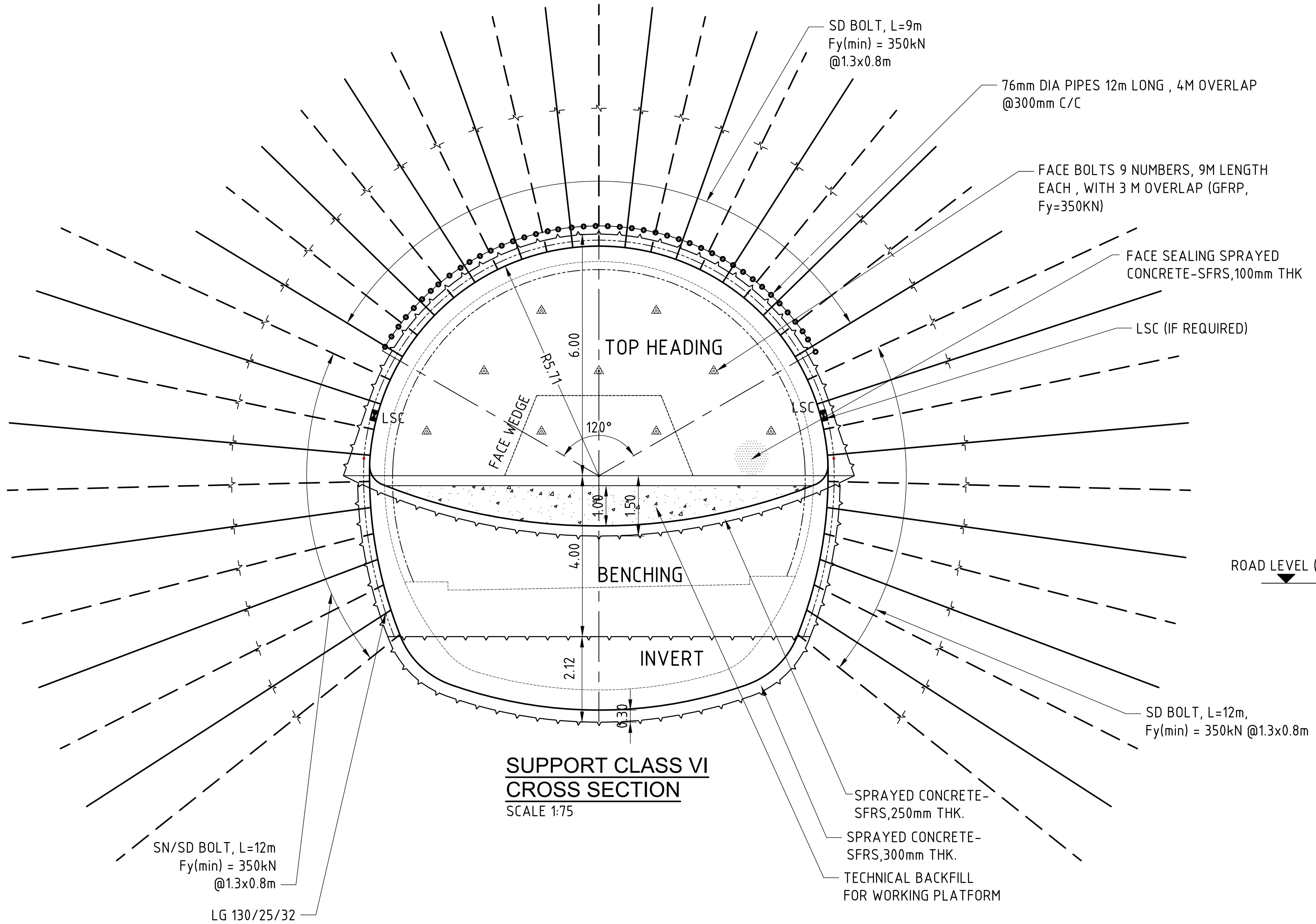
CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORT CLASS-V

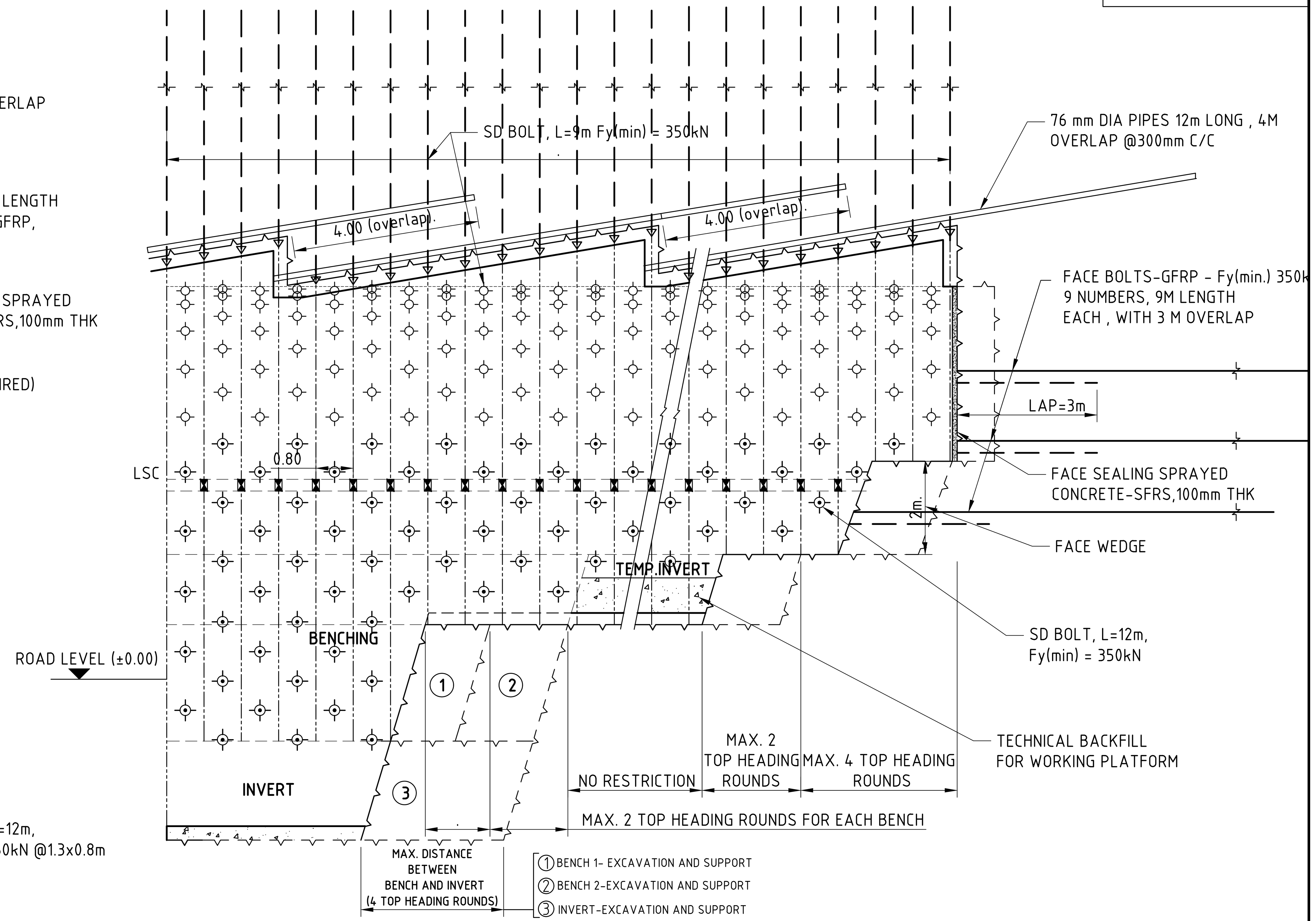
DRAWING NUMBER FOLA-SUP-MT-1110-02 | REV A

SCALE | MONTH (Current Issue) FEB 2025

Original Drawing Size A1

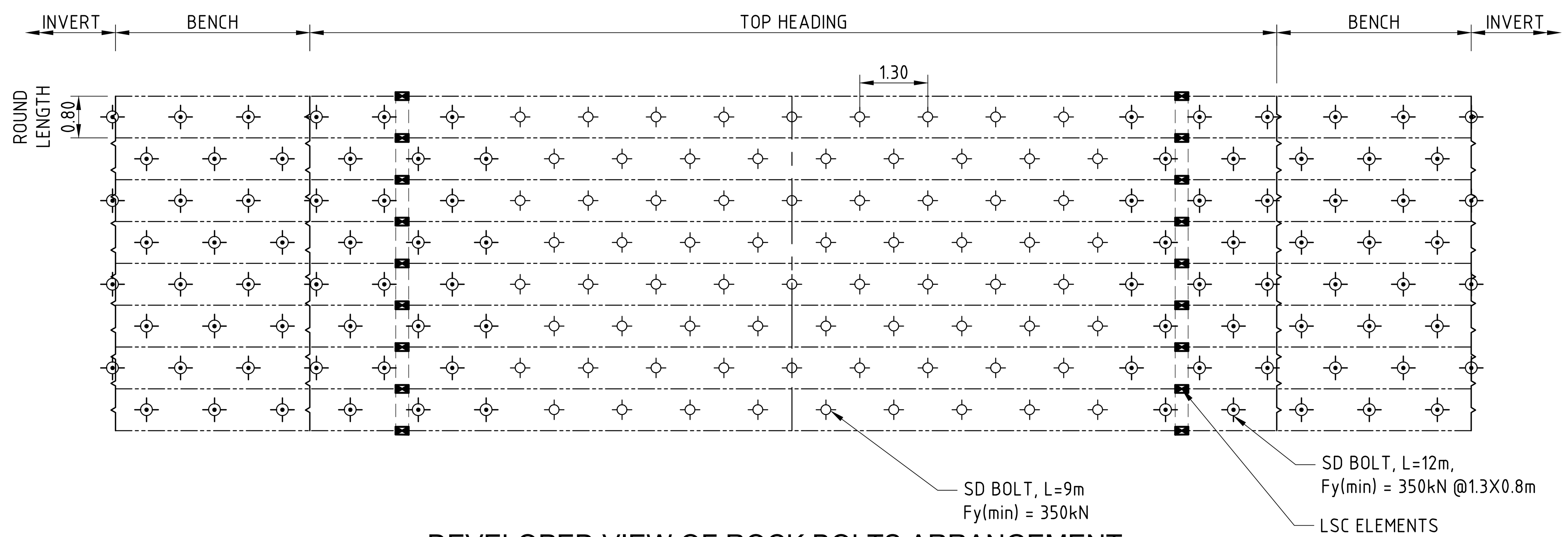


SUPPORT CLASS VI
CROSS SECTION
SCALE 1:75



LONGITUDINAL SECTION
SCALE 1:75

FOR EXCAVATION AND SUPPORT QUANTITIES/m,
REFER SHEET-2



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT
SCALE 1:75

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).
4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.

SCALE 1 : 75
2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:
- 9m SD BOLT- SN-Fy(min.) 350kN
- 12m SD BOLT , Fy(min) 350 kN
- FACE BOLTS-9M LONG Fy(min.) 350kN
- PIPE ROOFING 12M LONG, 76mm DIA
- LINING STRESS CONTROLLER (LSC)

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commissioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commissioned.

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
MAIN TUNNEL
EXCAVATION AND SUPPORT
SUPPORT CLASS-VI(OPTIONAL)

DRAWING NUMBER
FOLA-SUP-MT-1111-01

REV
A

SCALE

MONTH (Current Issue)
FEB 2025

Original Drawing Size A1

EXCAVATION AND SUPPORT QUANTITIES/m

TOP HEADING	Excavation	Round Length	Avg. 0.8 m
		Theoretical Excavation volume (Including temp invert)	69.87 m^3
		Theoretical Excavation Circumference(Including temp invert)	32.17 m
	Support	Sprayed Concrete-SFRS, 300mm THK	18.86 m^2
		Wire mesh 150X150X6	18.86 m^2
		Sprayed Concrete-SFRS, 250mm THK (temp inv)	13.86 m^2
		SD Bolts, L=9m	11.87 no.
		SD Bolts, L=12m	6.25 no.
		Lattice Girder 130/25/32	23.58 m
		Pipe Roofing ,76 mm dia, 12m Long	5.5 no.
		Face sealing SFRS, 100mm thk (min. section)	87.34 m^2
		Face bolts	1.5 Nos.
		Liner Stress Controller (LSC)	2 Nos.
BENCH	Excavation	Round Length	Avg. 1.6 m
		Theoretical Excavation Volume	33.23 m^3
		Theoretical Excavation Circumference (side walls only)	7.84 m
	Support	Sprayed Concrete-SFRS, 300mm THK	7.7 m^2
		Wire mesh 150X150X6	7.7 m^2
		SN/SD Bolts, L=12m	7.5 no.
		Lattice Girder 130/25/32	9.64 m
INVERT	Excavation	Round Length	Avg. 3.2 m
		Theoretical Excavation Volume	17.51 m^3
		Theoretical Excavation Circumference (Invert only)	12.01 m
	Support	Sprayed Concrete-SFRS, 300mm THK	11.53 m^2
		Wire mesh 150X150X6	11.53 m^2

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved
Originators					

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

MAIN TUNNEL
EXCAVATION AND SUPPORT QUANTITIES
SUPPORT CLASS-VI(OPTIONAL)

DRAWING NUMBER: FOLA-SUP-MT-1111-02

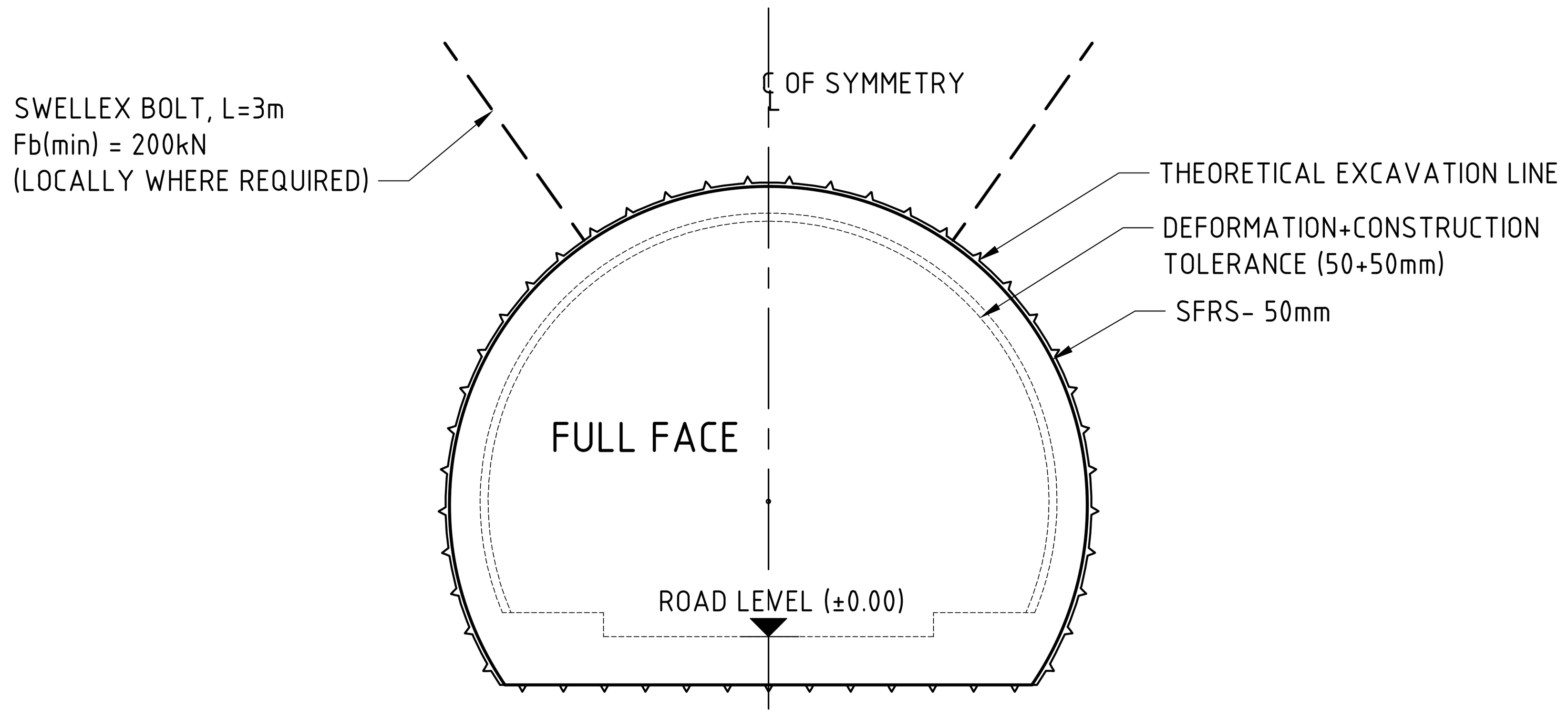
REV: A

SCALE

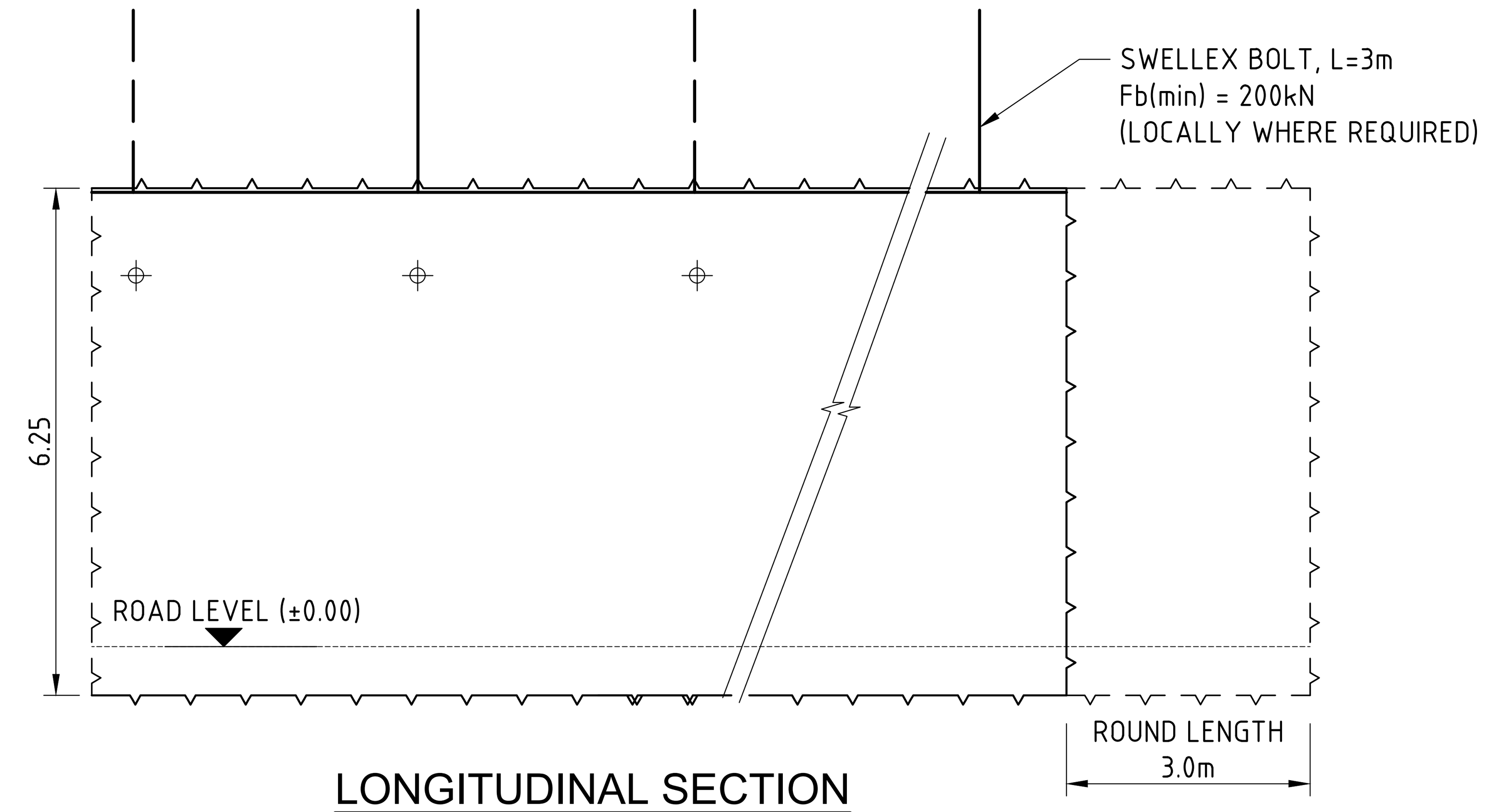
MONTH (Current Issue): FEB 2025

ANNEXURE 7 (Primary support drawings for Cross Passage)

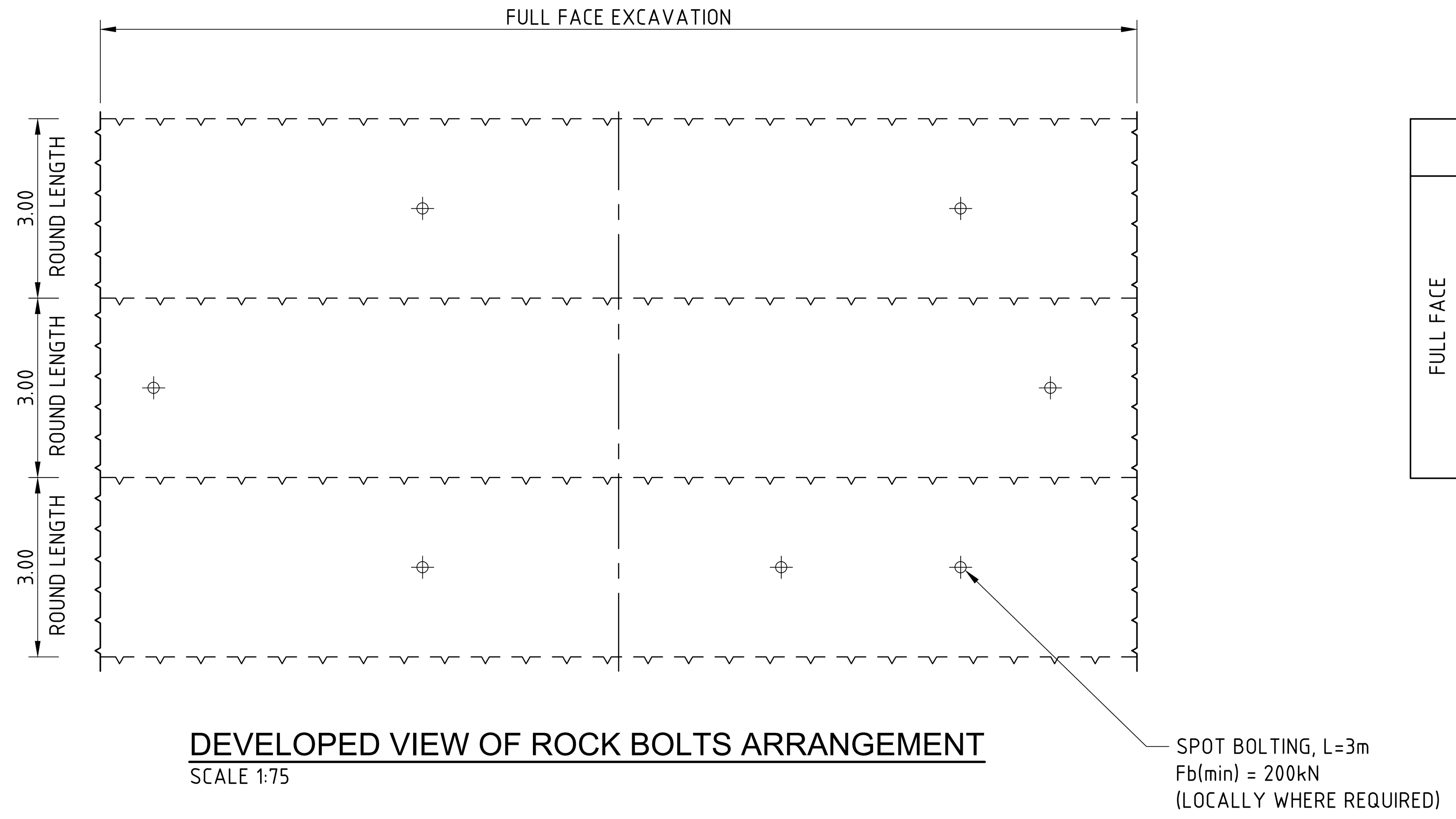
Original Drawing Size A1



SUPPORT CLASS I
CROSS SECTION
SCALE 1:75



LONGITUDINAL SECTION
SCALE 1:75



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT
SCALE 1:75

EXCAVATION AND SUPPORT QUANTITIES/m			
FULL FACE	Excavation	Round Length	Avg. 3.0m
		Theoretical Excavation Volume	42.26 m^3
		Theoretical Excavation Circumference(side walls only)	17.34 m
	Support	Sprayed concrete-SFRS-50mm	17.27 m^2
		Swellex Bolts, L=3m	as reqd.

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).

SCALE 1 : 75
2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:
3m BOLT -SWELLEX- Fb(min.) 200 kN

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved
Originators					

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commissioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commissioned.

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
VEHICULAR CROSS PASSAGE
EXCAVATION AND SUPPORT
SUPPORT CLASS-I

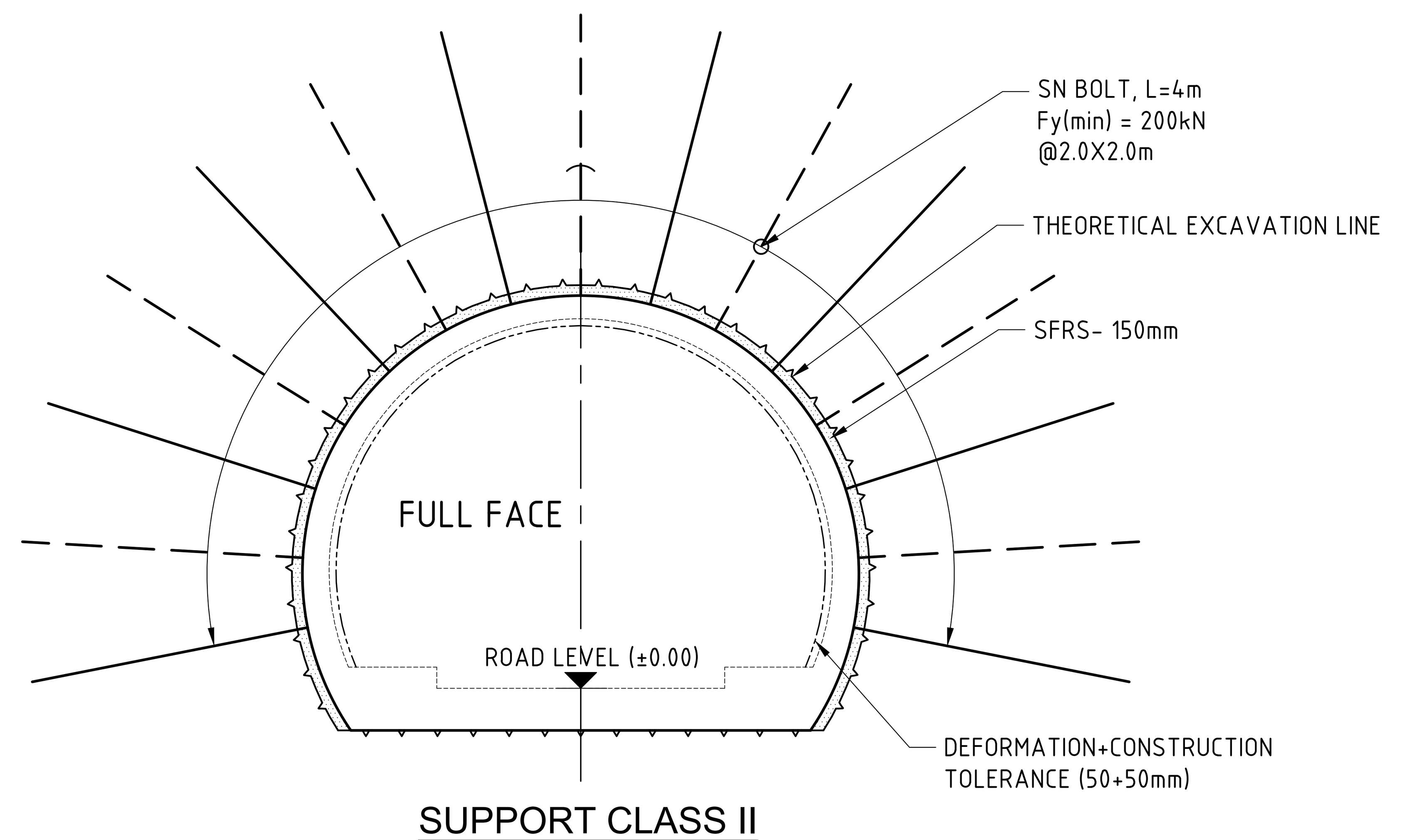
DRAWING NUMBER
FOLA-SUP-VCP-1156

REV
A

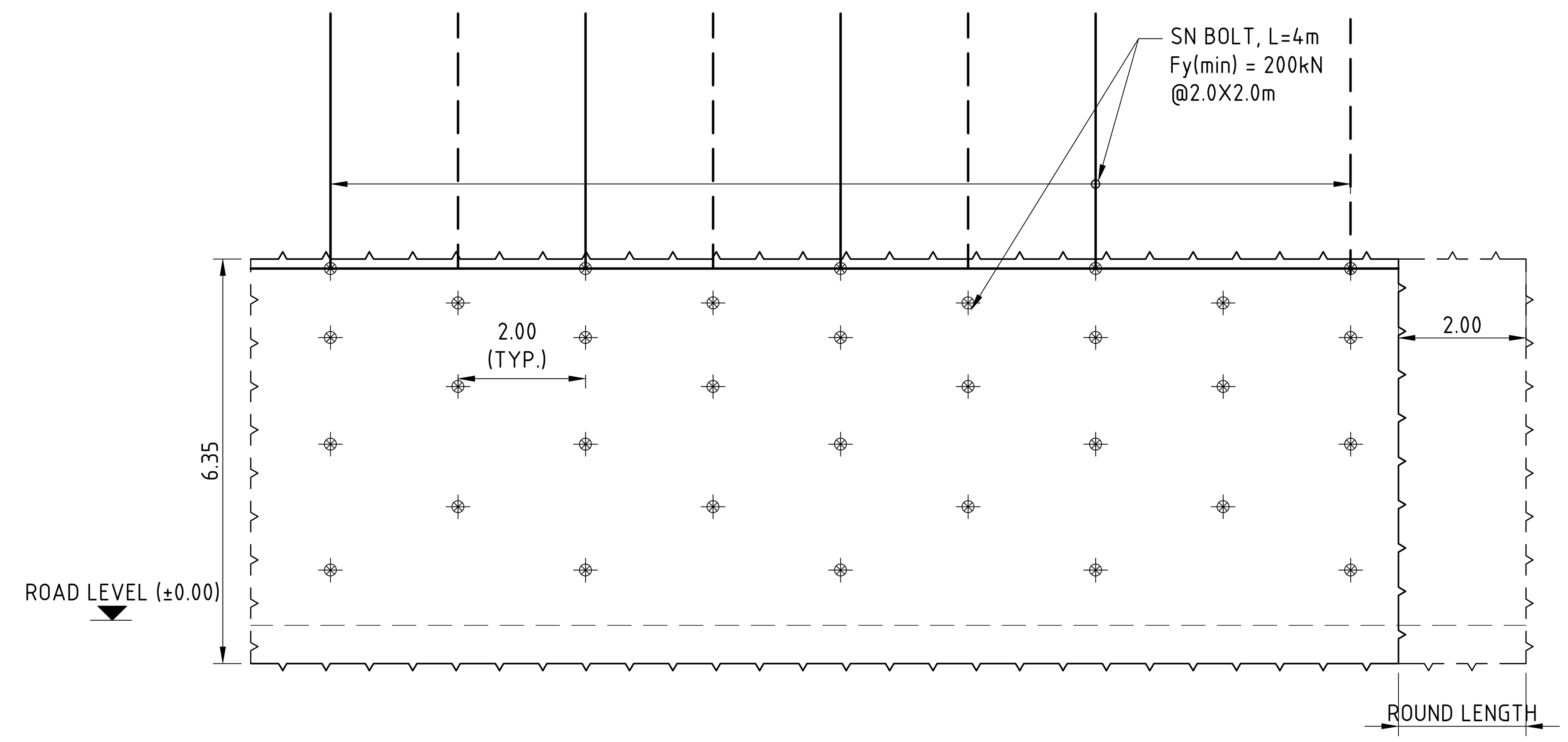
SCALE

MONTH (Current Issue)
FEB 2025

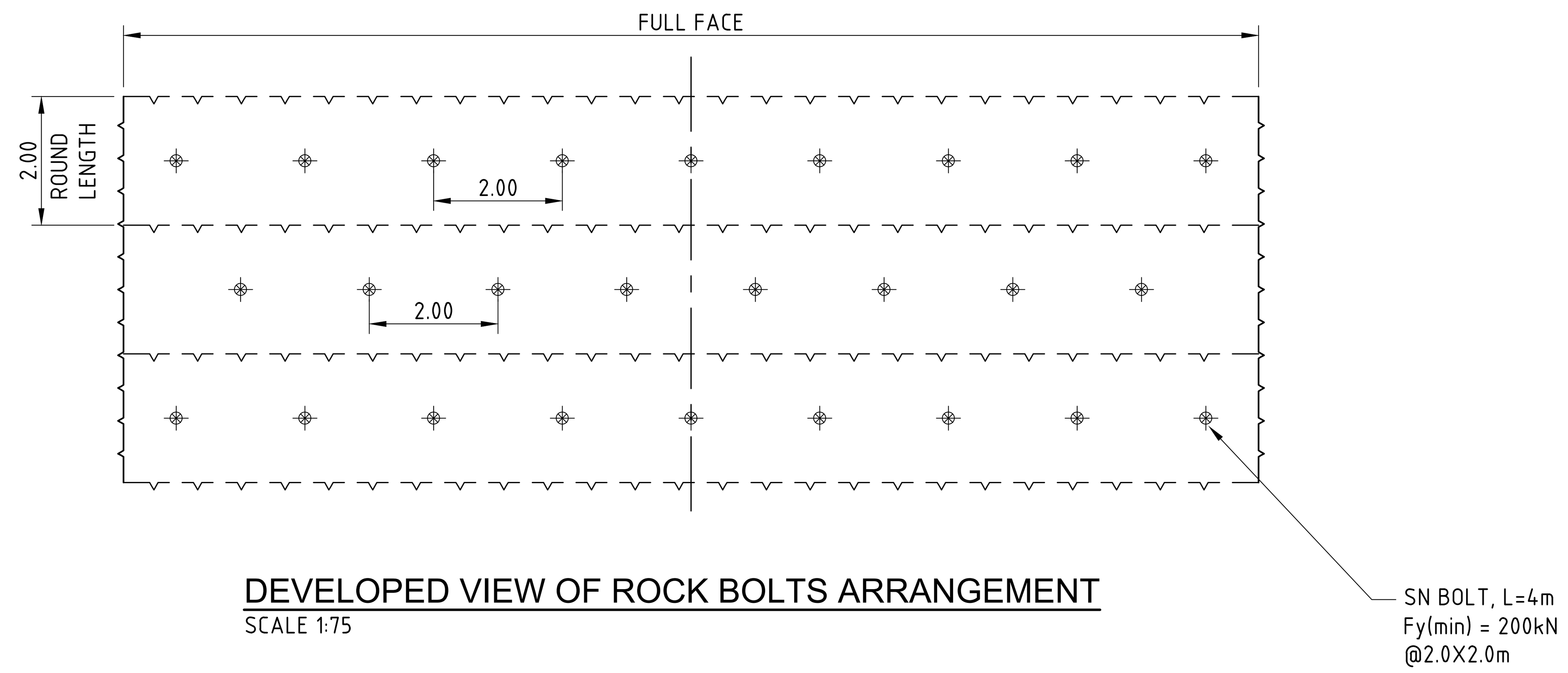
Original Drawing Size A1



SUPPORT CLASS II
CROSS SECTION
SCALE 1:75



LONGITUDINAL SECTION
SCALE 1:75



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT
SCALE 1:75

EXCAVATION AND SUPPORT QUANTITIES/m			
FULL FACE	Excavation	Round Length	Avg. 2m
		Theoretical Excavation Volume	44.01 m^3
		Theoretical Excavation Circumference(excluding invert)	17.64 m
	Support	Sprayed Concrete -SFRS-150mm thick	17.32 m^2
		SN Bolts, L=4m	3.75 no.

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3.. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).

SCALE 1 : 75

2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

4m SN BOLT , Fy(min) 200 kN

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commissioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commissioned.

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

VEHICULAR CROSS PASSAGE
EXCAVATION AND SUPPORT
SUPPORT CLASS-II

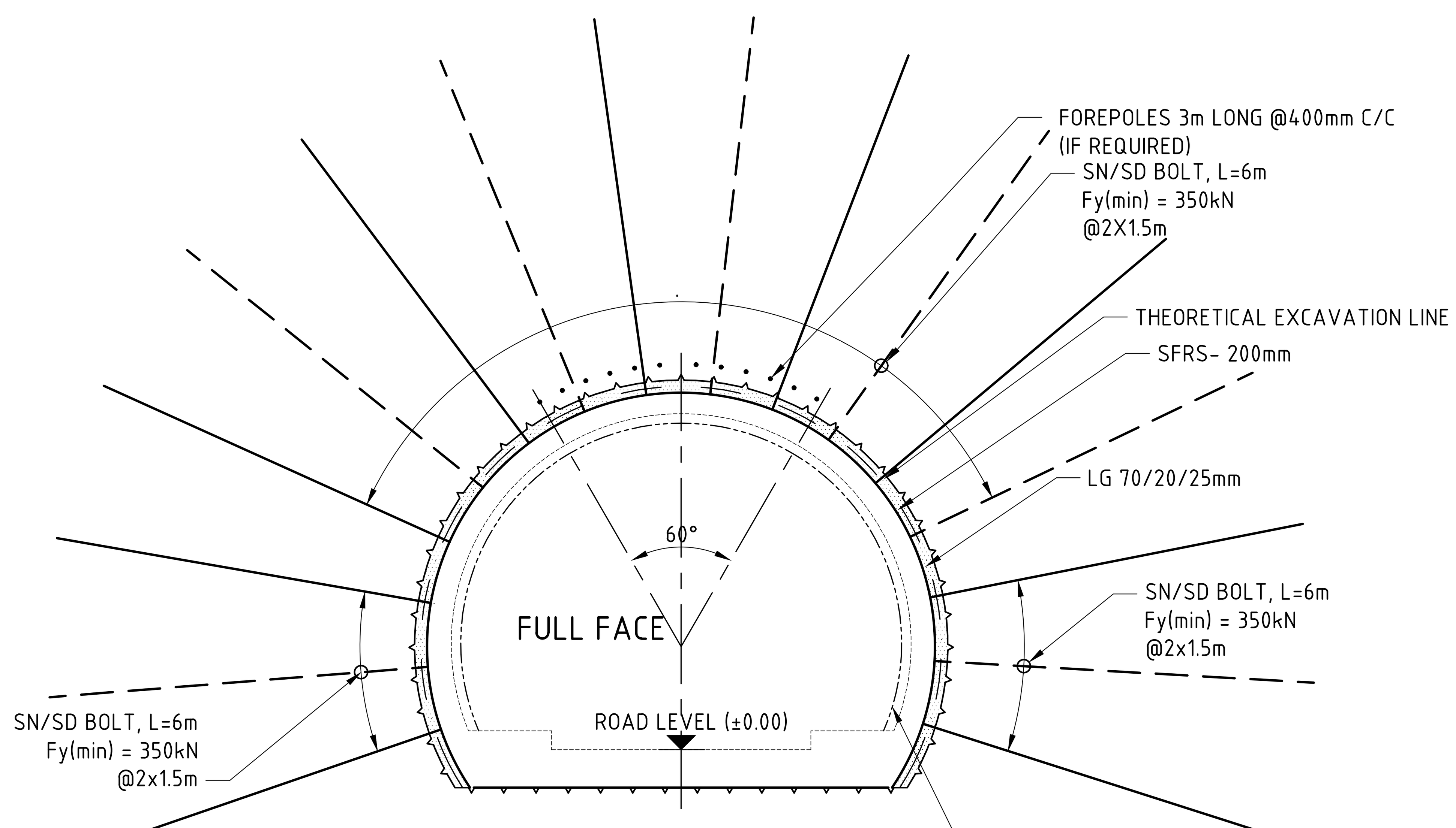
DRAWING NUMBER FOLA-SUP-VCP-1157

REV A

SCALE

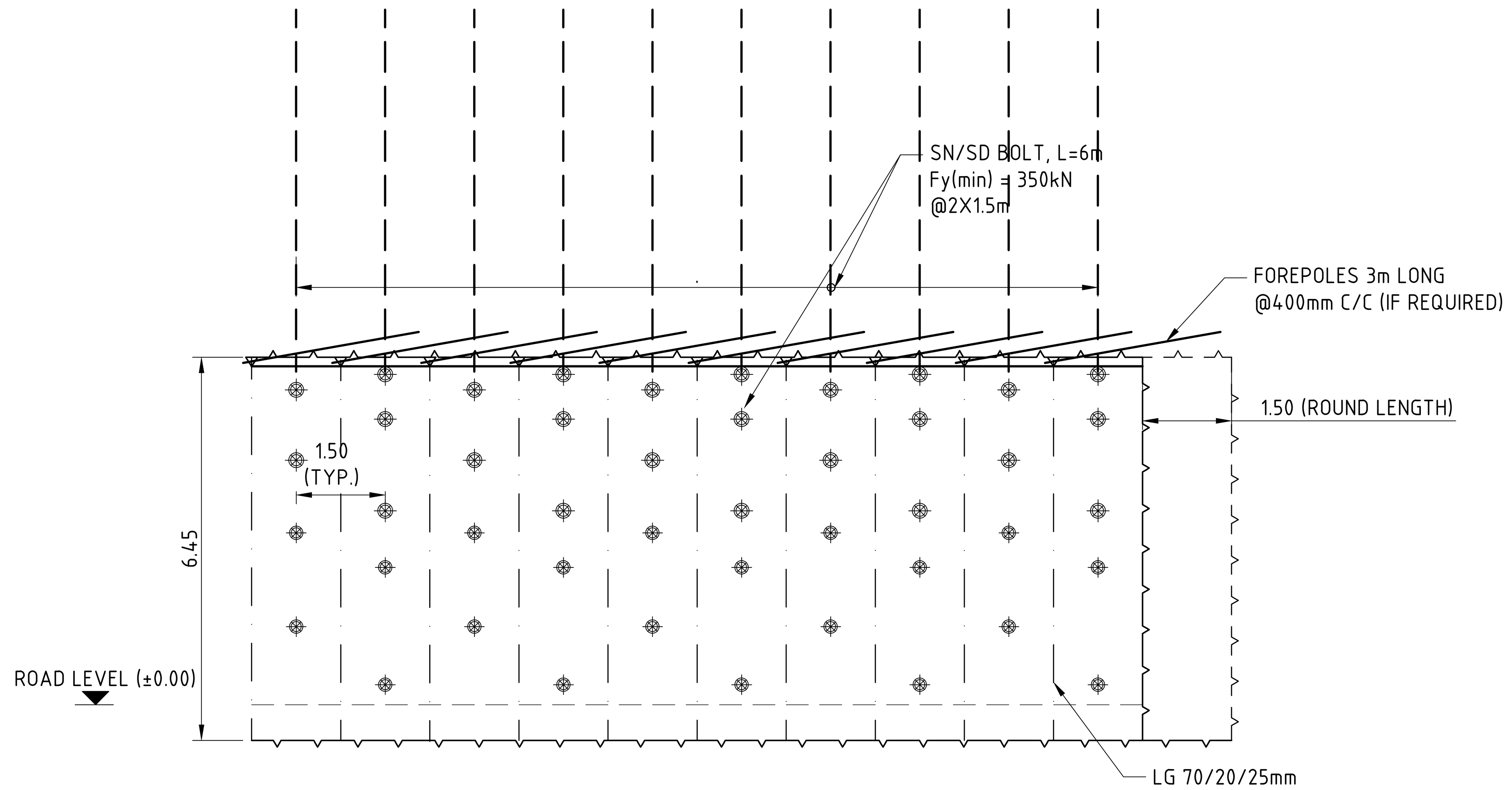
MONTH (Current Issue) FEB 2025

Original Drawing Size A1



SUPPORT CLASS III CROSS SECTION

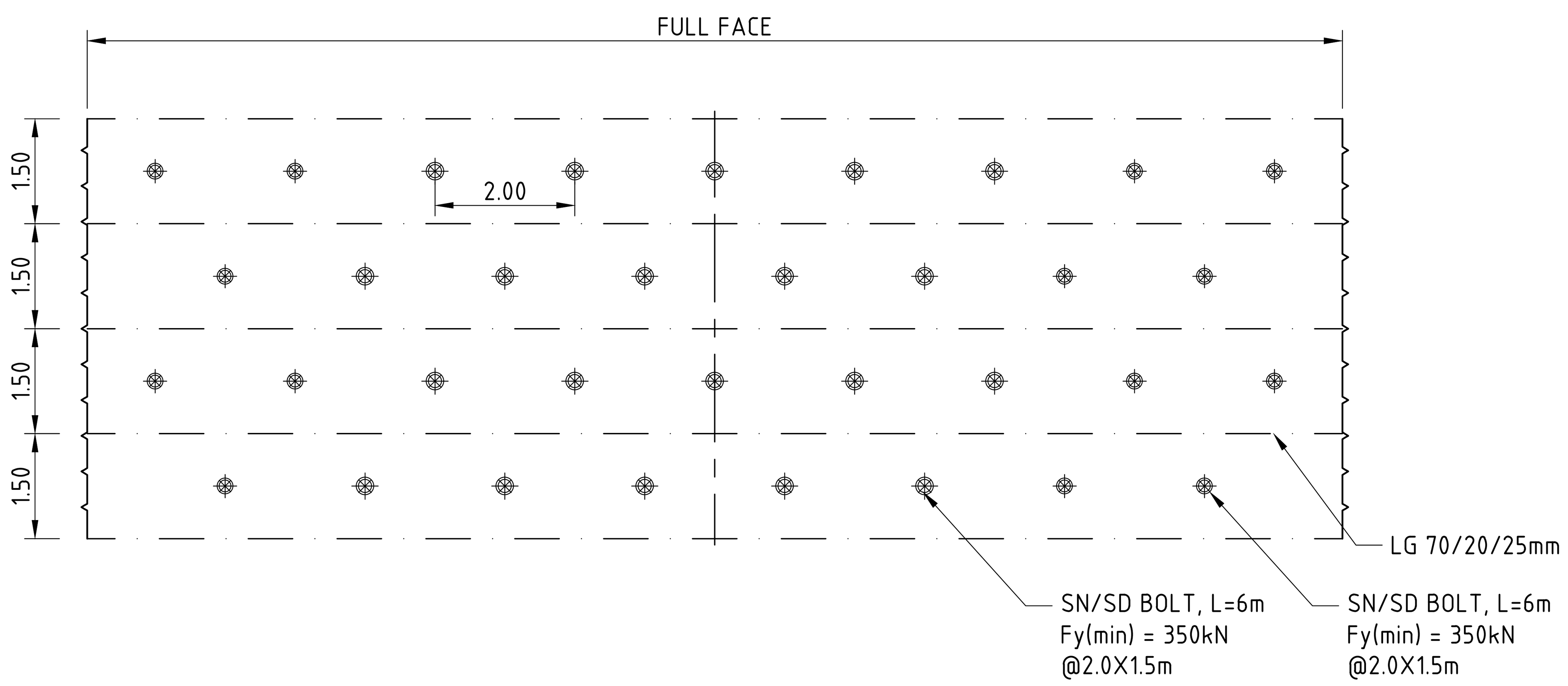
SCALE 1:75



LONGITUDINAL SECTION

SCALE 1:75

EXCAVATION AND SUPPORT QUANTITIES/m			
FULL FACE	Excavation	Round Length	Avg. 1.5m
		Theoretical Excavation Volume	45.8m³
		Theoretical Excavation Circumference(excluding invert)	17.94m
	Support	Sprayed concrete-SFRS, 200mm THK	17.64m²
		SN/SD Bolts, L=6m	5.33 no.
		Forepoles, 3m Long	8no.
		Lattice Girder 70/20/25	11.76m



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT

SCALE 1:75

NOTES

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).

SCALE 1 : 75
2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:
- 6m SN/SD BOLT , Fy(min) 350 kN
- FOREPOLES-3m LONG

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

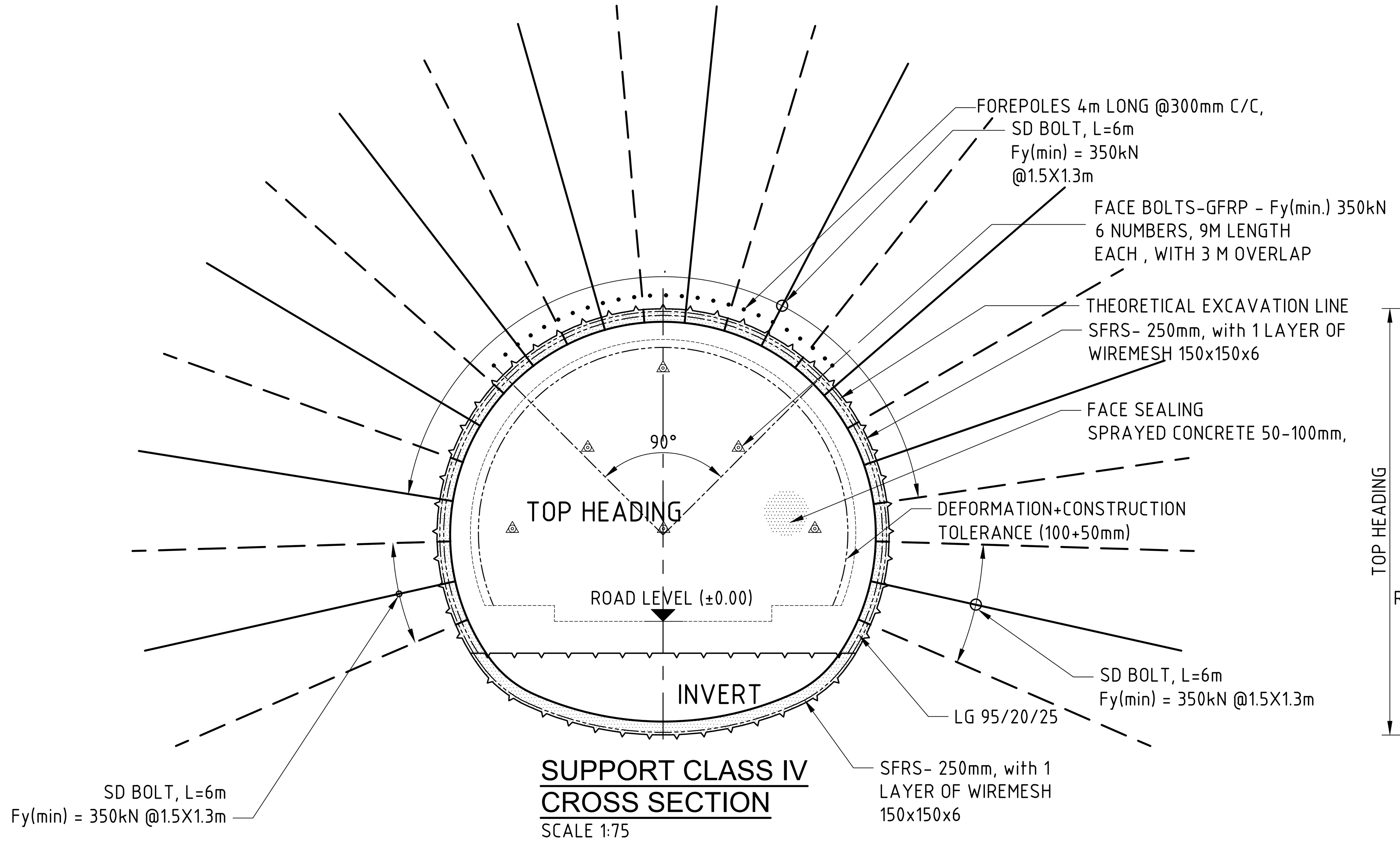
DRAWING TITLE
VEHICULAR CROSS PASSAGE
EXCAVATION AND SUPPORT
SUPPORT CLASS-III

DRAWING NUMBER: FOLA-SUP-VCP-1158
REV: A

SCALE

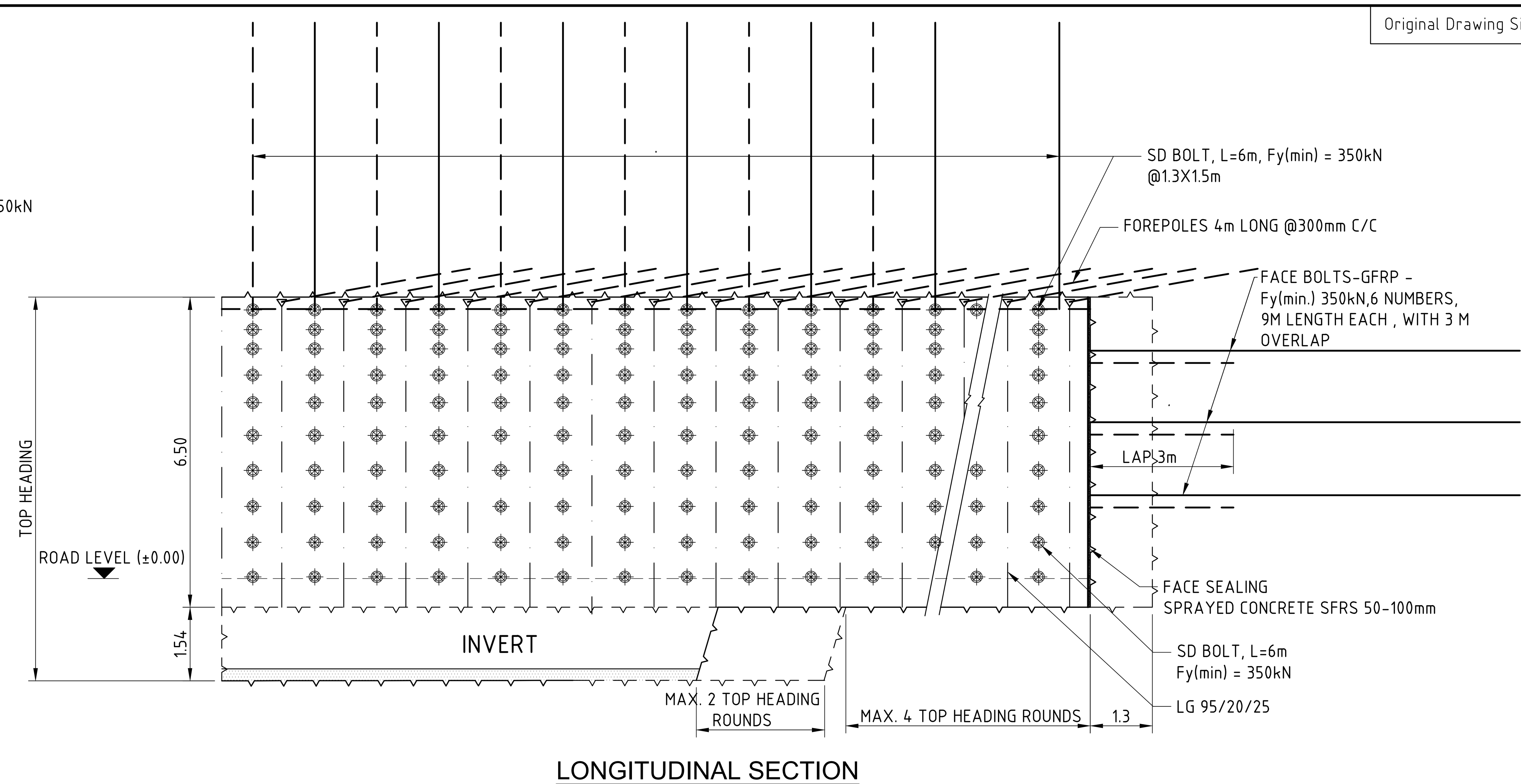
MONTH (Current Issue): FEB 2025

Original Drawing Size A1



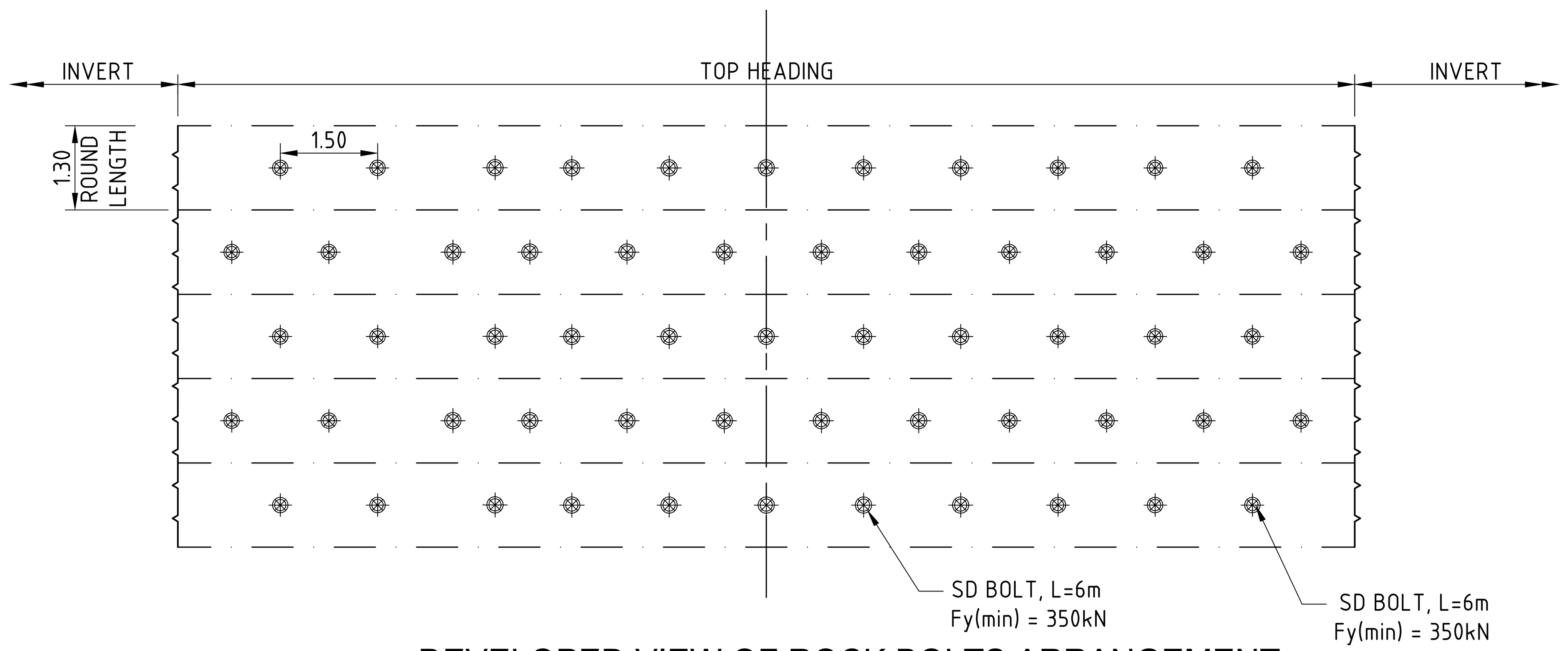
SUPPORT CLASS IV
CROSS SECTION

SCALE 1:75



LONGITUDINAL SECTION

SCALE 1:75



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT

SCALE 1:75

EXCAVATION AND SUPPORT QUANTITIES/m

TOP HEADING	Excavation	Round Length	Avg. 1.3m
		Theoretical Excavation Volume	46.7m³
		Theoretical Excavation Circumference	18.15 m
	Support	Sprayed Concrete-SFRS, 250mm THK	17.72 m²
		SDA Bolts, L=6m	8.46no.
		Forepoles, 4m Long	19.23no.
		Face sealing Shotcrete, 50mm thk	41.40 m²
		LG 95/20/25	13.63m
		Wiremesh 150X150X6mm	17.94 m²
INVERT	Excavation	Round Length	Avg. 2.6 m
		Theoretical Excavation Volume	8.26 m³
		Theoretical Excavation Circumference	8.24m
	Support	Sprayed Concrete-SFRS, 250mm THK	7.83 m²
		Wiremesh 150x150x6mm	8.13 m²

NOTES :

1. ALL DIMENSIONS ARE IN mm UNLESS NOTED OTHERWISE.
2. EXCAVATION IS TO BE MONITORED ACCORDING TO THE GEOTECHNICAL INSTRUMENTATION PROGRAM.
3. ALL QUANTITIES GIVEN ARE BASED ON AVERAGE ROUND LENGTHS (MEAN VALUE OF RANGE OF ROUND LENGTH GIVEN IN THE RESPECTIVE TABLES).

SCALE 1 : 75

2.5m 0 2.5m 5.0m 7.5m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

LEGEND:

- 6m SDA BOLT , Fy(min) 350 kN
- FACE BOLTS-9M LONG Fy(min.) 350kN
- FOREPOLES-4m LONG

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commisioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commisioned.

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

VEHICULAR CROSS PASSAGE
EXCAVATION AND SUPPORT
SUPPORT CLASS-IV

DRAWING NUMBER: FOLA-SUP-VCP-1159

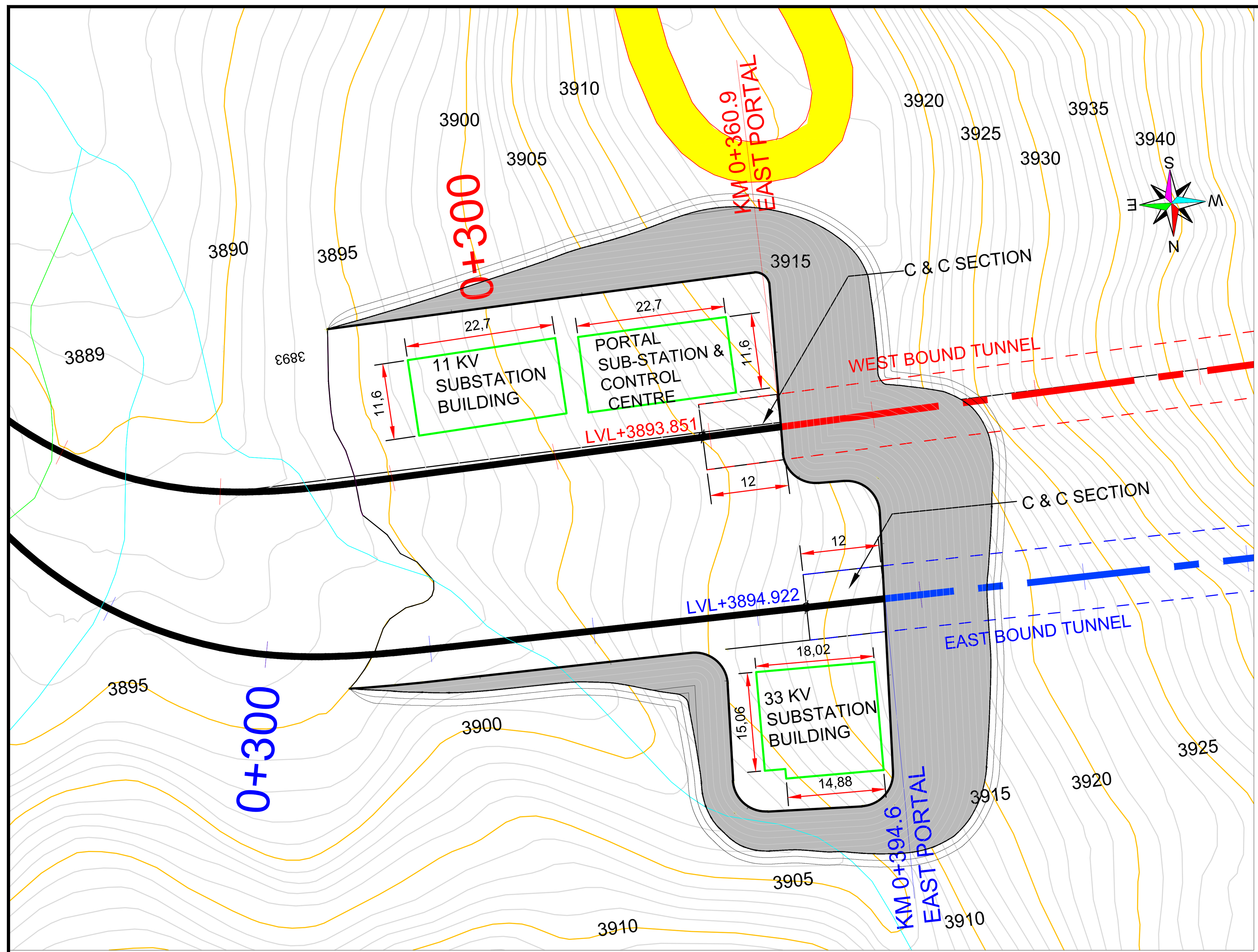
REV: A

SCALE

MONTH (Current Issue): FEB 2025

ANNEXURE 8 (Portal cut and support drawings)

Original Drawing Size A1



KEY PLAN
SCALE : 1:500

NOTES:
1. ALL DIMENSIONS ARE IN m UNLESS NOTED OTHERWISE
2. THIS DRAWINGS IS BASED ON APPROVED ALIGNMENT

LONGITUDINAL SECTION PORTAL POSITION WEST BOUND TUNNEL
SCALE : 1:150

SCALE 1 : 150

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:
- FOLA-ALG-GEN-1000
- FOLA-LAY-EPT-1062
- FOLA-SUP-EPT-1065

LEGEND:
- MAJOR CONTOURS
- MINOR CONTOURS
- ALIGNMENT-EAST BOUND TUNNEL
- ALIGNMENT-WEST BOUND TUNNEL
- ROCK BOLT
- DRAINAGE HOLE

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved

Originators

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commisioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commisioned.

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
MAIN TUNNEL EAST PORTAL EXCAVATION AND SUPPORT WEST BOUND TUNNEL POSITION

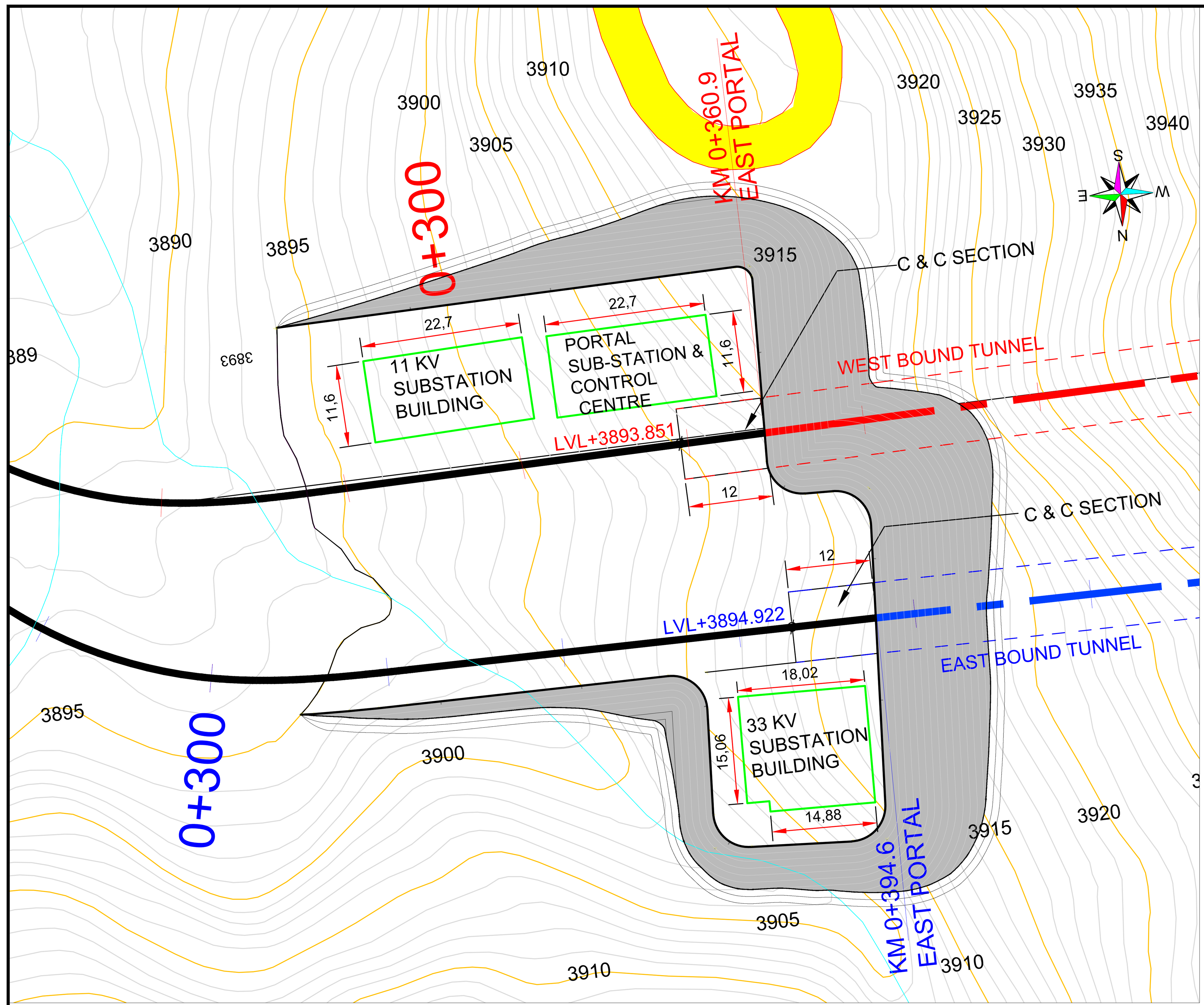
DRAWING NUMBER FOLA-SUP-EPT-1064

REV A

SCALE

MONTH (Current Issue) FEB 2025

Original Drawing Size A1



KEY PLAN

SCALE : 1:500

NOTES:

1. ALL DIMENSIONS ARE IN m UNLESS NOTED OTHERWISE
2. THIS DRAWINGS IS BASED ON APPROVED ALIGNMENT

LONGITUDINAL SECTION PORTAL POSITION EAST BOUND TUNNEL

SCALE : 1:150

SCALE 1 : 150

5m 0 5m 10m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

- FOLA-ALG-GEN-1000
- FOLA-LAY-EPT-1062
- FOLA-SUP-EPT-1064

LEGEND:

- MAJOR CONTOURS
- MINOR CONTOURS
- ALIGNMENT-EAST BOUND TUNNEL
- ALIGNMENT-WEST BOUND TUNNEL
- ROCK BOLT
- DRAINAGE HOLE

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved
Originators					

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commisioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commisioned.

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

MAIN TUNNEL EAST PORTAL EXCAVATION AND SUPPORT EAST BOUND TUNNEL POSITION

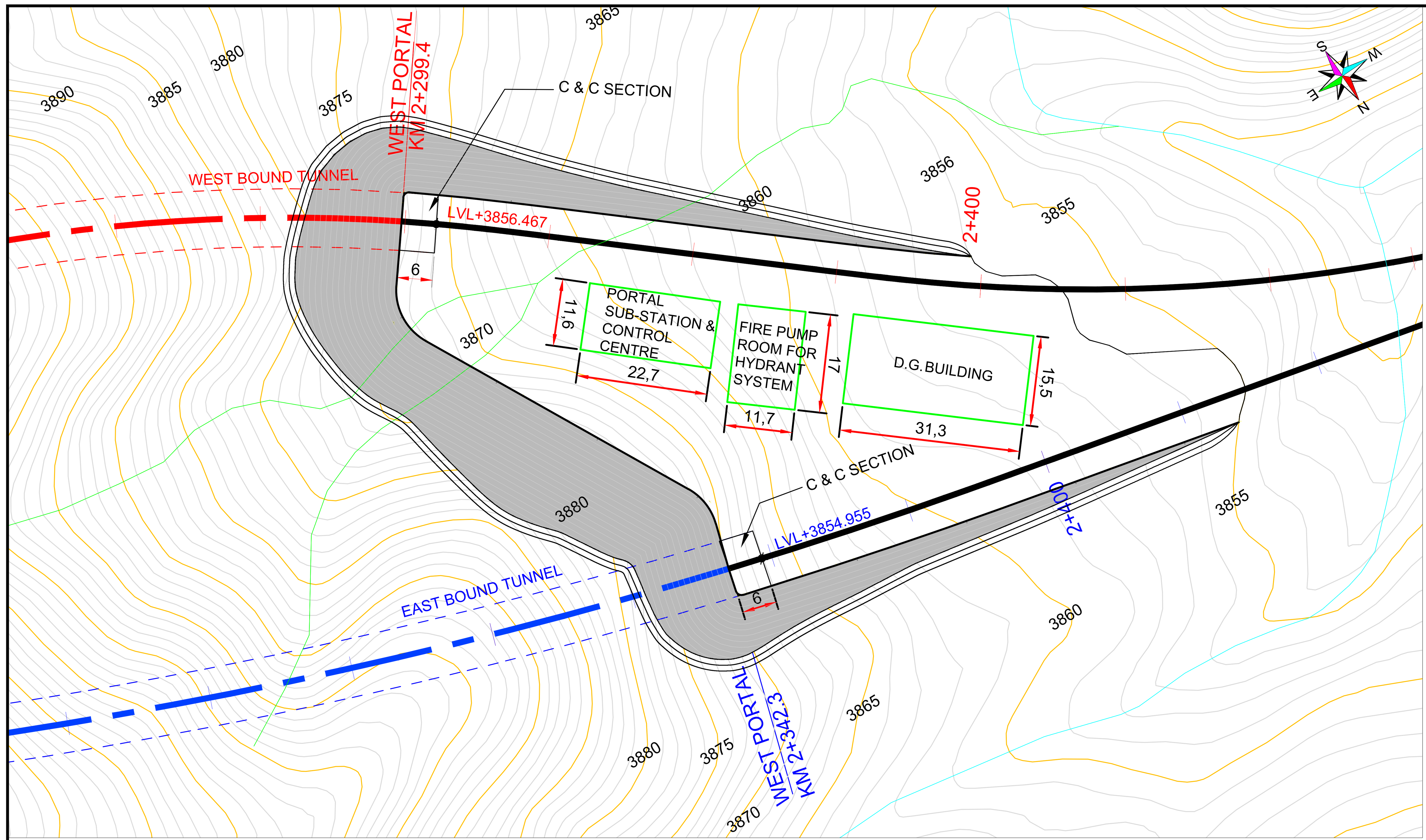
DRAWING NUMBER: FOLA-SUP-EPT-1065

REV: A

SCALE

MONTH (Current Issue): FEB 2025

Original Drawing Size A1



KEY PLAN

SCALE : 1:500

NOTES:

1. ALL DIMENSIONS ARE IN m UNLESS NOTED OTHERWISE

2. THIS DRAWINGS IS BASED ON APPROVED ALIGNMENT

LONGITUDINAL SECTION PORTAL POSITION WEST BOUND TUNNEL

SCALE : 1:150

SCALE 1 : 150

5m 0 5m 10m

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:

- FOLA-ALG-GEN-1000
- FOLA-LAY-WPT-1082
- FOLA-SUP-WPT-1085

LEGEND:

- MAJOR CONTOURS
- MINOR CONTOURS
- ALIGNMENT-EAST BOUND TUNNEL
- ALIGNMENT-WEST BOUND TUNNEL
- ROCK BOLT
- DRAINAGE HOLE

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
	Drawn	Drafting Chk	Designed	Design Chk	Approved
Originators					

DESIGN CONSULTANTS :

PROJECT TITLE

HIGHWAY TUNNEL- FOTULA PASS
Including Approaches in
U T of Ladakh

CLIENT

The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE

MAIN TUNNEL WEST PORTAL EXCAVATION AND SUPPORT WEST BOUND TUNNEL POSITION

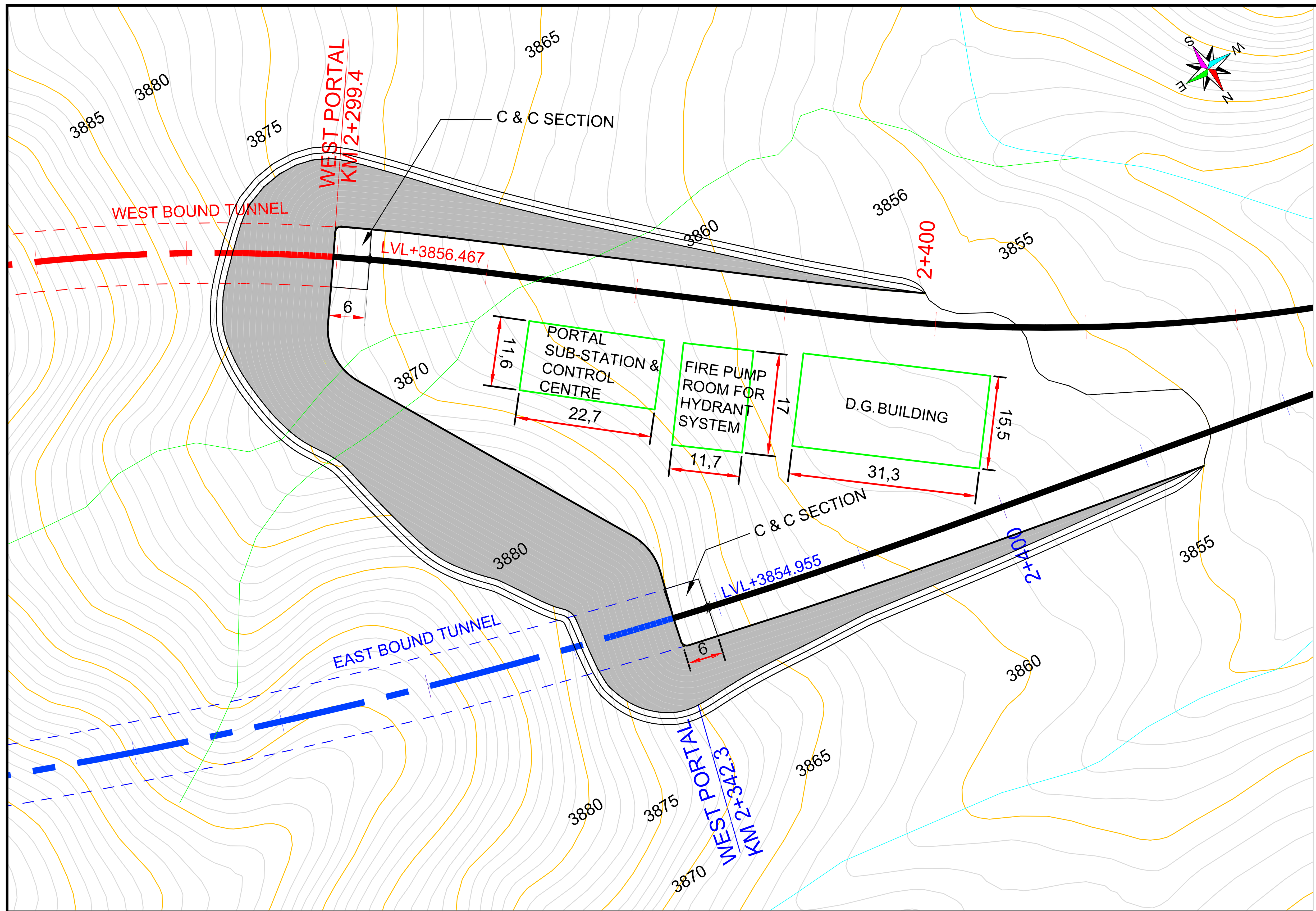
DRAWING NUMBER: FOLA-SUP-WPT-1084

REV: A

SCALE

MONTH (Current Issue): FEB 2025

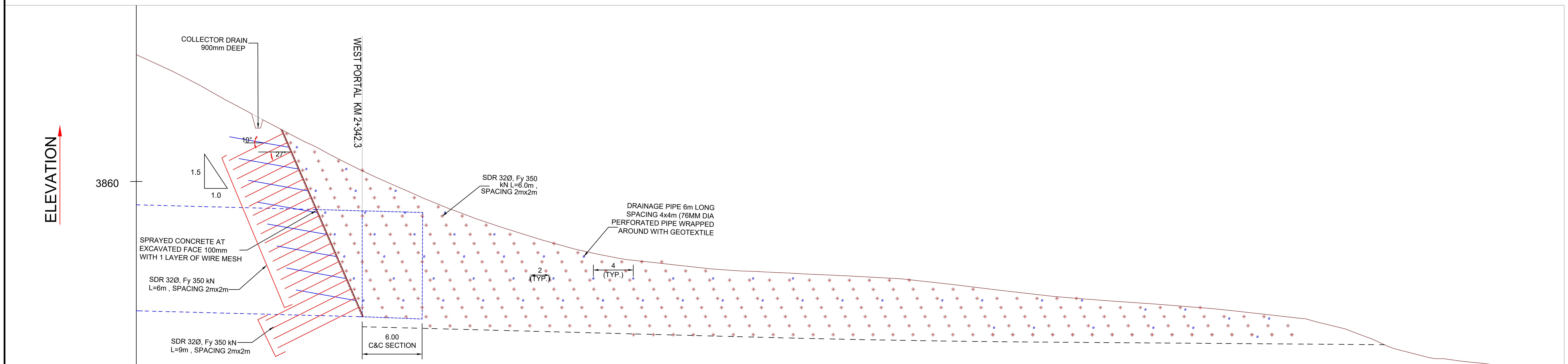
Original Drawing Size A1



KEY PLAN
SCALE : 1:500

NOTES:

1. ALL DIMENSIONS ARE IN m UNLESS NOTED OTHERWISE
2. THIS DRAWINGS IS BASED ON APPROVED ALIGNMENT



LONGITUDINAL SECTION PORTAL POSITION EAST BOUND TUNNEL
SCALE : 1:150

SCALE 1 : 150 (5m 0 5m 10m)

FOR DPR PURPOSE ONLY

REFERENCE DRAWINGS:
- FOLA-ALG-GEN-1000
- FOLA-LAY-WPT-1082
- FOLA-SUP-WPT-1084

LEGEND:
- MAJOR CONTOURS
- MINOR CONTOURS
- ALIGNMENT-EAST BOUND TUNNEL
- ALIGNMENT-WEST BOUND TUNNEL
- ROCK BOLT
- DRAINAGE HOLE

REVISION

REV.	DATE	PARTICULARS	Drawn	Checked	Approved
0	JULY	FIRST SUBMISSION (DPR)	PKH	RSSK	LK

QUALITY ASSURANCE

The responsibility of control, check and verification of accuracy, correctness, completeness, integration and full compliance of contract provisions in respect of design analysis and drawings rests with the design consultants and the contractor.

Date (FIRST ISSUE)	05.02.2025	05.02.2025	05.02.2025	05.02.2025	05.02.2025
Name	PKH	PKH	RSSK	LK	LK
Originators	Drawn	Drafting Chk	Designed	Design Chk	Approved

DESIGN CONSULTANTS :

PROJECT TITLE
HIGHWAY TUNNEL- FOTULA PASS Including Approaches in U T of Ladakh

This document should not be relied on or used in circumstances other than those for which it was originally prepared and for which Geoconsult was commisioned. Geoconsult accepts no responsibility for this document to any other party other than the person by whom it was commisioned.

CLIENT
The Administration of the U T of Ladakh
Office of the Chief Engineer PWD (R&B)

DRAWING TITLE
MAIN TUNNEL WEST PORTAL EXCAVATION AND SUPPORT EAST BOUND TUNNEL POSITION

DRAWING NUMBER FOLA-SUP-EPT-1085 | REV A

SCALE | MONTH (Current Issue) FEB 2025