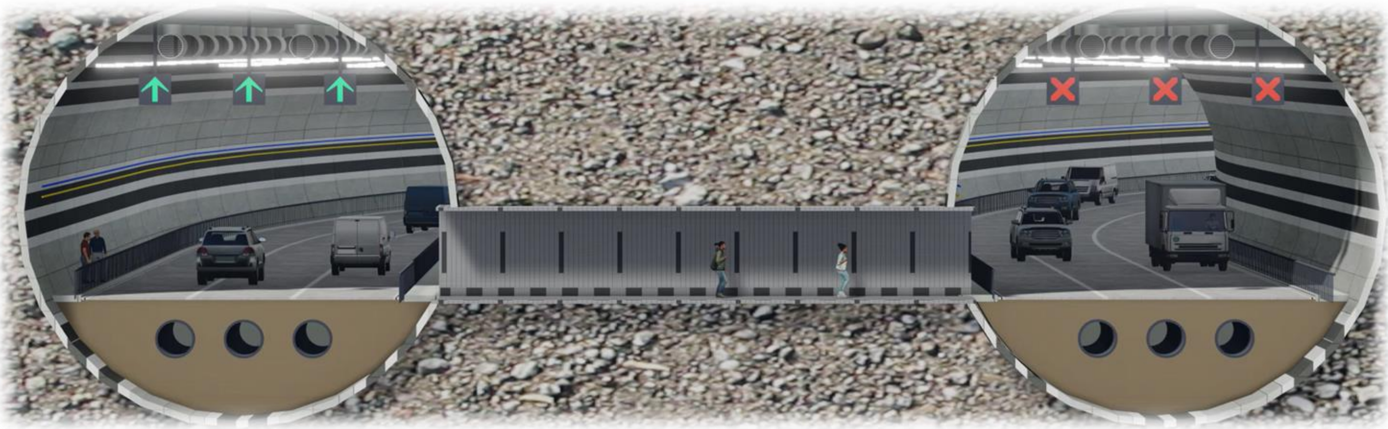
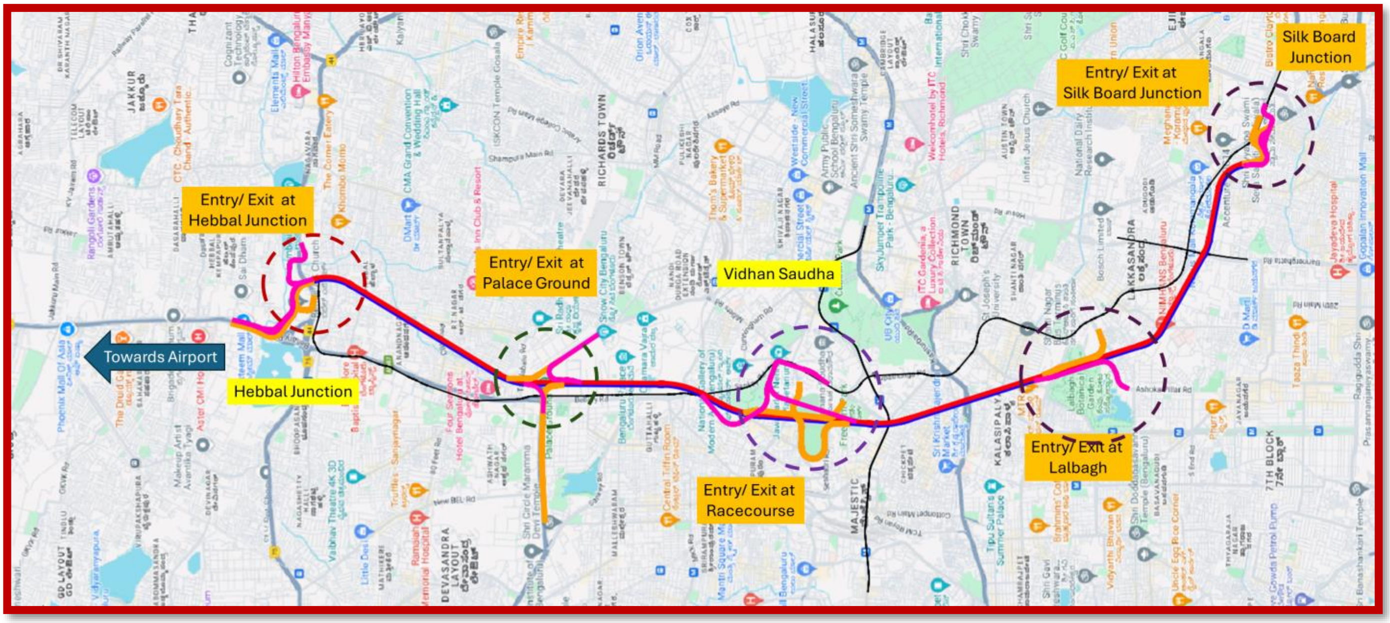
GOVERNMENT OF KARNATAKA



CONSULTANCY SERVICES FOR PREPARATION OF DPR FOR THE WORK OF CONSTRUCTION OF UNDERGROUND VEHICULAR TUNNEL FROM HEBBAL ESTEEM MALL JUNCTION TO SILK BOARD KSRP JUNCTION



DRAFT DETAILED PROJECT REPORT

VOLUME - II A
GEOTECH DESIGN REPORT

September 2024

RODIC CONSULTANTS PVT. LTD

BRUHAT BENGALURU MAHANAGARA PALIKE

DOCUMENT SUMMARY SHEET

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Rev. No.	R0	
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Page no.	61	
Project	**Consultancy services for preparation of DPR for the work of Construction of underground Vehicular Tunnel from Hebbal Esteem mall junction to Silk Board KSRP junction.**	
Report	***Executive Summary***	

Name and Designation				
Owner	**Rodic Consultants Pvt. Ltd.**			
Prepared By	***Name & Designation***	***Remarks***	***Name & Designation***	***Remarks***
	Mr. Ravi Ranjan	Ok		
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Reviewed By	Mr. Adarsh Kumar Tiwari Project Co-Ordinator	Ok	Mr. Jagdish Sharma Asst. Vice President	Ok
Approved By	Dr H R Yadav Executive Director	Ok		

Revision Summary

Sl. No	Date	Modifications	Version	Remarks

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CHAPTER 1
INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 General

Bruhat Bengaluru Mahanagara Palike (BBMP) intends to Construct a Underground Vehicular Tunnel for the North – South Corridor starting from Hebbal Esteem Mall junction to Silk Board KSRP Junction.

In pursuance of the above**, Rodic Consultants Pvt Ltd., New Delhi** has been appointed as consultants to carry out **Consultancy Services for Preparation of DPR for the work of Construction of Underground Vehicular Tunnel from Hebbel Esteem Mall junction to Silk Board KSRP junction.**

1.2 Project Location

The entire project is located in Bengaluru city.

The North – South Corridor starting from Hebbal Esteem Mall junction to Silk Board KSRP Junction is going to develop as Underground Vehicular tunnel having 04 connecting stretches with Entry and Exit are as below:

- Esteem Mall-Hebbal-Mekri circle-Palace Ground
- Palace Ground- Golf Course-Race Course-Palace Road Jn
- Racecourse/Chalyuka circle-Lalbagh BG
- Lalbagh Botanical Garden- Silk Board KSRP Jn

1.3 Scope

The report covers the stability analysis for the deep excavation of Shaft and Cut and Cover Portion along with analytical design for NATM tunnel (main tunnel with 2 lanes), including vehicular cross passage.

CHAPTER 2
REFERENCES

CHAPTER 2: REFERENCES

2.1 Documents Made Available

[1] Feasibility Study Report (North South Corridor)

[2] Alignment Drawings

2.2 References

[1] IS 456: 2000 Plain and reinforced concrete – Code of practice (Fourth Revision)

[2] IS 14448-1979: Code of Practice for Reinforcement of Rock Slopes with Plane Wedge Failure

[3] BS 8081:2015 – Code of practice for grouted anchors

[4] EN 1992-1-1 (2004) (English): Eurocode 2: Design of Concrete Structures – Part-1-1: General rules and rules for buildings

[5] FHWA-IF-99-015 (1999): Ground Anchors and Anchored Systems

[6] FHWA-NHI-14-007 (2015): Soil Nail Walls Reference Manual

[7] IS 10270-1982: Guidelines for Design and Construction of Prestressed Rock Anchors

[8] IS 1556-1982: Specification for Hard-Drawn Steel Wire Fabric for Concrete Reinforcement

[9] IS: 15026 (2002) – Tunnelling Methods in Rock Masses-Guidelines.

[10] Duddeck H. and Erdmann J.: Structural design models for tunnels

[11] Duddeck Duddeck H. and Erdmann J.: Vergleich ebener und Entwicklung räumlicherBerechnungsverfahren für Tunnel

[12] Austrian Society for Rock Mechanics: Geotechnical Underground Structures Design (Tunneling in Rock)

[13] Austrian Standard ONORM B2203 Part 1, Underground Works – Conventional Excavation, 2001

[14] Austrian Society for Concrete and Construction technology: Guideline Sprayed concrete, 2013

[15] Practical Rock Engineering by Evert Hoek

[16] Soil Mechanics & Engineering in Practice by Karl Terzaghi and Ralph B. Peck

[17] Foundation Analysis and Design by Joseph E Bowles.

2.3 Documents Submitted

[1] Geotechnical Interpretative Report (GIR) Report No. – I40172-GIR

[2] Structural Design Report, Report No- I40172-Structure-DRP

2.4 Software

[1] RS2 (Version 10) – Rocscience Software, Finite Element Analysis for Excavations and Slopes

CHAPTER 3
GEOTECHNICAL DESIGN REPORT

CHAPTER 3: GEOTECHNICAL DESIGN PARAMETERS

The Following parameters have been considered from GIR report [1] based on the available information.

Table 1 : Geotechnical Parameters for Soil

*Depth from Surface	**Strata Description**	**Bulk Unit Weight**	**Cohesion (c')**	**Friction Angle(Ø')**	**(E')**	**Ko**	**Poisson's Ratio (ν)**	**Permeability (k)**
		[kN/m3]	[kPa]	[o]	[MPa]		[-]	[m/sec]
0-2 (7.5)m	Fill Material	16	0	25	5	0.58	0.3	5x10-5
2-4(12)m	Silty Sand/ Sandy silts with Clayey Sand	18	0-3	27-29	**EXP(Z+2.85)/ 3.15**	0.52	0.3	1x10-5
4-8m	Residual Soil	19	3-5	27-30	**100**	0.52	0.3	1x10-6

- The depths of soil and its types from ground surface to bedrock contact is variable. A tentative stratification interpreted is shown in the Geological L-Section developed from the available borehole data. Depending on the local topography/Geomorphological setup, the thickness of soil layers can increase beyond the general thickness anticipated (given in brackets)

Table 2 : Geotechnical Parameters for Rock

Overburden (m)		**Design Parameters for Rock Mass**			**(General Case) D=0**								
		Strata	**Grade**	**γb**	**GSI**	**σci**	**(MR)**	**Ko**	**Em**	**νm**	**(c)**	**(Ø')**	**(k)**
				[kN/m3]	[-]	[MPa]			[MPa]	[-]	[MPa]	[o]	[m/sec]
<30	Laterite	**CW -HW**	V-IV	23	15	25	400	0.42	300	0.30	0.6	22	1x10-5
		MW*	III	25	40	35	465	0.35	1600	0.26	1.8	30	1x10-6
	>30	**MW**	III	25	40	45	500	0.35	3600	0.26	2.7	37	1x10-7
		SW	II	26	70	55	500	0.27	15000	0.22	5.0	45	1x10-8
		FR	I	26	80	75	525	0.25	35000	0.20	8.0	50	1x10-8

A Case for segregating the Design Parameters for rock mass based on Overburden thickness (wrt Formation Level) has been interpreted, to consider for the marginally lower competence in the Moderately weathered rock masses (MW) under influence of deeper influence of weathering, applicable for portal areas, drain/ nalla sections, Shafts etc. The valuations are evaluated for the General case, as per RocLab.

For the analysis of deep excavation and from the data available the nearest geological data near to the deep cut section is considered, which is the conservative due to higher thickness of soil layer and the parameters considered for the design are tabulated below.

Table 3 : Geotechnical Design Parameters for Soil -Deep Excavation

Depth below GL	**Strata**	**Undrained Parameters**				**Drained Parameters**				
		ɣ	**c**	**φ**	**E**	**c'**	**φ'**	**E'**	**Ko**	**k**
[m]		[kN/m3]	[kPa]	[o]	[MPa]	[kPa]	[o]	[MPa]		[m/sec]
0.0-7.5	Fill Material	16	0	30	6	0	25	5+1.5Z	0.58	$5x10^{-7}$
7.5-12	Silty Sand/ Clayey Sand	18	0	30	30	2	25	25	0.58	$1x10^{-7}$

Table 4 : Geotechnical Design Parameters for Rock -Deep Excavation

										Slope		
Depth below GL	**Strata**	**Grade of Rock**	**γ**	**GSI**	**UCS**	**Ei**	**K_o**	**Em**	**ν**	**c'**	**φ'**	**k**
[m]			[kN/m³]	[-]	[MPa]	[GPa]		[GPa]	[-]	[MPa]	[º]	[m/sec]
12-22	Completely to Highly Weathered	V-IV	22	25	25	10	0.43	0.3	0.3	0.12	39	$1x10^{-6}$
22-30	Moderately Weathered rock	III	25	45	35	16.65	0.33	1.3	0.25	0.25	52	$1x10^{-7}$
>30	Slightly Weathered to Fresh Rock	II-I	26	80	55	30.2	0.25	14.4	0.2	1.3	65	$1x10^{-8}$

CHAPTER 4
LAYOUT

CHAPTER 4: LAYOUT

Temporary shafts are located in the project area for the launch / retrieval of TBM as well for the zones of Cut and Cover and Ramp portion. The excavation support consists of a combination of secant pile wall with steel waler beam and ground anchors, and the details of the secant pile is mentioned below.

4.1 General Section detail for secant pile

Th secant pile wall would be used to support the excavation of shaft / Cut and Cover. Secant pile walls consist of an alternate series of unreinforced soft piles (M15 grade) and reinforced hard piles (M35 grade). Initially, a 1.0m / 0.8m diameter soft pile will be installed in the ground, once the soft pile is constructed, 1.0m diameter of the hard pile will be installed in the ground with overlap of 200mm/150mm between the hard and soft pile. The general details of the secant pile arrangement is show in the figure below

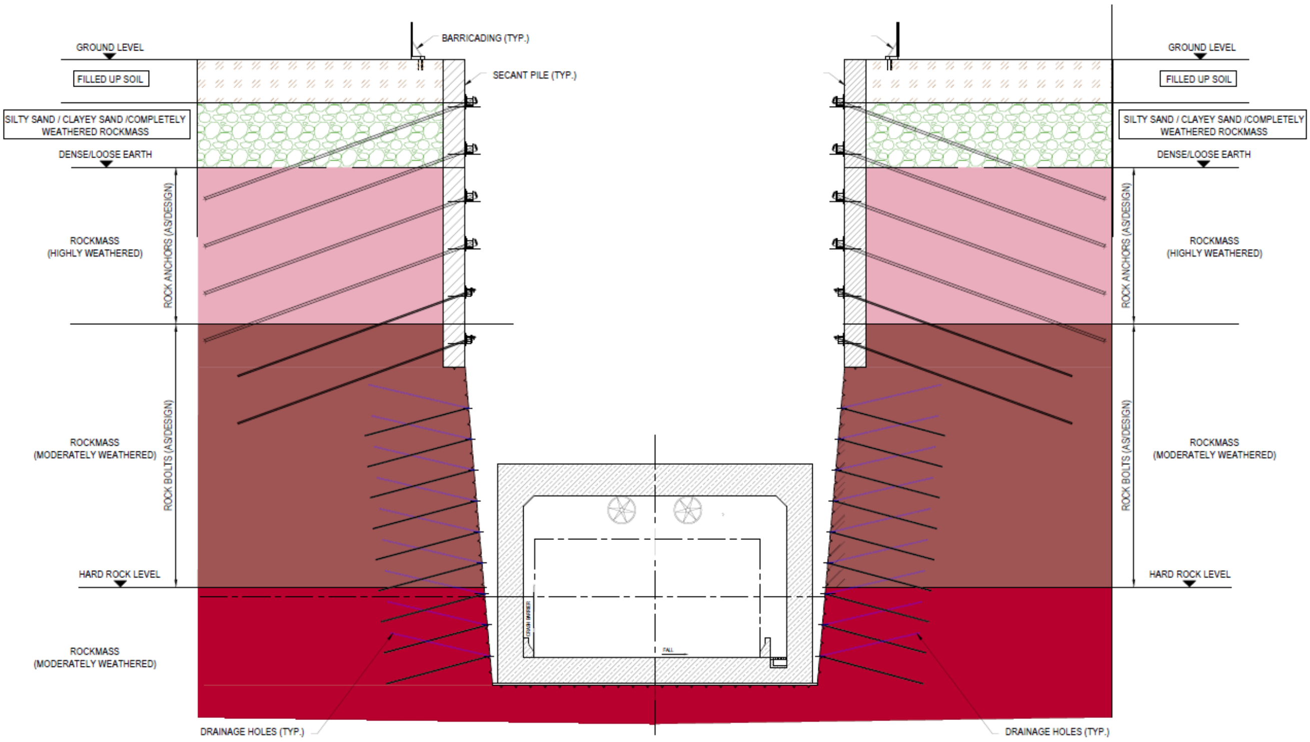


Figure 1: Typical Section Detail of Deep Excavation for Shaft & Cut and Cover Zone

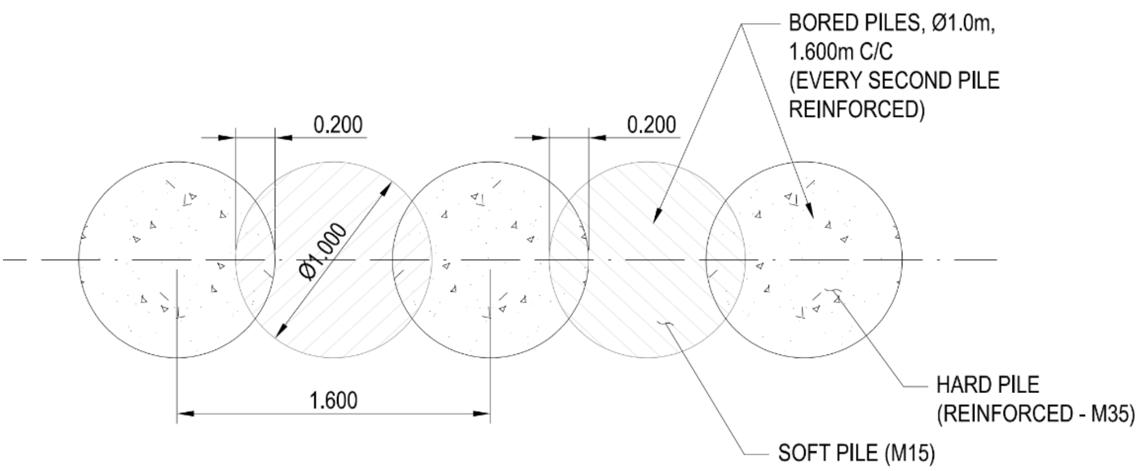


Figure 2: General details of Secant piles of 1.0m Diameter

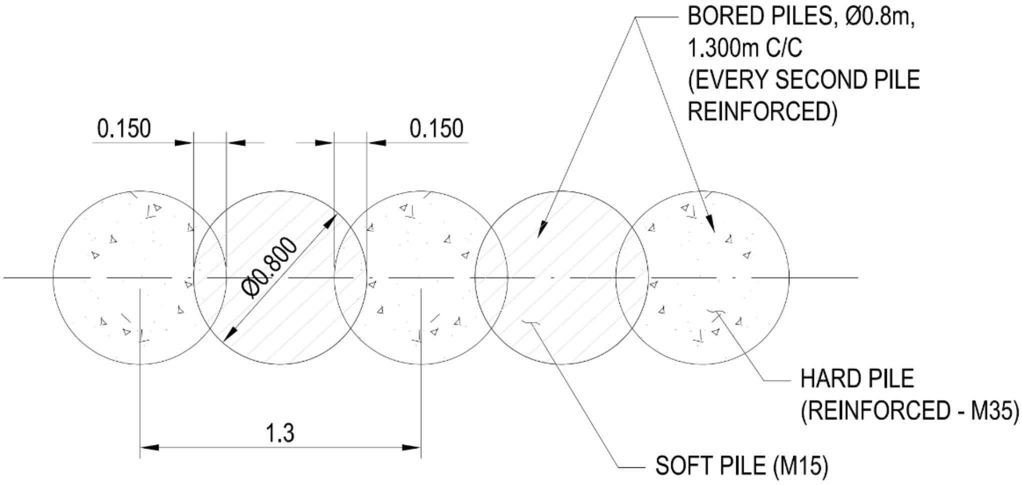


Figure 3: General details of Secant piles of 0.8m Diameter

4.2 Overlapping

The unreinforced soft pile will be installed in the ground 1.0m/0.8m diameter. Once the soft pile (M15) has been constructed, 1.0m/0.8 diameter of the hard pile (M35) will be installed in the ground with an overlap of 200mm/150mm between the soft and hard pile.

The maximum vertical tolerance of the finished secant pile is 1 in 200. For 12m height of pile the maximum deviation is 60mm at soffit of pile.

As temporary casing would be used during casting of secant pile, therefore uncertainty related to positioning of pile center is reduced to practically zero.

CHAPTER 5
MATERIAL PROPERTIES

CHAPTER 5: MATERIAL PROPERTIES

The material properties values provided in this section refer only to design values. The requirements of the Technical Specification ref Table, still apply and need to be achieved and verified in the field.

5.1 Concrete

The hard pile is proposed with a minimum M35 grade of concrete according to IS 456:2000. The following properties of the concrete are stated in Table 5.

Table 5 : Properties of M35 grade concrete for Hard Pile.

Parameter	Unit	Value
Pile Diameter	M	0.8 / 1.0
Grade of Concrete	-	M35
Characteristic Compressive Strength (28 days)	MPa	35
Young's modulus $(E_{conc})_{35}$	MPa	29580
Spacing	m	1.3 / 1.6
Unit weight	kN/m^3	25
Poisson's ratio	-	0.2
Soft Pile to hard pile overlap	[m]	0.15 / 0.2

5.2 Sprayed Concrete

The early strength development of sprayed concrete shall be according to the Austrian Guidelines for Sprayed Concrete, April 2013 and should conform to Class J2 (between B and C) as shown in the Figure 4. The following typical parameters for the properties of shotcrete are stated.

Table 6 : Early Strength Development of Sprayed Concrete

Parameter	Unit	Value
Grade of Concrete	-	M25
Characteristic Compressive Strength (f_{ck})	MPa	25
Youngs Modulus, 5000 x $f_{ck}^{1/2}$	MPa	25000
Unit weight:	kN/m^3	24
Poisson's ratio	-	0.2

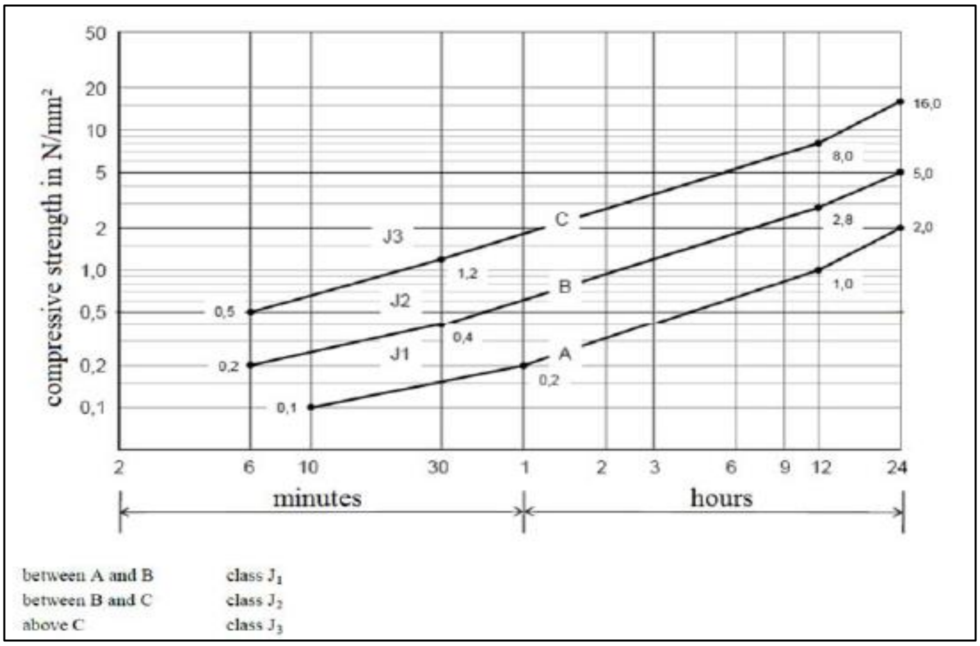


Figure 4: Early Strength Requirement for Sprayed concrete

The thickness of sprayed concrete lining will vary from 10 cm to 30 cm depending on the support class and NATM tunnel section size.

5.3 Steel Fiber Reinforced Shotcrete (SFRS)

Steel fibres can be added to sprayed concrete as a reinforcement supplement. The steel fibres shall be in accordance with IS 432. The fibre dosage and type shall be arrived after the field tests that suit the required strength of Sprayed concrete used in the design. However as per IS 15026, the minimum criteria of important parameters for steel fibres are provided below.

- Geometrical shape= Length of fibres (20 to 40mm) & Recommended sizes are 25 to 35mm x 0.40mm diameter.
- Aspect Ratio (Length / Equivalent diameter) = 60 to 75.
- Ultimate tensile strength= > 1000 MPa

5.4 Rock Bolts

Rock bolt support measures will consist of fully grouted steel rebar rock bolts.

Table 7 : Rock bolt support measures

Parameter	Unit	Value
Grade of Steel	-	Fe 500D
Type	-	Fully Grouted (SN)
Design Strength	kN	350 / 213
Diameter	mm	32 / 25

5.5 Pre-stressed soil anchors in secant pile (Tie Back)

Table 8 : Pre-stressed soil anchors in secant pile

Parameter	Unit	Value
Type	-	PT Anchor
Design Capacity	kN	As per design
Anchor Length	m	Varies
Bond Length	m	5
Pretension Force	kN	Varies
Bond strength*	kN/m2	500 As per IS 14448
Hole Dia	mm	150
Pullout Capacity*	kN/m	π x hole dia x bond strength = 235

*To be confirmed at site

5.6 Lattice Girders

Two types of lattice girders are used depending on the thickness of the sprayed concrete liner used.

- Steel Grade: Fe500D (as per IS1786-2008)
- Types: 90/20/25130/25/32

5.7 Pipe roof

A pipe roof is a special type of long forepoling (typically 9-15m). Pipe roof is required in the low cover zone and as well to treat the soft zones (soil/ weak rock) especially in the crown portion and enhance the tunnel stability. The fore poling elements shall consist of steel pipes hollow in nature, the length and spacing of the pipes shall be as per the design and drawings.

- 114mm Dia. pipe with 6.3mm thickness

These loosening zones can develop into collapses, especially when the overburden is low.

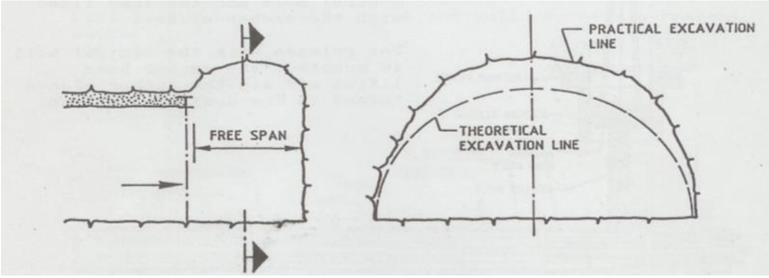


Figure 5: Without forepoling

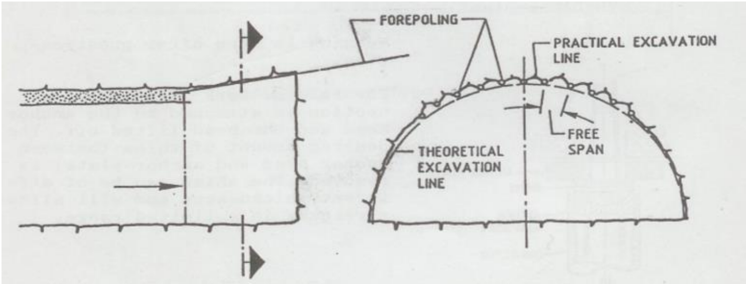
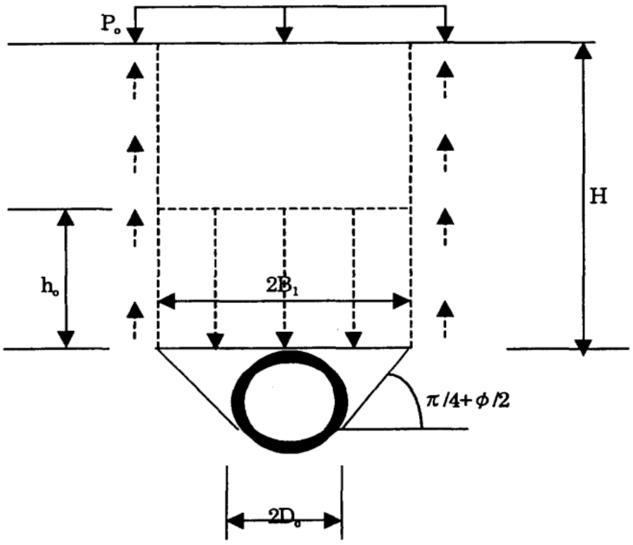


Figure 6: With Forepoling

The design of the Pipe roof is based upon the assumption that the overburden stress is there during excavation when the round is open (i.e. right after opening, with no other support). The calculation of center-to-center distance of Pipe roof takes into account the number of Pipe roof layers above the opened round. The Pipe roof is regarded as beams which are loaded up to the yield load. It has to be stated that under normal conditions this approach is rather conservative as the arching in the immediate excavation area is not taken into account. The loading for the Pipe roof design is estimated as per the figure given below:



$$h_0 = B_1\{1 - C/B_1\gamma)\}\{1 - \exp(-k_0 \tan(\phi) H/B_1)\}/K_0 \tan(\phi) + P_0 \exp\{-K_0 \tan(\phi) H/B_1\}/\gamma$$

Figure 7: Terzaghi's equation for estimation of vertical load

The detailed calculations of Pipe roof are given in **Annexure 5.**

5.8 Face Stability

Tunnel face stability for heading excavation is assessed using Terzaghi vertical load (Silo theory). The tunnel face stability during excavation is evaluated depending on the basis of ground parameters and the temporary support method. The detailed calculations of tunnel face stability are given in **Annexure 6.**

CHAPTER 6
LOADS & LOAD COMBINATION

CHAPTER 6: LOADS & LOAD COMBINATION

6.1 Loads

For the purpose of computing stresses and deformations, the following minimum load types and consequential effects shall be considered as applicable.

Table 9 : Minimum Load Types and Consequential Effects

Loads	Symbol
Dead loads	DL
Earth Pressure	EP
Surcharge	SR
Hydrostatic	WP

i. Dead Loads

The design will consider all dead loads that will act on the structure, including the self-weight of the structure. The unit weight of the reinforced concrete will be considered as 25 kN/m^3 and for plain concrete it will be 24 kN/m^3.

ii. Earth Pressure

The effective lateral earth pressure is equal to the product of load due to the weight of overburden and coefficient of lateral earth pressure $K_{0.}$

iii. Water Pressure

As no level has been reported in BH, the water level from the adjacent lakes is considered. For the derivation of hydrostatic pressure, the maximum groundwater level considered at 5m bgl for design purpose as per the available information.

iv. Earthquake Load

The proposed structures are temporary in Nature, no seismic analysis shall be considered for the design.

v. Surcharge Loads

The design shall also consider loads from surrounding structures for a value of 60 kN/m^2

6.2 Load Factors

The following load factors will be considered in the design of the Secant pile with waler:

6.3 Partial Factors of Safety for Materials

The design strengths are obtained by dividing the characteristic strength by the material factors defined below:

Table 10: Partial Factors of Safety for Materials

Material	Ultimate (ULS)	Serviceability (SLS)
Concrete	1.5	1.0
Reinforcement	1.15	1.0

6.4 Factor of Safety

The Factor of safety for slope stability based on temporary support system shall be 1.3 for static case.

CHAPTER 7
MODELLING & ANALYSIS

CHAPTER 7: MODELLING & ANALYSIS

The numerical analysis for complete excavation of Shafts & Cut and Cover portion has been carried out with support system as secant pile walls, ground anchors, rock bolts & Sprayed Concrete is carried out in the FEM software RS2 [1]. The pile depth will vary as per geological conditions along the Cut and Cover or Shaft portion. Analysis has been carried out for 2 cases with 32m deep excavation (Shaft & CNC) as well 12m deep excavation for Ramp portion.

7.1 Numerical Analysis

The software used for the numerical analysis is the two-dimensional finite element software RS2 . RS2 is a powerful and user-friendly finite-element (FE) package for 2D analysis of deformation and stability in geotechnical engineering and rock mechanics. It is used in geotechnical challenges ranging from excavations, embankments, onshore or offshore foundations to tunneling, mining, and reservoir geomechanics.

RS2 employ various constitutive models ranging from simple linear to advanced highly nonlinear models that allow accurate simulation of most soil and rock types. The material behaviour of the ground is simulated according to material model by Mohr-Coulomb considering drained condition.

The 2D plane strain analysis is used to simulate the deep excavation and support sequences. The half model representing the symmetrical model is considered with Graded 6node triangular element with mesh type. External boundaries of the model are considered far from excavation so that they are not influenced by the excavation impact. The external boundaries of the model are fixed in the horizontal direction on each side, which means that vertical movement is allowed, and the bottom part of the boundary is pinned, so both vertical and horizontal movements are fixed. The top surface of the model represents the ground surface, and it is free in both directions.

In RS2 secant pile and sprayed concrete lining is modelled as plate element with, properties are elastic and isotropic in nature. Secant pile wall is supported with PT anchors at different levels along with rock bolts to resist the movement of pile for stable excavation.

The representative cross section consist of encountered stratification is considered for numerical analysis. The Figure 8 & Figure 9 below shows a typical FEM analysis cross section considered for 32m pile depth & 12m Pile depth case to simulate the excavation and support system.

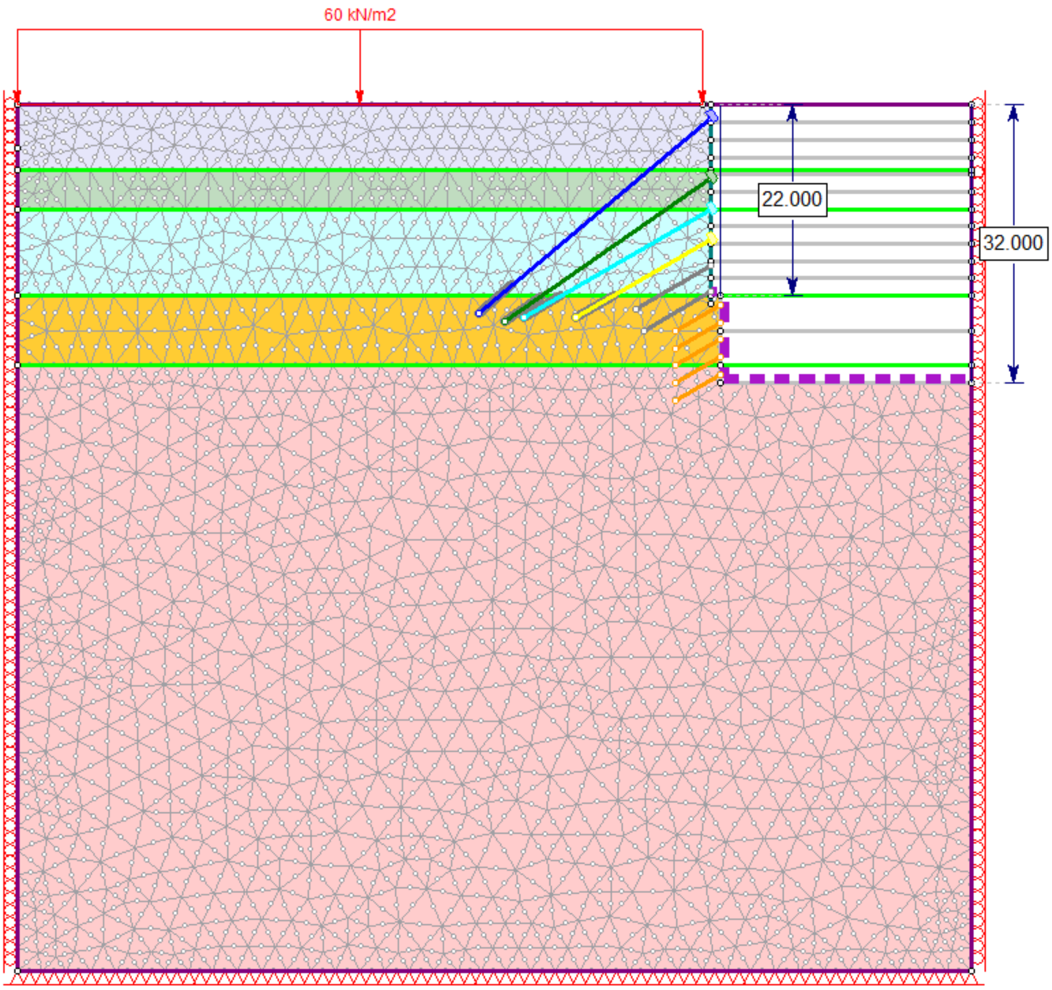


Figure 8: Typical FEM cross section for 32m Deep Excavation

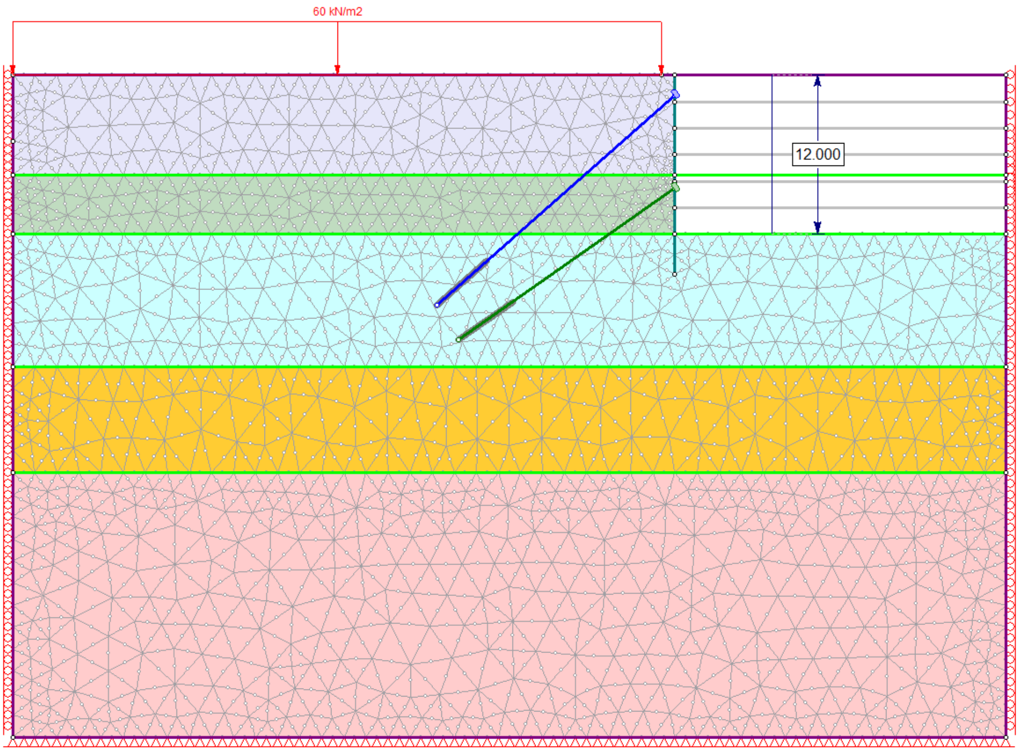


Figure 9: Typical FEM cross section for 12m Deep Excavation

7.2 FEM Modelling Stages

The excavation and behaviour of deep excavation for shafts / Cut and Cover and Ramp portion is simulated as per step-by-step process through numerical analysis. The **Table 11** & **Table** 12 below show the steps involved in performing FEM analysis for 2 cases (32m & 12m Deep).

Table 11: FEM modelling stages to simulate 32m Deep excavation (Shafts / C&C)

Construction Stage Number	Description of calculation stages
1	Grid setup and initial stress field, reset displacement to zero and set design water table of 5.0m BGL
2	Activation of surcharge load of 60 kPa, reset displacement to zero
3	Installation of secant pile of 1m dia, Reset displacement to zero
4	Excavate in soil up to 2m from ground level
5	Installation of 1st level of Support-Anchor @ 1.5m BGL
6	Excavate further 2.0m in soil i.e., upto 4.0m BGL
7	Excavate further 2.0m in soil i.e., upto 6.0m BGL and lowering the water table up to 1m from excavation level i.e., 7.0 m BGL
8	Excavate further 2.0m in soil i.e., upto 8.0m BGL and lowering the water table up to 1m from excavation level i.e., 9.0 m BGL
9	Excavate further 2.0m in soil i.e., upto 10.0m BGL and lowering the water table up to 1m from excavation level i.e., 11 m BGL
10	Installation of 2nd level of Support- Anchor @ 8.5m BGL
11	Excavate further 2.0m in soil i.e., upto 12.0m BGL and lowering the water table up to 1m from excavation level i.e., 13 m BGL
12	Excavate further 2.0m in soil i.e., upto 14.0m BGL and lowering the water table up to 1m from excavation level i.e., 15 m BGL
13	Installation of 3rd level of Support- Anchor @ 12.0m BGL
14	Excavate further 2.0m in soil i.e., upto 16.0m BGL and lowering the water table up to 1m from excavation level i.e., 17 m BGL
15	Installation of 4th level of Support- Anchor @ 12.0m BGL
16	Excavate further 2.0m in soil i.e., upto 18.0m BGL and lowering the water table up to 1m from excavation level i.e., 19 m BGL
17	Excavate further 2.0m in soil i.e., upto 20.0m BGL and lowering the water table up to 1m from excavation level i.e., 21 m BGL
18	Installation of 5th Level of Support -Rock Bolt i.e., 18.5m BGL
19	Excavate further 2.0m in soil i.e., upto 22.0m BGL and and maintain zero groundwater pressure at rock level
20	Installation of 5th Level of Support -Rock Bolt i.e., 21.5m BGL
21-27	From start of rock level to final excavation level (Excavation in Rock) • Excavate in stages of 4m till final stage of excavation. • Maintain zero groundwater pressure at rock levels (i.e. lowering of water table up to excavation level) • Installation of rock bolts Installation of sprayed concrete after each stage of excavation

Table 12: FEM modelling stages to simulate 12m Deep excavation (Ramp Portion)

Construction Stage Number	Description of calculation stages
1	Grid setup and initial stress field, reset displacement to zero and set design water table of 5.0m BGL
2	Activation of surcharge load of 60 kPa, reset displacement to zero
3	Installation of secant pile of 0.8m dia, Reset displacement to zero

Construction Stage Number	Description of calculation stages
4	Excavate in soil up to 2m from ground level
5	Installation of 1st level of Support-Anchor @ 1.5m BGL
6	Excavate further 2.0m in soil i.e., upto 4.0m BGL
7	Excavate further 2.0m in soil i.e., upto 6.0m BGL and lowering the water table up to 1m from excavation level i.e., 7.0 m BGL
8	Excavate further 2.0m in soil i.e., upto 8.0m BGL and lowering the water table up to 1m from excavation level i.e., 9.0 m BGL
9	Excavate further 2.0m in soil i.e., upto 10.0m BGL and lowering the water table up to 1m from excavation level i.e., 11 m BGL
10	Installation of 2nd level of Support- Anchor @ 8.5m BGL
11	Excavate further 2.0m in soil i.e., upto 12.0m BGL and lowering the water table up to 1m from excavation level i.e., 13 m BGL

Annexure 1 for RS2 Input and Output results.

CHAPTER 8
RESULTS SUMMARY -DEEP EXCAVATION

CHAPTER 8: RESULTS SUMMARY -DEEP EXCAVATION

8.1 Analysis Results

The below shows the numerical analysis results for the two cases of 32m and 12m deep excavation.

Table 13: FEM analysis results (Maximum Unfactored forces) for 32m and 12m Excavation depth

Excavation Depth	Axial Force (KN/m)	Bending Moment (kN-m/m)	Shear Force (kN/m)	Horizontal Dis. (mm)	Load Case
32m	1510	790	299	35	60 kPa
12m	511	543	131	24	

8.1.1 Global Stability:

Strength reduction factor (SRF) tool of RS2 is adopted to get the factor of safety for slope stability analysis. The Factor of Safety is estimated at end of excavation stages. The shear strength reduction option performs a finite element slope stability analysis and computes a critical strength reduction factor for the model. The critical strength reduction factor is equivalent to the "safety factor" of the slope. The FoS is compared to the minimum desired value of 1.3 for temporary works at the end of excavation stages.

Table 14: Global Stability Check for for 32m and 12m Excavation depth

Excavation Depth	FOS-Static	Load Case
32m	1.35	60 kPa
12m	2.25	

Table 15: Summary of Anchor/ Bolt Forces -FEM Analysis

Pile Depth	Support	Level (m)	Load Case	Anchor/ Bolt Forces (kN)
32m	Anchor-1	1.5m bgl	60 kPa	691
	Anchor-2	8.5m bgl		555
	Anchor-3	12m bgl		628
	Anchor-4	15.m bgl		641
	Rock Bolt-1	18.5m bgl		193
	Rock Bolt-2	21.5m bgl		202
12m	Anchor-1	1.5m bgl		478
	Anchor-2	8.5m bgl		439

8.1.2 Support Summary

The following table shows the recommended support system.

Table 16: Support Summary for Secant Pile wall

Excavation Depth	Support Measure						Case
	Anchor			Rock Bolts			
	Anchor Length (m)	Hor. Spacing (m)	Inclination (Deg)	Bolt Length (m)	Spacing (m)	Inclination (Deg)	
32m	35	1.6 (H)	40	10m	3.2 (H)	30	60 kPa
	29	1.6 (H)	35	10	3.2 (H)	30	
	25	3.2 (H)	30	-	-	-	
	18	3.2 (H)	30	-	-	-	
12m	24	2.6 (H)	30	-	-	-	60 kPa
	20	2.6 (H)	30	-	-	-	

8.2 Open cut support summary

8.2.1 Local Stability

The Kinematic analysis is to be performed based on face mapping data. In absence of structural data, the slope support for rock face has been carried out using stress analysis in FEM and found to be safe with the provided support.

For the 32m deep excavation, the remaining depth to be excavated in hard rock which is already explained in the FEM modelling analysis. The **Table 17** below shows the complete summary of support elements proposed in deep excavation design.

Table 17: Support Summary – Open Cut

Excavation Support Recommendations (Depth: 22m to 32m)	
Sprayed Concrete	M30, 100mm thick
Wire mesh	150/150/6.0 mm (1 layer)
Rock Bolts	<u>**Excavation in Rock (Rock Support)**</u> <u>Rock grade III</u> • Fully grouted, 4m long, 25mm dia SN bolt, 213kN • spacing 2.0m (V) x 3.0m(H) Staggered <u>Rock grade I/II</u> • Fully grouted, 4m long, 25mm dia SN bolt, 213kN • spacing 3mx3m Staggered <u>Spot Bolting (If required)</u>
Drainage holes	50mm dia, 6m long @6x6 spacing

8.2.2 Pile Bearing Capacity Check

The secant pile load carrying capacity is derived in accordance with IRC 78 Table, considering only the end bearing in grade III (MW) rockmass for 32m deep excavation and in end bearing in grade IV-V (CW-HW) rockmass for 12m deep excavation.

The total axial on the secant pile wall is taken from the pile tip from the analysis output for all the pile cases, which is verified against the pile bearing capacity check. Refer **Annexure-2** for bearing capacity calculation of secant pile walls.

8.2.3 Toe Stability Check

A toe stability check is performed for the determination of suitable embedment depth of secant pile wall for 32m and 12m excavation depth with water table at 5.0m BGL using the widely accepted method suggested in Euro code- EC7.

In toe stability check minimum required toe embedment is calculated by ensuring FOS=1.3.

Refer **Annexure – 3** for Toe Stability check

8.2.4 Structural Reinforcement Detail Design for secant pile wall

The structural design is carried out in accordance with IS 456 with load combination as discussed in Chapter-6. As a general construction practice, a crack width check is not done for temporary structures, hence no check for cracks will be carried out.

All components of the secant pile and associated elements have been checked for Ultimate Limit State only.

For detailed calculations refer **Annexure – 5 & 6** of Structural Report (I40172-STR Design report)

CHAPTER 9
NATM TUNNEL

CHAPTER 9: NATM TUNNELS

9.1 NATM Tunnel – Design Basis

9.1.1 Typical Cross Section of NATM Regular Section

The following typical cross section for NATM Regular section 2 lane and 1 lane as shown in the figure below, shall be considered for concept design of primary and secondary lining.

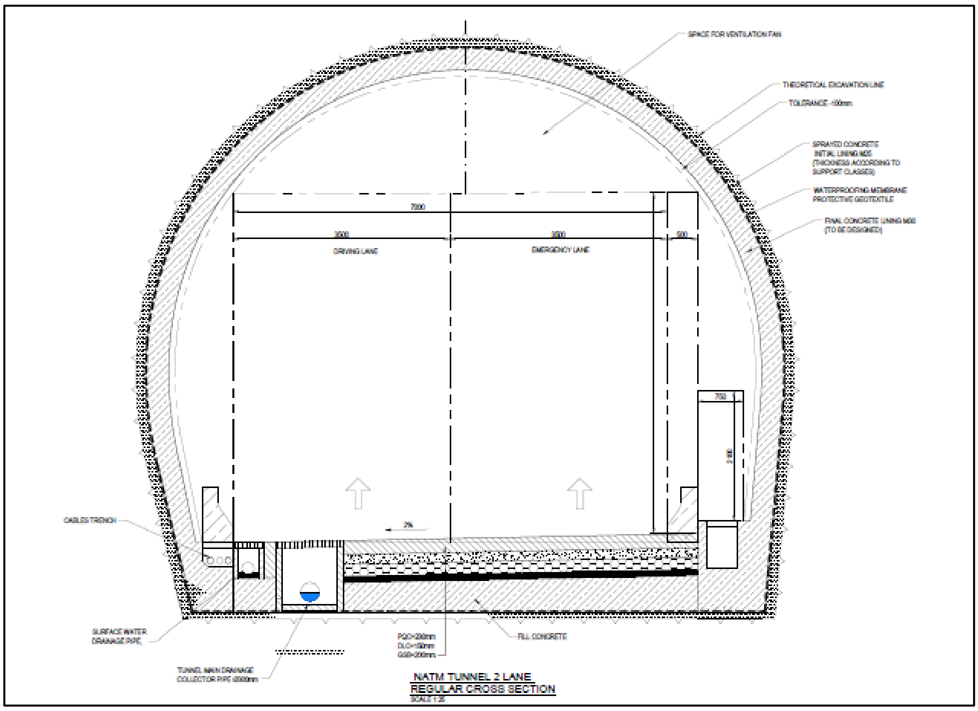


Figure 10: Typical Regular cross-section of NATM- 2 Lane

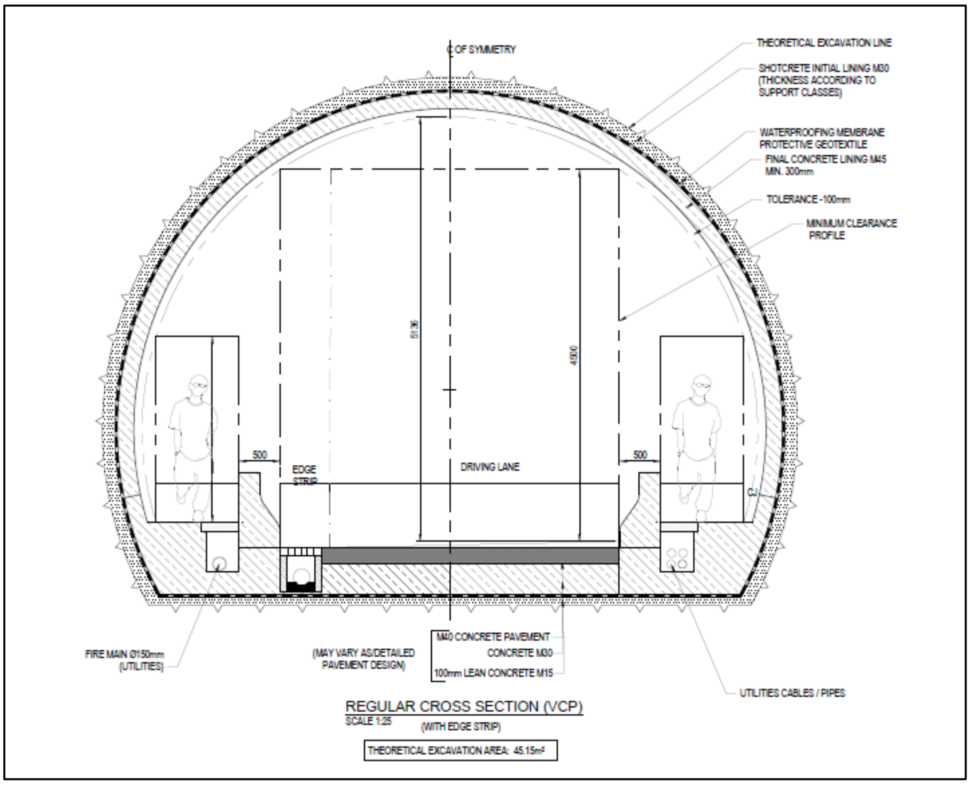


Figure 11: Typical Regular cross-section of NATM (Vehicular Cross Passage)-1 Lane

9.2 Design Approach

The design methodology covers the design phases (preliminary design & detail design) prior to construction. The design will be refined and adjusted during construction in an "observational approach".

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.

The primary support design shall be based on well accepted analytical methods and/or finite element analysis.

Design for the NATM tunnelling sections will be driven by the following philosophy:

- Flexibility in design in the framework of the existing contract
- Employment of State-of-the-Art materials and construction methods

The following flowchart shows the general design approach for the primary lining of NATM tunnelling sections.

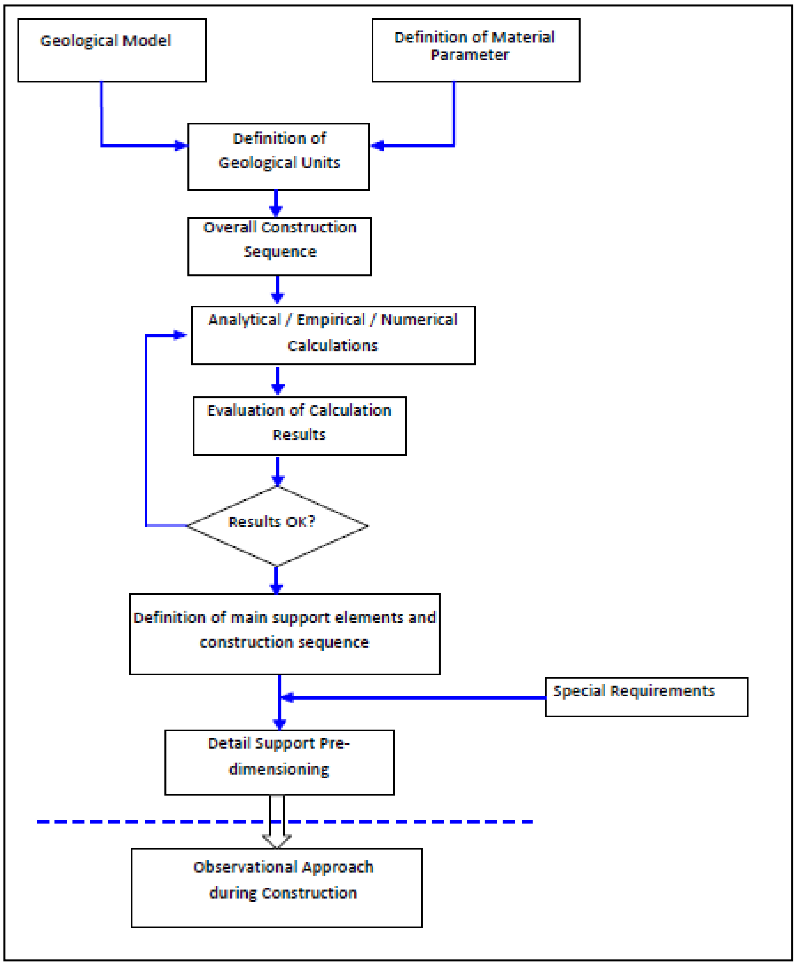


Figure 12: General design methodology for NATM Tunnelling sections.

The main task of the geotechnical design is the economic optimization of the construction considering the ground conditions as well as safety, long term stability, and environmental requirements. The variability of the geological composition including the local ground structure, ground parameters, stress and groundwater conditions requires that a consistent and specific procedure be used during the design process. The key influences governing the geotechnical design are the ground conditions and Ground Behavior.

Geotechnical design is typically accomplished in two main phases, namely the design phase and the construction phase.

9.3 Design Consideration for Primary Support

Primary lining design would be taking a direct reference of Austrian guidelines being them the most appropriate document for NATM design. The manual is in compliance to employer requirement.

The NATM method is based on the concept of the Observational Approach and relies on Geotechnical Monitoring during execution.

Based on the geological-geotechnical data available from the geotechnical investigations, different support classes shall be developed for different tunnelling sections which reflect the support measures for different ground conditions encountered. Due to the nature of the ground, combinations of soil types are possible and are expected to be encountered during tunnelling.

The primary support, which consists of sprayed concrete, generally reinforced by wire mesh, or steel fiber/polypropylene fiber reinforced sprayed concrete, lattice girders (where required) and rock bolts/soil nails, will provide the immediate support and stability of the excavation. The inner lining, which consists of cast in-situ concrete (plain or reinforced), will provide the long-term support and durability of the tunnel.

A subdivision of the tunnel cross-section into top heading and bench/invert may be required, as well as fore poling for crown stability and face bolting & face sealing sprayed concrete will be required for face stability depending on the ground conditions. Further it is required to close the supporting ring immediately for all soil and soil like support classes. It may be required to excavate the top heading in multiple sections to further reduce the deformations and guarantee a smooth load transfer in case soft / weak ground is encountered.

The adjustment and refinement of the primary support, as well as its applicability for different ground conditions identified by regular face mapping and probe drilling will be carried out with basis on the evaluation of the results of the geotechnical monitoring, which constitutes an essential element of the proposed construction method. Geotechnical Monitoring is carried out at instrumentation sections installed at regular and specific spacing along the tunnel.

9.4 Design Phase

This phase involves the determination of expected ground properties, the classification into Ground Types (GT), the assessment of the Ground Behaviours (GB), its categorization into Behaviour Types (BT), as well as the determination of support measures derived from the Ground Behaviour under consideration of the project specific boundary conditions. On this basis the expected system Behaviour (SB) is predicted.

9.5 Ground Types

A Ground Type is defined as a geo-technically relevant ground volume, including discontinuities and tectonic structures, which is similar with respect to following properties

- in rock: mechanical properties (intact rock – rock mass), discontinuity characteristics and properties, rock type, rock- and rock mass conditions hydraulic properties
- in soil: mechanical properties, grain size distribution, density, mineral composition, parameters of the soil components, matrix parameters, water content and hydraulic properties

Different Ground Types have different characteristic parameters that influence their mechanical behaviour. To determine different ground types relevant key parameters, have to be evaluated and defined. Different ground masses with similar combinations of relevant parameters are distinguished as one Ground Type.

The final task in this step is to assign the Ground Types to the alignment.

9.6 Behaviour Types

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:

Table 18: Ground Behaviour Type

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, occasional 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 narrowly 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 sil 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)

9.7 Calculations according to Duddeck/Erdmann

This analytical calculation approach uses elastic, uniform soil/rock conditions and full shear bond between the elastic lining and the subsoil. Further circular shaped full-face excavation is assumed. As result of the Erdmann / Duddeck calculation normal forces N, bending moments M and shear forces V in the sprayed concrete shell at the crown, bench and invert – sections are obtained.

The analysis after Erdmann/Duddeck is generally used for shallow tunnels with a low stress-level.

9.8 Numerical Analysis

Numerical analysis of tunnel initial support shall be carried out using finite element software RS2 from Rocscience. The tunnel initial support estimated from empirical method shall be considered and verified with Numerical analysis to check the excavation stability in terms of ground movements at tunnel excavation boundary.

Actual representation of site conditions (shallow overburden and deep overburden) with actual topography along the tunnel cross-section and tunnel construction sequence can be modelled in Finite Element Modelling (FEM). From the FEM analysis, all the values of closure shall be checked within permissible limits with the proposed support system.

9.9 Construction Phase

During construction, all ground parameters relevant to the geotechnical design must be collected, recorded, and evaluated to determine the ground type. Considering these influencing factors, the actual system behaviour in the excavation area is assessed according to the stipulations of the design.

The basic procedure for geotechnical design begins with the determination of the Ground Types and ends with the definition of the excavation classes. The outline of the design procedure during construction phase is illustrated in the flow chart shown in Figure 13.

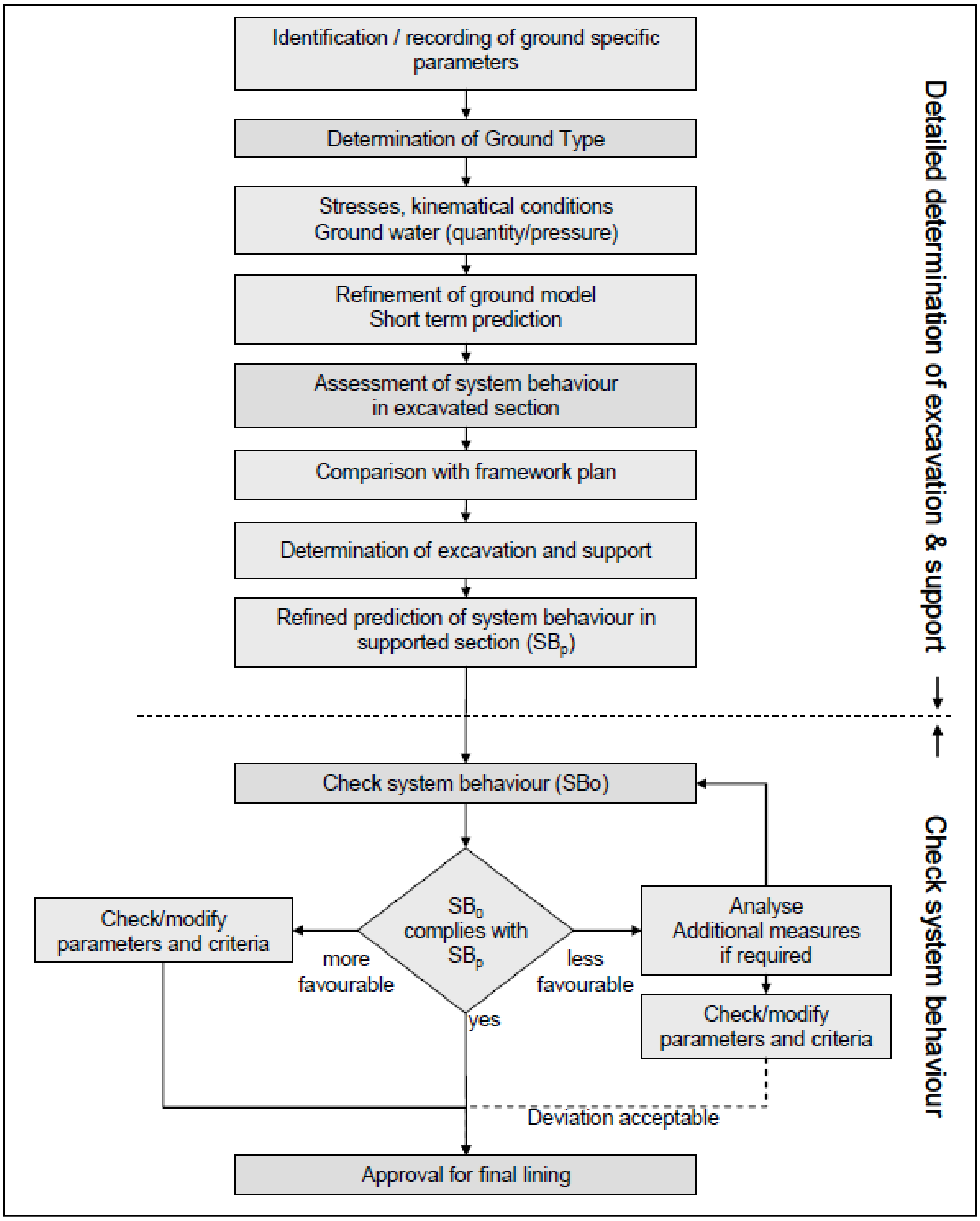


Figure 13: Flow chart showing geotechnical design procedure during construction.

9.10 Construction Material Properties

For Construction material properties refer chapter -5

9.11 Design loads and Safety Factors

For loads and load factors refer Chapter - 6.

9.11.1 Earth Pressure

The Earth pressure acting on the lining will be the result of the interaction between the ground surrounding the tunnel, the deformation of the ground during excavation support installation and the bending and axial stiffness of the lining. The earth pressure for the analysis is derived in consideration of overburden and soil weight.

9.11.2 Water Load

For "drained" tunnels, water pressures are not considered as design load case. Weep holes and drainage holes shall ensure that no water pressure builds up.

9.11.3 Earthquake

For the primary supports, no earthquake loads will be considered. It is common practice in NATM design to consider earthquake loads for the final lining in specific situations only and not at all for the primary supports.

9.12 Analysis Results for Primary Support

The analysis is carried out according to Duddeck Erdmann analysis. For low overburden cases Duddeck Erdmann analysis falling in soil, completely to highly weathered, (CW-HW), Moderately weathered rock (MW) and Fresh or slightly weathered rock (SW) [10], [11] will be done, as this method is best suited for tunnels with shallow overburden. For the purpose of analysis, the maximum cross section of NATM regular section is considered. The geotechnical parameters are considered from the GIR [1] for analysis.

9.12.1 Results of Analysis according to Duddeck/Erdmann NATM Regular Section 2 Lane

The results of the analysis for different cases are tabulated in the Table 19**.** The detailed calculations are given in the **Annexure 4.**

Table 19: Duddeck/Erdmann analysis results

Analysis No.	Ground type/ Support class	Crown			Side Wall			Invert		
		N_{max} [kN/m]	M_{max} [kN-m/m]	V_{max} [kN/m]	N_{max} [kN/m]	M_{max} [kN-m/m]	V_{max} [kN/m]	N_{max} [kN/m]	M_{max} [kN-m/m]	V_{max} [kN/m]
1	**SW/SC-I**	-10.15	0.02	0	78.76	-0.02	0	-10.15	0.02	0
2	**MW/SC-II**	134.4	1.23	0	1007.20	-1.23	0	134.45	1.23	0
3	**CW/Soil/SC-III**	978.07	41.83	0	1491.82	-41.83	0	978.07	41.83	0

Where:

N_{max} maximum normal force

M_{max} maximum bending moment

V_{max} maximum shear force

The Support classes assigned for the SW, MW , CW/Soil and overburden prove to be sufficient and undergo sustainable deformations before the equilibrium is attained.

The analytical calculation results according to Duddeck / Erdmann show that the support classes defined are sufficient and within M-N curve limits as well as the deformation in the tunnel wall and formation of plastic zone within the allowable limits.

9.12.2 Proposed Primary Support for NATM Regular Section 2 Lane

For the NATM based on the geology of NATM Regular Section 2 Lane has been divided into three support classes, i.e., (SC-I, II & III) and provided in **Table 20**.

Table 20: NATM Regular Section 2 Lane Support Class

Stage	Support Class (SC)	SC-I	SC-II	SC-III
TOP HEADING	Rock type	I-II/ SW/Fresh	III/MW	V/CW -Soil
	Excavation	Heading + Invert	Heading + Invert	Heading +Bench +Invert
	Round Length, m	2.5	1.5	1
	SPrC (M25)	100 mm	200 mm	300 mm
	Bolts	Spot bolting	SN 25mm, 4m long, 2m x 1.5 m spacing	SN/SD 25mm/R32, 6m long, 1m x 1 m spacing
	Forepole	-	-	-
	Pipe roof	-	-	114mm, thick ness 6.3mm Dia pipe @ 0.3m C/C, length - 12m, 4m Overlap
	Lattice Girder	-	90/20/25	130/25/32
	Wire mesh	-	-	-
	Fibers	Steel fibre - 25kg/m3	Steel fibre - 30kg/m3	Steel fibre - 30kg/m3
	Face bolts	-	-	9 no's - SD R32, 9m long, 3m overlap
	Face sealing (M25)	-	100 mm	150mm
BENCHING	Round Length, m	-	-	2
	SPrC (M25)	100mm	200mm	300 mm
	Lattice Girder	-	-	130/25/32
	Bolts	-	-	SN/SD 25mm/R32, 6m long, 1m x 1 m spacing
INVERT	Round Length, m	5	3	2
	SPrC (M25)	100 mm	200 mm	300 mm
	Lattice Girder	-	-	130/25/32

9.12.3 Results of Analysis according to Duddeck/Erdmann NATM Vehicular Cross passage

The results of the analysis for different cases are tabulated in the **Table 21.** The detailed calculations are given in the **Annexure 4.**

Table 21: Duddeck/Erdmann analysis results

Analysis No.	Ground type/ Support class	Crown			Side Wall			Invert		
		N_{max}	M_{max}	V_{max}	N_{max}	M_{max}	V_{max}	N_{max}	M_{max}	V_{max}
		[kN/m]	[kN-m/m]	[kN/m]	[kN/m]	[kN-m/m]	[kN/m]	[kN/m]	[kN-m/m]	[kN/m]
2	**MW/SC-II**	106.9	1.2	0	650.4	-1.2	0	106.9	1.2	0

Where:

N_{max} maximum normal force

M_{max} maximum bending moment

V_{max} maximum shear force

The Support classes assigned for the Grade III (MW) and overburden prove to be sufficient and undergo sustainable deformations before the equilibrium is attained.

The analytical calculation results according to Duddeck / Erdmann show that the support classes defined are sufficient and within M-N curve limits as well as the deformation in the tunnel wall and formation of plastic zone within the allowable limits.

9.12.4 Proposed Primary Support for NATM Vehicular Cross Passage 1 Lane

For the NATM based on the geology of NATM Regular Section 1 Lane has been divided into SC-II and provided in **Table 22**.

Table 22: Support Class-Vehicular Cross Passage- 1 Lane (NATM)

Stage	Support Class (SC)	SC-II
TOP HEADING	Rock type	III/MW
	Excavation	Heading + Invert
	Round Length, m	1.5
	SPrC (M25)	200 mm
	Bolts	SN 25mm, 4m long, 2m x 1.5 m spacing
	Forepole	-
	Pipe roof	-
	Lattice Girder	90/20/25
	Wire mesh	-
	Fibers	Steel fibre - 30kg/m3
	Face bolts	-
	Face sealing (M25)	100 mm
BENCHING	Round Length, m	-
	SPrC (M25)	-
	Lattice Girder	-
	Bolts	-
INVERT	Round Length, m	3
	SPrC (M25)	200 mm
	Bolts	-

According to Duddeck/Erdmann analysis done for ground type (Soil / Rock) for the existing overburden conditions, the combined system “rock mass / support measures” does not fail and the system behaviour remains stable. This can be attributed to the load-bearing capacity of the rock mass, which is able to take on the additional stresses, and to the properties of the modelled support system, which has sufficient ductility to accommodate the non-elastic deformations occurring.

It has to be emphasized that a comprehensive monitoring program during construction is part of the design (observational approach) to allow for a continuous assessment of the primary lining behaviour and the verification of the design assumptions. The excavation sequence in terms of top heading (TH), benching/ invert and temporary invert as shown in support class drawings are inherent components of support classes and shall be executed accordingly. Adjustment to support measures and round lengths is permissible based on the actual geological conditions and the monitoring results.

CHAPTER 10
LIST OF ANNEXURES

CHAPTER 10: LIST OF ANNEXURES

ANNEXURE - 1 - RS2 FEM OUTPUT

ANNEXURE - 2 - PILE BEARING CAPACITY CHECK

ANNEXURE - 3 - TOE STABILITY CHECK

ANNEXURE - 4 - ANALYTICAL ANALYSIS – DUDDECK/ERDMANN RESULTS

ANNEXURE - 5 - PIPE ROOF CHECK

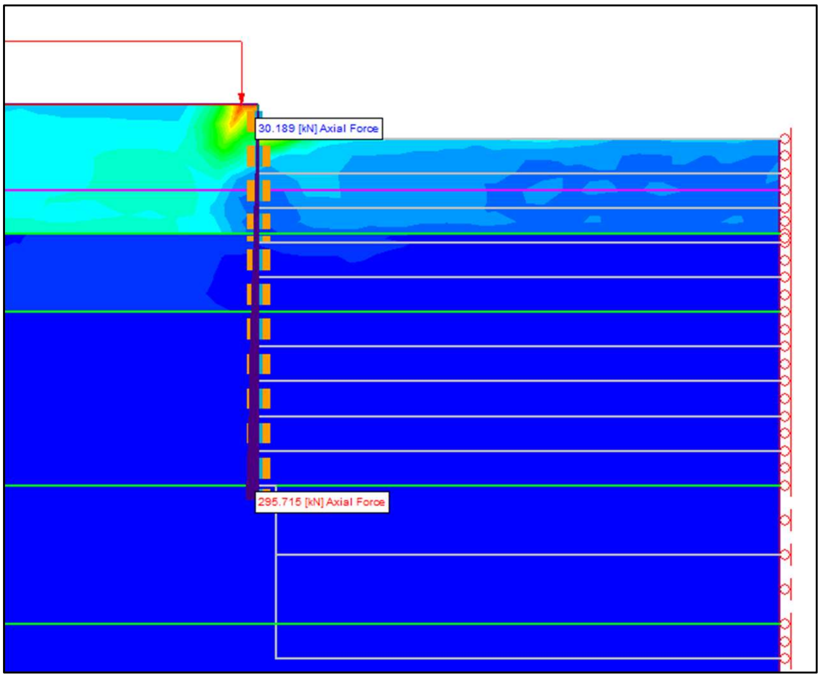
ANNEXURE - 6 - FACE STABILITY

ANNEXURE - 7 - DRAWINGS

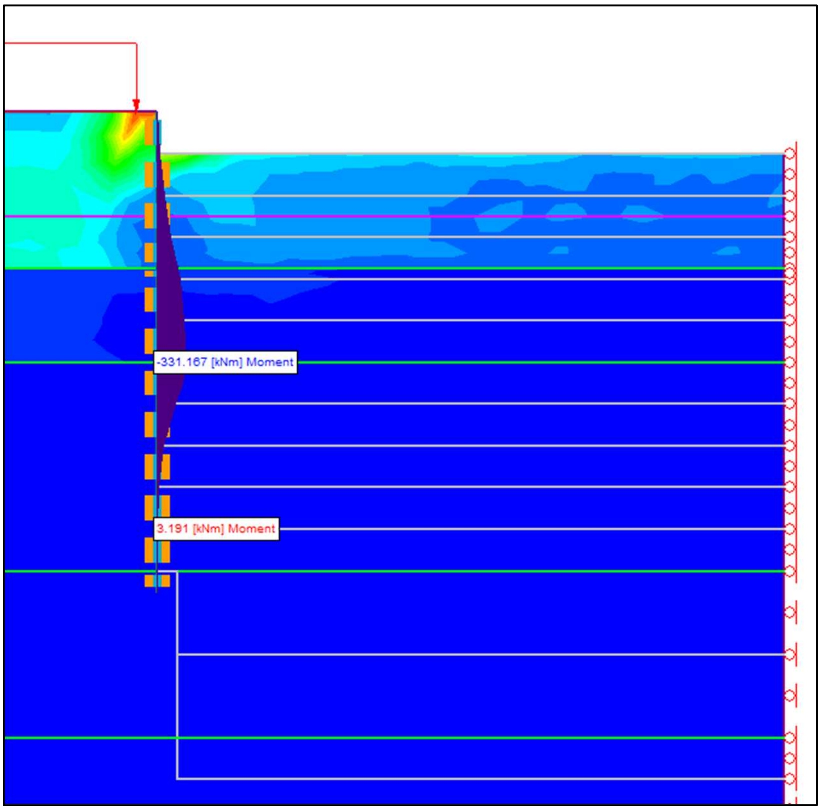
ANNEXURES

ANNEXURE - 1
RS2 FEM OUTPUT

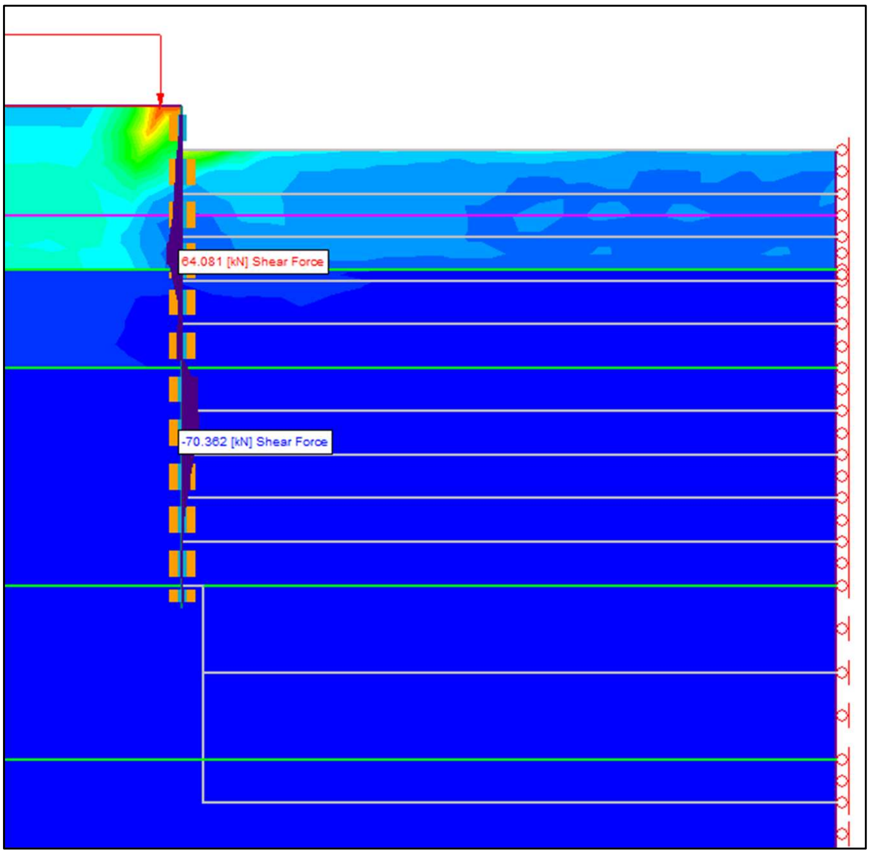
FEM ANALYSIS OUTPUT 32 M DEEP EXCAVATION



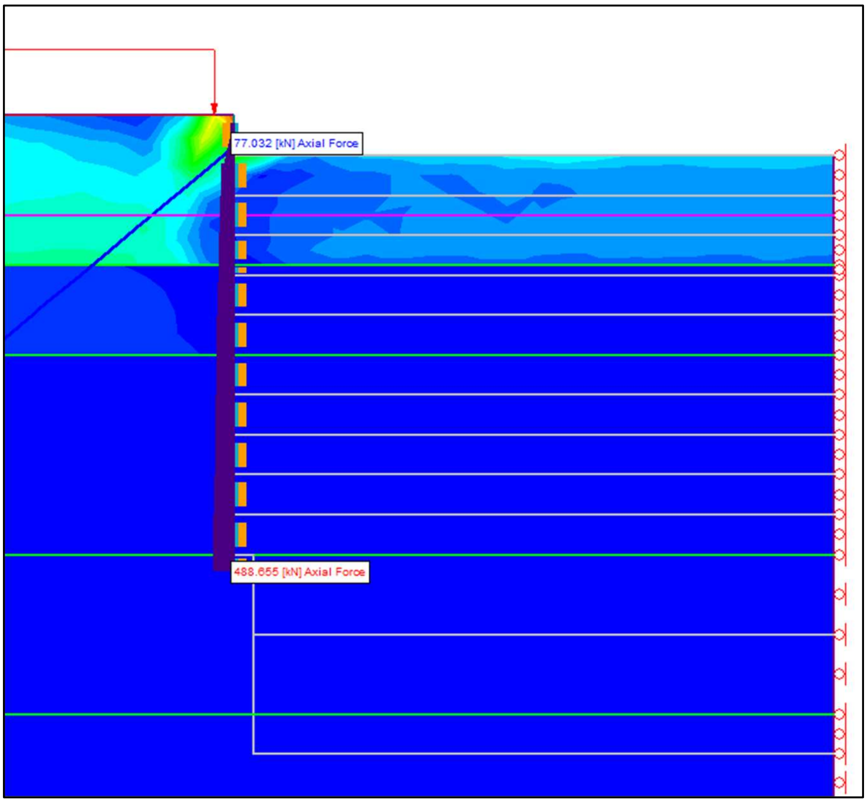
Plot 1: Axial Force for Secant Pile Wall – Stage-3



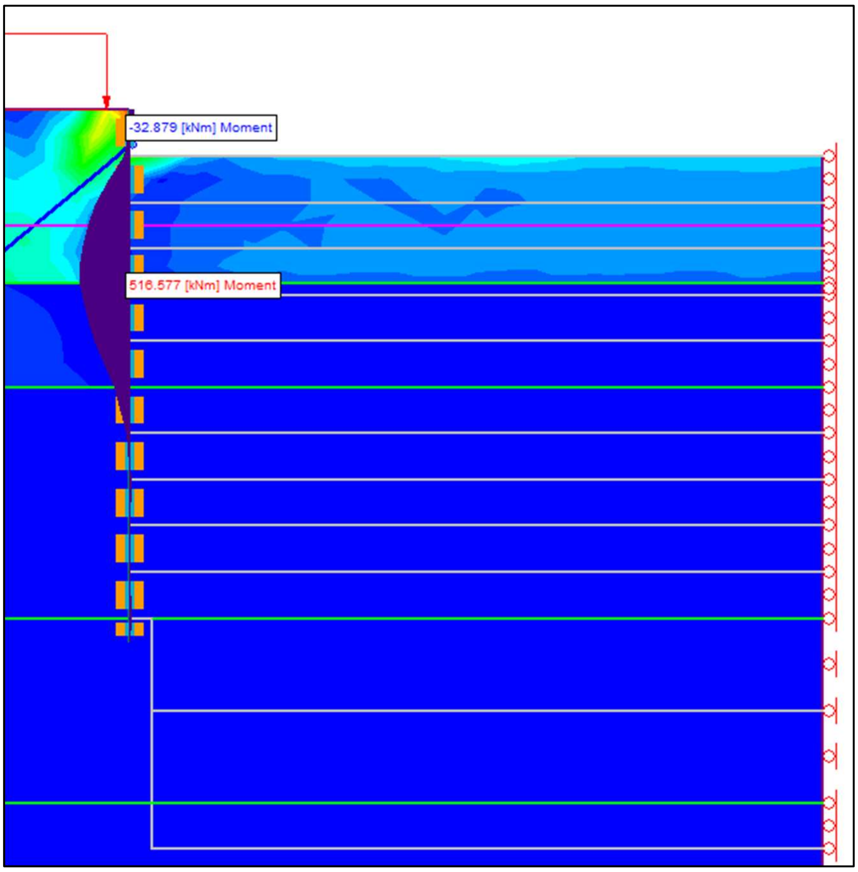
Plot 2: Bending Moment for Secant Pile Wall – Stage-3



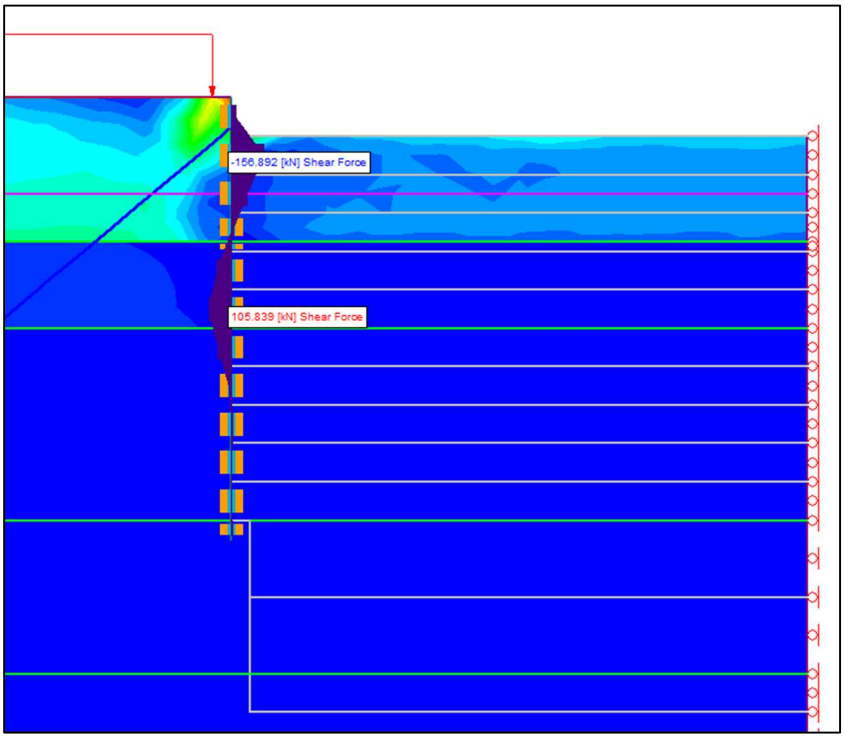
Plot 3: Shear Force for Secant Pile Wall – Stage-3



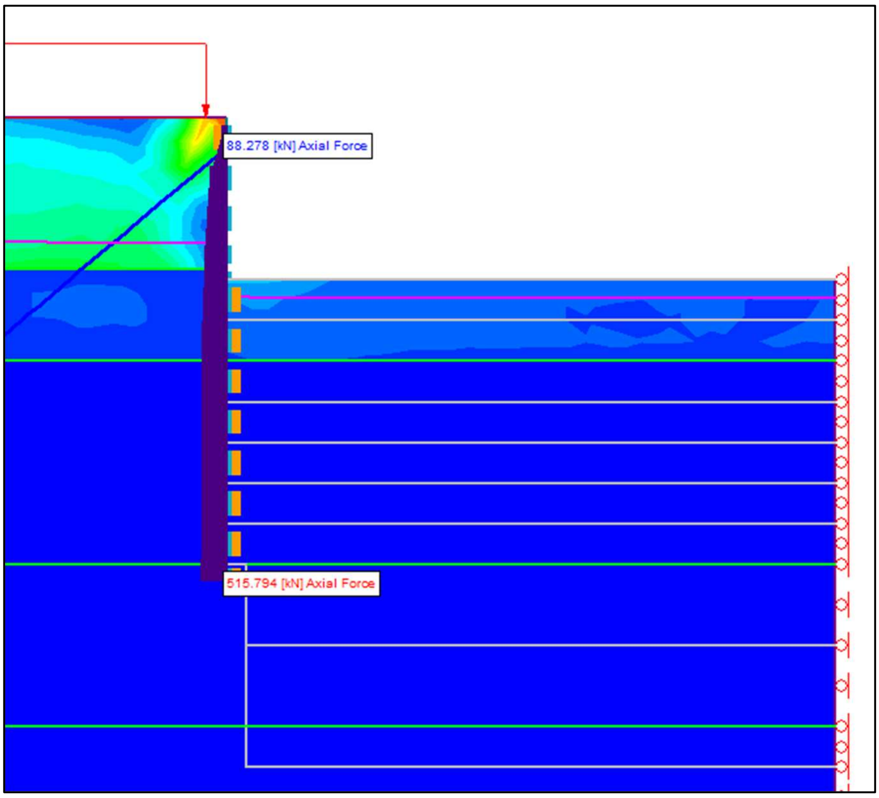
Plot 4*: Axial Force *for Secant Pile Wall – Stage-4



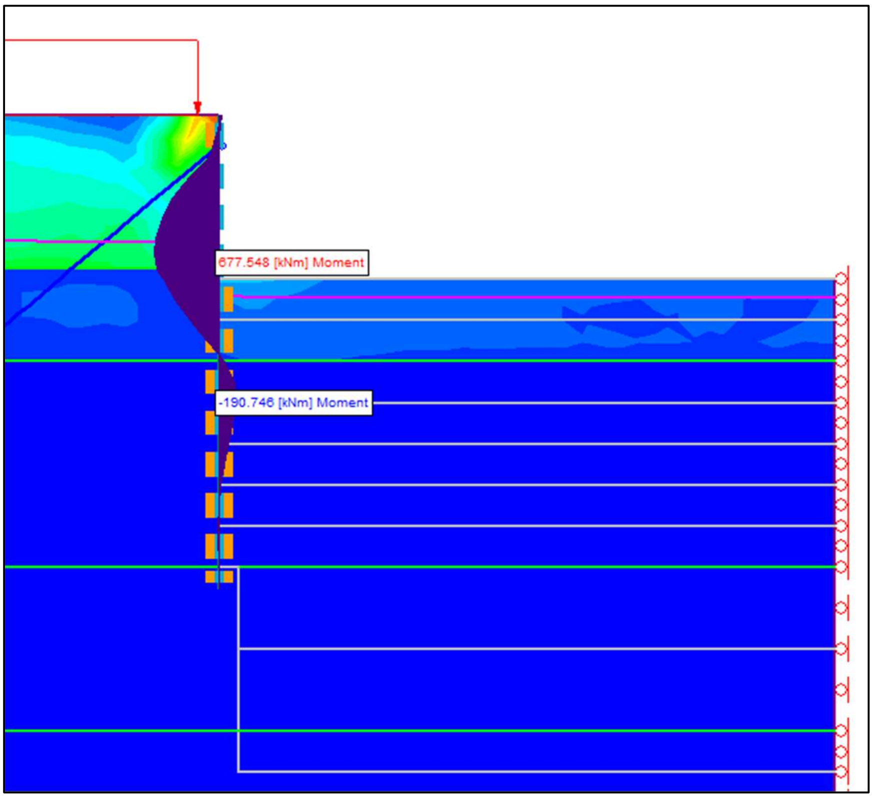
Plot 5*: *Bending Moment for Secant Pile Wall – Stage-4



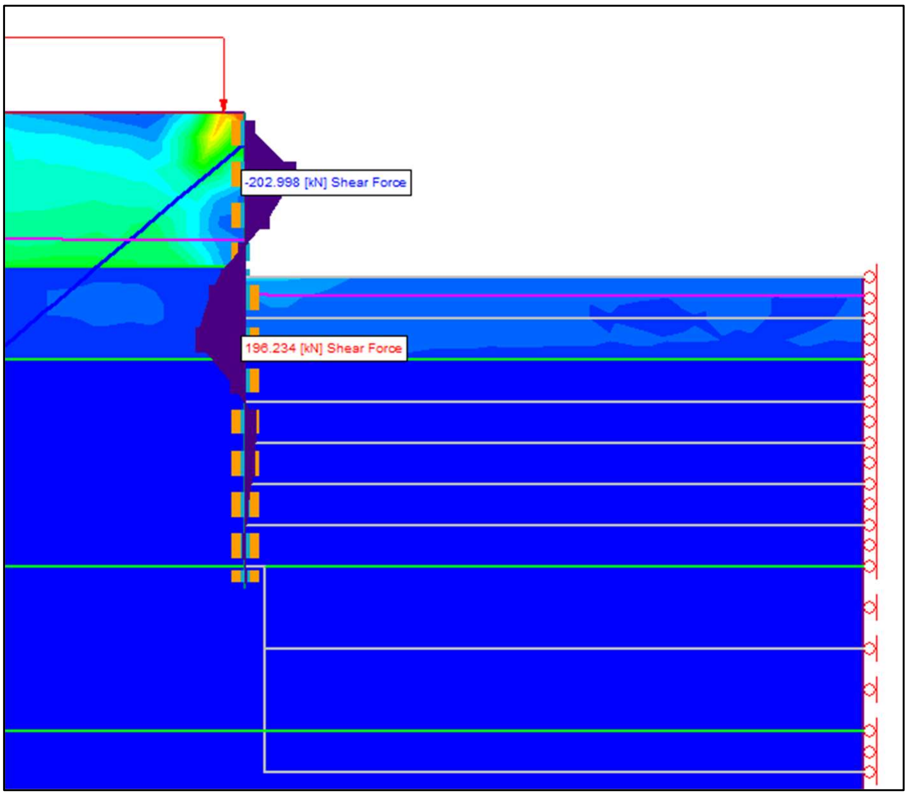
Plot 6: Shear Force for Secant Pile Wall – Stage-4



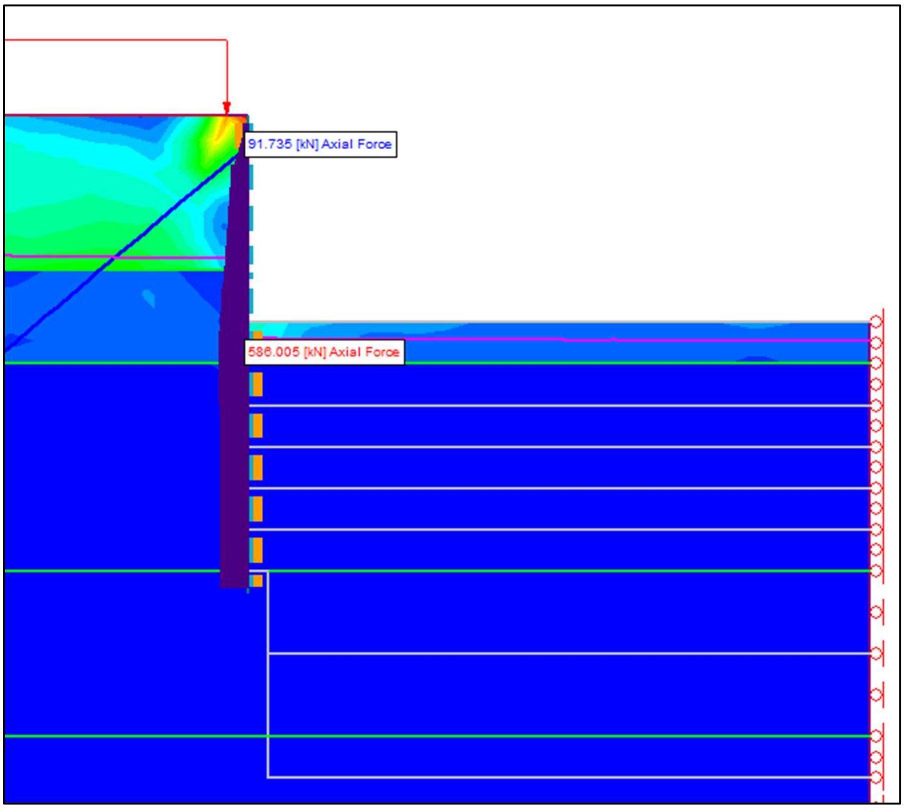
Plot 7: Axial Force for Secant Pile Wall – Stage-5



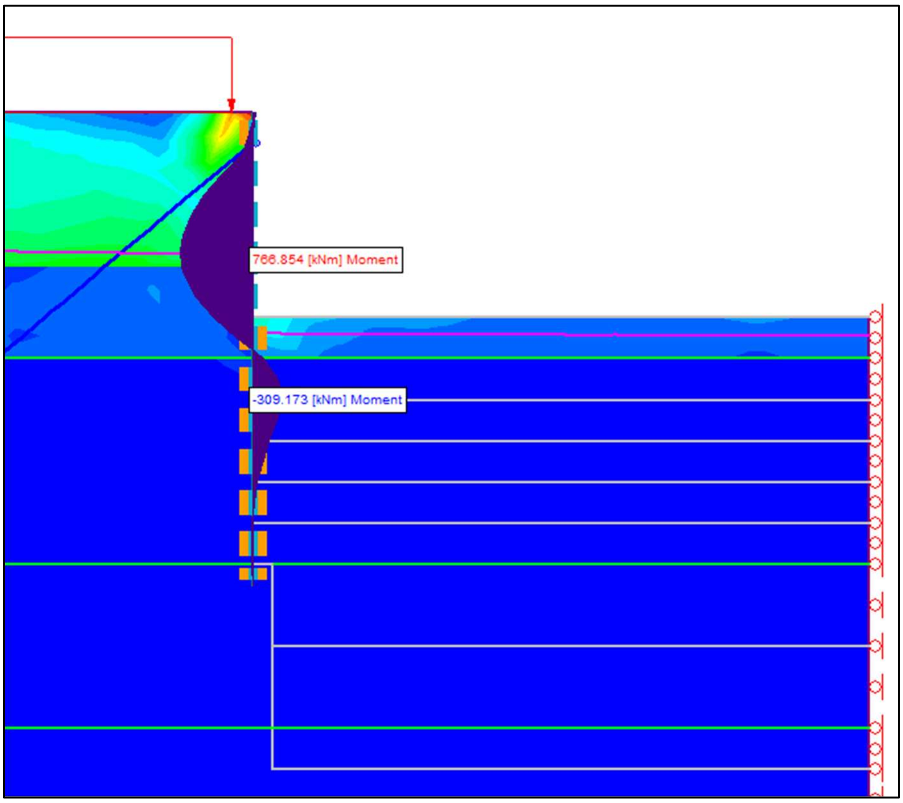
Plot 8: Bending Moment for Secant Pile Wall – Stage-5



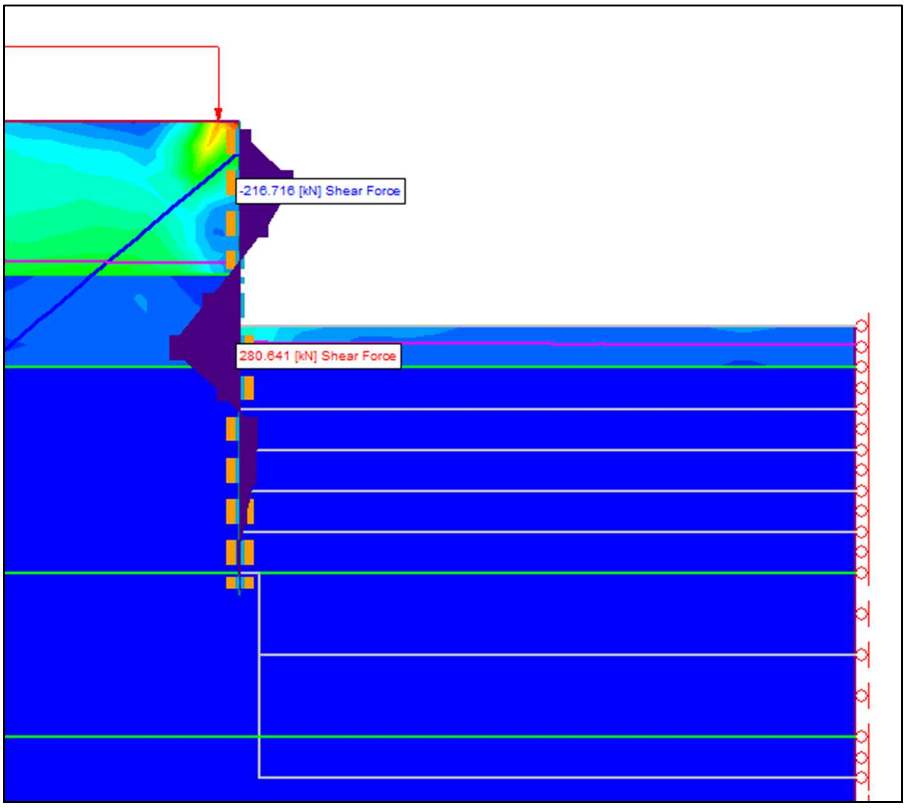
Plot 9: Shear Force for Secant Pile Wall – Stage-5



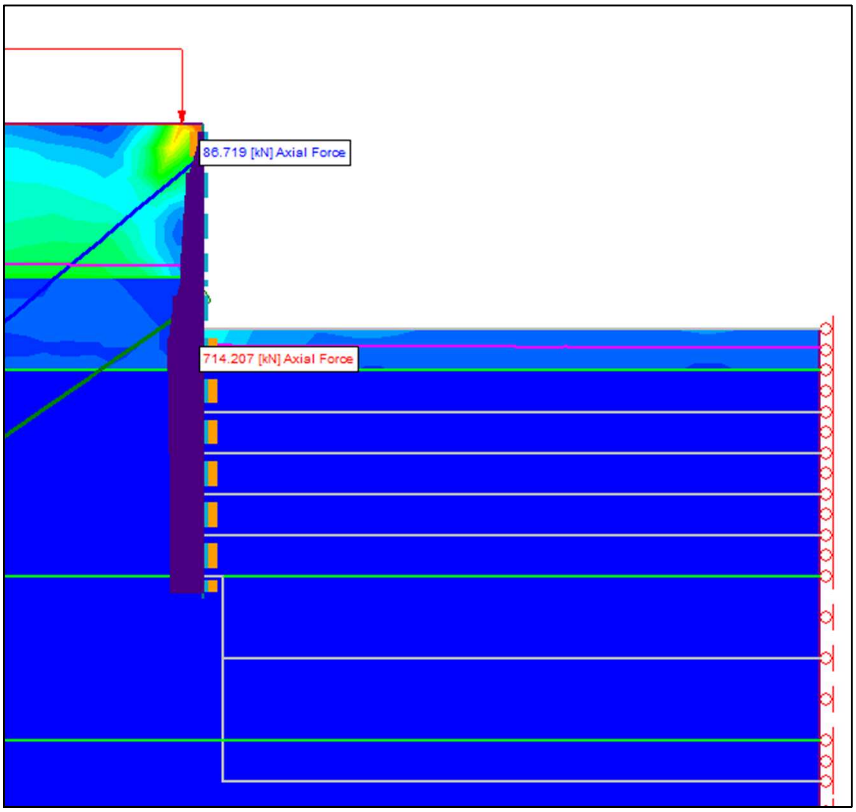
Plot 10: Axial Force for Secant Pile Wall – Stage-6



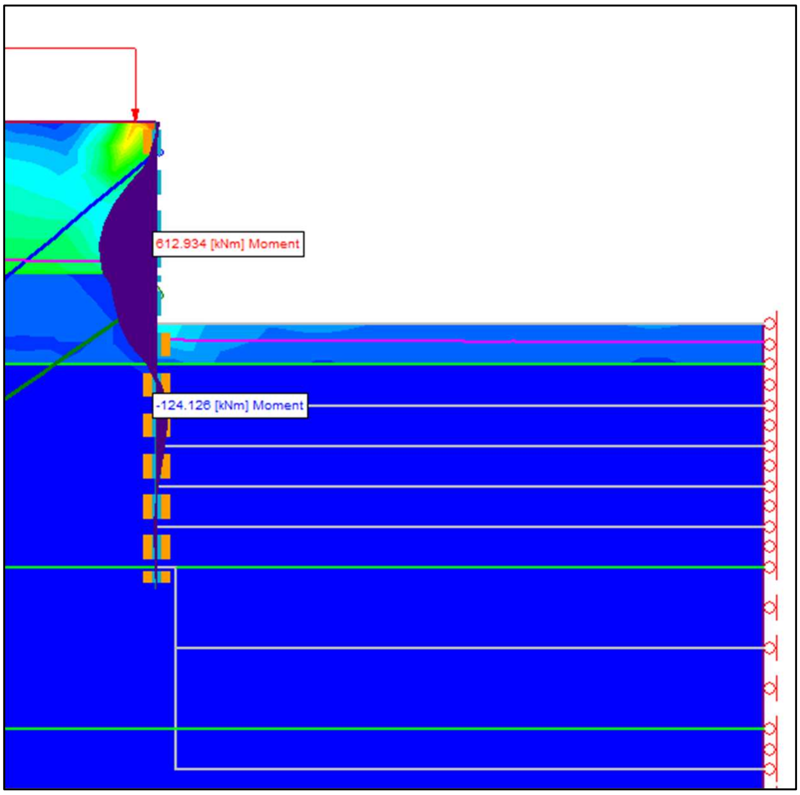
Plot 11: Bending Moment for Secant Pile Wall – Stage-6



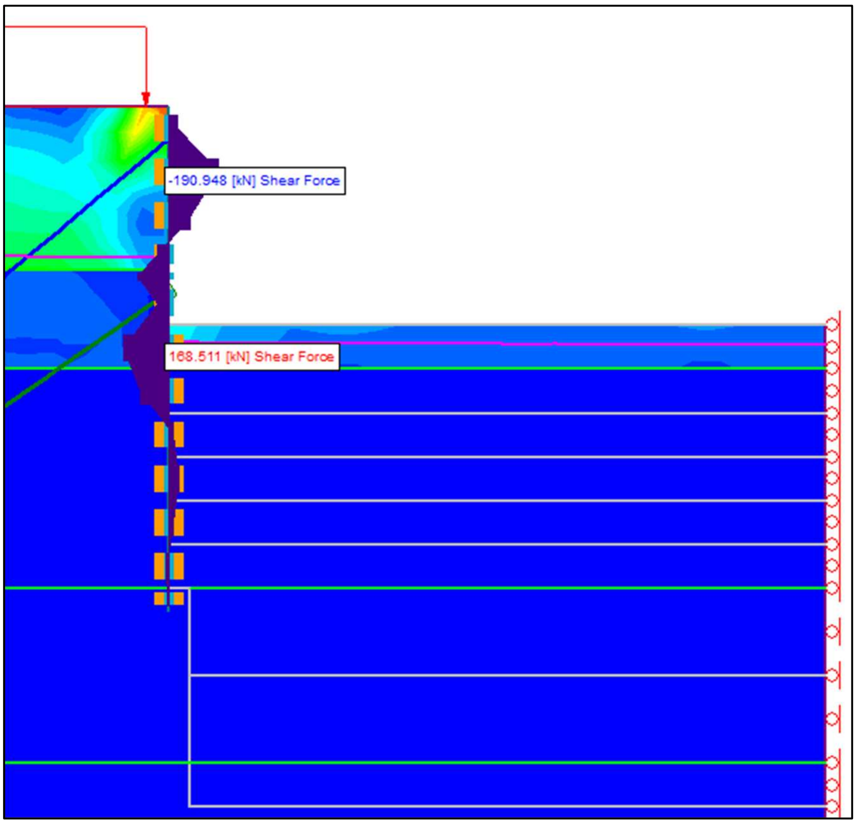
Plot 12: Shear Force for Secant Pile Wall – Stage-6



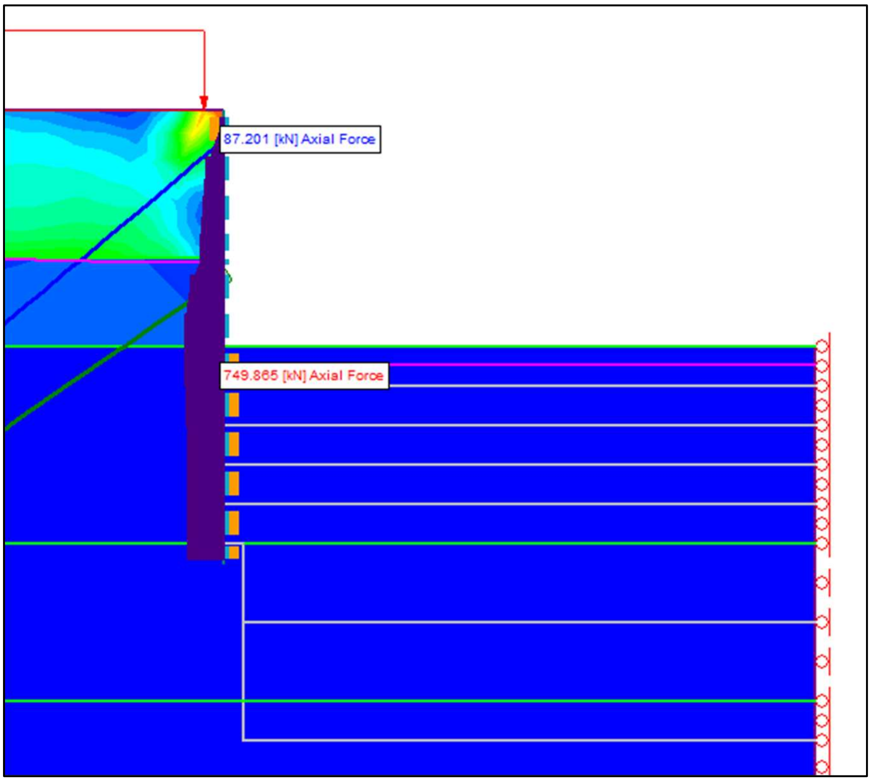
Plot 13: Axial Force for Secant Pile Wall – Stage-7



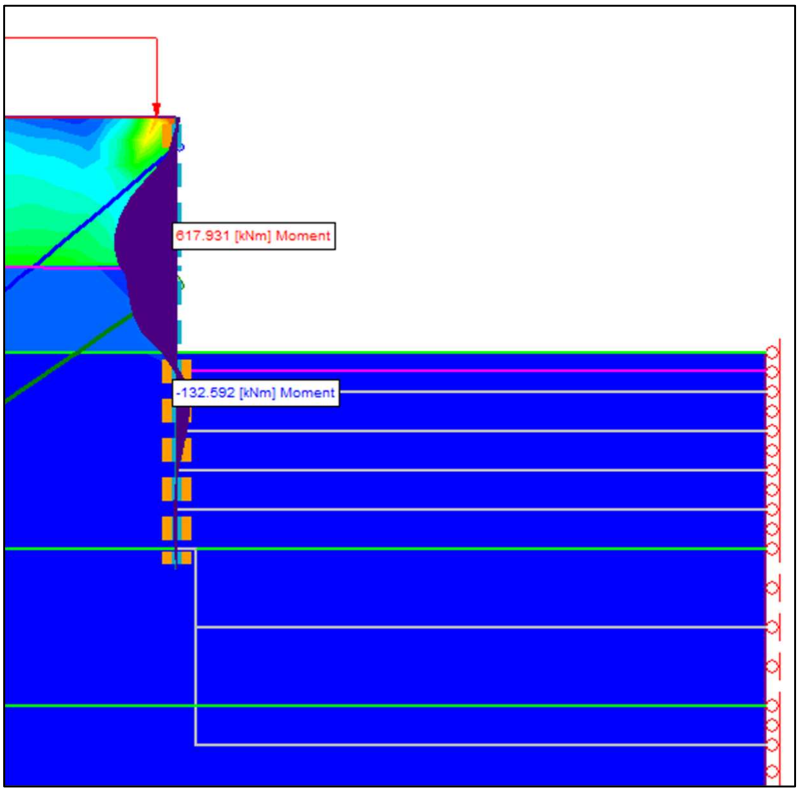
Plot 14: Bending Moment for Secant Pile Wall – Stage-7



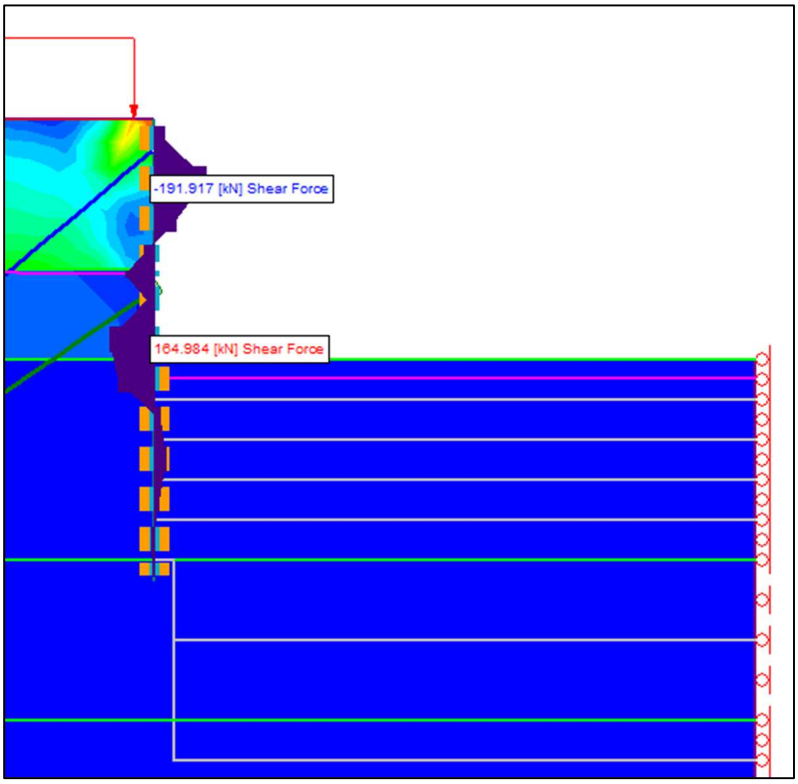
Plot 15: Shear Force for Secant Pile Wall – Stage-7



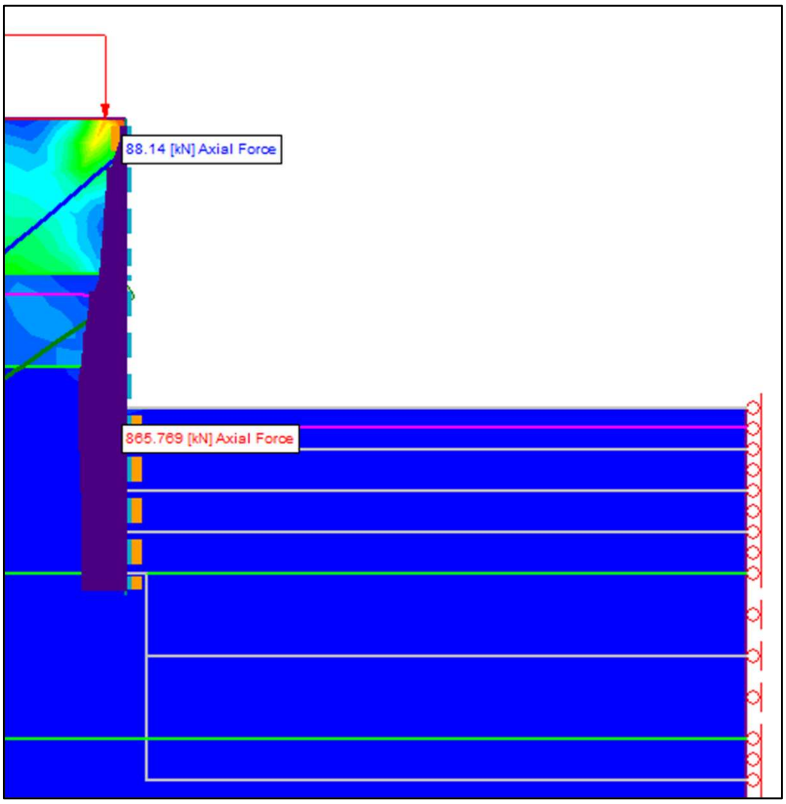
Plot 16: Axial Force for Secant Pile Wall – Stage-8



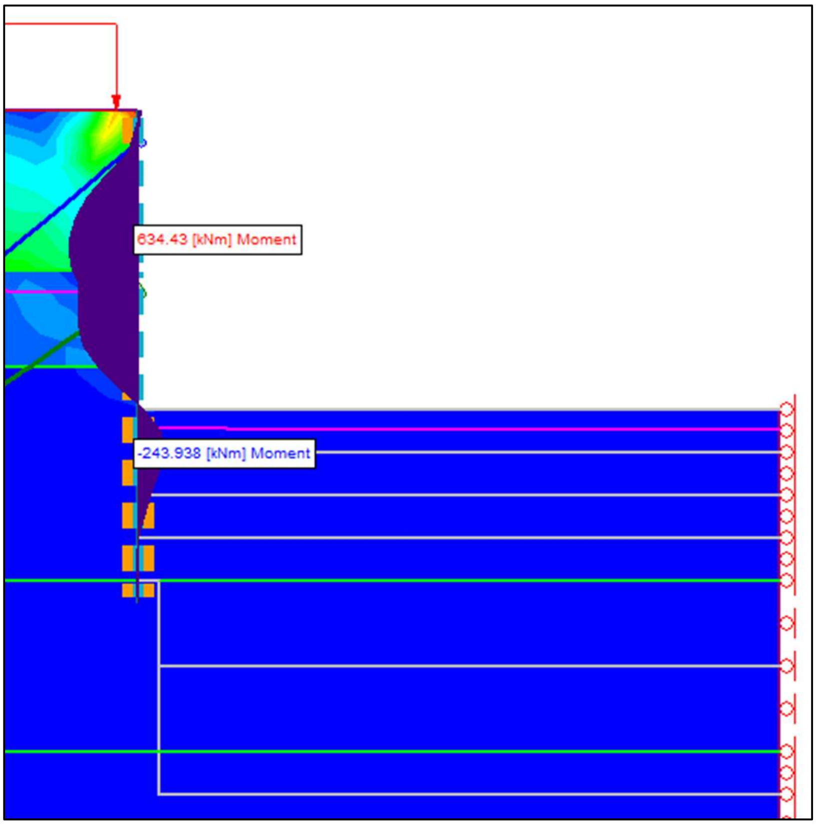
Plot 17: Bending Moment for Secant Pile Wall – Stage-8



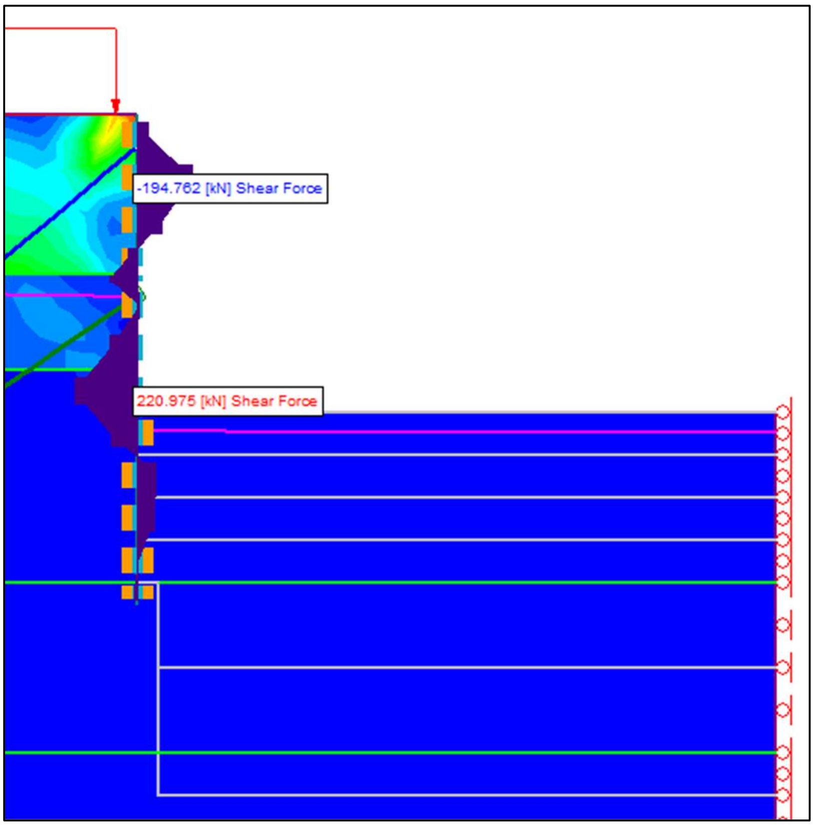
Plot 18: Shear Force for Secant Pile Wall – Stage-8



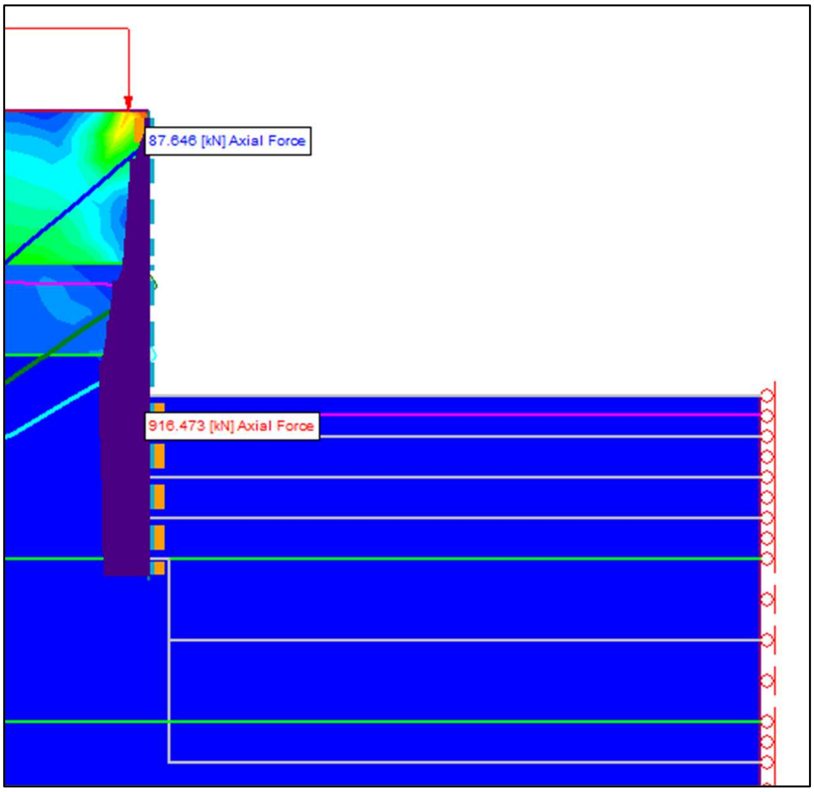
Plot 19: Axial Force for Secant Pile Wall – Stage-9



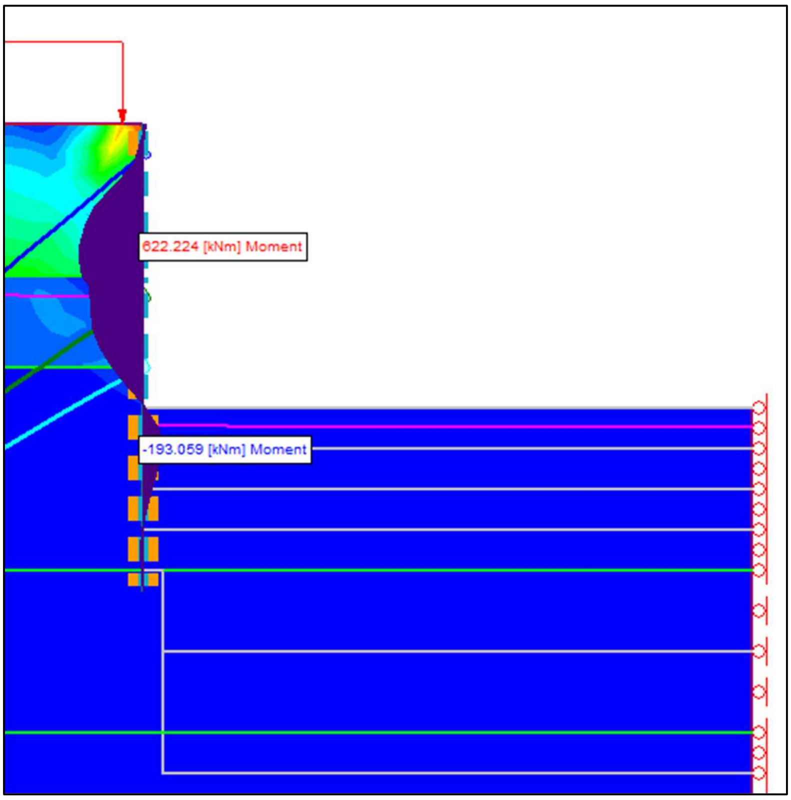
Plot 20: Bending Moment for Secant Pile Wall – Stage-9



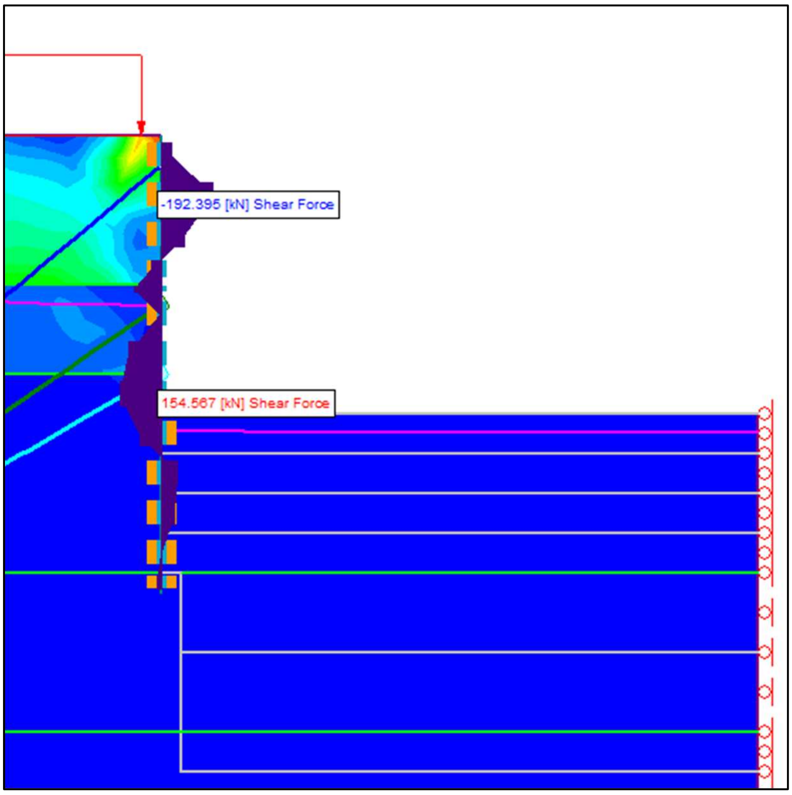
Plot 21: Shear Force for Secant Pile Wall – Stage-9



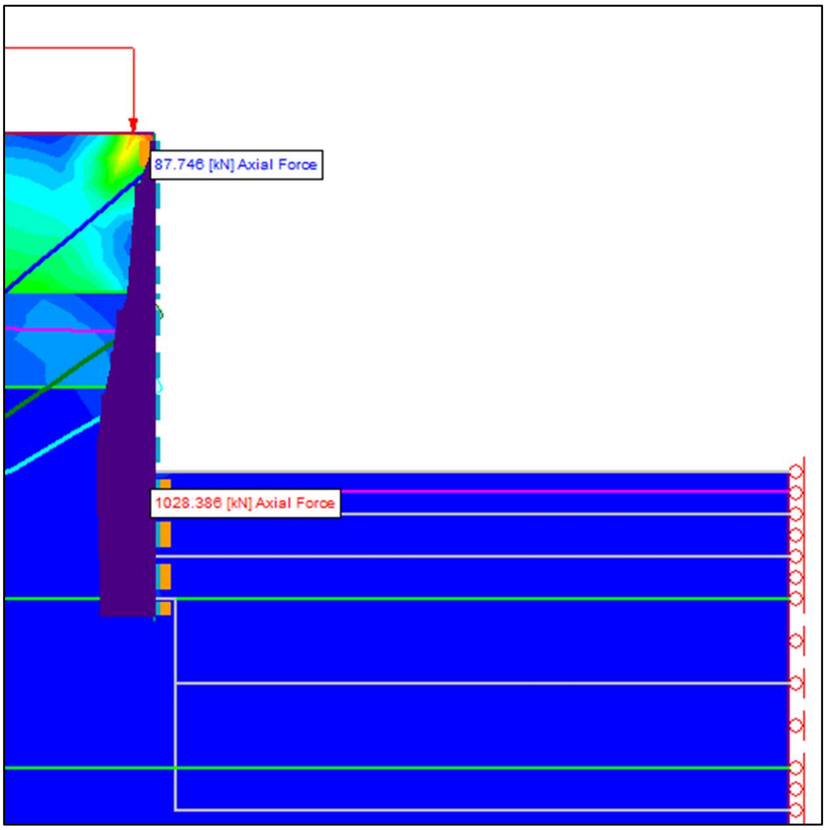
Plot 22: Axial Force for Secant Pile Wall – Stage-10



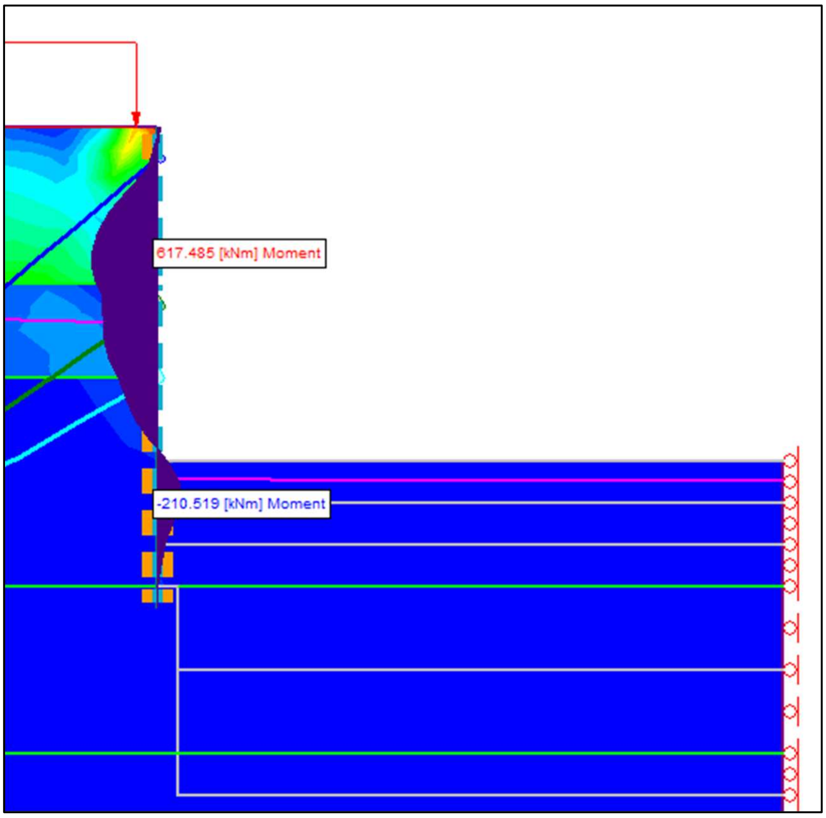
Plot 23: Bending Moment for Secant Pile Wall – Stage-10



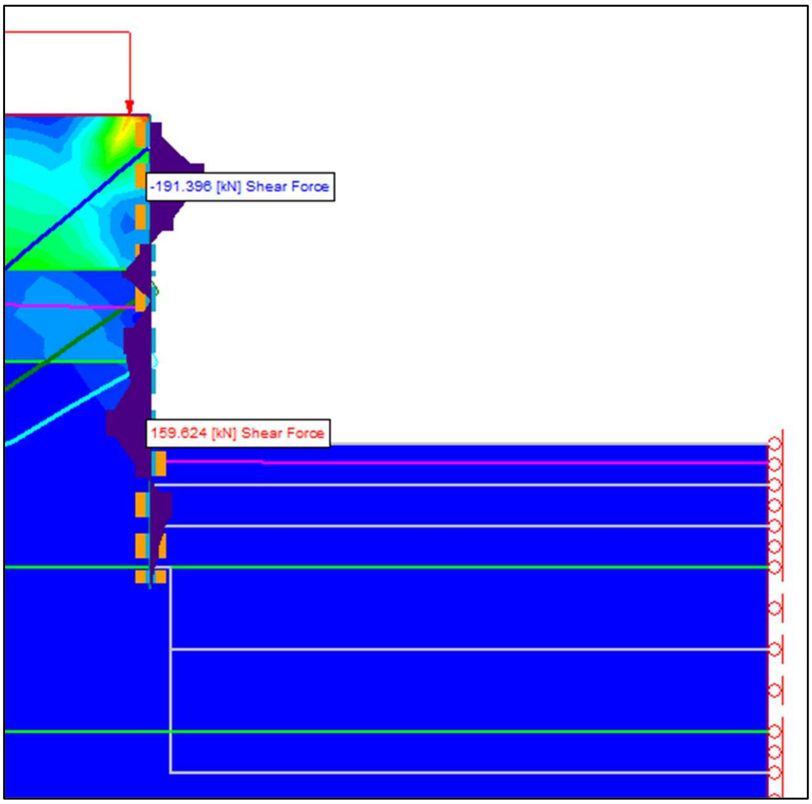
Plot 24: Shear Force for Secant Pile Wall – Stage-10



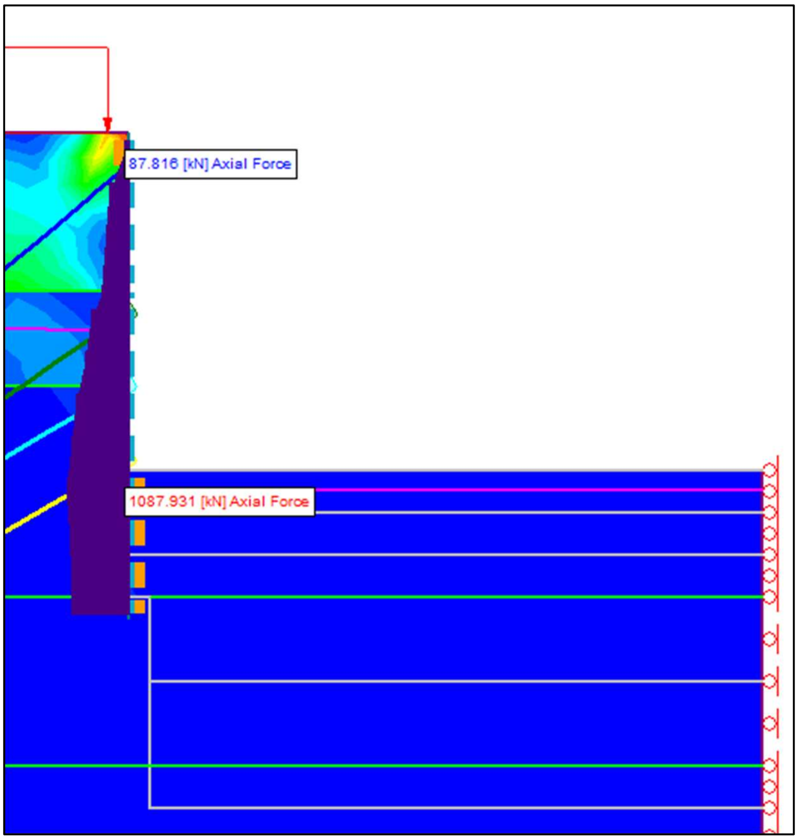
Plot 25: Axial Force for Secant Pile Wall – Stage-11



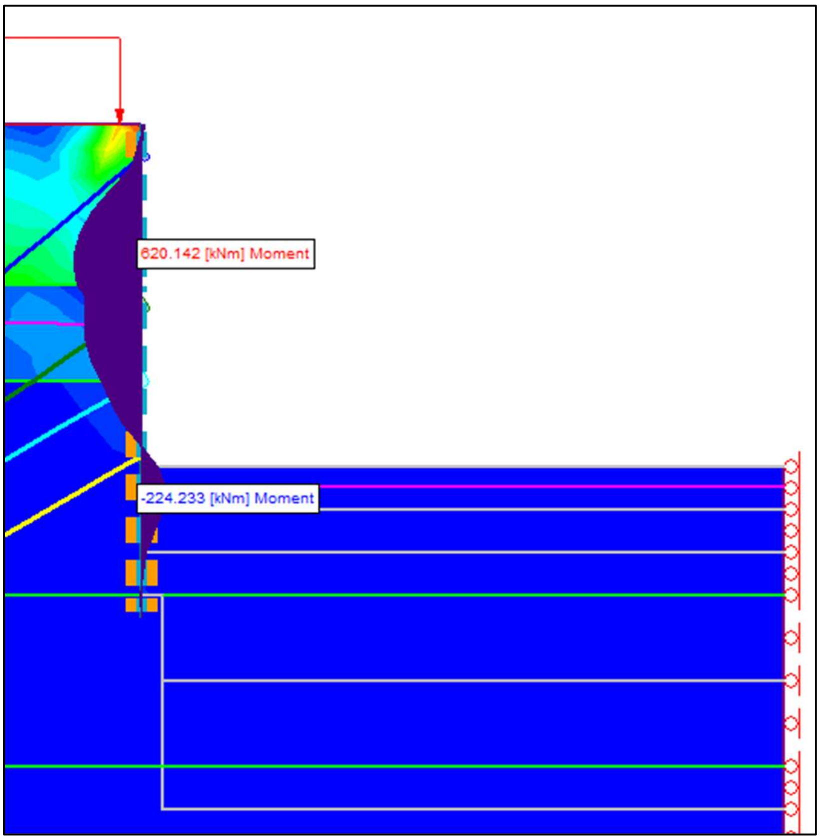
Plot 26: Bending Moment for Secant Pile Wall – Stage-11



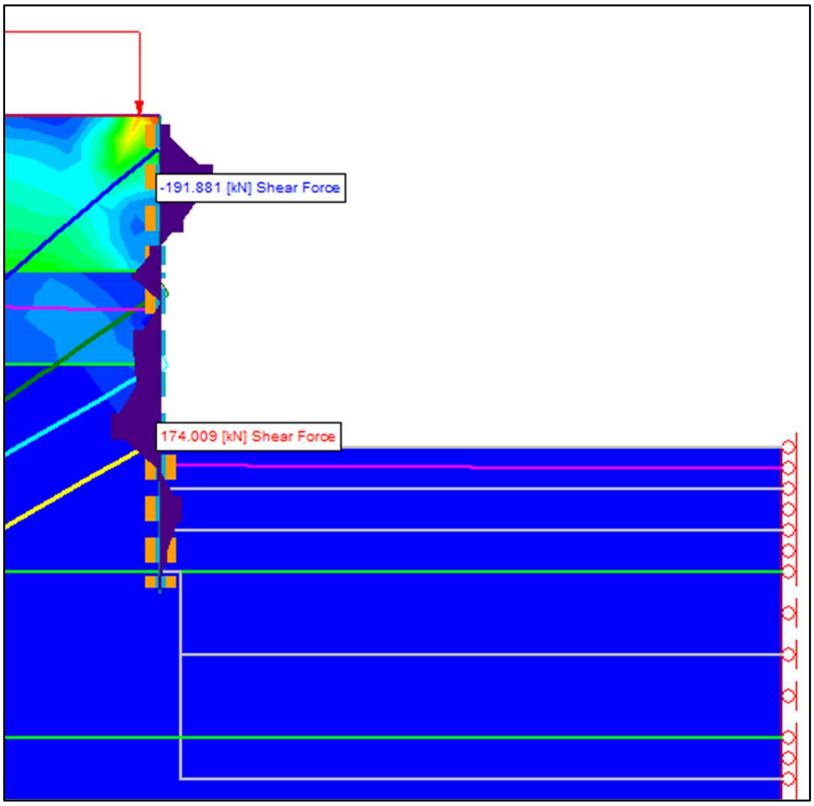
Plot 27: Shear Force for Secant Pile Wall – Stage-11



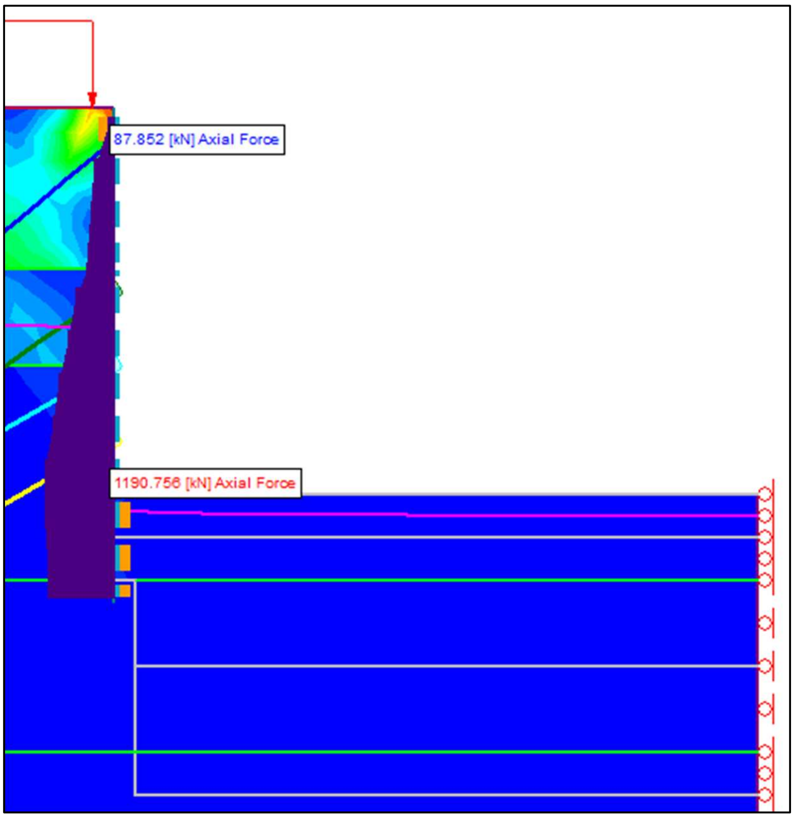
Plot 28: Axial Force for Secant Pile Wall – Stage-12



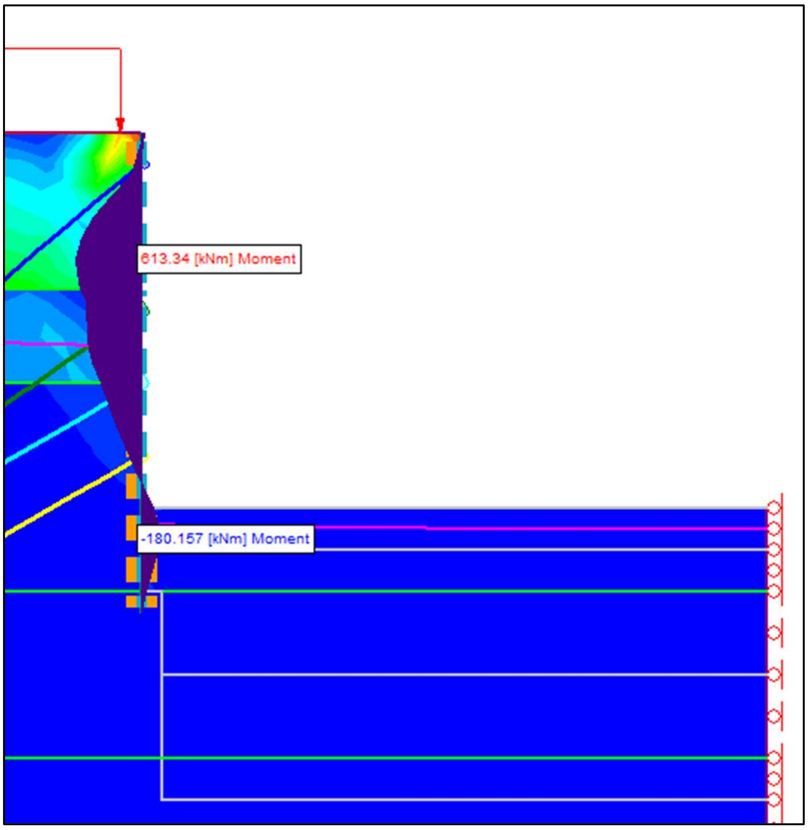
Plot 29: Bending Moment for Secant Pile Wall – Stage-12



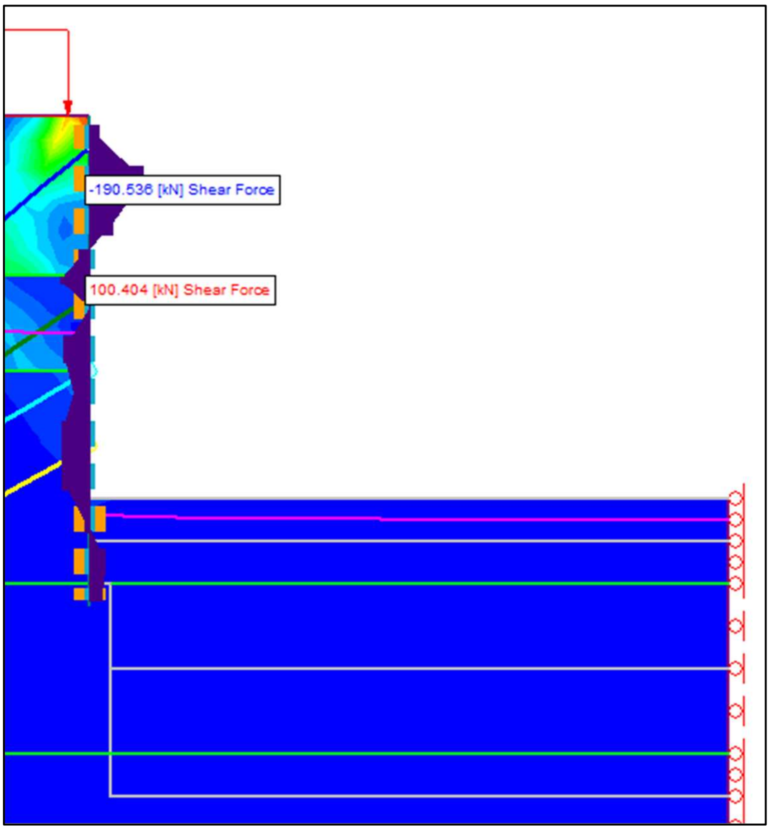
Plot 30: Shear Force for Secant Pile Wall – Stage-12



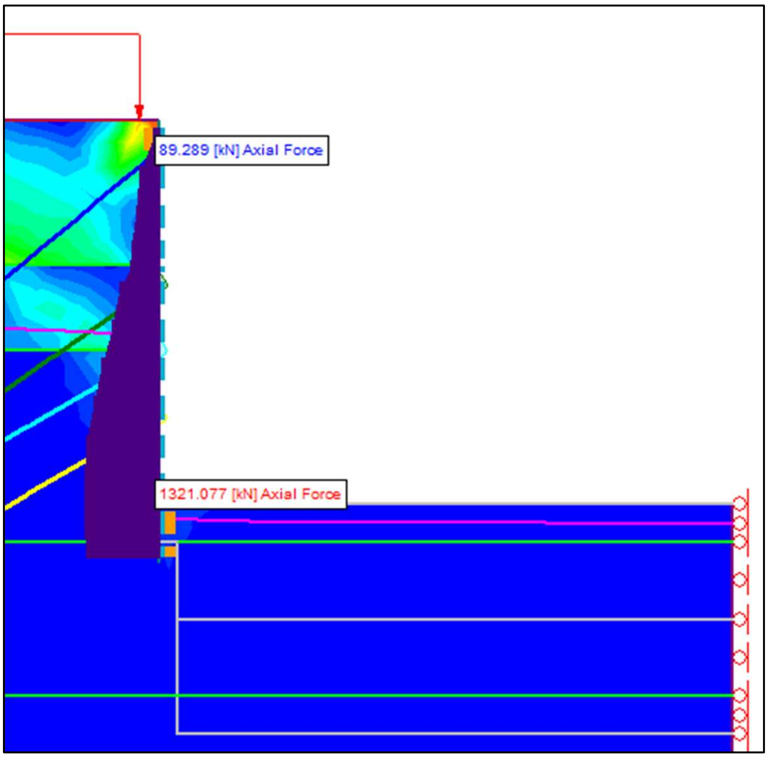
Plot 31: Axial Force for Secant Pile Wall – Stage-13



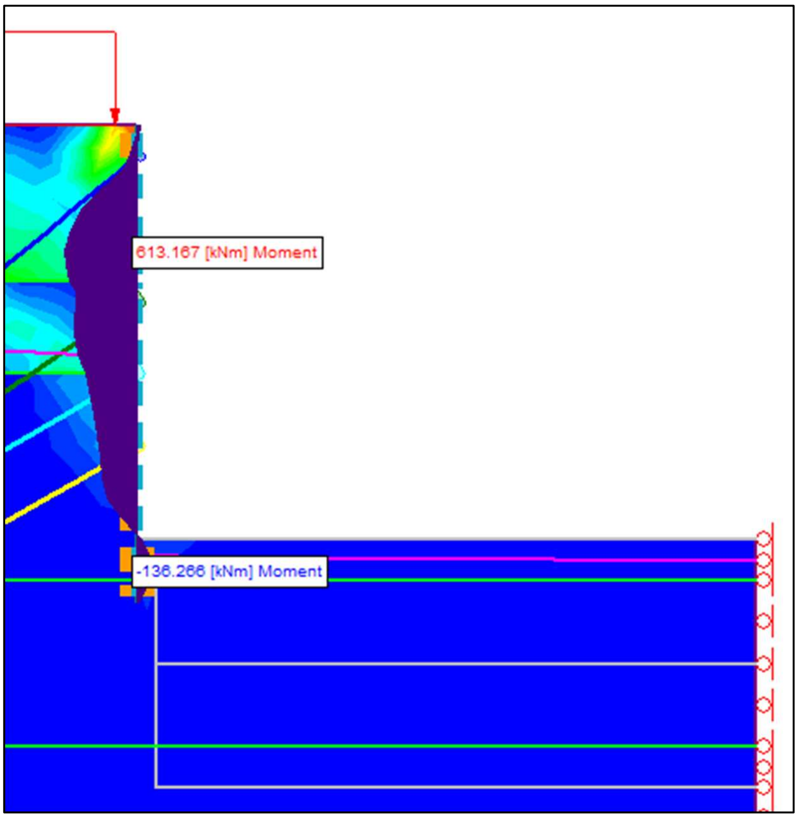
Plot 32: Bending Moment for Secant Pile Wall – Stage-13



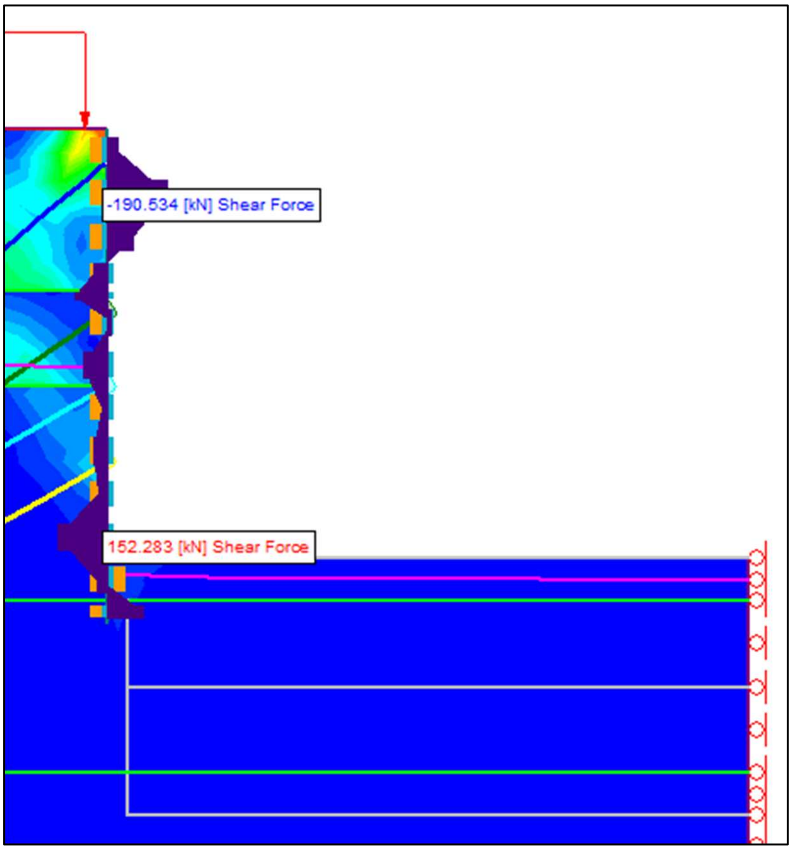
Plot 33: Shear Force for Secant Pile Wall – Stage-13



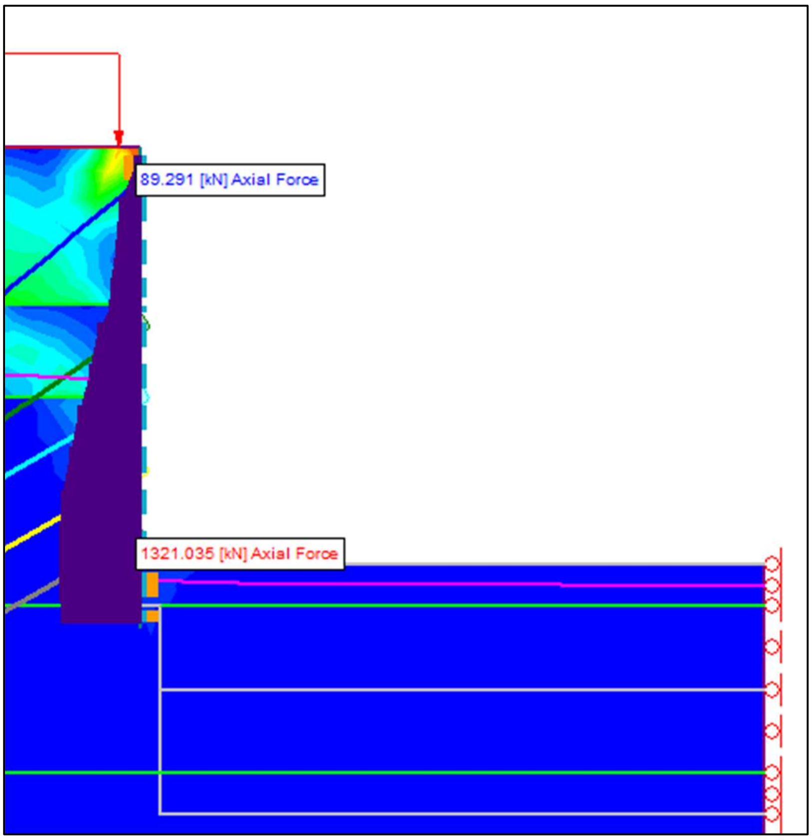
Plot 34: Axial Force for Secant Pile Wall – Stage-14



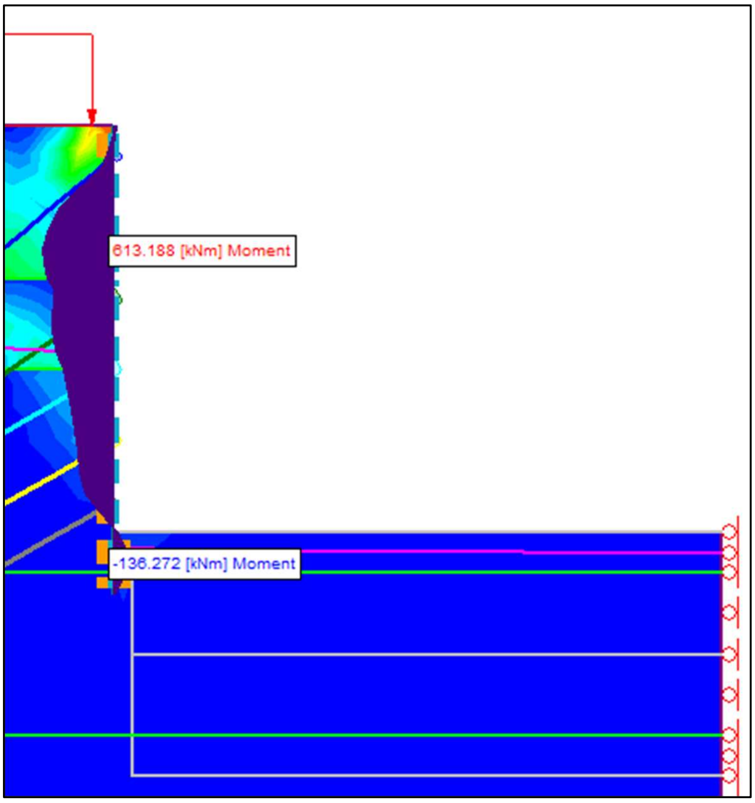
Plot 35: Bending Moment for Secant Pile Wall – Stage-14



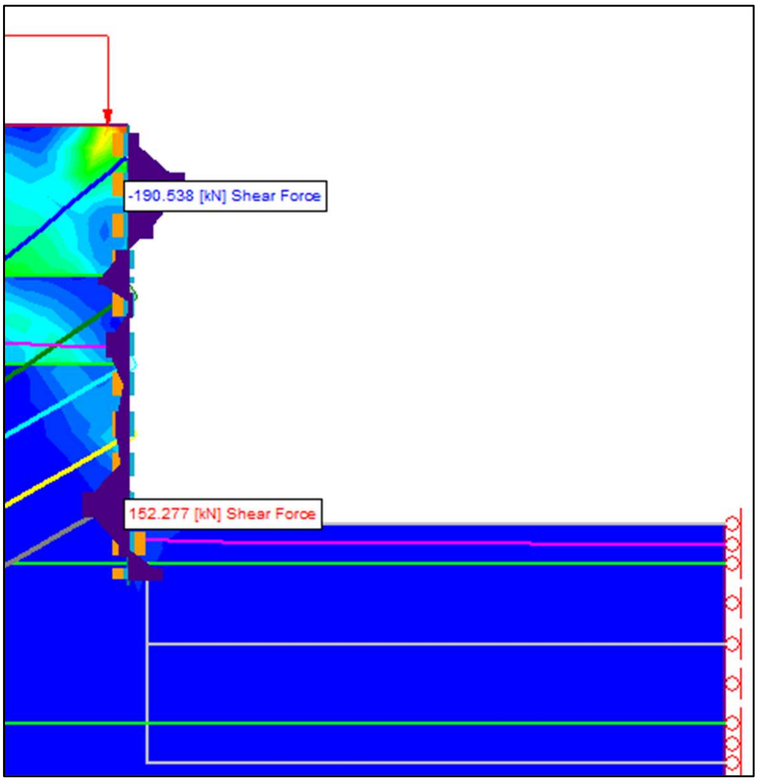
Plot 36: Shear Force for Secant Pile Wall – Stage-14



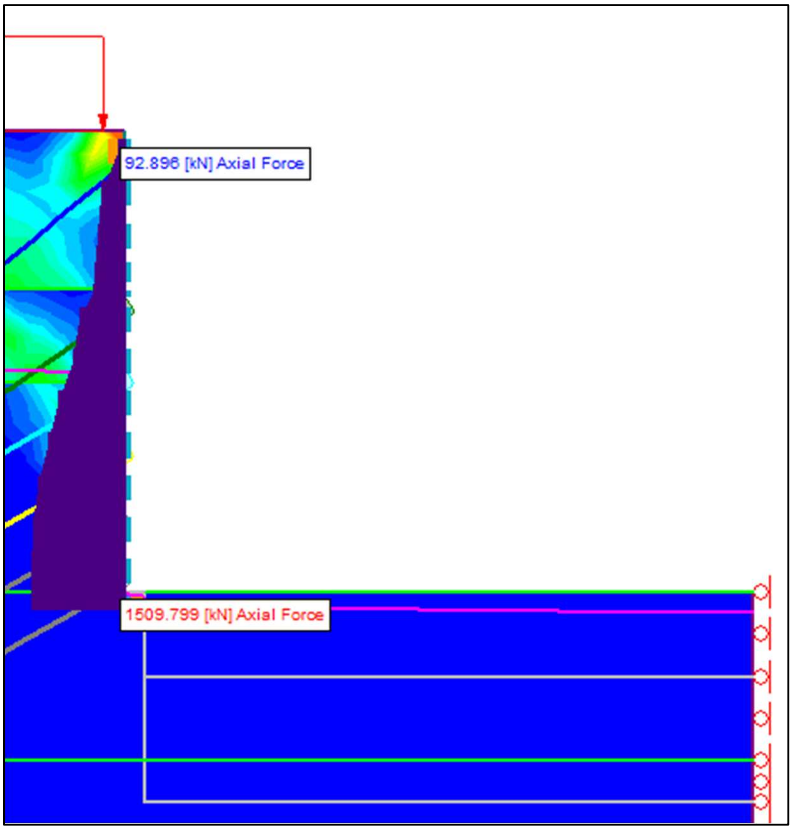
Plot 37: Axial Force for Secant Pile Wall – Stage-15



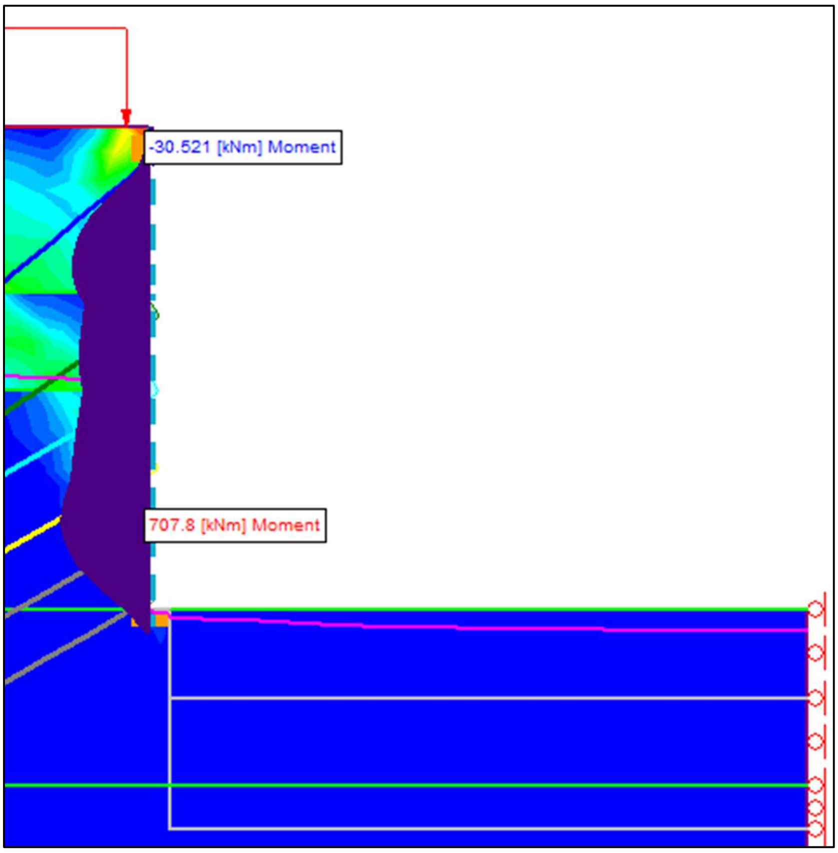
Plot 38: Bending Moment for Secant Pile Wall – Stage-15



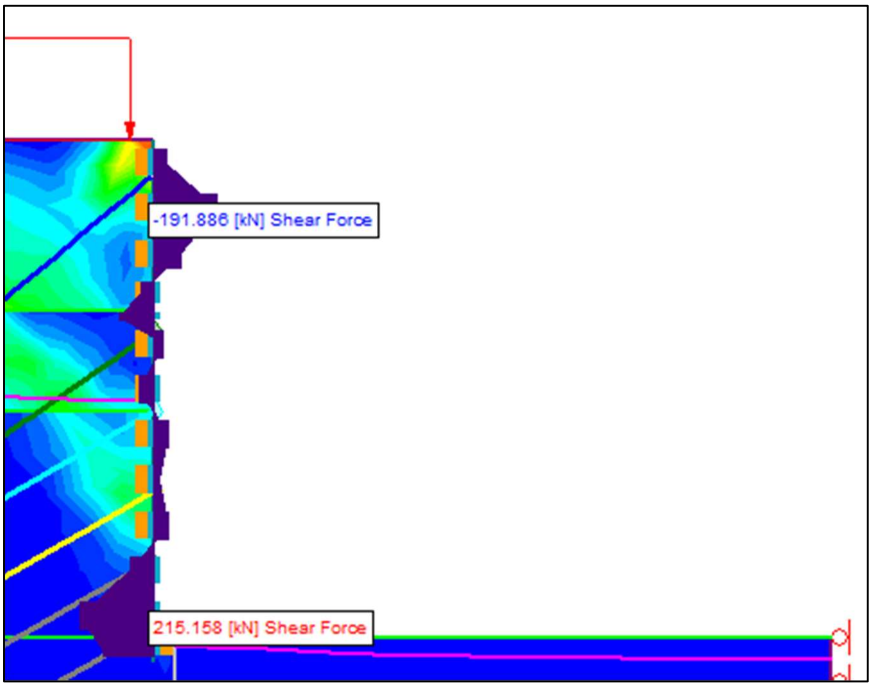
Plot 39: Shear Force for Secant Pile Wall – Stage-15



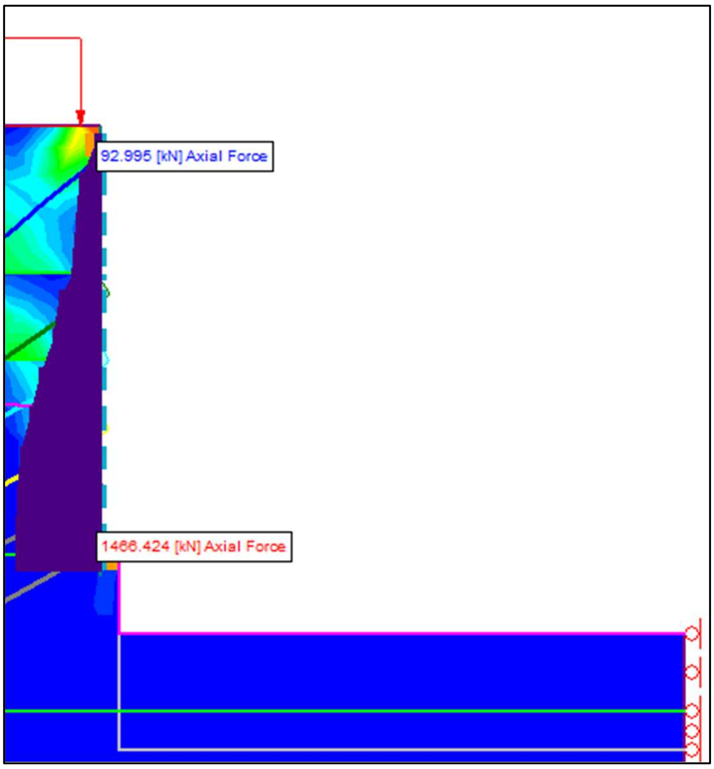
Plot 40: Axial Force for Secant Pile Wall – Stage-16



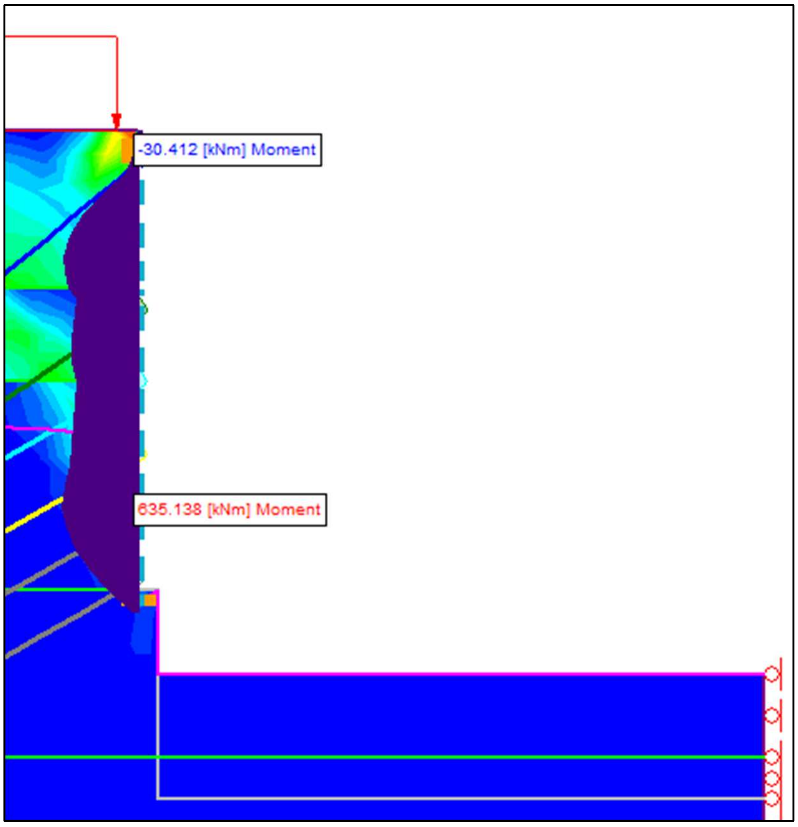
Plot 41: Bending Moment for Secant Pile Wall – Stage-16



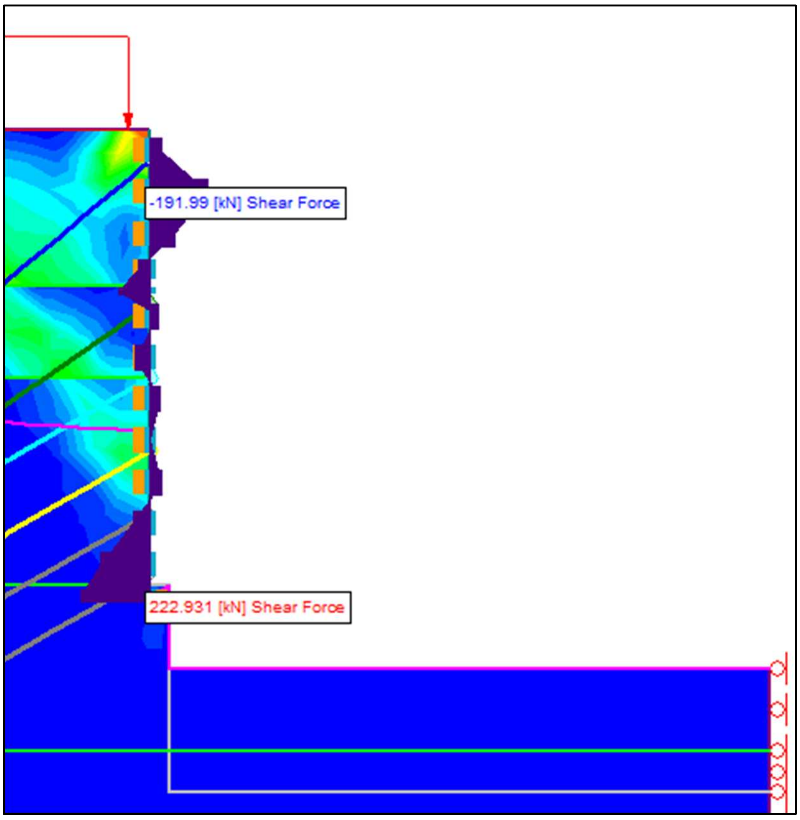
Plot 42: Shear Force for Secant Pile Wall – Stage-16



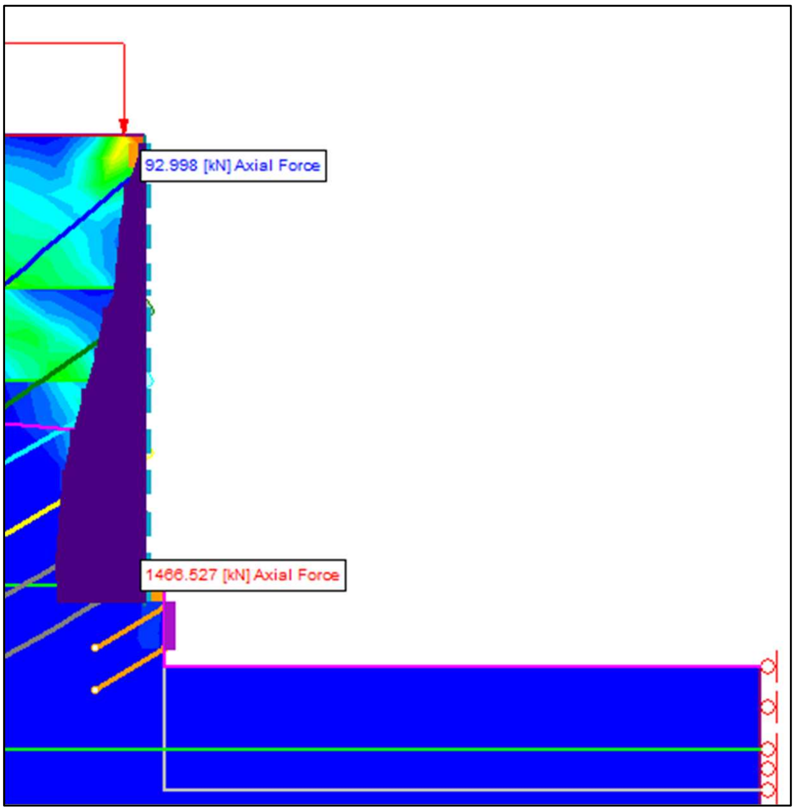
Plot 43: Axial Force for Secant Pile Wall – Stage-17



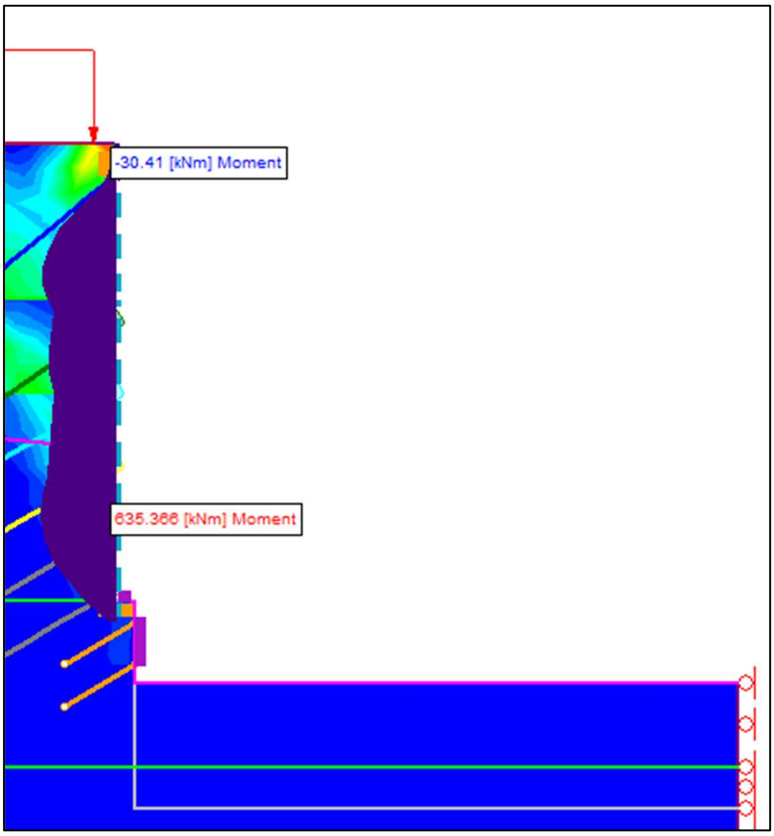
Plot 44: Bending Moment for Secant Pile Wall – Stage-17



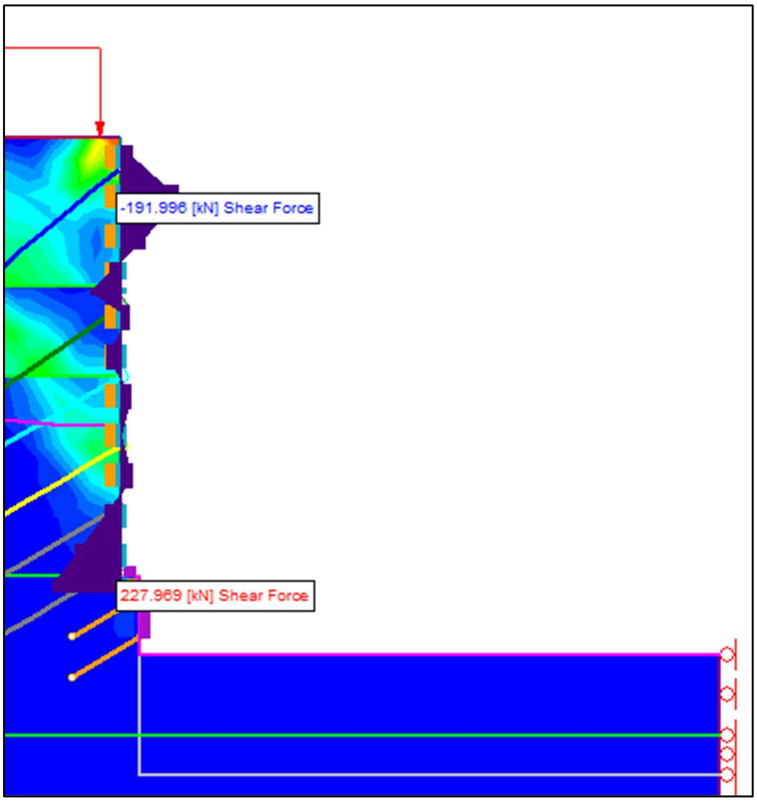
Plot 45: Shear Force for Secant Pile Wall – Stage-17



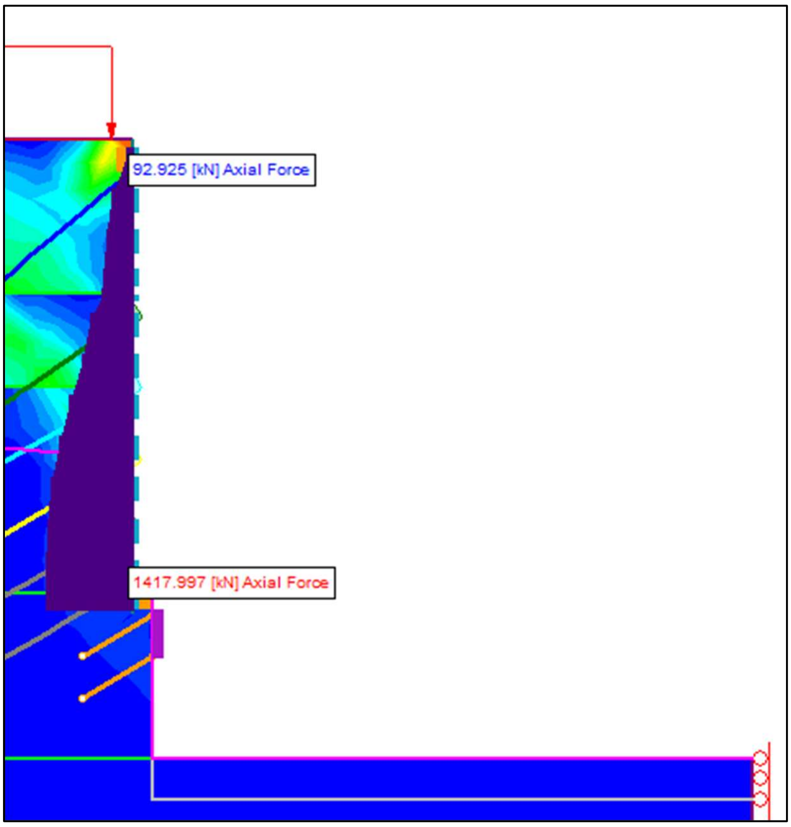
Plot 46: Axial Force for Secant Pile Wall – Stage-18



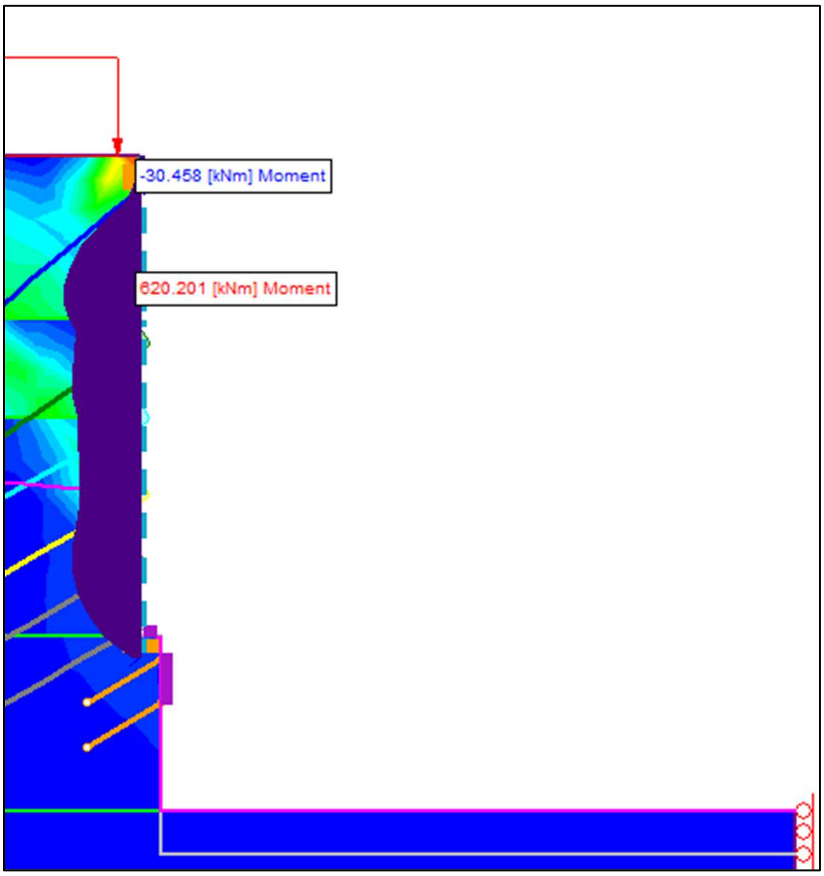
Plot 47: Bending Moment for Secant Pile Wall – Stage-18



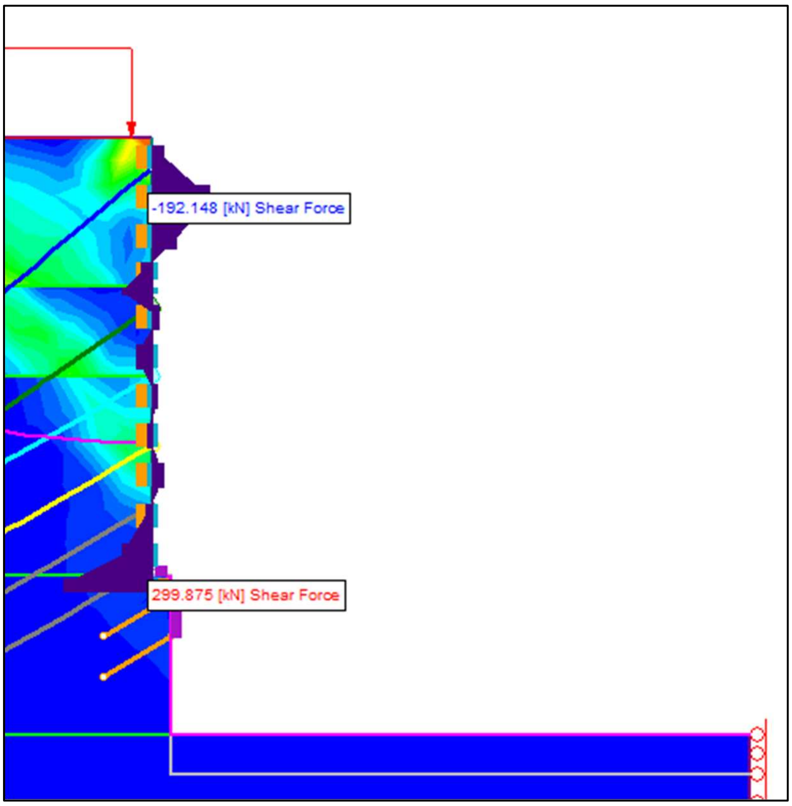
Plot 48: Shear Force for Secant Pile Wall – Stage-18



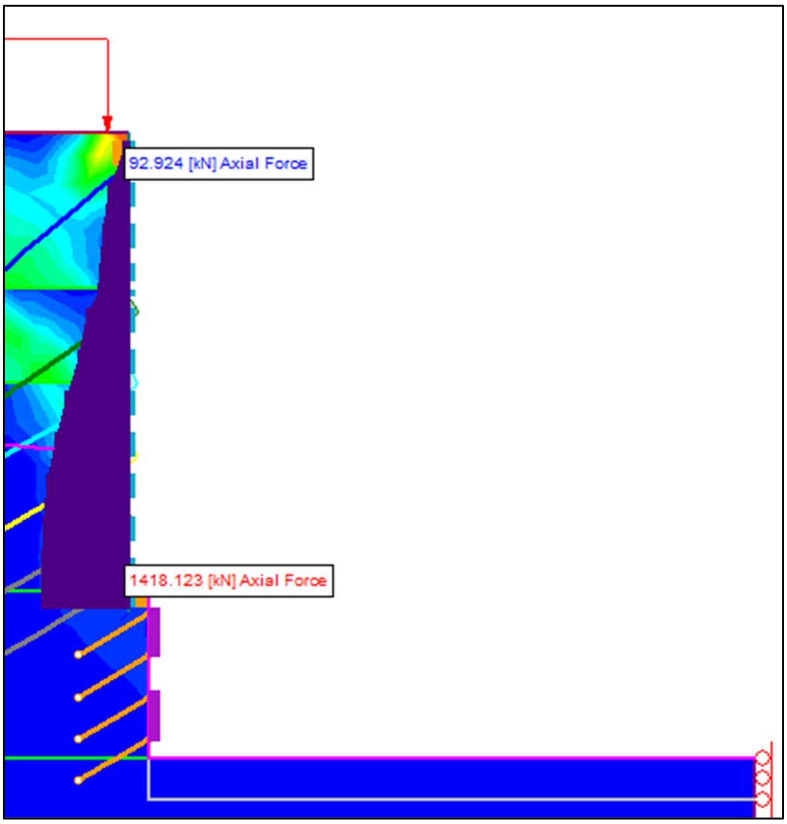
Plot 49: Axial Force for Secant Pile Wall – Stage-19



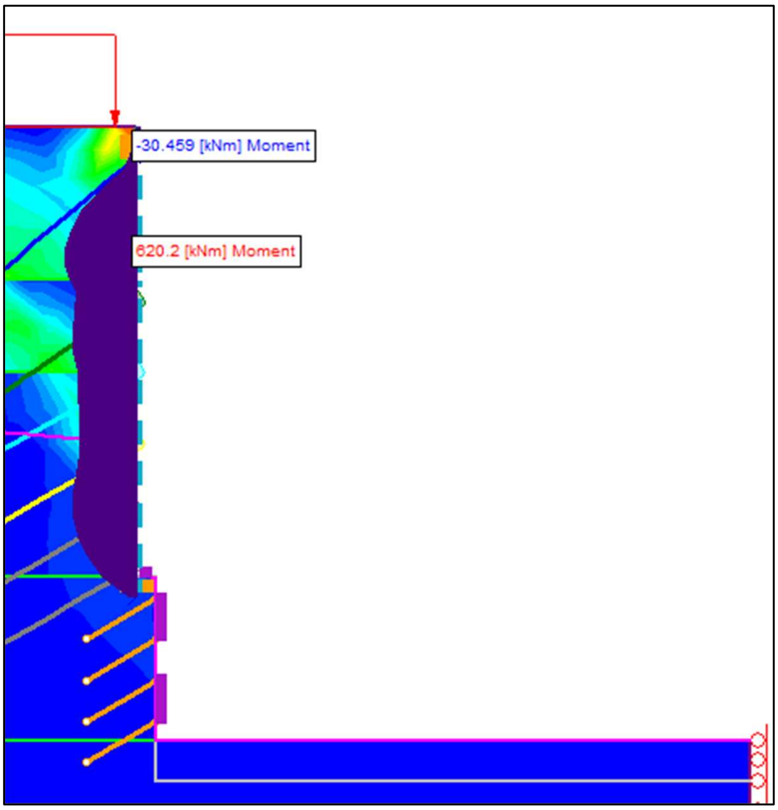
Plot 50: Bending Moment for Secant Pile Wall – Stage-19



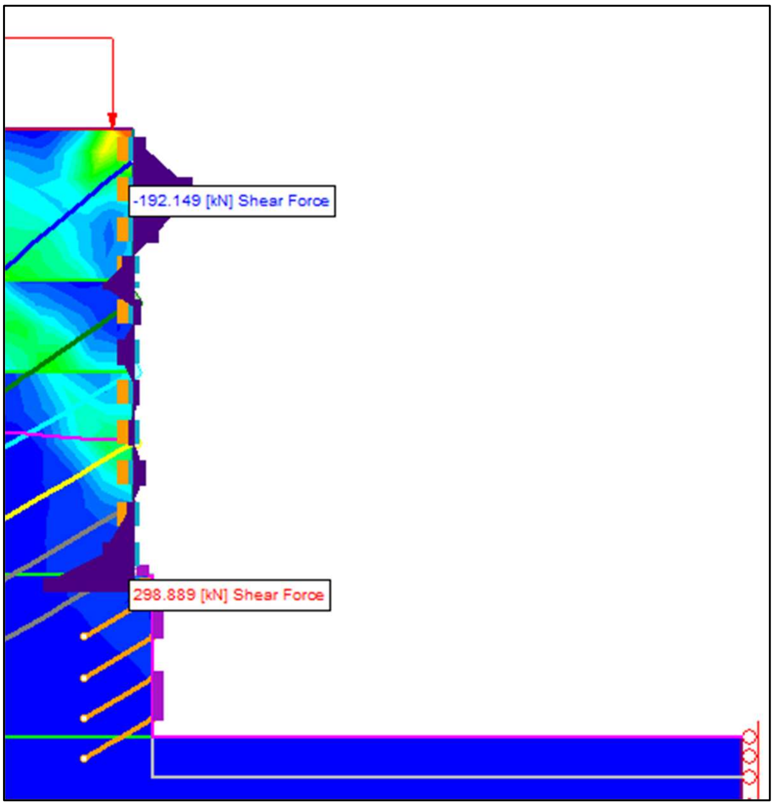
Plot 51: Shear Force for Secant Pile Wall – Stage-19



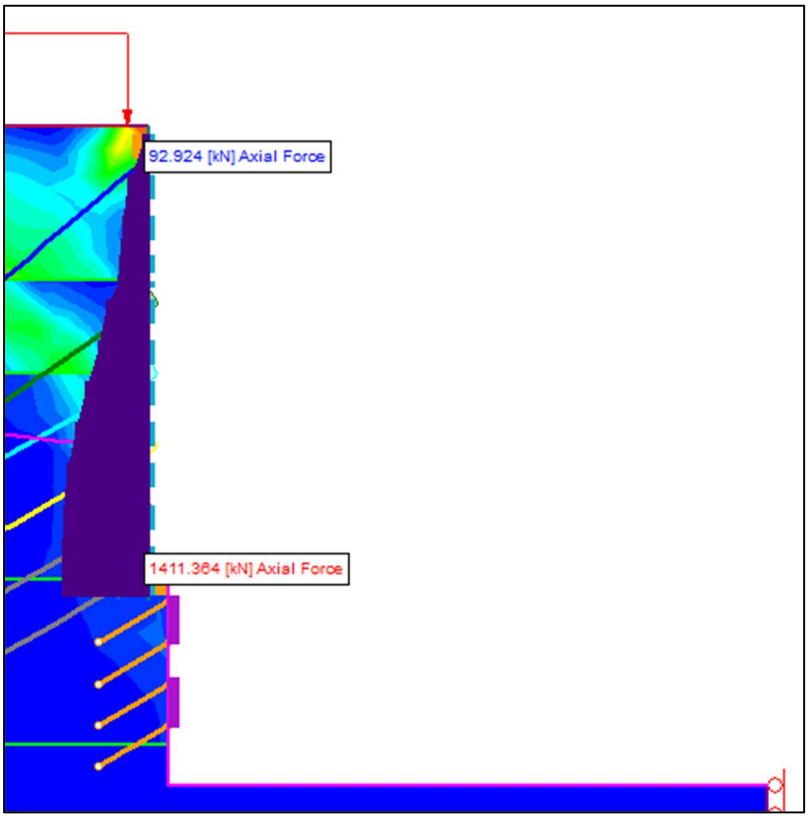
Plot 52: Axial Force for Secant Pile Wall – Stage-20



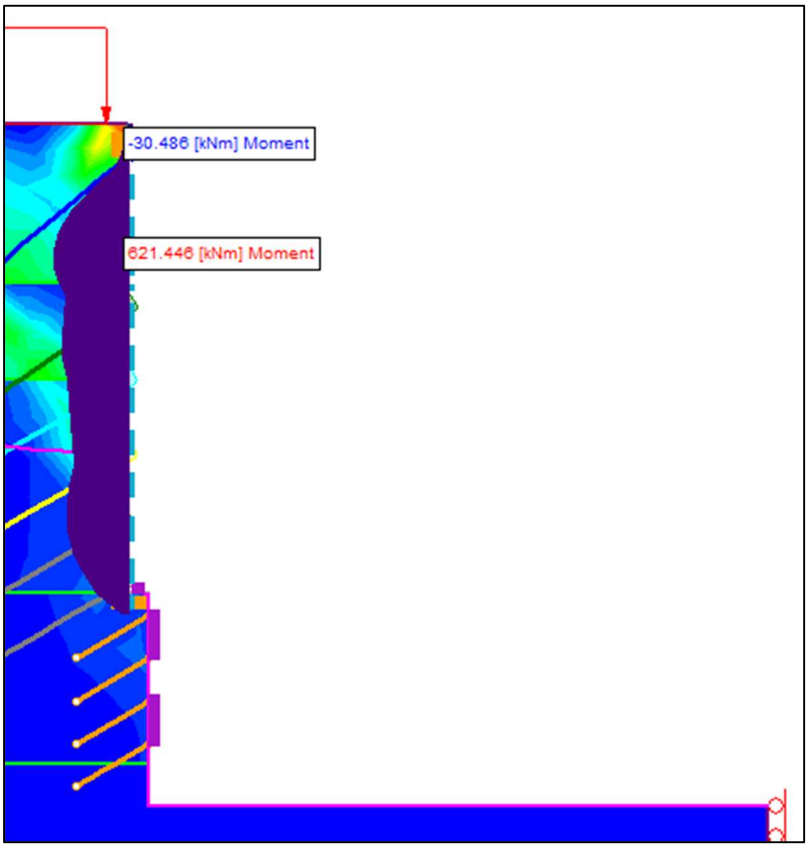
Plot 53: Bending Moment for Secant Pile Wall – Stage-20



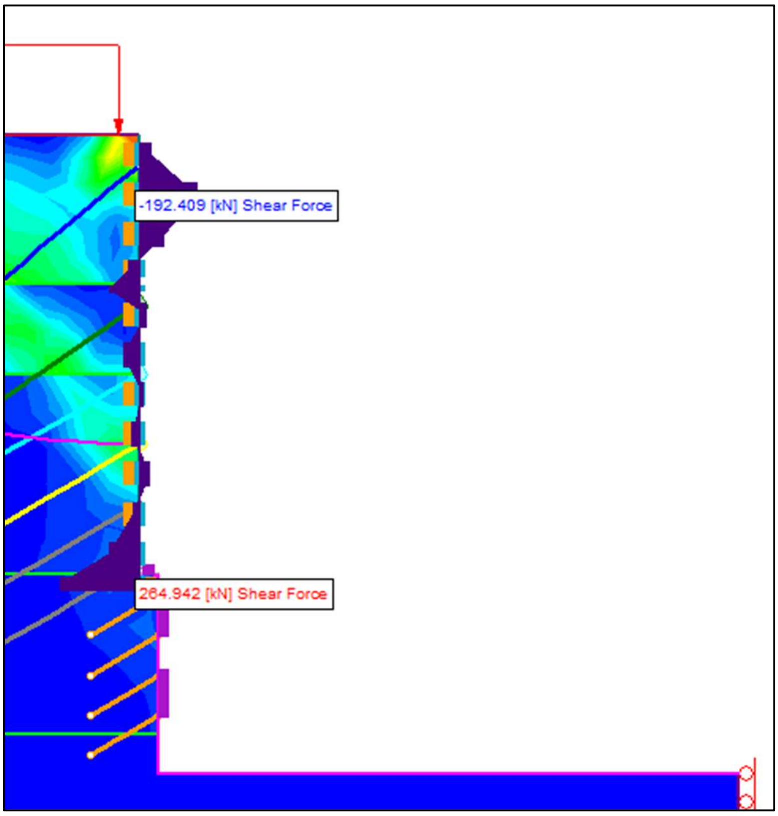
Plot 54: Shear Force for Secant Pile Wall – Stage-20



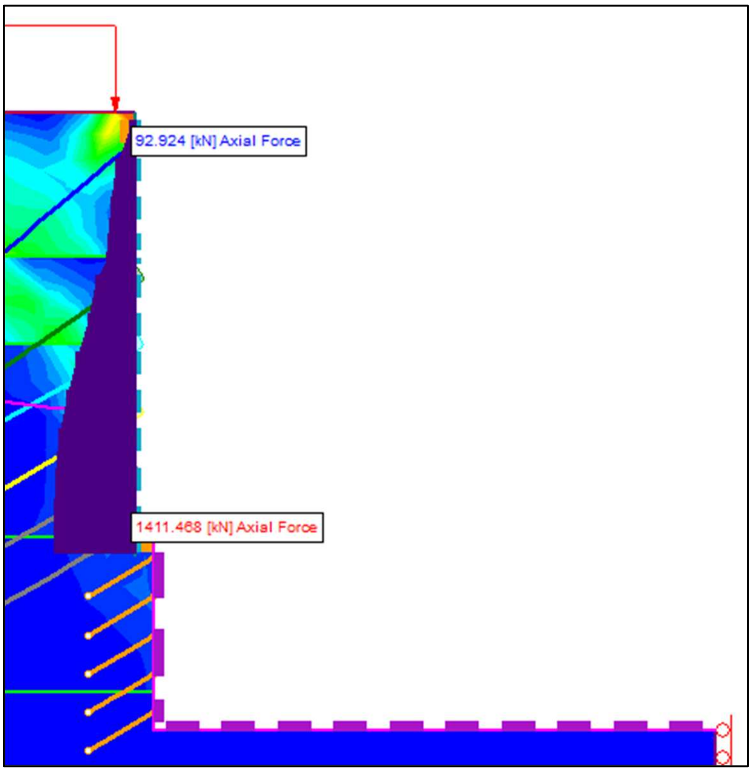
Plot 55: Axial Force for Secant Pile Wall – Stage-21



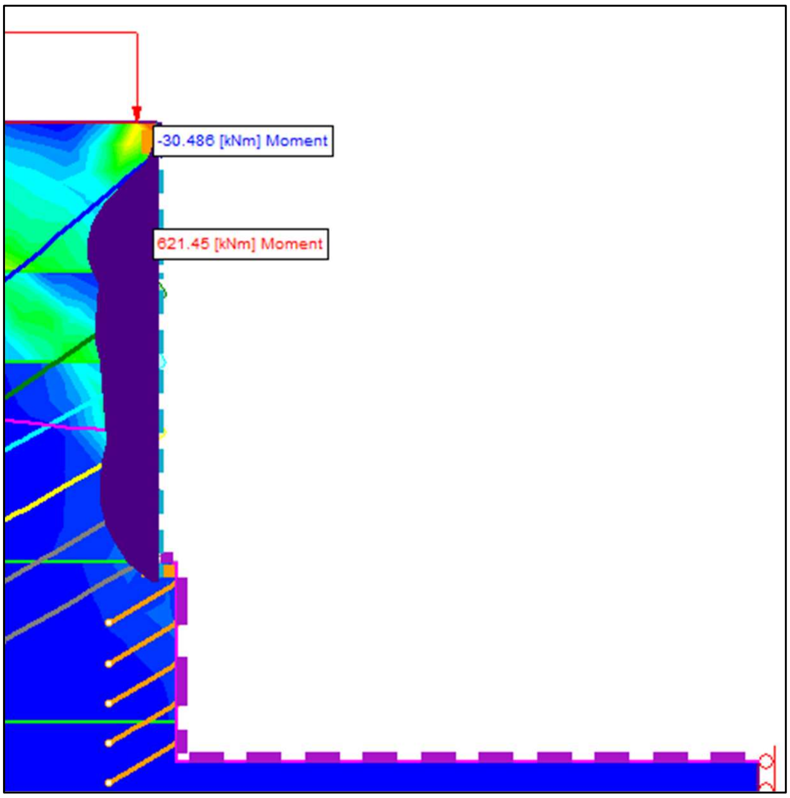
Plot 56: Bending Moment for Secant Pile Wall – Stage-21



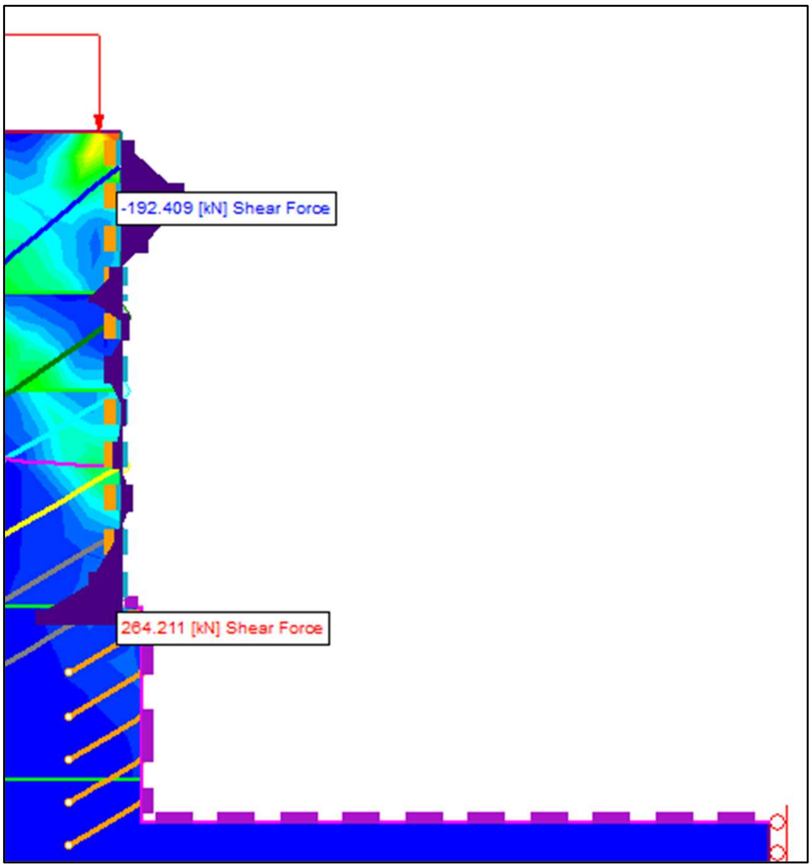
Plot 57: Shear Force for Secant Pile Wall – Stage-21



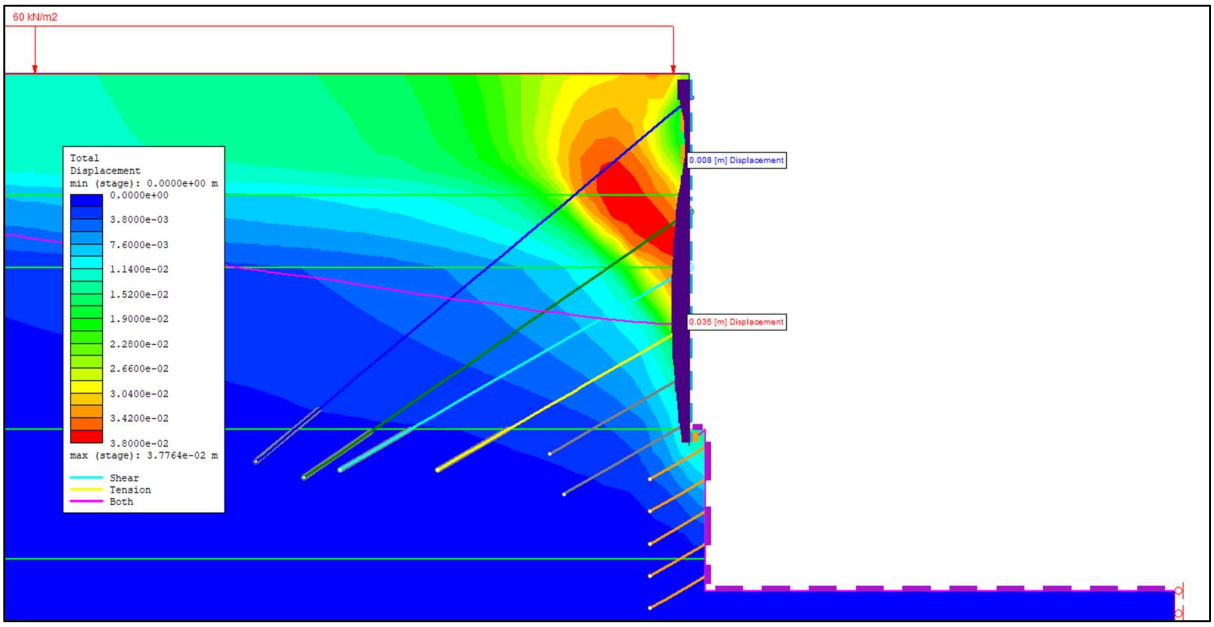
Plot 58: Axial Force for Secant Pile Wall – Stage-22



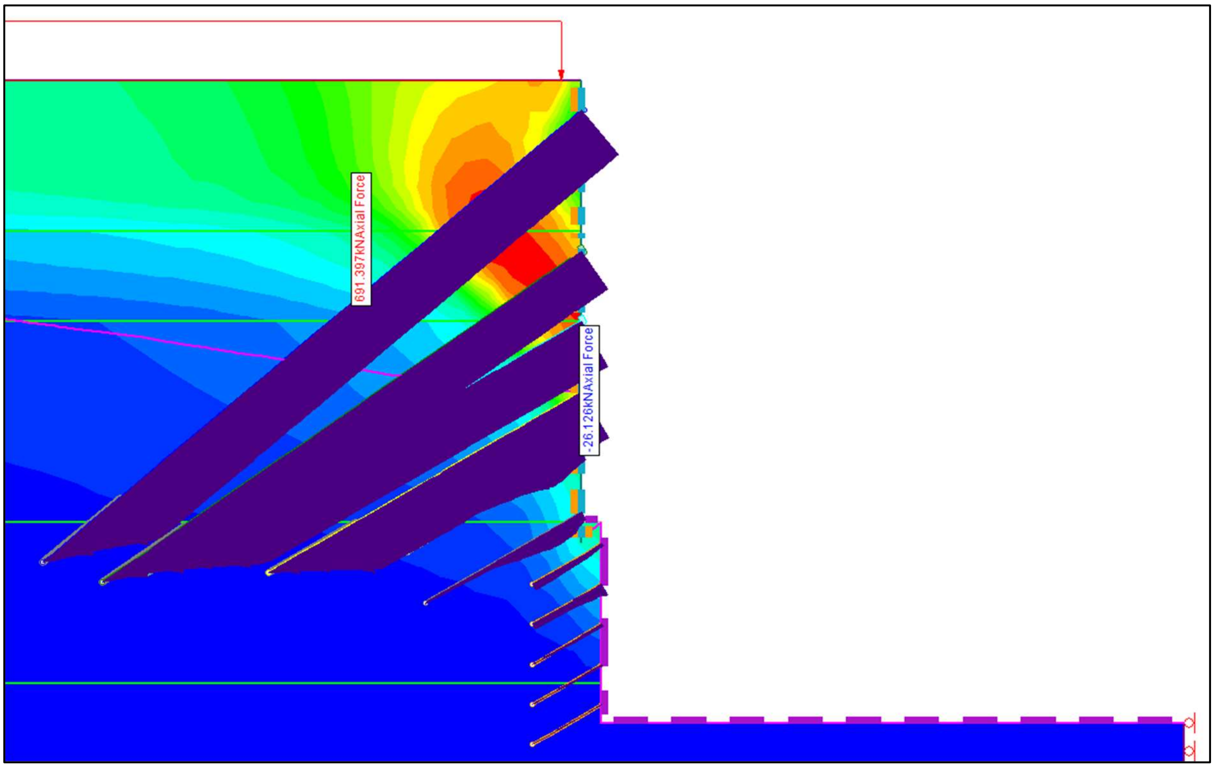
Plot 59: Bending Moment for Secant Pile Wall – Stage-22



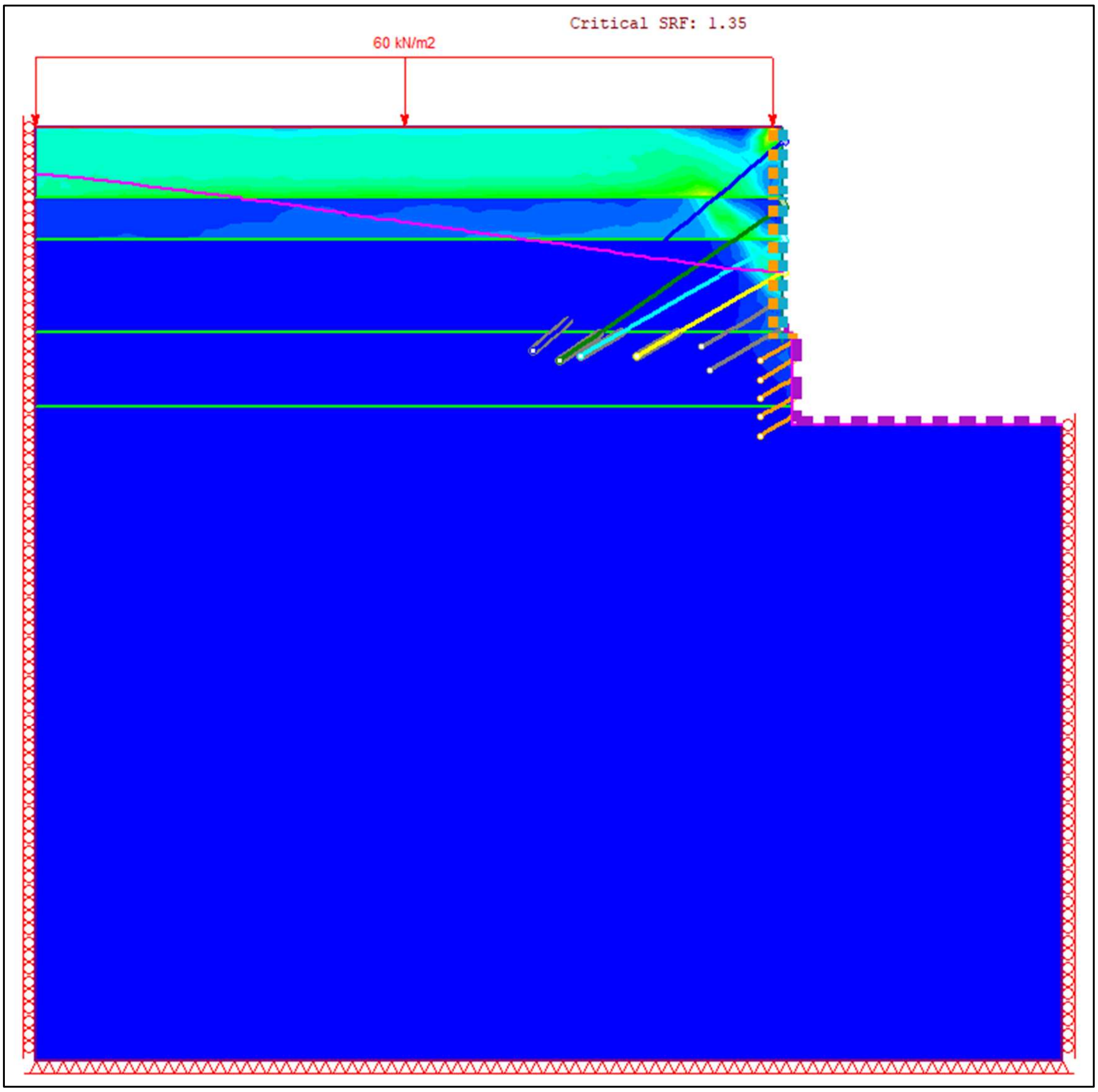
Plot 60: Shear Force for Secant Pile Wall – Stage-22



Plot 61: Displacement for Secant Pile Wall – Stage-22



Plot 62: Anchor bolt Axial force – Stage-22



Plot 63: SRF – Stage-22

RS2 Analysis Information

Project1

Project Summary

File Name:	240902-CNC-32m Deep-R6-F_1
Last saved with RS2 version:	10.012
Project Title:	Project1

General Settings

Number of Stages:	28
Analysis Type:	Plane Strain
Solver Type:	Gaussian Elimination
Units:	Metric, stress as kPa
Permeability Units:	meters/second
Time Units:	seconds

Analysis Options

Maximum Number of Iterations:	1500
Tolerance:	0.003
Number of Load Steps:	Automatic
Convergence Type:	Absolute Force & Energy
Tensile Failure:	Reduces Shear Strength

Strength Reduction Settings

Inital Estimate of SRF:	1
Step Size:	Automatic
Tolerance (SRF):	0.01
Limit SSR Search Area:	No
Accelerate SSR Analysis:	Yes
Reduce SSR Iterations after failure:	Yes
Apply SSR to Mohr-Coulomb Tensile Strength:	Yes
Convergence Parameters:	Automatic

Groundwater Analysis

Method:	Steady State
Pore Fluid Unit Weight:	9.81 kN/m3
Maximum Number of Iterations:	500
Tolerance:	0.001
Use Fluid Potential:	Yes

Probability: None

Field Stress

Field stress: Gravity
Using actual ground surface
Effective stress ratio (horizontal/vertical in-plane): 0.5
Effective stress ratio (horizontal/vertical out-of-plane): 0.5
Locked-in horizontal stress (in-plane): 0
Locked-in horizontal stress (out-of-plane): 0

Mesh

Mesh type: Uniform

Element type: 6 Noded triangles

Stage Name	# of Elements	# of Nodes
In-situ	2327	4835
Surcharge	2327	4835
E-1	2305	4790
Anchor I	2305	4790
E-2	2283	4744
E-3	2261	4698
A-2	2261	4698
E-4	2217	4606
A	2217	4606
E-5	2195	4560
Anchor II	2195	4560
E-6	2173	4514
A-4	2173	4514
E-7	2151	4468
Anchor II	2151	4468
E-8	2129	4422
Anchor IV	2129	4422
E-9	2107	4376
A	2107	4376
E-10	2085	4330
Anchor IV	2085	4330
E-11	2063	4284
E-12	2043	4244
S-1	2043	4244
E-13	2015	4188
S-2	2015	4188
E-14	1995	4148
S-3	1995	4148

Mesh Quality

All elements are of good quality

Poor quality elements defined as:

Side length ratio (maximum / minimum) > 30.00
Minimum interior angle < 2.0 degrees
Maximum interior angle > 175.0 degrees

Reset Displacements

Displacements reset after:	In-situ
Displacements reset after:	Surcharge

Material Properties

L-1: Fill

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	16 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.3
Young's Modulus	5000 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	25 degrees
Peak Cohesion	1 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	25 degrees
Residual Cohesion	1 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	5e-07 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.58
Effective stress ratio (horizontal/vertical out-of-plane)	0.58
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-2: Silty Sand / Clayey Sand

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	18 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.3
Young's Modulus	25000 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	25 degrees
Peak Cohesion	2 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	25 degrees
Residual Cohesion	2 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-07 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.58
Effective stress ratio (horizontal/vertical out-of-plane)	0.58
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-3: CW / HW

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	22 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.3
Young's Modulus	305000 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	39 degrees
Peak Cohesion	120 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	39 degrees
Residual Cohesion	120 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-06 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.43
Effective stress ratio (horizontal/vertical out-of-plane)	0.43
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-4: MW

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	25 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.25
Young's Modulus	1.3e+06 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	52 degrees
Peak Cohesion	250 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	52 degrees
Residual Cohesion	250 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-07 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.33
Effective stress ratio (horizontal/vertical out-of-plane)	0.33
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-5: SW / Fresh

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	26 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.2
Young's Modulus	1.445e+07 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	65 degrees
Peak Cohesion	1300 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	65 degrees
Residual Cohesion	1300 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-08 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.25
Effective stress ratio (horizontal/vertical out-of-plane)	0.25
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

Joint Properties

Joint 1

Joint Color	
Slip Critirion	Material Dependent
Define Stiffness	Define Parameter
Normal Stiffness	100000 kPa/m
Shear Stiffness	10000 kPa/m
Initial Deformation	Yes
Pressure from Groundwater Analysis	Yes
Apply Pressure to Linear Side Only	No
Apply Additional Pressure inside Joint	Not Included
Interface Coefficient	0.7
Apply Stage Factors	No

Liner Properties

Liner: SPW-1m

Color	
Liner Type	Standard Beam
Formulation	Timoshenko
Area	0.4908 m2
Moment of Inertia	0.03067 m4

Elastic Properties

Young's modulus	2.958e+07 kPa
Poisson's ratio	0.2
Liner Unit Weight	25 kN/m3

Liner: SC-100mm

Color	
Liner Type	Standard Beam
Formulation	Timoshenko
Thickness	0.1 m

Elastic Properties

Young's modulus	2.5e+07 kPa
Poisson's ratio	0.2

Structural Interface Properties

Structural Interface:	Structural 1
Joint (positive side):	Joint 1
Liner:	SPW-1m
Joint (negative side):	Joint 1

Bolt Properties

Ground Anchor-1

Bolt Color	
Bolt Type	Tieback
Bolt Diameter	33.98 mm
Bolt Modulus,E	2e+08 kPa
Bolt Model	No
Tensile Capacity	1303.5 kN
Residual Tensile Capacity	130 kN
Out-of-Plane Spacing	1.6 m
Bond Shear Stiffness	2500 kN/m/m
Bond Strength	235.6 kN/m
Joint Shear	Yes
Borehole Diameter	150 mm
Pre-Tensioning Force	650 kN
Constant Pre-tensioning Force in Install Stage	Yes
Face Plates	Attached
Bond Length	5 m

Ground Anchor-II

Bolt Color	
Bolt Type	Tieback
Bolt Diameter	33.98 mm
Bolt Modulus,E	2e+08 kPa
Bolt Model	No
Tensile Capacity	1303.5 kN
Residual Tensile Capacity	130 kN
Out-of-Plane Spacing	1.6 m
Bond Shear Stiffness	2500 kN/m/m
Bond Strength	235.6 kN/m
Joint Shear	Yes
Borehole Diameter	150 mm
Pre-Tensioning Force	488 kN
Constant Pre-tensioning Force in Install Stage	Yes
Face Plates	Attached
Bond Length	5 m

SN-32

Bolt Color	
Bolt Type	Fully Bonded
Bolt Diameter	32 mm
Bolt Modulus,E	2e+08 kPa
Tensile Capacity	350 kN
Residual Tensile Capacity	35 kN
Out-of-Plane Spacing	3.2 m
Pre-Tensioning Force	0 kN
Constant Pre-tensioning Force in Install Stage	Yes
Joint Shear	Yes

SN-25

Bolt Color	
Bolt Type	Fully Bonded
Bolt Diameter	25 mm
Bolt Modulus,E	2e+08 kPa
Tensile Capacity	213 kN
Residual Tensile Capacity	21 kN
Out-of-Plane Spacing	2 m
Pre-Tensioning Force	0 kN
Constant Pre-tensioning Force in Install Stage	Yes
Joint Shear	Yes

Ground Anchor-III

Bolt Color	
Bolt Type	Tieback
Bolt Diameter	37.23 mm
Bolt Modulus,E	2e+08 kPa
Bolt Model	No
Tensile Capacity	1564.2 kN
Residual Tensile Capacity	156 kN
Out-of-Plane Spacing	3.2 m
Bond Shear Stiffness	2500 kN/m/m
Bond Strength	235.6 kN/m
Joint Shear	Yes
Borehole Diameter	150 mm
Pre-Tensioning Force	520 kN
Constant Pre-tensioning Force in Install Stage	Yes
Face Plates	Attached
Bond Length	5 m

Ground Anchor-IV

Bolt Color	
Bolt Type	Tieback
Bolt Diameter	33.98 mm
Bolt Modulus,E	2e+08 kPa
Bolt Model	No
Tensile Capacity	1303.5 kN
Residual Tensile Capacity	130 kN
Out-of-Plane Spacing	3.2 m
Bond Shear Stiffness	2500 kN/m/m
Bond Strength	235.6 kN/m
Joint Shear	Yes
Borehole Diameter	150 mm
Pre-Tensioning Force	520 kN
Constant Pre-tensioning Force in Install Stage	Yes
Face Plates	Attached
Bond Length	5 m

List of All Coordinates

External boundary

X	Y
-80	0
-80	-5
-80	-7.5
-80	-12
-80	-22
-80	-30
-80	-100
30	-100
30	-32
30	-30
30	-26
30	-22
30	-20
30	-18
30	-16
30	-14
30	-12
30	-10
30	-8
30	-7.5
30	-6
30	-4
30	-2
30	0
0	0
-1	0

Stage boundary

X	Y
1	-22
1	-26
1	-30
1	-32
30	-32

Stage boundary

X	Y
0	-22
1	-22

Stage boundary

X	Y
0	-2
30	-2

Stage boundary

X	Y
0	-4
30	-4

Stage boundary

X	Y
0	-6
30	-6

Stage boundary

X	Y
0	-8
30	-8

Stage boundary

X	Y
0	-10
30	-10

Stage boundary

X	Y
0	-14
30	-14

Stage boundary

X	Y
0	-16
30	-16

Stage boundary

X	Y
0	-18
30	-18

Stage boundary

X	Y
0	-20
30	-20

Stage boundary

X	Y
1	-26
30	-26

Material boundary

X	Y
-80	-7.5
0	-7.5
30	-7.5

Material boundary

X	Y
-80	-12
0	-12

Material boundary

X	Y
-80	-22
0	-22

Material boundary

X	Y
-80	-30
1	-30
30	-30

Material boundary

X	Y
1	-22
30	-22

Material boundary

X	Y
0	-12
30	-12

Structural interface

X	Y
0	0
0	-2
0	-4
0	-6
0	-7.5
0	-8
0	-10
0	-12
0	-14
0	-16
0	-18
0	-20
0	-22
0	-23

Bolt

X	Y
0	-1.5
-26.8116	-23.9976

Bolt

X	Y
0	-12
-21.6506	-24.5

Bolt

X	Y
0	-21.5
-7.79423	-26

Bolt

X	Y
0	-8.5
-23.8551	-24.9921

Bolt

X	Y
0	-15.5081
-15.5885	-24.5081

Bolt

X	Y
0	-18.5081
-8.66025	-23.5081

Bolt

X	Y
1	-23.0657
-2.4641	-25.0657

Bolt

X	Y
1	-25.0657
-2.4641	-27.0657

Bolt

X	Y
1	-27.0657
-2.4641	-29.0657

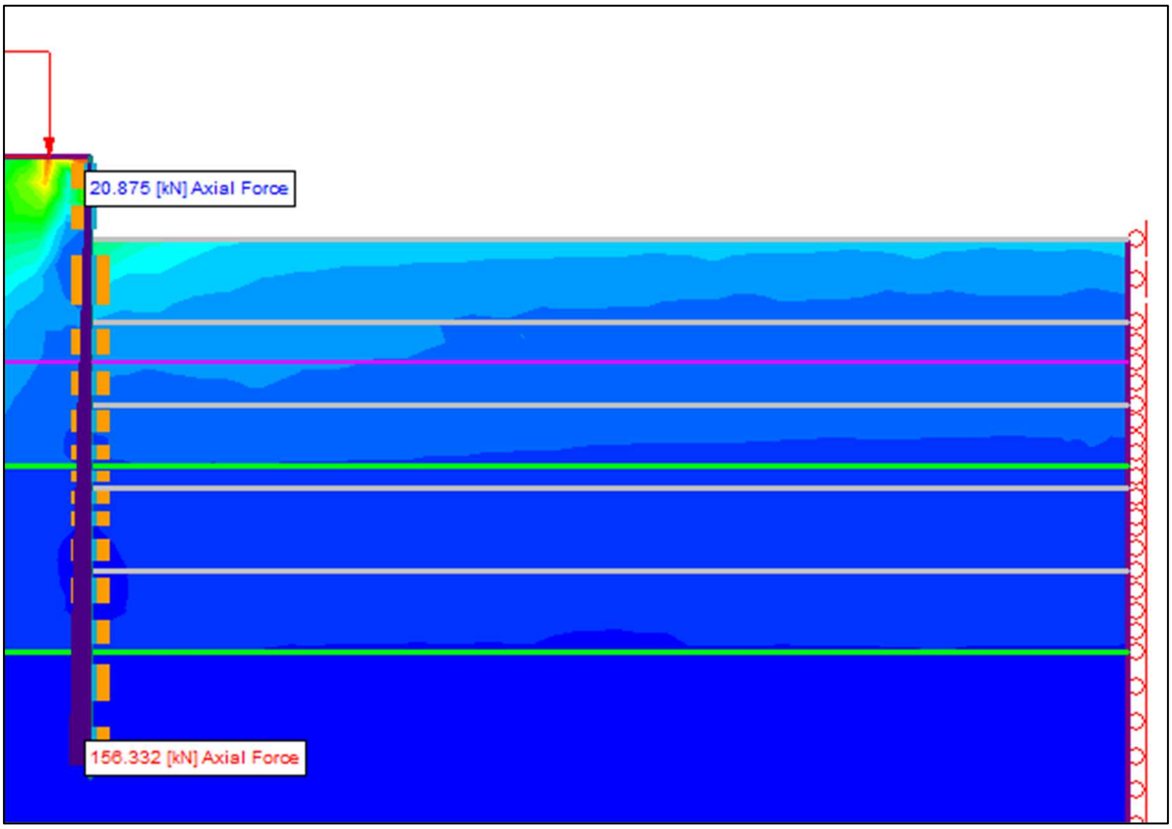
Bolt

X	Y
1	-29.0657
-2.4641	-31.0657

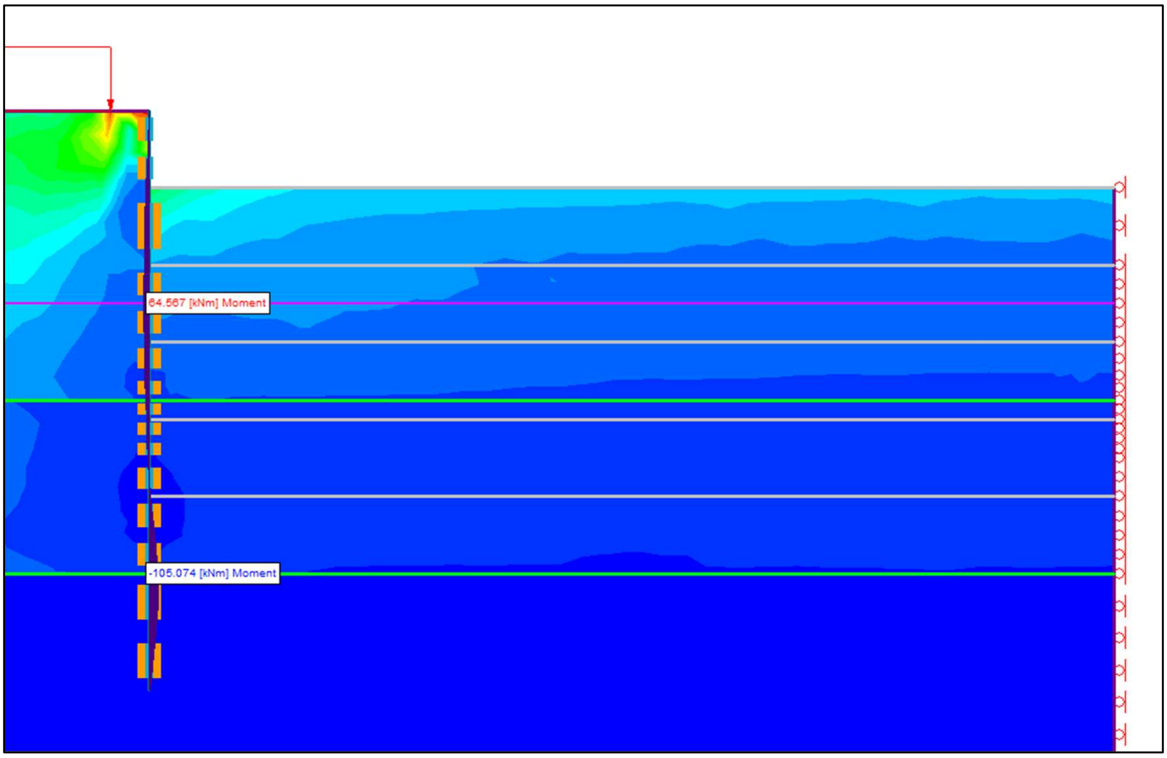
Bolt

X	Y
1	-31.0657
-2.4641	-33.0657

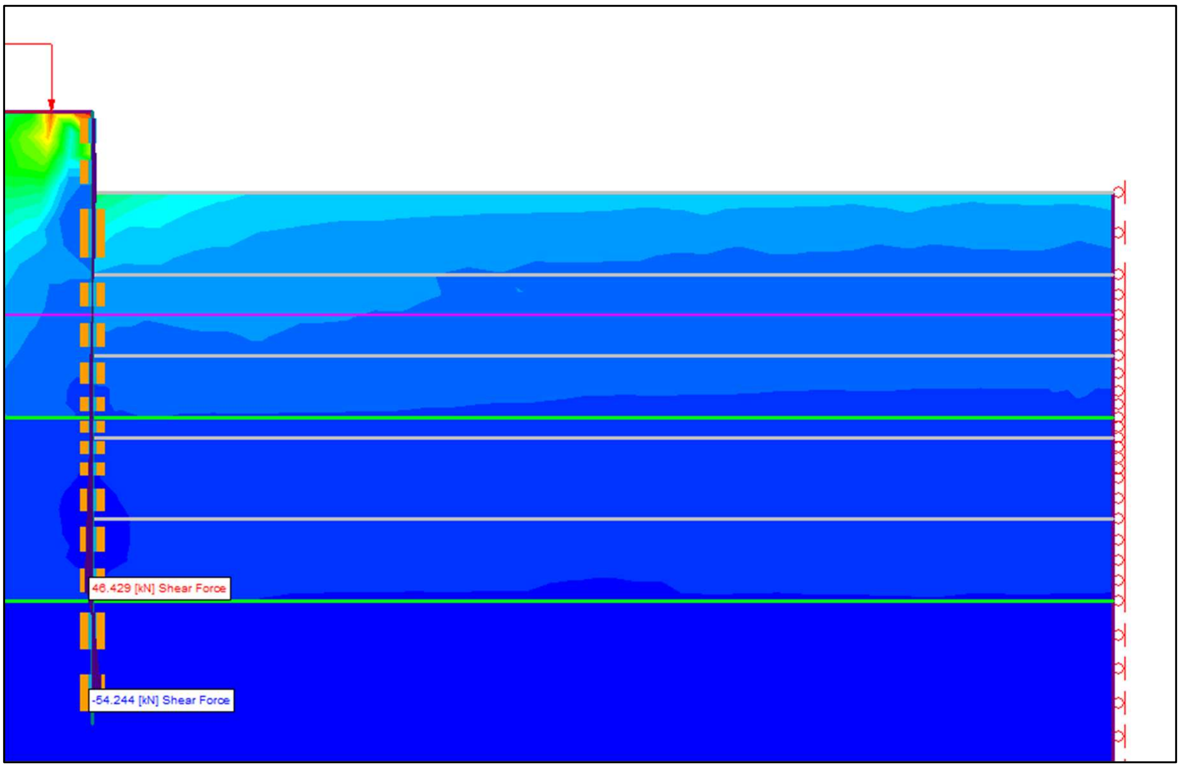
FEM ANALYSIS OUTPUT 12 M DEEP EXCAVATION



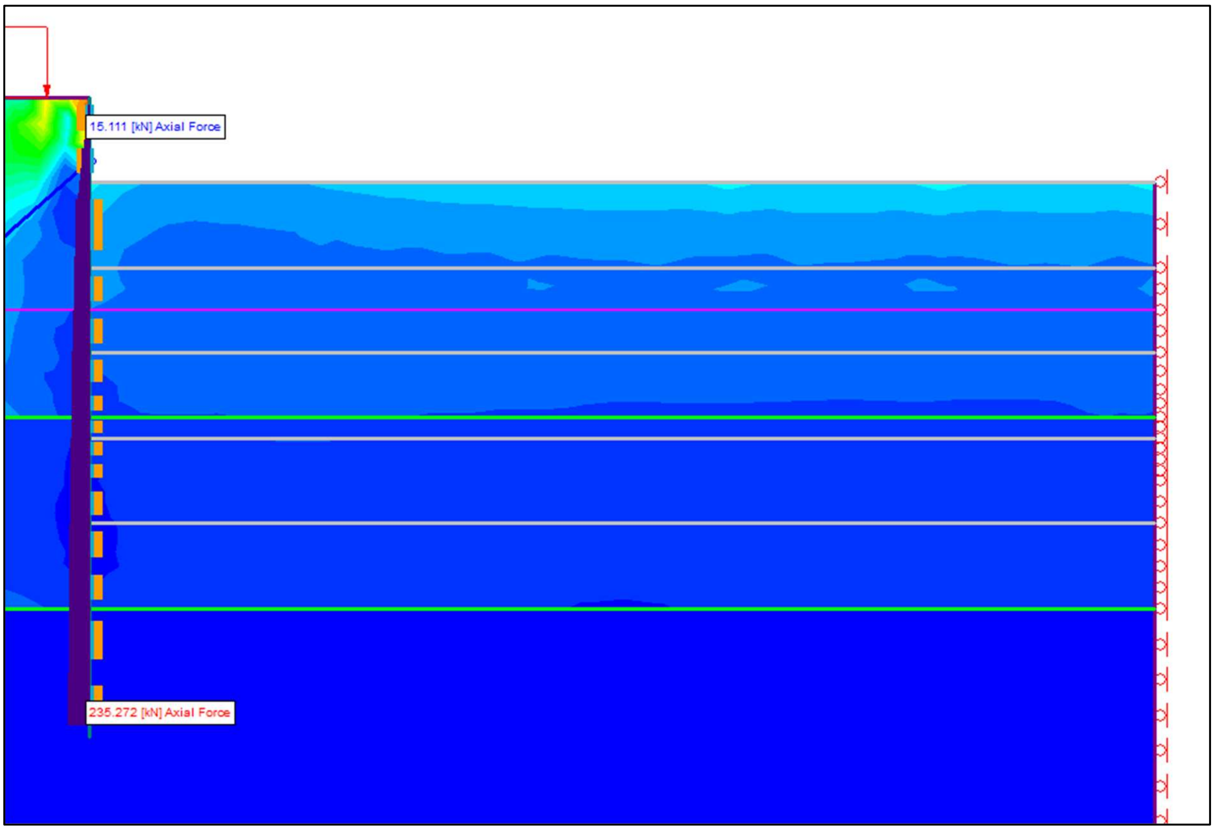
Plot 1*: Axial Force *for Secant Pile Wall – Stage-3



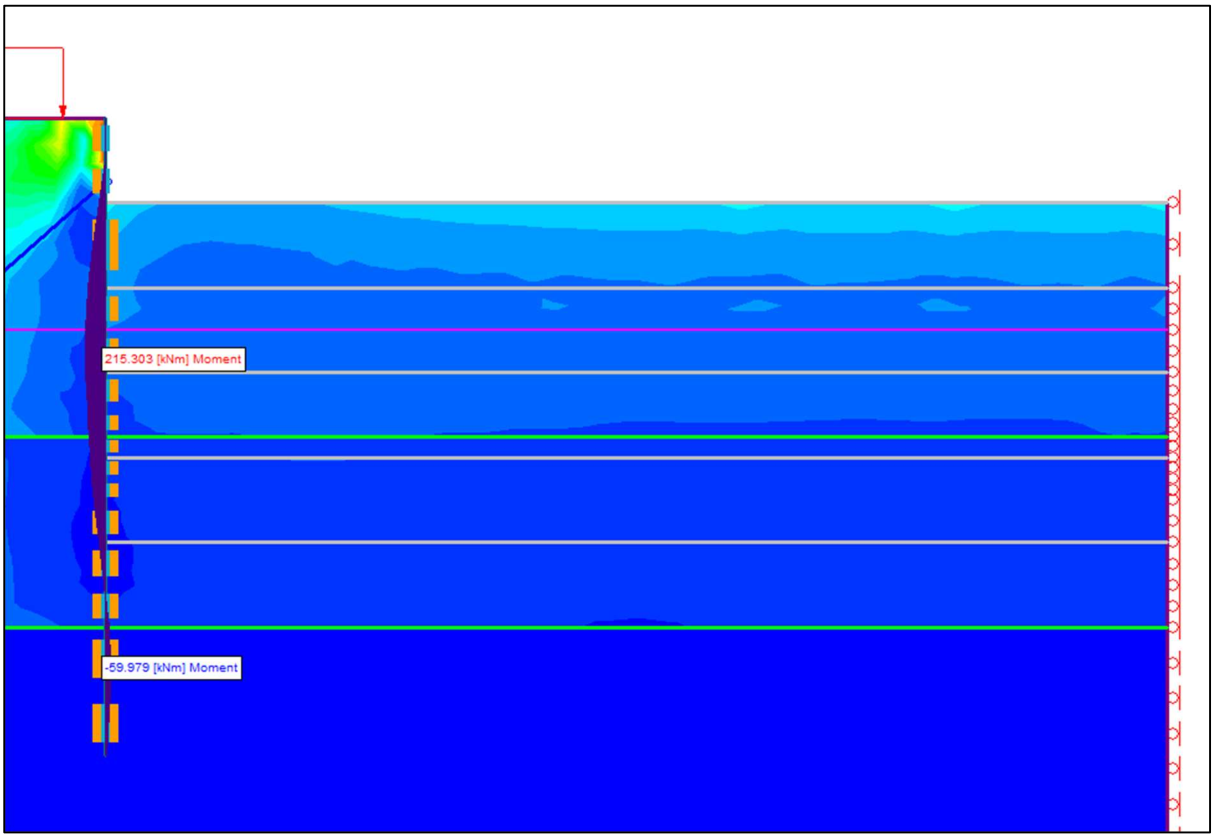
Plot 2: Bending Moment for Secant Pile Wall – Stage-3



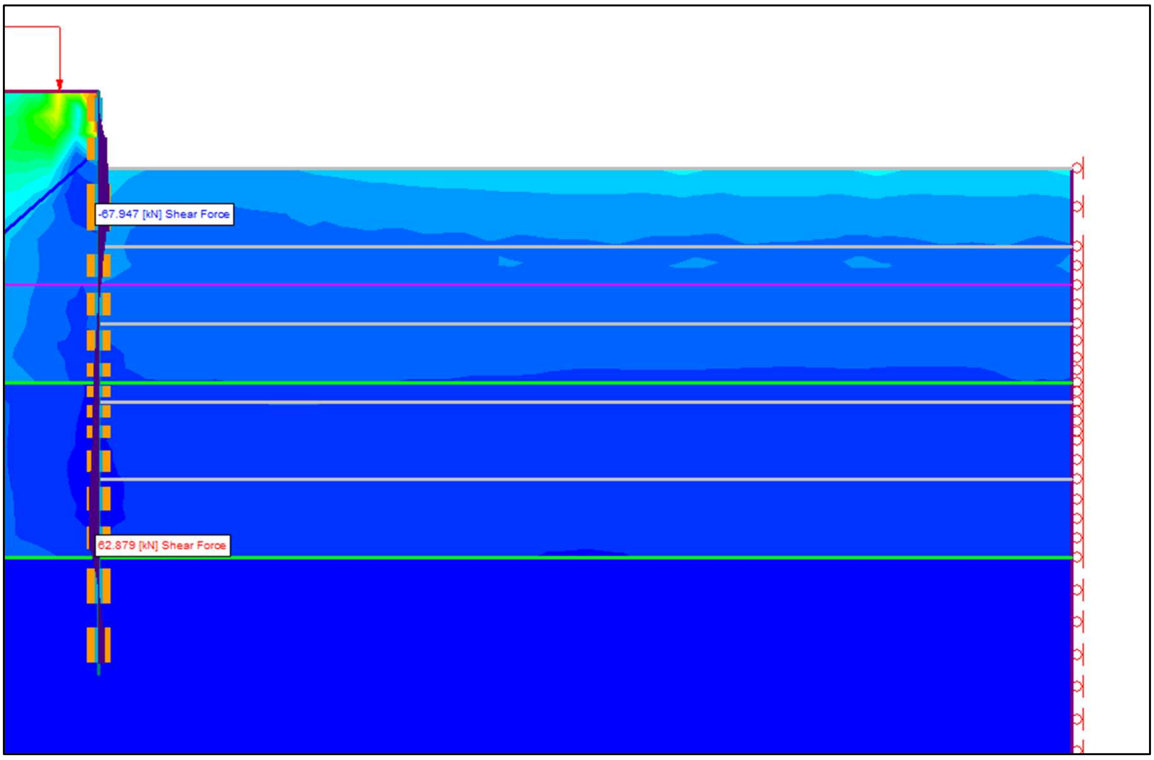
Plot 3: Shear Force for Secant Pile Wall – Stage-3



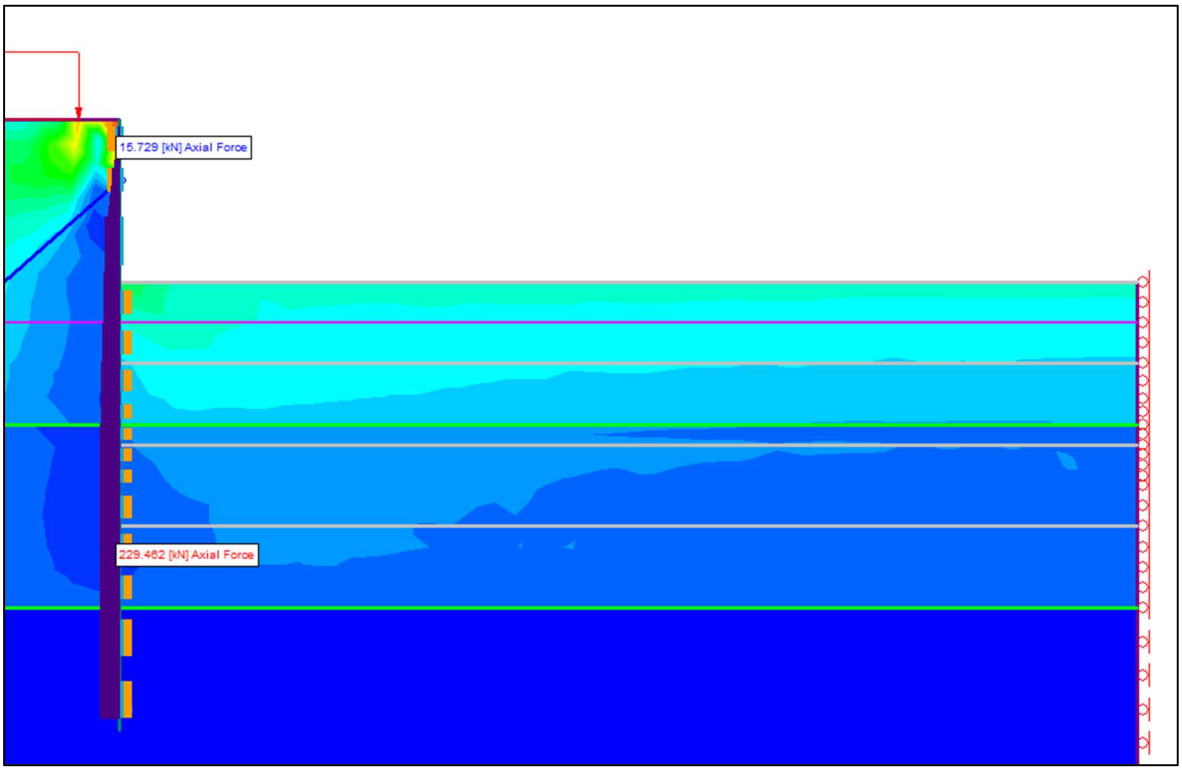
Plot 4*: Axial Force *for Secant Pile Wall – Stage-4



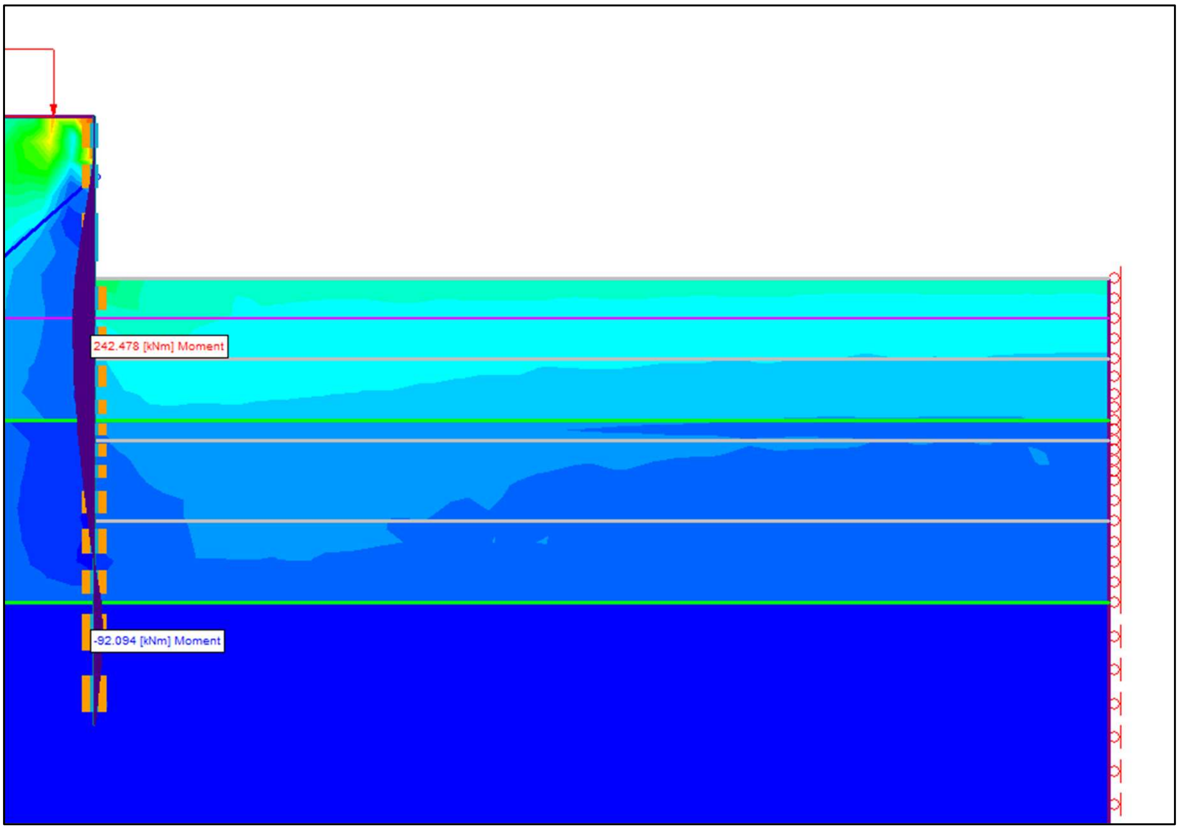
Plot 5: Bending Moment for Secant Pile Wall – Stage-4



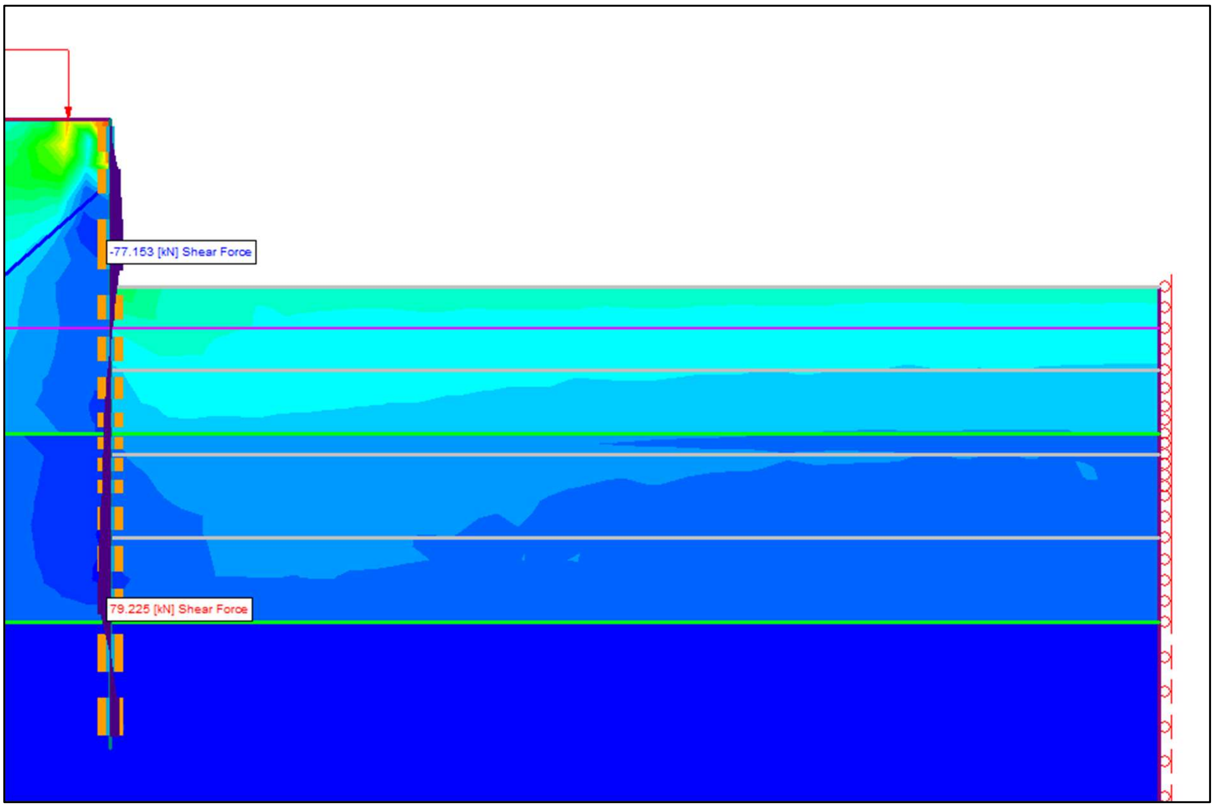
Plot 6: Shear Force for Secant Pile Wall – Stage-4



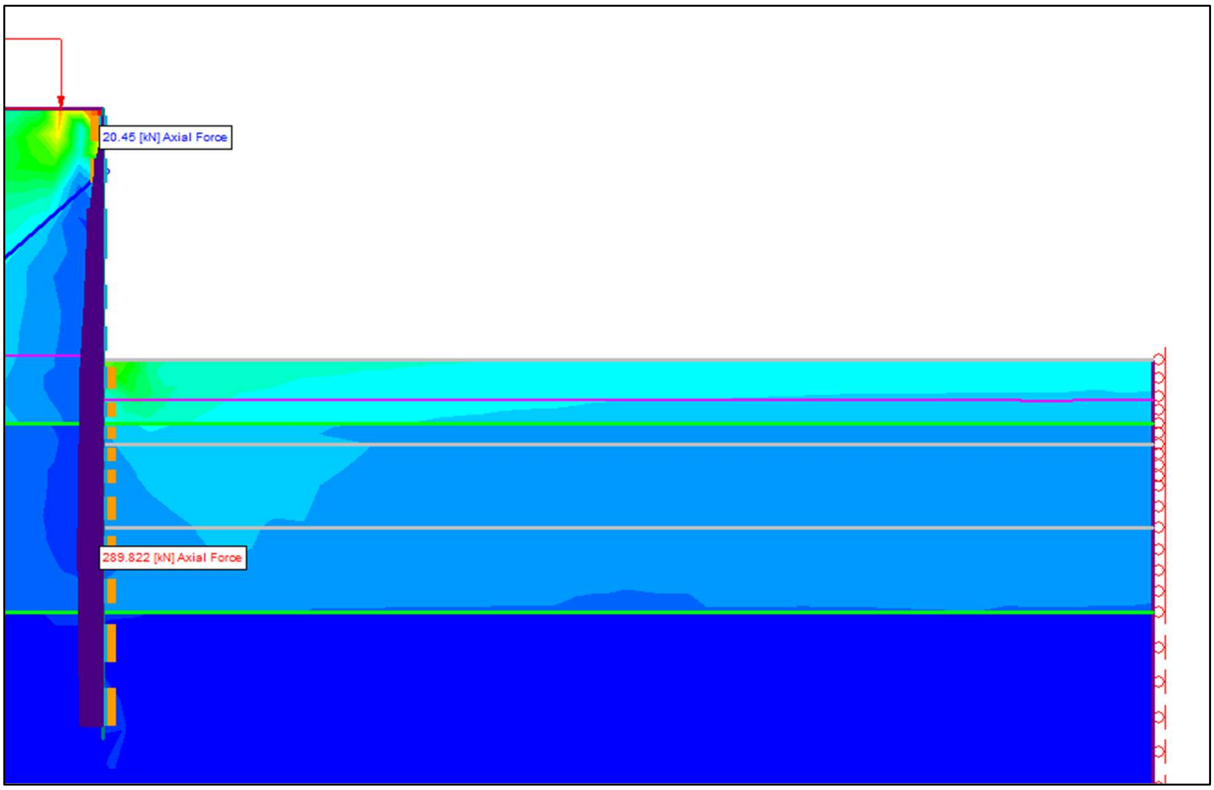
Plot 7: Axial Force for Secant Pile Wall – Stage-5



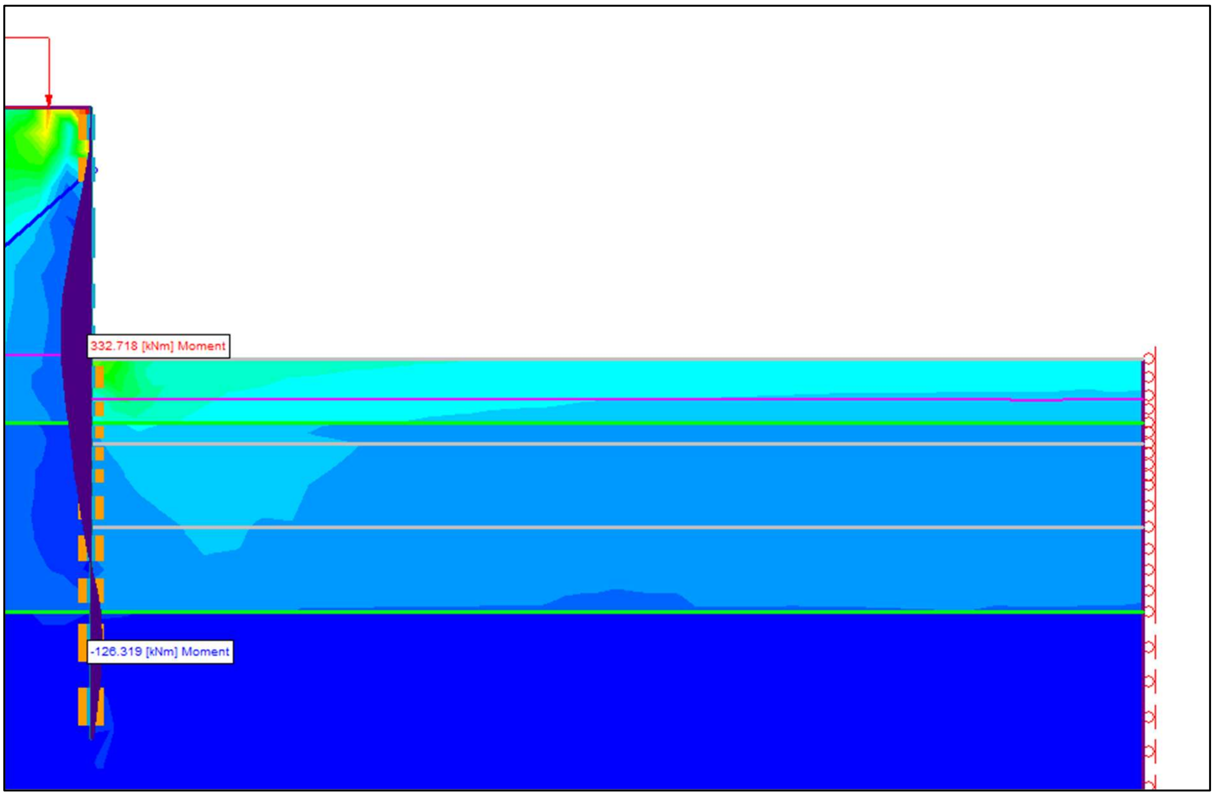
Plot 8: Bending Moment for Secant Pile Wall – Stage-5



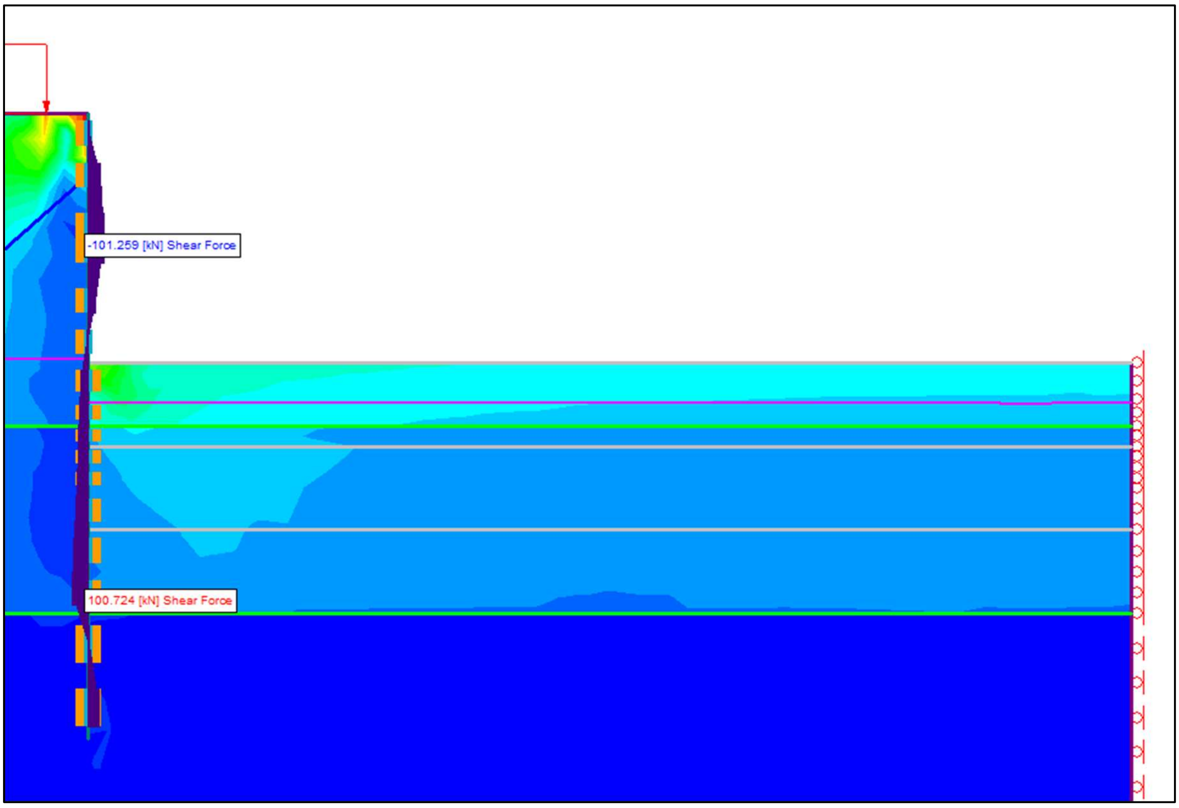
Plot 9: Shear Force for Secant Pile Wall – Stage-5



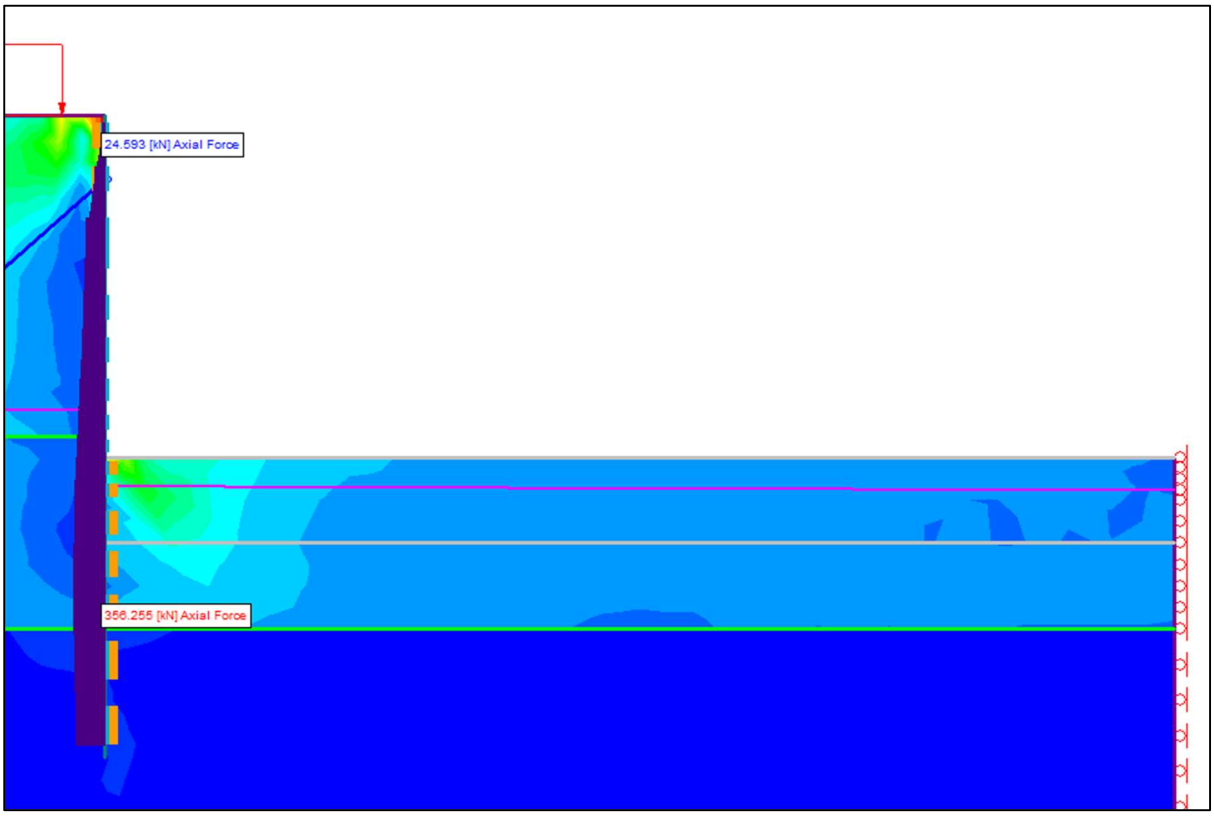
Plot 10: Axial Force for Secant Pile Wall – Stage-6



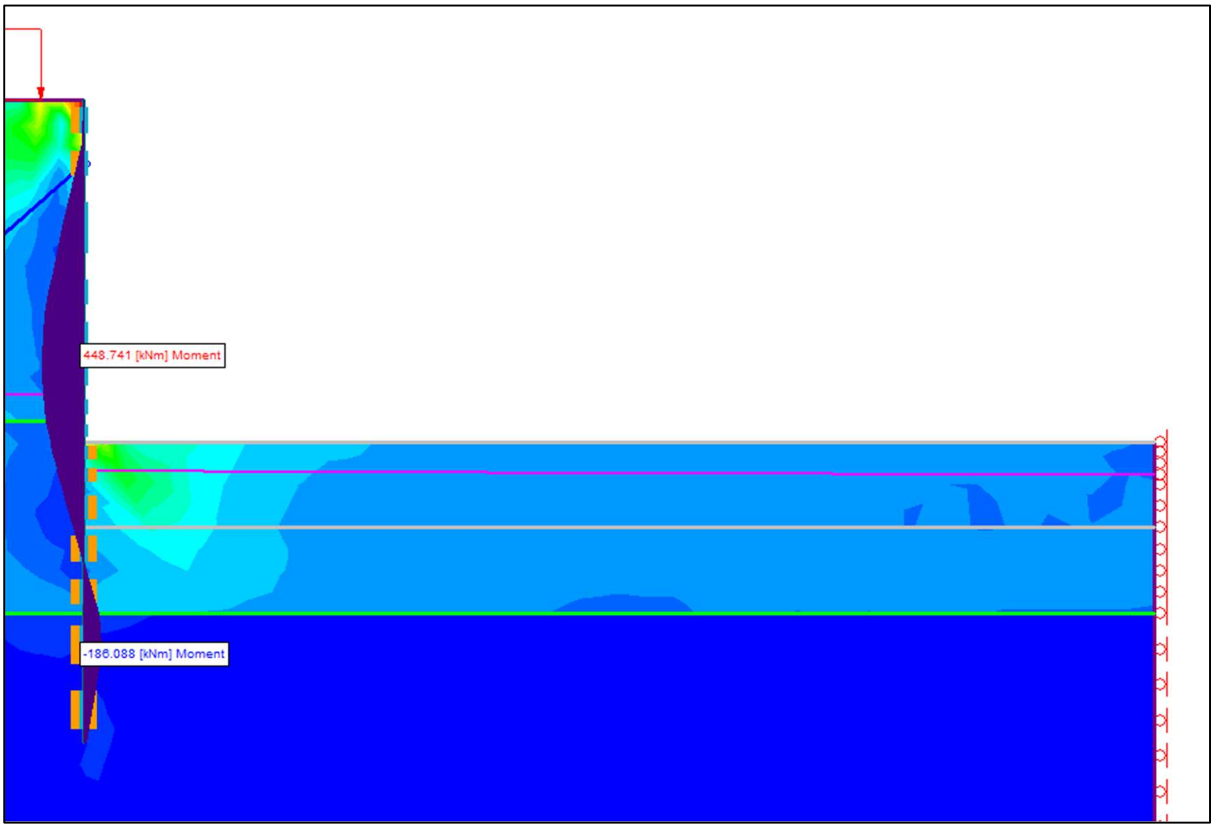
Plot 11: Bending Moment for Secant Pile Wall – Stage-6



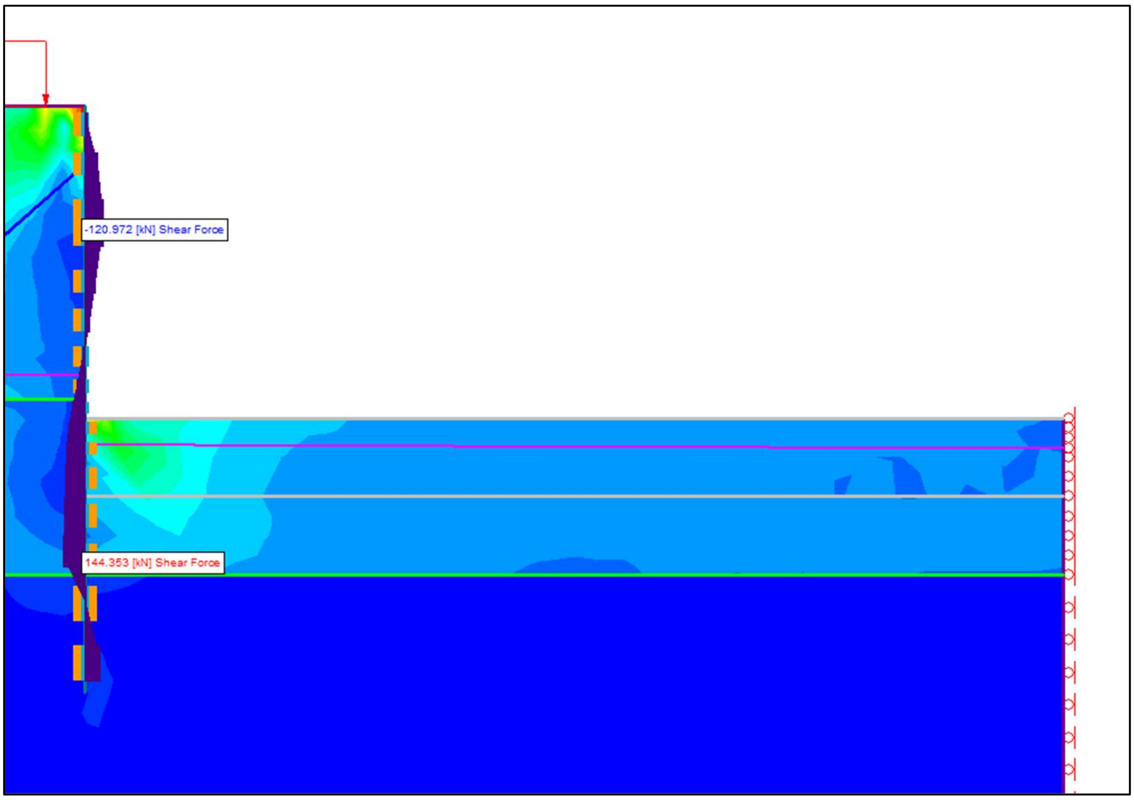
Plot 12: Shear Force for Secant Pile Wall – Stage-6



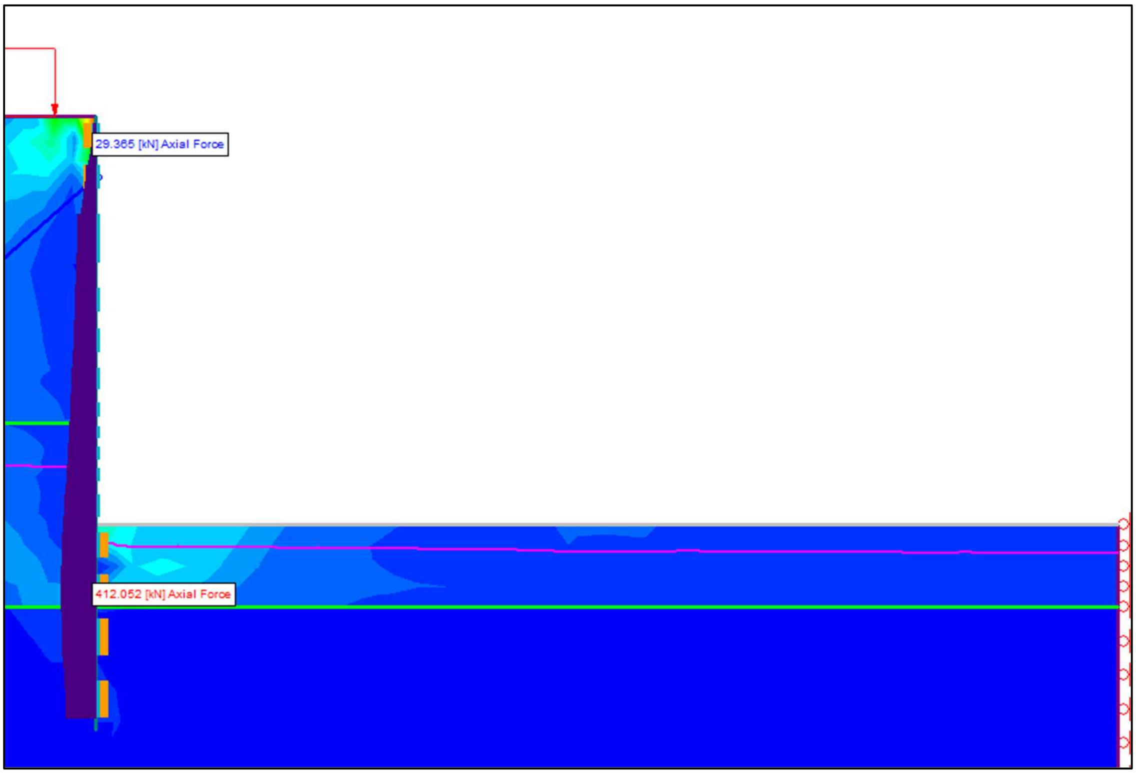
Plot 13: Axial Force for Secant Pile Wall – Stage-7



Plot 14: Bending Moment for Secant Pile Wall – Stage-7



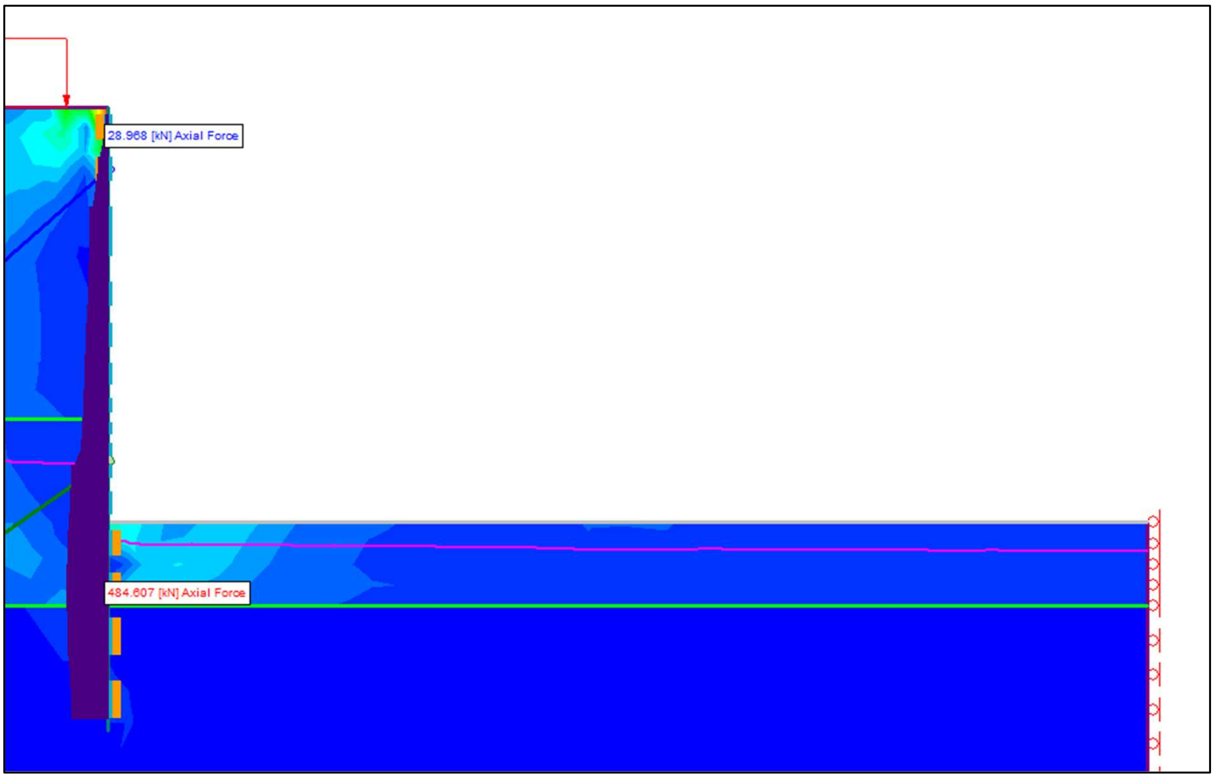
Plot 15: Shear Force for Secant Pile Wall – Stage-7



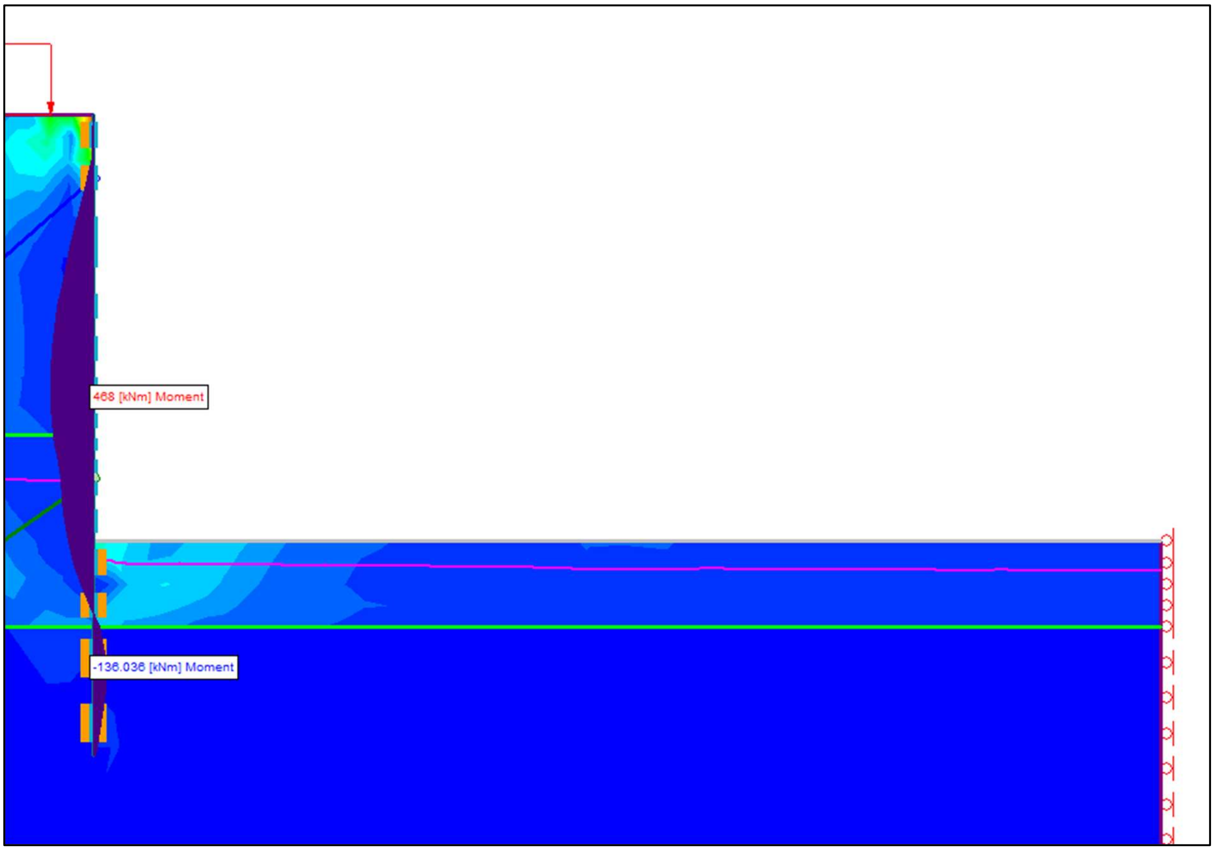
Plot 16: Axial Force for Secant Pile Wall – Stage-8

Plot 17: Bending Moment for Secant Pile Wall – Stage-8

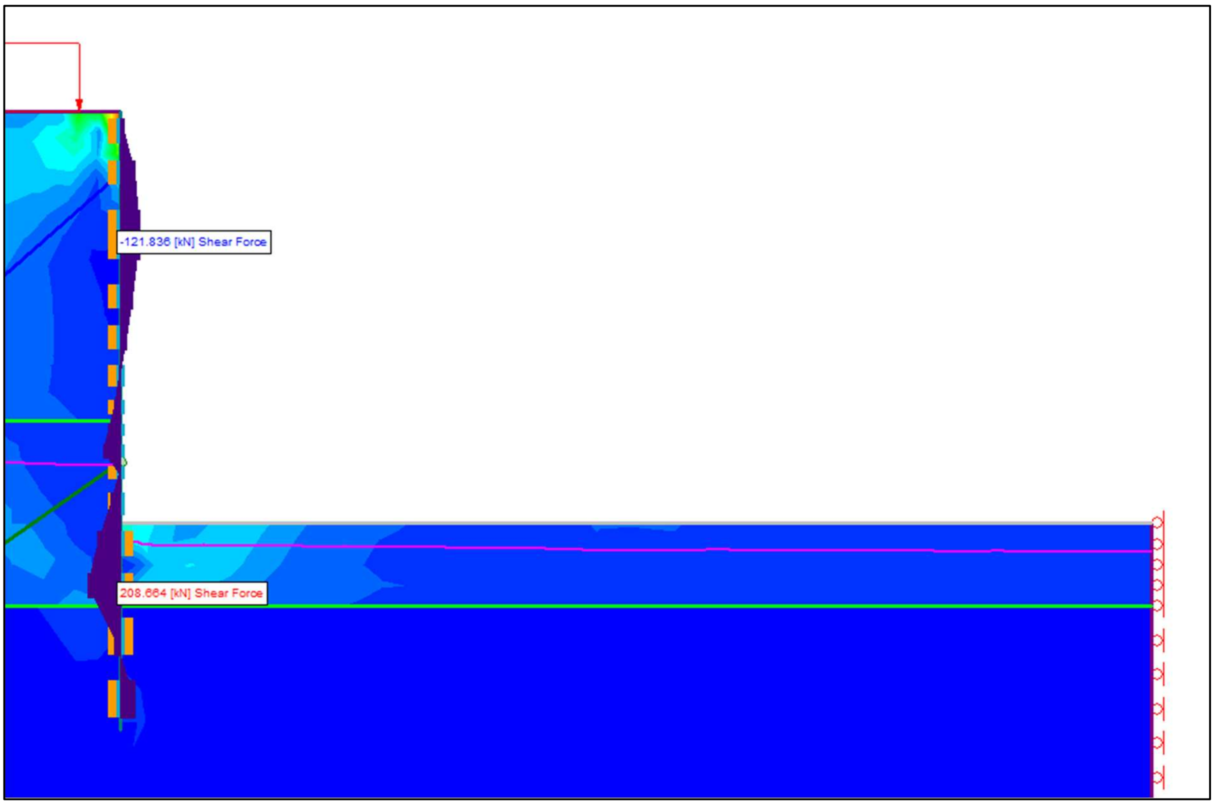
Plot 18: Shear Force for Secant Pile Wall – Stage-8



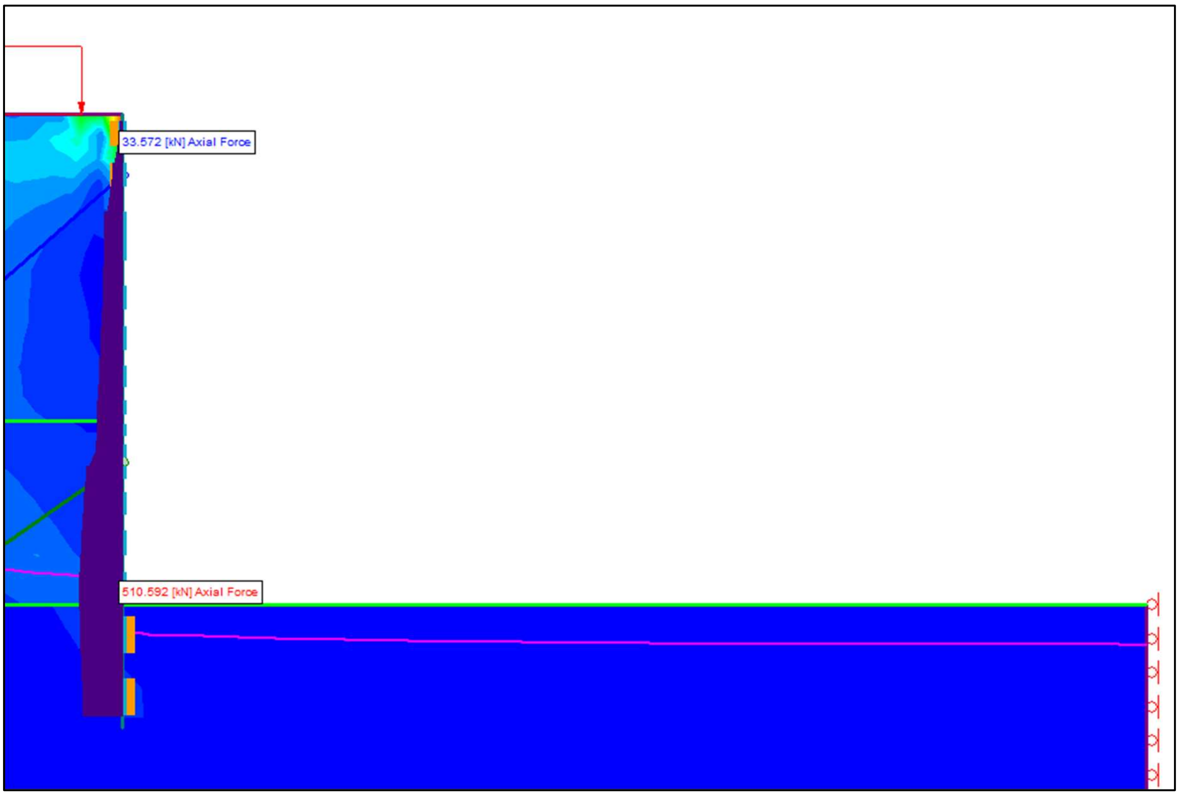
Plot 19: Axial Force for Secant Pile Wall – Stage-9



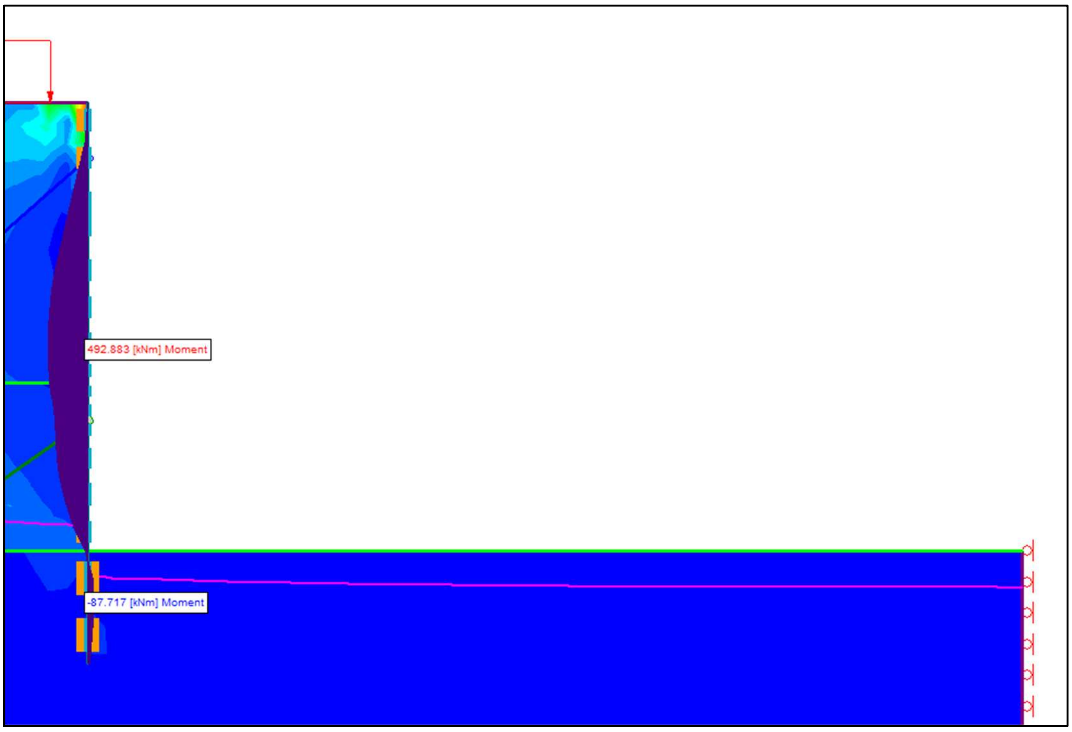
Plot 20: Bending Moment for Secant Pile Wall – Stage-9



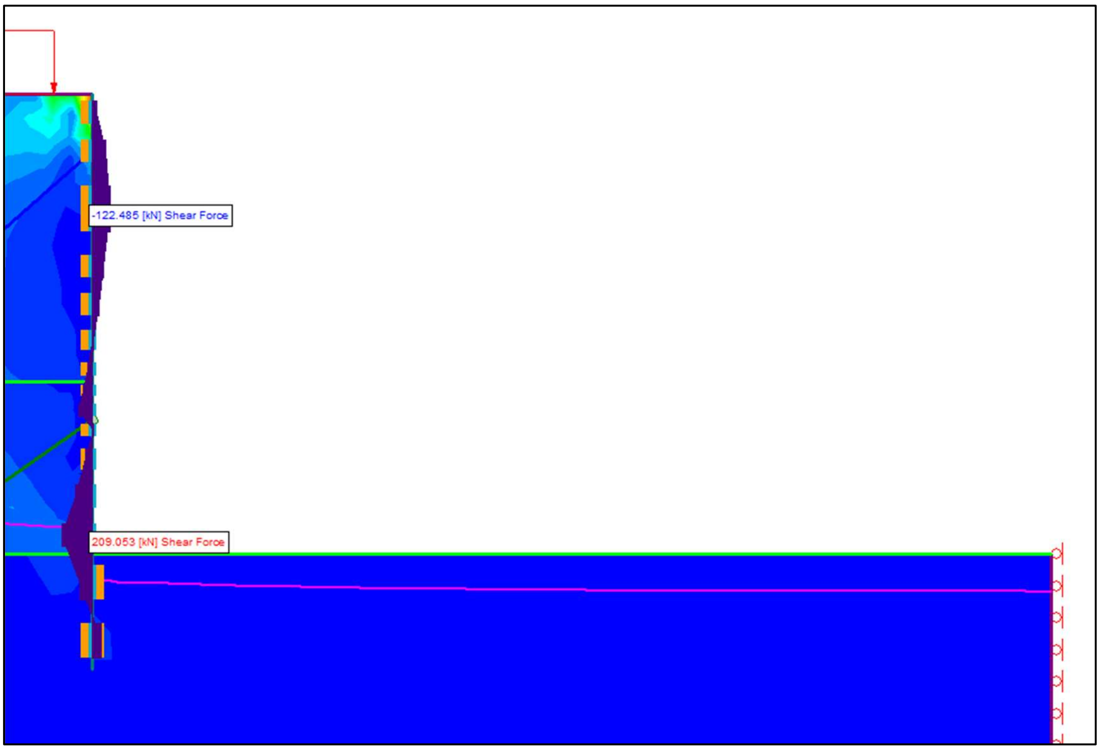
Plot 21: Shear Force for Secant Pile Wall – Stage-9



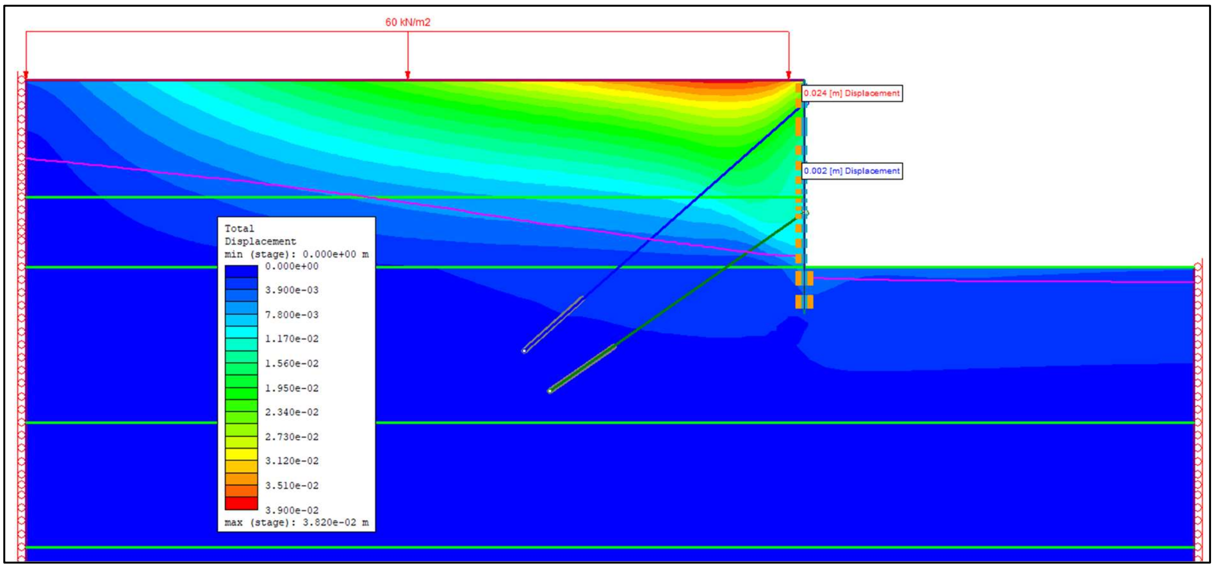
Plot 22: Axial Force for Secant Pile Wall – Stage-10



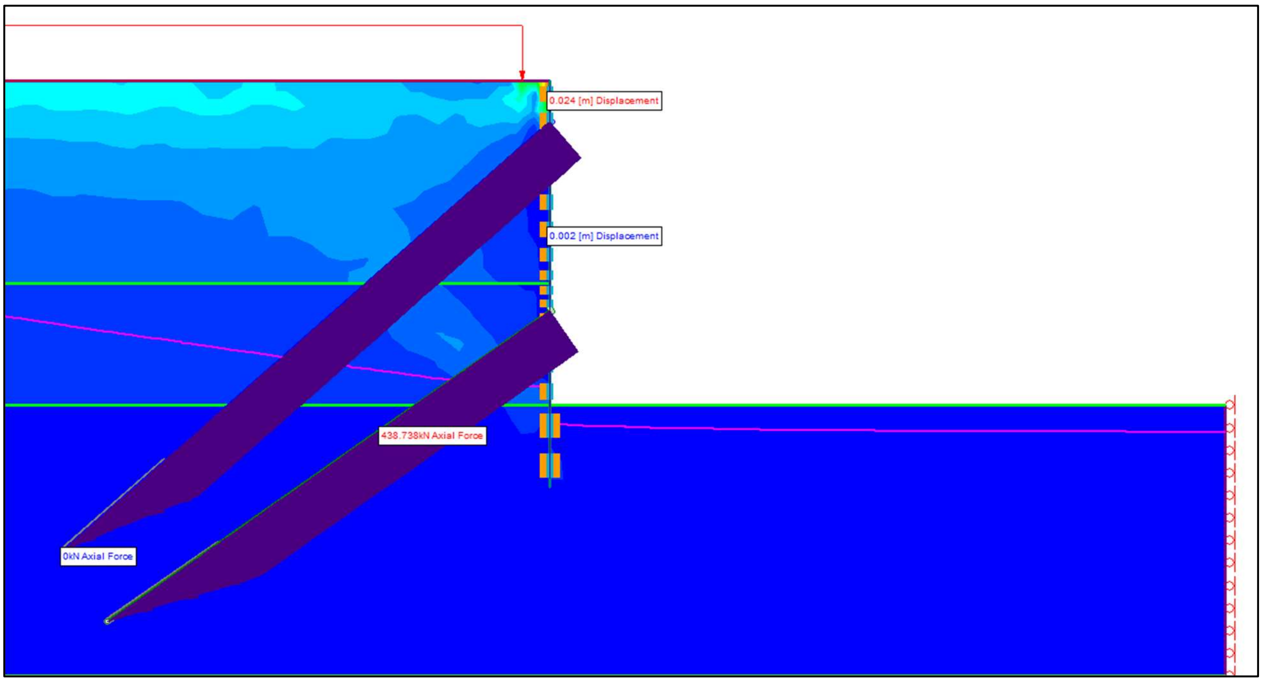
Plot 23: Bending Moment for Secant Pile Wall – Stage-10



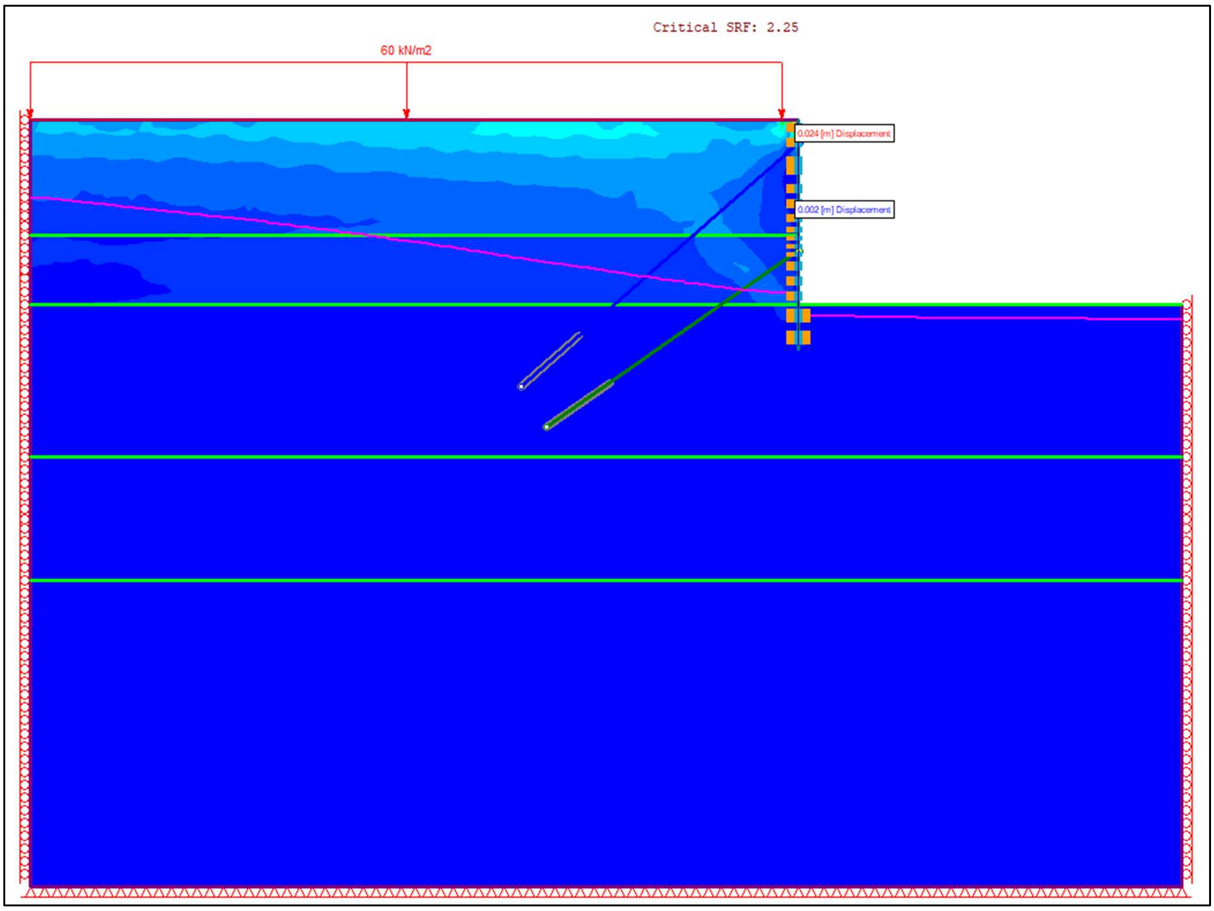
Plot 24: Shear Force for Secant Pile Wall – Stage-10



Plot 25: Displacement for Secant Pile Wall – Stage-10



Plot 26: Anchor Bolt Force – Stage-10



Plot 27: SRF – Stage-10

RS2 Analysis Information
Project1

Project Summary

File Name:	240906-CNC-12m Deep-R5_3_3-Final
Last saved with RS2 version:	10.011
Project Title:	Project1

General Settings

Number of Stages:	10
Analysis Type:	Plane Strain
Solver Type:	Gaussian Elimination
Units:	Metric, stress as kPa
Permeability Units:	meters/second
Time Units:	seconds

Analysis Options

Maximum Number of Iterations:	1500
Tolerance:	0.001
Number of Load Steps:	Automatic
Convergence Type:	Absolute Force & Energy
Tensile Failure:	Reduces Shear Strength

Strength Reduction Settings

Inital Estimate of SRF:	1
Step Size:	Automatic
Tolerance (SRF):	0.01
Limit SSR Search Area:	No
Accelerate SSR Analysis:	Yes
Reduce SSR Iterations after failure:	Yes
Apply SSR to Mohr-Coulomb Tensile Strength:	Yes
Convergence Parameters:	Automatic

Groundwater Analysis

Method:	Steady State
Pore Fluid Unit Weight:	9.81 kN/m3
Maximum Number of Iterations:	500
Tolerance:	0.001
Use Fluid Potential:	Yes

Probability: None

Field Stress

Field stress:	Gravity
Using actual ground surface	
Effective stress ratio (horizontal/vertical in-plane):	0.58
Effective stress ratio (horizontal/vertical out-of-plane):	0.58
Locked-in horizontal stress (in-plane):	0
Locked-in horizontal stress (out-of-plane):	0

Mesh

Mesh type: Graded

Element type: 6 Noded triangles

Stage Name	# of Elements	# of Nodes
In-situ	2246	4680
Surchage	2246	4680
E-1	2214	4613
A-1	2214	4613
E-2	2184	4551
E-3	2109	4398
E-4	2029	4234
E-5	1982	4131
A-2	1982	4131
E-6	1912	3987

Mesh Quality

All elements are of good quality

Poor quality elements defined as:

Side length ratio (maximum / minimum) > 30.00
Minimum interior angle < 2.0 degrees
Maximum interior angle > 175.0 degrees

Reset Displacements

Displacements reset after: In-situ
Displacements reset after: Surchage

Material Properties

L-1: Fill

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	16 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.3
Young's Modulus	5000 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	25 degrees
Peak Cohesion	1 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	25 degrees
Residual Cohesion	1 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	5e-07 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.58
Effective stress ratio (horizontal/vertical out-of-plane)	0.58
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-2: Silty Sand / Clayey Sand

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	18 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.3
Young's Modulus	25000 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	25 degrees
Peak Cohesion	2 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	25 degrees
Residual Cohesion	2 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-07 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.58
Effective stress ratio (horizontal/vertical out-of-plane)	0.58
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-3: CW / HW

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	22 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.3
Young's Modulus	305000 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	39 degrees
Peak Cohesion	120 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	39 degrees
Residual Cohesion	120 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-06 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.43
Effective stress ratio (horizontal/vertical out-of-plane)	0.43
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-4: MW

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	25 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.25
Young's Modulus	1.3e+06 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	52 degrees
Peak Cohesion	250 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	52 degrees
Residual Cohesion	250 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-07 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.33
Effective stress ratio (horizontal/vertical out-of-plane)	0.33
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

L-5: SW / Fresh

Material Color	
Initial Element Loading	Field Stress and Body Force
Unit Weight	26 kN/m3
Initial Water Condition	Dry
Elastic Type	Isotropic
Poisson's Ratio	0.2
Young's Modulus	1.445e+07 kPa
Use Residual Young's Modulus	No
Failure Criterion	Mohr-Coulomb
Material Type	Plastic
Peak Tensile Strength	0 kPa
Peak Friction Angle	65 degrees
Peak Cohesion	1300 kPa
Residual Tensile Strength	0 kPa
Residual Friction Angle	65 degrees
Residual Cohesion	1300 kPa
Dilation Angle	0 degrees
Apply SSR (Shear Strength Reduction)	Yes
Use Unsaturated Parameters	No
Material Behaviour	Drained
Porosity Value	0.5
Ks	1e-08 m/s
K2 / K1	1
K1 Angle	0 degrees
Soil Type	General
Field Stress	Gravity
Using actual ground surface	Yes
Effective stress ratio (horizontal/vertical in-plane)	0.25
Effective stress ratio (horizontal/vertical out-of-plane)	0.25
Locked-in horizontal stress (in-plane)	0
Locked-in horizontal stress (out-of-plane)	0

Joint Properties

Joint 1

Joint Color	
Slip Critirion	Material Dependent
Define Stiffness	Define Parameter
Normal Stiffness	100000 kPa/m
Shear Stiffness	10000 kPa/m
Initial Deformation	Yes
Pressure from Groundwater Analysis	Yes
Apply Pressure to Linear Side Only	No
Apply Additional Pressure inside Joint	Not Included
Interface Coefficient	0.7
Apply Stage Factors	No

Liner Properties

Liner: SPW-0.8m

Color	
Liner Type	Standard Beam
Formulation	Timoshenko
Area	0.3866 m2
Moment of Inertia	0.01546 m4

Elastic Properties

Young's modulus	2.958e+07 kPa
Poisson's ratio	0.2
Liner Unit Weight	25 kN/m3

Structural Interface Properties

Structural Interface:	Structural 1
Joint (positive side):	Joint 1
Liner:	SPW-0.8m
Joint (negative side):	Joint 1

Bolt Properties

Ground Anchor-1

Bolt Color	
Bolt Type	Tieback
Bolt Diameter	33.98 mm
Bolt Modulus,E	2e+08 kPa
Bolt Model	No
Tensile Capacity	800 kN
Residual Tensile Capacity	130 kN
Out-of-Plane Spacing	2.6 m
Bond Shear Stiffness	2500 kN/m/m
Bond Strength	235.6 kN/m
Joint Shear	Yes
Borehole Diameter	150 mm
Pre-Tensioning Force	450 kN
Constant Pre-tensioning Force in Install Stage	Yes
Face Plates	Attached
Bond Length	5 m

Ground Anchor-II

Bolt Color	
Bolt Type	Tieback
Bolt Diameter	33.98 mm
Bolt Modulus,E	2e+08 kPa
Bolt Model	No
Tensile Capacity	800 kN
Residual Tensile Capacity	130 kN
Out-of-Plane Spacing	2.6 m
Bond Shear Stiffness	2500 kN/m/m
Bond Strength	235.6 kN/m
Joint Shear	Yes
Borehole Diameter	150 mm
Pre-Tensioning Force	450 kN
Constant Pre-tensioning Force in Install Stage	Yes
Face Plates	Attached
Bond Length	5 m

List of All Coordinates

External boundary

X	Y
-50	0
-50	-5
-50	-7.5
-50	-12
-50	-22
-50	-30
-50	-50
25	-50
25	-30
25	-22
25	-12
25	-10
25	-8
25	-7.5
25	-6
25	-4
25	-2
25	0
0	0
-1	0

Stage boundary

X	Y
0	-2
25	-2

Stage boundary

X	Y
0	-4
25	-4

Stage boundary

X	Y
0	-6
25	-6

Stage boundary

X	Y
0	-8
25	-8

Stage boundary

X	Y
0	-10
25	-10

Material boundary

X	Y
25	-7.5
0	-7.5
-50	-7.5

Material boundary

X	Y
25	-12
0	-12
-50	-12

Material boundary

X	Y
25	-22
-50	-22

Material boundary

X	Y
-50	-30
25	-30

Structural interface

X	Y
0	0
0	-2
0	-4
0	-6
0	-7.5
0	-8
0	-10
0	-12
0	-15

Bolt

X	Y
0	-1.5
-18.0063	-17.368

Bolt

X	Y
0	-8.5
-16.3654	-19.9966

ANNEXURE - 2
PILE BEARING CAPACITY CHECK

Pile Bearing Capacity Check for 1.0m Dia Pile -32m Excavation Depth

Structure	=	Shafts / C&C	
Chainage	=	-	m
Bore holes	=	BH-1	
Pile Diameter, D	=	1	m
Spacing of Pile, S	=	1.6	m
Ultimate Capacity of Pile, Qu	=	$Re = K_{sp} * q_c * d_f * A_b$	
Core recovery, CR %	=	50	
Rock Quality Designation, RQD %	=	50	
Emperical Coefficient, Ksp	=	0.56	
Average Compression Strength, qu MPa	=	35	
Cross Sectional area of base of pile, A_b m2	=	0.785	
Depth factor, d_f	=	1.2	
Ultimate End bearing capacity of Pile, Re	=	18378	
Factor of safety for End bearing capacity	=	3	
Allowable end bearing capacity of Pile, kN	=	3927	
Allowable Vertical pile capacity , Qa kN	=	3927	
Axial Load on the pile tip, Q kN/m	=	1510	[FEM Result]
Axial load on the pile tip, Q kN [FEM Analysis]	=	2416	SAFE

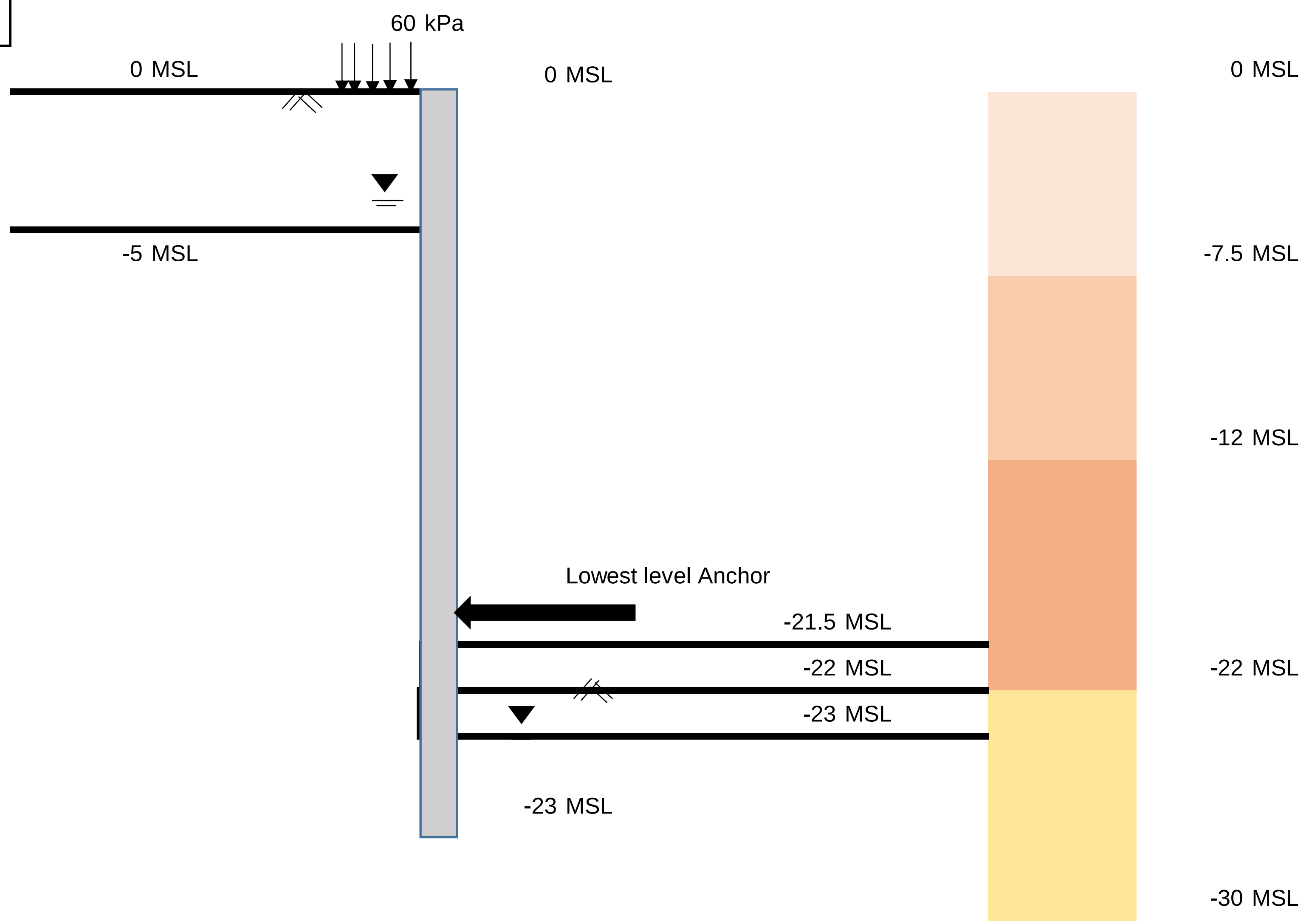
Pile Bearing Capacity Check for 0.8m Dia Pile -12m Excavation Depth

Structure	=	Ramp Portion	
Chainage	=	-	m
Bore holes	=	BH-1	
Pile Diameter, D	=	0.8	m
Spacing of Pile, S	=	1.3	m
Ultimate Capacity of Pile, Qu	=	$Re = K_{sp} * q_c * d_f * A_b$	
Core recovery, CR %	=	30	
Rock Quality Designation, RQD %	=	30	
Emperical Coefficient, Ksp	=	0.30	
Average Compression Strength, qu MPa	=	25	
Cross Sectional area of base of pile, A_b m2	=	0.503	
Depth factor, d_f	=	1.2	
Ultimate End bearing capacity of Pile, Re	=	4524	
Factor of safety for End bearing capacity	=	3	
Allowable end bearing capacity of Pile, kN	=	1508	
Allowable Vertical pile capacity , Qa kN	=	1508	
Axial Load on the pile tip, Q kN/m	=	460	[FEM Result]
Axial load on the pile tip, Q kN [FEM Analysis]	=	598	SAFE

ANNEXURE – 3
TOE STABILITY CHECK

TOE STABILITY CALCULATIONS - Shaft/ CNC -32m Excavation Depth

Project	I40172	
Location	Shaft	
Chainage	-	m
Bore Hole	BH-1	m
Geological conditions		
Ground level	0	MSL
Depth of GWT	5	m below GL
Ground water level	-5	MSL
Properties of Embedded Pile wall		
Top of Pile Wall	0	MSL
Toe of PileWall	-23	MSL
Thickness of pile Wall	1	m
Moment Capacity		kNm/m
Lowest level strut	-21.5	MSL
Surcharge at GL	60	kPa
Final Excavation level	-22	MSL



ACTIVE SIDE (Earth Pressure, Water Pressure & due to Surcharge)

Depth (MSL)		Soil Type	Thickness (m)	γ_b (kN/m³)	Cohesion (kPa)	Φ (deg)	Pressure coefficient (k0)	Overburden (kPa)	P_w (kPa)	P_{a1} (Earth Pressure) kPa		P_{a2} (Surcharge) (kPa)	$P_a = P_{a1} + P_{a2} + P_w$ (kPa)		Active Force (kN/m)	Centroid (m)	Lever arm (m)	M_a (kNm/m)
From	to									at Start of layer	at End of layer		at Start of layer	at End of layer				
0	-7.5	L-1	7.5	16	1	25	0.58	120.00	24.53		53.85	34.80		113.18	424.42	2.500	0	0
-7.5	-12	L-2	4.5	18	2	25	0.58	201.00	68.67	52.33	73.71	34.80	111.65	177.18	649.87	2.080	0.00	0.00
-12	-21.5	L-3	9.5	22	120	39	0.43	410.00	161.87	0.00	0.00	25.80	94.47	187.67	1340.14	4.227	0.00	0.00
-21.5	-22	L-3	0.5	22	120	39	0.43	421.00	166.77	0.00	0.00	25.80	187.67	192.57	95.06	0.249	0.25	23.87
-22	-23	L-4	1	25	250	52	0.33	435.00	176.58	0.00	0.00	19.80	186.57	196.38	191.48	0.496	1.00	192.29

Passive side (Earth Pressure & Water Pressure)

Depth (MSL)		Soil Type	Thickness (m)	γ_b (kN/m³)	Cohesion (kPa)	Φ (deg)	Pressure coefficient (k_p)	Overburden (kPa)	P_w (kPa)	P_{p1} (Earth Pressure) kPa		$P_p = P_{p1} + P_w$ (kPa)		Passive Force (kN/m)	Centroid (m)	Lever arm (m)	M_p (kNm/m)
From	to									at Start of layer	at End of layer	at Start of layer	at End of layer				
-22	-23	L-4	1	25	250	52	3.03	25.00	0.00	870.39	946.15	870.39	946.15	908.27	0.493	1.01	914.5802

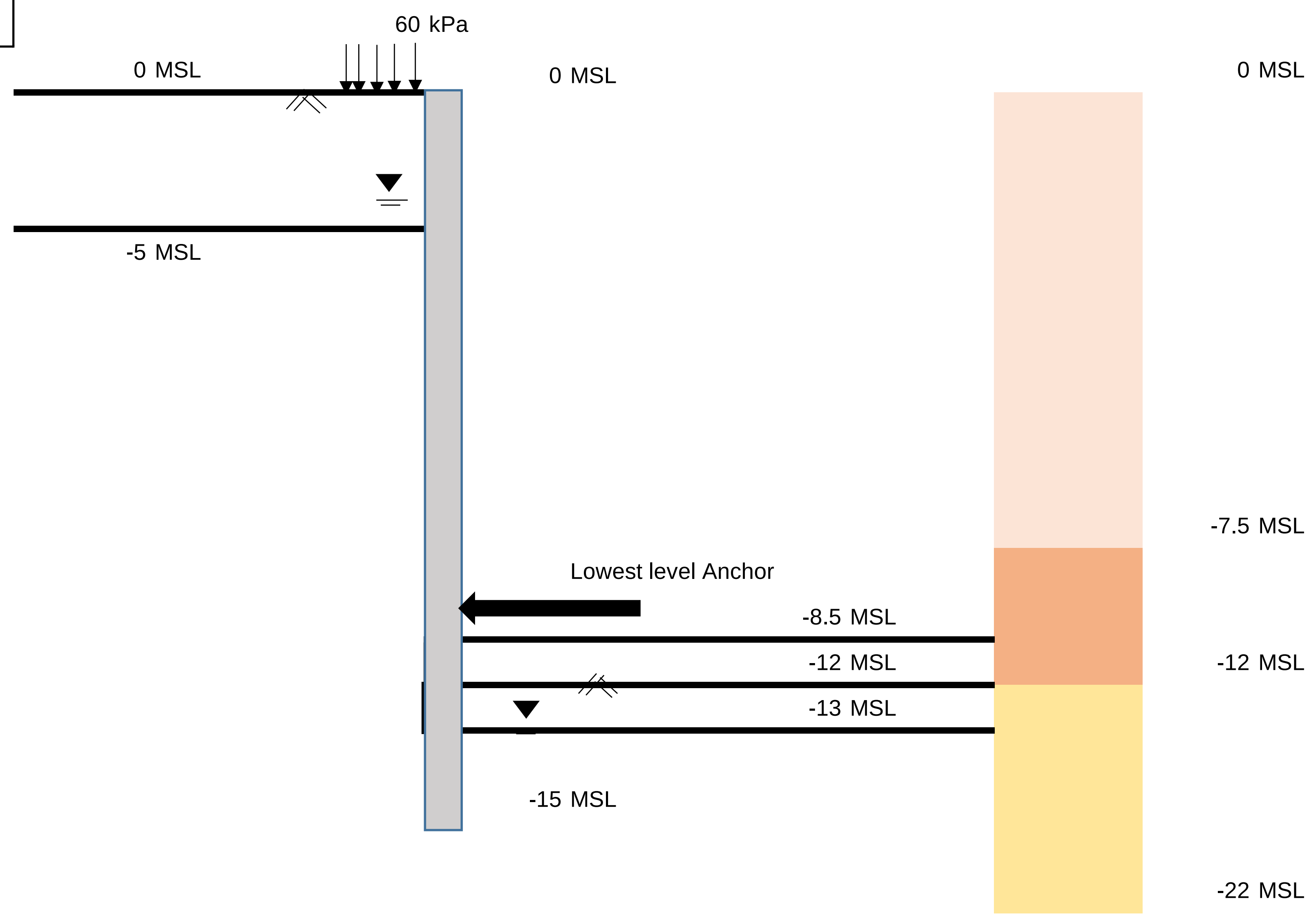
Driving Moment	216.1594	kNm/m
Resisting Moment	914.5802	kNm/m
Factor of Safety	4.23	SAFE

Assumptions

1. If active earth pressure is observed to be negative at any depth, it has been considered as zero to be on conservative side.
2. FOS of 1.3 is assumed to be safe.
3. GWT on passive side is considered 5m below Excavation level.
4. Rankine's Earth pressure coefficients are considered.
5. Here for the conservative purpose, the At rest Earth pressure coefficient has been considered against Active earth pressure coefficient
6. Moments are taken as per lowest level struts and resistance offered by top struts is ignored.

TOE STABILITY CALCULATIONS - Shaft/ CNC -12m Excavation Depth

Project	I40172	
Location	Ramp	
Chainage	-	m
Bore Hole	BH-1	m
Geological conditions		
Ground level	0	MSL
Depth of GWT	5	m below GL
Ground water level	-5	MSL
Properties of Embedded Secant Pile wall		
Top of Pile Wall	0	MSL
Toe of PileWall	-15	MSL
Thickness of pile Wall	0.8	m
Moment Capacity		kNm/m
Lowest level strut	-8.5	MSL
Surcharge at GL	60	kPa
Final Excavation level	-12	MSL



ACTIVE SIDE (Earth Pressure, Water Pressure & due to Surcharge)

Depth (MSL)		Soil Type	Thickness (m)	γ_b (kN/m³)	Cohesion (kPa)	Φ (deg)	Pressure coefficient (k0)	Overburden (kPa)	P_w (kPa)	P_{a1} (Earth Pressure) kPa		P_{a2} (Surcharge) (kPa)	$P_a = P_{a1} + P_{a2} + P_w$ (kPa)		Active Force (kN/m)	Centroid (m)	Lever arm (m)	M_a (kNm/m)
From	to									at Start of layer	at End of layer		at Start of layer	at End of layer				
0	-7.5	L-1	7.5	16	1	25	0.58	120.00	24.53		53.85	34.80		113.18	424.42	2.500	0	0
-7.5	-8.5	L-2	1	18	2	25	0.58	138.00	34.34	52.33	57.08	34.80	111.65	126.21	118.93	0.490	0.00	0.00
-8.5	-12	L-2	3.5	18	2	25	0.58	201.00	68.67	57.08	73.71	34.80	126.21	177.18	530.93	1.652	1.85	981.15
-12	-15	L-3	3	22	120	39	0.43	267.00	98.10	0.00	0.00	25.80	94.47	123.90	327.56	1.433	5.07	1659.85

Passive side (Earth Pressure & Water Pressure)

Depth (MSL)		Soil Type	Thickness (m)	γ_b (kN/m³)	Cohesion (kPa)	Φ (deg)	Pressure coefficient (k_p)	Overburden (kPa)	P_w (kPa)	P_{p1} (Earth Pressure) kPa		$P_p = P_{p1} + P_w$ (kPa)		Passive Force (kN/m)	Centroid (m)	Lever arm (m)	M_p (kNm/m)
From	to									at Start of layer	at End of layer	at Start of layer	at End of layer				
-12	-15	L-3	3	22	120	39	2.33	66.00	19.62	366.00	473.86	366.00	493.48	1289.21	1.426	5.07	6541.662

Driving Moment	2641	kNm/m
Resisting Moment	6541.662	kNm/m
Factor of Safety	2.48	**SAFE**

Assumptions

1. If active earth pressure is observed to be negative at any depth, it has been considered as zero to be on conservative side.
2. FOS of 1.3 is assumed to be safe.
3. GWT on passive side is considered 5m below Excavation level.
4. Rankine's Earth pressure coefficients are considered.
5. Here for the conservative purpose, the At rest Earth pressure coefficient has been considered against Active earth pressure coefficient
6. Moments are taken as per lowest level struts and resistance offered by top struts is ignored.

ANNEXURE – 4
ANALYTICAL ANALYSIS – DUDDECK/ERDMANN RESULTS

Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Regular Section 2 Lane				
Object:	SC-I				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

LINING CALCULATION ACCORDING TO H.DUDDECK / J.ERDMANN

Structure: *Temporary Shotcrete Lining*

Lining Thickness	=	100	[mm]	
Lining Stiffness	=	5.000	[MPa]	[J-II Class - 24 Hr Strength]
Radius	=	5.200	[m]	
Outer Radius of tunnel	=	5.3	[m]	
Overburden above tunnel axis	=	30.000	[m]	
Surcharge	=	60.00	[kPa]	
Unit Weight	=	26.00	[kN/m^3]	
Total vertical stress at tunnel axis	=	840.00	[kPa]	
Avg. unit weight including surcharge	=	30.00	[kN/m^3]	
Young's Modulus of ground	=	14450.00	[MPa]	
Poisson's ratio of ground	=	0.20		
Horizontal earth pressure coefficient	=	0.25		
Young's Modulus of concrete lining	=	7500.00	[MPa]	
Cross-sectional area of Lining	=	0.10	[m^2]	b = 1.00 [m]
Moment of Inertia	=	0.00008	[m^4]	
Average tunnel radius	=	5.25	[m]	

Stiffness ratio coefficients

Ratio of soil stiffness over the compressibility stiffness of the lining	Ratio of soil stiffness over the bending stiffness of the lining
3442036.2	102.1133333

Shear bond between lining and ground, basic specific values for sectional forces					
n0	n2	m2	N0	N2	M2
-	-	-	[kN]	[kN]	[kN-m]
0.012	0.025	0.000	34.30	44.455186	0.02

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
-10.15	78.76	-10.15	0.02	-0.02	0.02

Basic Specific values for lining deformations			Basic values for lining deformations		
w0	w2	x2	W0	W2	V2
[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[mm]	[mm]	[mm]
0.00000044	0.00000096	0.00000095	0.24	0.32	0.32

Shear bond between lining and ground, Lining deformations		
rdc	rdb	rdi
[mm]	[mm]	[mm]
0.57	-0.08	0.57

NOTE: The above calculation is based on the geometry of a full circle.

Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	**NATM Regular Section 2 Lane**				
Object:	**SC-I**				
Constr. Stage	**Final Stage / Primary Lining**				
Chainage:	**Low overburden**				

Structure: *Temporary Shotcrete Lining*

Steel

Characteristic strength of steel	=	500	[N/mm^2]
Partial safety factor for steel	=	1.15	
E-modulus of steel	=	200000	[N/mm^2]

Concrete

Characteristic strength of concrete	=	25	[N/mm^2]
Partial safety factor for concrete	=	1.500	
Width of sections	=	1000	[mm]
Depth of sections	=	100	[mm]
Distance from compression / tension face to centroid of steel	=	50	[mm]
Effective depth of sections	=	50	[mm]

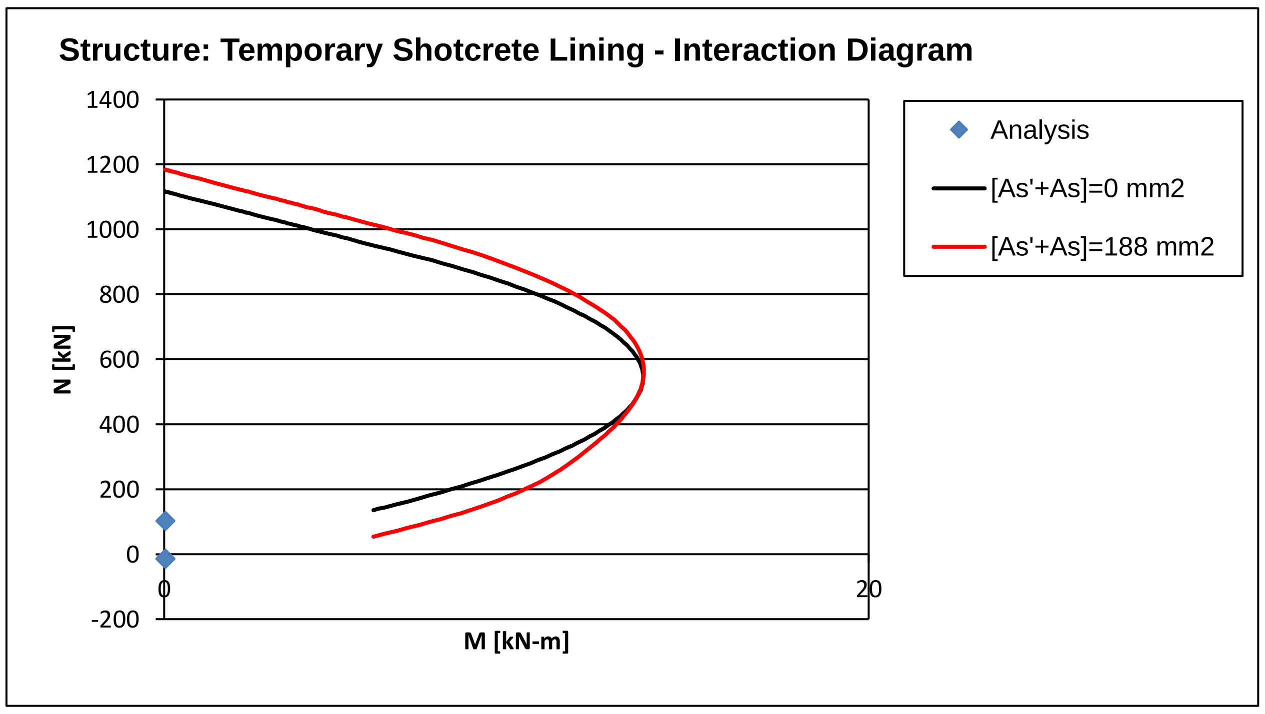
Load factor for N	1.3
Load factor for M	1.3

ANALYSIS

Location	N	M	N/bh	M/bh^2	N (To account for Load Factors)	M (To account for Load Factors)
	[kN]	[kNm]	[N/mm^2]	[N/mm^2]	[kN]	[kNm]
Main Tunnel - Crown	-10.15	0.02	-0.13	0.00	-13.20	0.03
Main Tunnel - Bench	78.76	-0.02	1.02	0.00	102.38	0.03
Main Tunnel - Invert	-10.15	0.02	-0.13	0.00	-13.20	0.03
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00

Draw Curves for …

	Reinforcement			
	1st layer [As']	2nd layer [As]	As'	As
	[mm^2]	[mm^2]	[%]	[%]
Curve 1 (Unreinforced)	0	0	0	0
Curve 2 (Reinforced)	188	0	0.188	0.000



Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Regular Section 2 Lane				
Object:	SC-I				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

LINING CALCULATIONS - DISTRIBUTION OF MOMENTS AND SHEAR FORCES

Structure: *Temporary Shotcrete Lining*

Distribution of Shear Forces

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
-10.15	78.76	-10.15	0.02	-0.02	0.02

Shear Forces (V) at sections				
Crown 0^0	45^o	Bench 90^0	135^o	Invert 180^0
0	-0.008	0	0.008	0

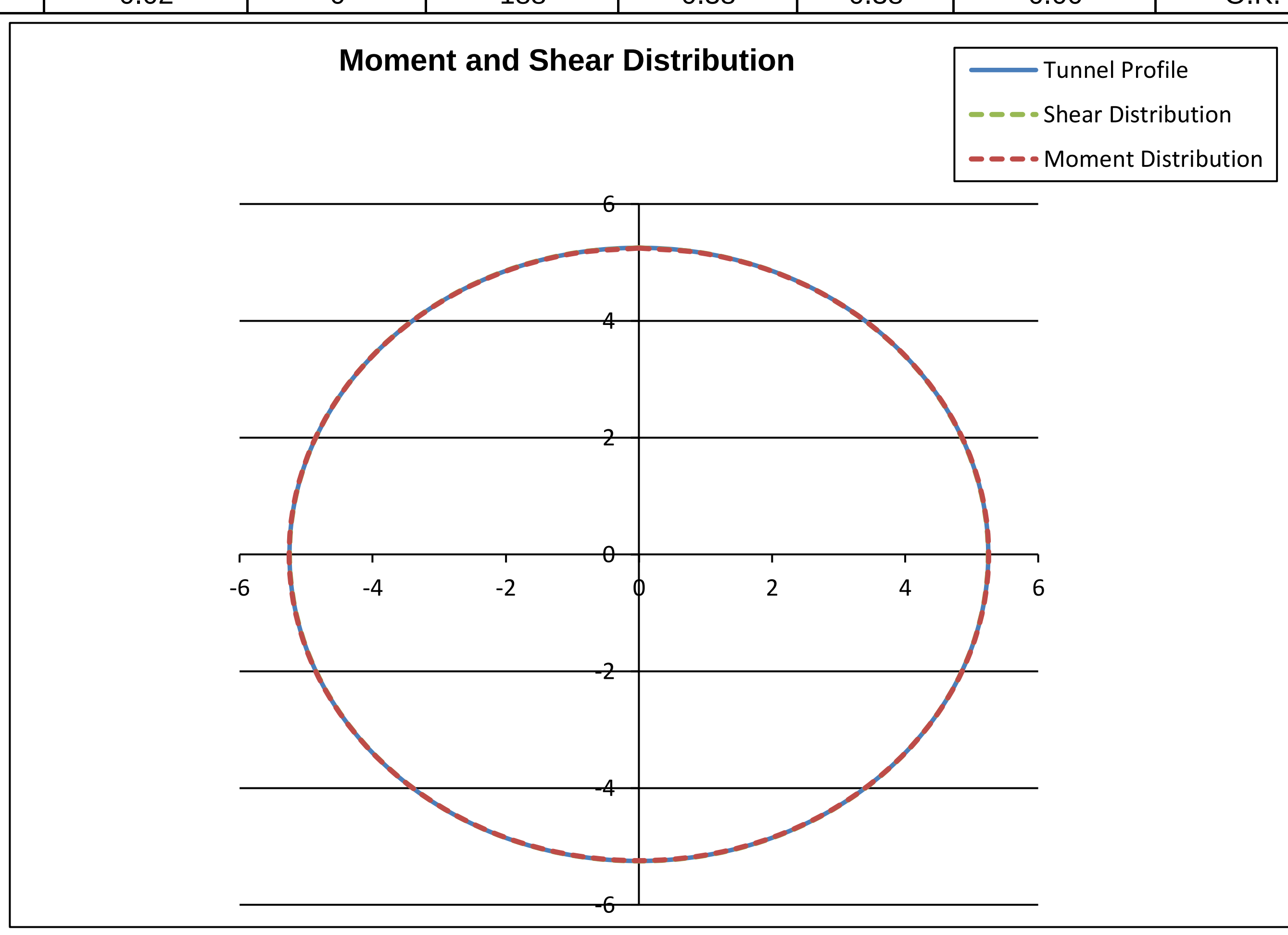
Distribution of Bending Moments and Shear Forces

Average Tunnel Radius = 5.25 m

Load Factor = 1.3

As = 188

Location	M	V	As	100 As / bd	Vc	Actual V	Check	Utilisation
[^{0}]	[kN-m/m]	[kN/m]	[mm^2]	[-]	[N/mm^2]	[N/mm^2]		[%]
0	0.02	0	188	0.38	0.38	0.00	O.K.	0.00
10	0.02	0.00	188	0.38	0.38	0.00	O.K.	0.02
20	0.02	-0.01	188	0.38	0.38	0.00	O.K.	0.04
30	0.01	-0.01	188	0.38	0.38	0.00	O.K.	0.05
40	0.00	-0.01	188	0.38	0.38	0.00	O.K.	0.06
50	0.00	-0.01	188	0.38	0.38	0.00	O.K.	0.06
60	-0.01	-0.01	188	0.38	0.38	0.00	O.K.	0.05
70	-0.02	-0.01	188	0.38	0.38	0.00	O.K.	0.04
80	-0.02	0.00	188	0.38	0.38	0.00	O.K.	0.02
90	-0.02	0	188	0.38	0.38	0.00	O.K.	0.00
100	-0.02	0.00	188	0.38	0.38	0.00	O.K.	0.02
110	-0.02	0.01	188	0.38	0.38	0.00	O.K.	0.04
120	-0.01	0.01	188	0.38	0.38	0.00	O.K.	0.05
130	0.00	0.01	188	0.38	0.38	0.00	O.K.	0.06
140	0.00	0.01	188	0.38	0.38	0.00	O.K.	0.06
150	0.01	0.01	188	0.38	0.38	0.00	O.K.	0.05
160	0.02	0.01	188	0.38	0.38	0.00	O.K.	0.04
170	0.02	0.00	188	0.38	0.38	0.00	O.K.	0.02
180	0.02	0	188	0.38	0.38	0.00	O.K.	0.00



Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Regular Section 2 Lane				
Object:	SC-II (MW)				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

LINING CALCULATION ACCORDING TO H.DUDDECK / J.ERDMANN

Structure: *Temporary Shotcrete Lining*

Lining Thickness	=	200	[mm]	
Lining Stiffness	=	5.000	[MPa]	[J-II Class - 24 Hr Strength]
Radius	=	5.150	[m]	
Outer Radius of tunnel	=	5.35	[m]	
Overburden above tunnel axis	=	26.000	[m]	
Surcharge	=	60.00	[kPa]	
Unit Weight	=	25.00	[kN/m^3]	
Total vertical stress at tunnel axis	=	710.00	[kPa]	
Avg. unit weight including surcharge	=	29.62	[kN/m^3]	
Young's Modulus of ground	=	1300.00	[MPa]	
Poisson's ratio of ground	=	0.25		
Horizontal earth pressure coefficient	=	0.33		
Young's Modulus of concrete lining	=	7500.00	[MPa]	
Cross-sectional area of Lining	=	0.20	[m^2]	b = 1.00 [m]
Moment of Inertia	=	0.00067	[m^4]	
Average tunnel radius	=	5.25	[m]	

Stiffness ratio coefficients

Ratio of soil stiffness over the compressibility stiffness of the lining	Ratio of soil stiffness over the bending stiffness of the lining
39813.9	4.636666667

Shear bond between lining and ground, basic specific values for sectional forces					
n0	n2	m2	N0	N2	M2
-	-	-	[kN]	[kN]	[kN-m]
0.212	0.322	0.000	570.82	436.372014	1.23

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
134.45	1007.20	134.45	1.23	-1.23	1.23

Basic Specific values for lining deformations			Basic values for lining deformations		
w0	w2	x2	W0	W2	V2
[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[mm]	[mm]	[mm]
0.00000405	0.00000946	0.00000780	2.07	2.44	2.01

Shear bond between lining and ground, Lining deformations		
rdc	rdb	rdi
[mm]	[mm]	[mm]
4.51	-0.36	4.51

NOTE: The above calculation is based on the geometry of a full circle.

Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	**NATM Regular Section 2 Lane**				
Object:	**SC-II (MW)**				
Constr. Stage	**Final Stage / Primary Lining**				
Chainage:	**Low overburden**				

Structure: *Temporary Shotcrete Lining*

Steel

Characteristic strength of steel	=	500	[N/mm^2]
Partial safety factor for steel	=	1.15	
E-modulus of steel	=	200000	[N/mm^2]

Concrete

Characteristic strength of concrete	=	25	[N/mm^2]
Partial safety factor for concrete	=	1.500	
Width of sections	=	1000	[mm]
Depth of sections	=	200	[mm]
Distance from compression / tension face to centroid of steel	=	50	[mm]
Effective depth of sections	=	150	[mm]

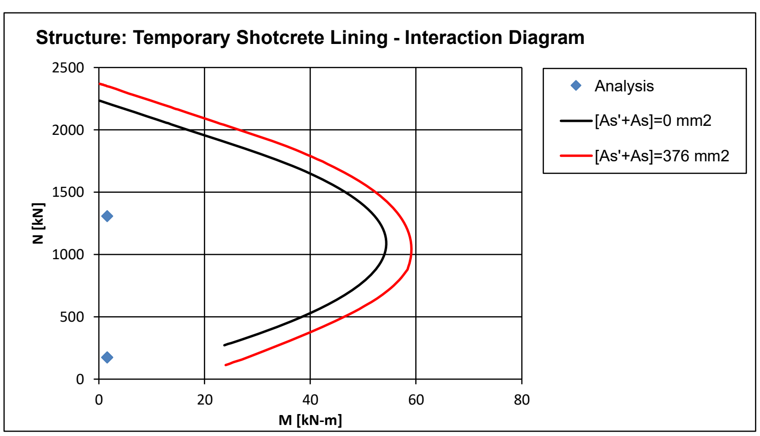
Load factor for N	1.3
Load factor for M	1.3

ANALYSIS

Location	N	M	N/bh	M/bh^2	To account for Load Factors N	To account for Load Factors M
	[kN]	[kNm]	[N/mm^2]	[N/mm^2]	[kN]	[kNm]
Main Tunnel - Crown	134.45	1.23	0.87	0.04	174.79	1.60
Main Tunnel - Bench	1007.20	-1.23	6.55	0.04	1309.35	1.60
Main Tunnel - Invert	134.45	1.23	0.87	0.04	174.79	1.60
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00

Draw Curves for …

	Reinforcement 1st layer [As']	2nd layer [As]	As'	As
	[mm^2]	[mm^2]	[%]	[%]
Curve 1 (Unreinforced)	0	0	0	0
Curve 2 (Reinforced)	188	188	0.094	0.094



Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Regular Section 2 Lane				
Object:	SC-II (MW)				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

LINING CALCULATIONS - DISTRIBUTION OF MOMENTS AND SHEAR FORCES

Structure: *Temporary Shotcrete Lining*

Distribution of Shear Forces

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
134.45	1007.20	134.45	1.23	-1.23	1.23

Shear Forces (V) at sections				
Crown 0^0	45^o	Bench 90^0	135^o	Invert 180^0
0	-0.469	0	0.469	0

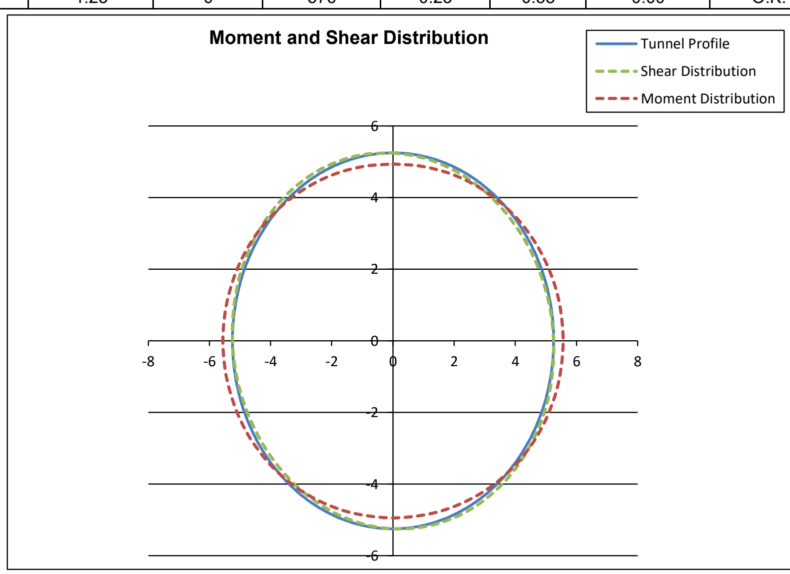
Distribution of Bending Moments and Shear Forces

Average Tunnel Radius = 5.25 m

Load Factor = 1.3

As = 376

Location	M	V	As	100 As / bd	Vc	Actual V	Check	Utilisation
[^{0}]	[kN-m/m]	[kN/m]	[mm^2]	[-]	[N/mm^2]	[N/mm^2]		[%]
0	1.23	0	376	0.25	0.38	0.00	O.K.	0.00
10	1.16	-0.16	376	0.25	0.38	0.00	O.K.	0.37
20	0.94	-0.30	376	0.25	0.38	0.00	O.K.	0.69
30	0.62	-0.41	376	0.25	0.38	0.00	O.K.	0.93
40	0.21	-0.46	376	0.25	0.38	0.00	O.K.	1.06
50	-0.21	-0.46	376	0.25	0.38	0.00	O.K.	1.06
60	-0.62	-0.41	376	0.25	0.38	0.00	O.K.	0.93
70	-0.94	-0.30	376	0.25	0.38	0.00	O.K.	0.69
80	-1.16	-0.16	376	0.25	0.38	0.00	O.K.	0.37
90	-1.23	0	376	0.25	0.38	0.00	O.K.	0.00
100	-1.16	0.16	376	0.25	0.38	0.00	O.K.	0.37
110	-0.94	0.30	376	0.25	0.38	0.00	O.K.	0.69
120	-0.62	0.41	376	0.25	0.38	0.00	O.K.	0.93
130	-0.21	0.46	376	0.25	0.38	0.00	O.K.	1.06
140	0.21	0.46	376	0.25	0.38	0.00	O.K.	1.06
150	0.62	0.41	376	0.25	0.38	0.00	O.K.	0.93
160	0.94	0.30	376	0.25	0.38	0.00	O.K.	0.69
170	1.16	0.16	376	0.25	0.38	0.00	O.K.	0.37
180	1.23	0	376	0.25	0.38	0.00	O.K.	0.00



Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Vehicular Cross Passage 1 Lane				
Object:	SC-II (MW)				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

GC GROUP

LINING CALCULATION ACCORDING TO H.DUDDECK / J.ERDMANN

Structure: *Temporary Shotcrete Lining*

Lining Thickness	=	200	[mm]	
Lining Stiffness	=	5.000	[MPa]	[J-II Class - 24 Hr Strength]
Radius	=	3.700	[m]	
Outer Radius of tunnel	=	3.9	[m]	
Overburden above tunnel axis	=	26.000	[m]	
Surcharge	=	0.00	[kPa]	
Unit Weight	=	25.00	[kN/m^3]	
Total vertical stress at tunnel axis	=	555.00	[kPa]	
Avg. unit weight including surcharge	=	21.35	[kN/m^3]	
Young's Modulus of ground	=	1300.00	[MPa]	
Poisson's ratio of ground	=	0.25		
Horizontal earth pressure coefficient	=	0.33		
Young's Modulus of concrete lining	=	7500.00	[MPa]	
Cross-sectional area of Lining	=	0.20	[m^2]	b = 1.00 [m]
Moment of Inertia	=	0.00067	[m^4]	
Average tunnel radius	=	3.80	[m]	

Stiffness ratio coefficients

Ratio of soil stiffness over the compressibility stiffness of the lining	Ratio of soil stiffness over the bending stiffness of the lining
15422.9	3.38

Shear bond between lining and ground, basic specific values for sectional forces					
n0	n2	m2	N0	N2	M2
-	-	-	[kN]	[kN]	[kN-m]
0.270	0.385	0.000	378.62	271.748535	1.18

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
106.87	650.37	106.87	1.18	-1.18	1.18

Basic Specific values for lining deformations			Basic values for lining deformations		
w0	w2	x2	W0	W2	V2
[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[mm]	[mm]	[mm]
0.00000274	0.00000677	0.00000533	1.01	1.26	0.99

Shear bond between lining and ground, Lining deformations		
rdc	rdb	rdi
[mm]	[mm]	[mm]
2.27	-0.25	2.27

NOTE: The above calculation is based on the geometry of a full circle.

Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Vehicular Cross Passage 1 Lane				
Object:	SC-II (MW)				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

Structure: *Temporary Shotcrete Lining*

Steel

Characteristic strength of steel	=	500	[N/mm^2]
Partial safety factor for steel	=	1.15	
E-modulus of steel	=	200000	[N/mm^2]

Concrete

Characteristic strength of concrete	=	25	[N/mm^2]
Partial safety factor for concrete	=	1.500	

Width of sections	=	1000	[mm]
Depth of sections	=	200	[mm]
Distance from compression / tension face to centroid of steel	=	50	[mm]
Effective depth of sections	=	150	[mm]

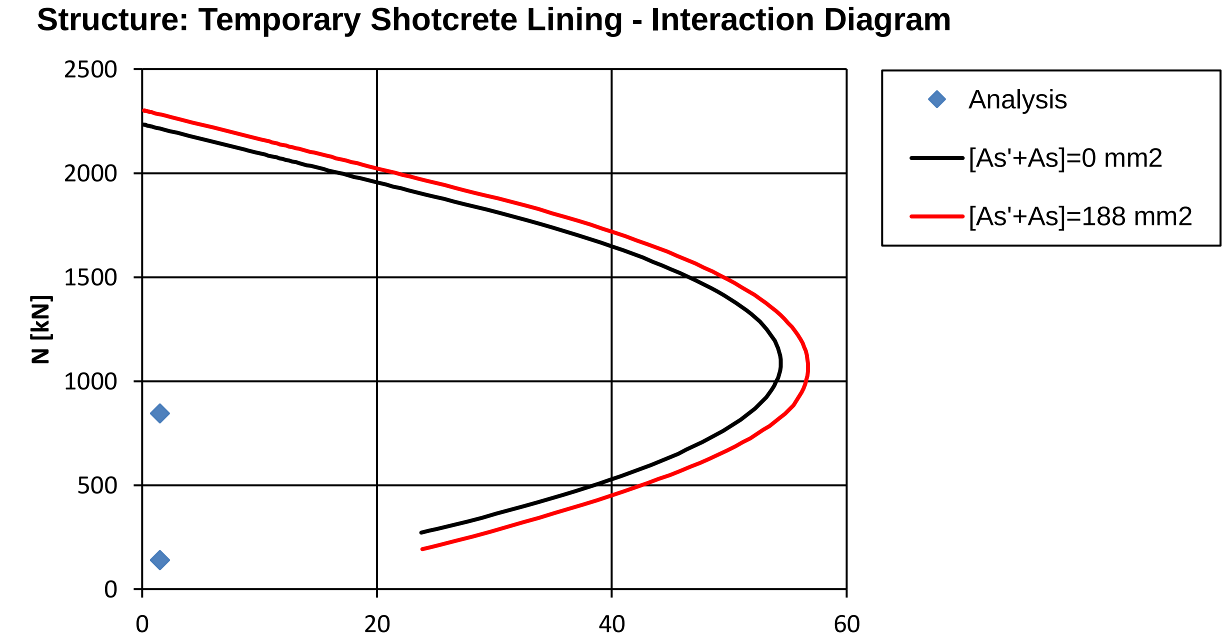
Load factor for N	1.3
Load factor for M	1.3

ANALYSIS

Location	N	M	N/bh	M/bh^2	N (To account for Load Factors)	M (To account for Load Factors)
	[kN]	[kNm]	[N/mm^2]	[N/mm^2]	[kN]	[kNm]
Main Tunnel - Crown	106.87	1.18	0.69	0.04	138.93	1.53
Main Tunnel - Bench	650.37	-1.18	4.23	0.04	845.48	1.53
Main Tunnel - Invert	106.87	1.18	0.69	0.04	138.93	1.53
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00

Draw Curves for …

	Reinforcement			
	1st layer [As']	2nd layer [As]	As'	As
	[mm^2]	[mm^2]	[%]	[%]
Curve 1 (Unreinforced)	0	0	0	0
Curve 2 (Reinforced)	188	0	0.094	0.000



Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Vehicular Cross Passage 1 Lane				
Object:	SC-II (MW)				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

LINING CALCULATIONS - DISTRIBUTION OF MOMENTS AND SHEAR FORCES

Structure: *Temporary Shotcrete Lining*

Distribution of Shear Forces

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
106.87	650.37	106.87	1.18	-1.18	1.18

Shear Forces (V) at sections				
Crown 0^0	45^o	Bench 90^0	135^o	Invert 180^0
0	-0.621	0	0.621	0

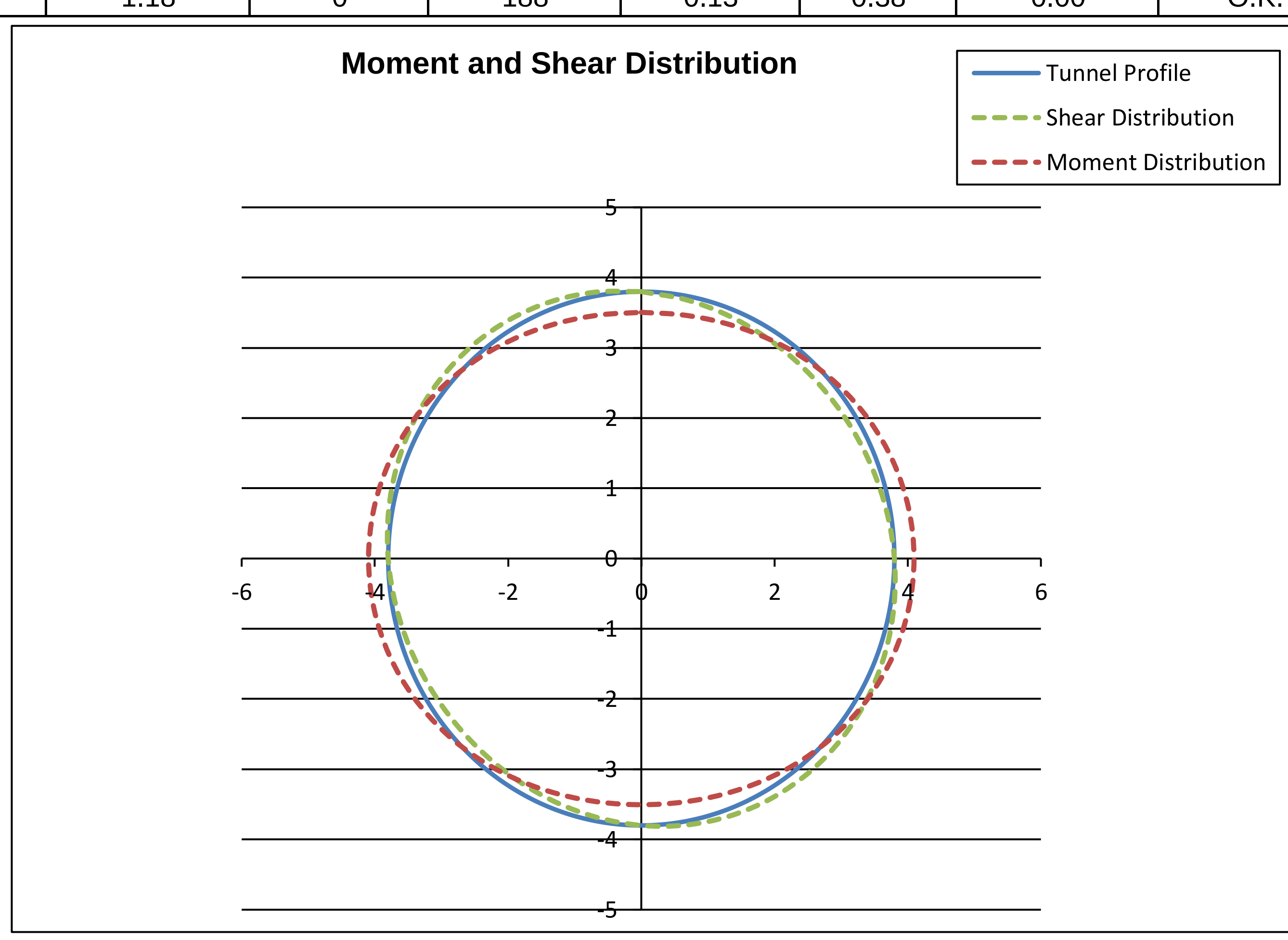
Distribution of Bending Moments and Shear Forces

Average Tunnel Radius = 3.80 m

Load Factor = 1.3

As = 188

Location	M	V	As	100 As / bd	Vc	Actual V	Check	Utilisation
[^{0}]	[kN-m/m]	[kN/m]	[mm^2]	[-]	[N/mm^2]	[N/mm^2]		[%]
0	1.18	0	188	0.13	0.38	0.00	O.K.	0.00
10	1.11	-0.21	188	0.13	0.38	0.00	O.K.	0.49
20	0.90	-0.40	188	0.13	0.38	0.00	O.K.	0.92
30	0.59	-0.54	188	0.13	0.38	0.00	O.K.	1.24
40	0.20	-0.61	188	0.13	0.38	0.01	O.K.	1.41
50	-0.20	-0.61	188	0.13	0.38	0.01	O.K.	1.41
60	-0.59	-0.54	188	0.13	0.38	0.00	O.K.	1.24
70	-0.90	-0.40	188	0.13	0.38	0.00	O.K.	0.92
80	-1.11	-0.21	188	0.13	0.38	0.00	O.K.	0.49
90	-1.18	0	188	0.13	0.38	0.00	O.K.	0.00
100	-1.11	0.21	188	0.13	0.38	0.00	O.K.	0.49
110	-0.90	0.40	188	0.13	0.38	0.00	O.K.	0.92
120	-0.59	0.54	188	0.13	0.38	0.00	O.K.	1.24
130	-0.20	0.61	188	0.13	0.38	0.01	O.K.	1.41
140	0.20	0.61	188	0.13	0.38	0.01	O.K.	1.41
150	0.59	0.54	188	0.13	0.38	0.00	O.K.	1.24
160	0.90	0.40	188	0.13	0.38	0.00	O.K.	0.92
170	1.11	0.21	188	0.13	0.38	0.00	O.K.	0.49
180	1.18	0	188	0.13	0.38	0.00	O.K.	0.00



Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Regular Section 2 Lane				
Object:	SC-III (CW-Soil)				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

LINING CALCULATION ACCORDING TO H.DUDDECK / J.ERDMANN

Structure: *Temporary Shotcrete Lining*

Lining Thickness	=	300	[mm]	
Lining Stiffness	=	5.000	[MPa]	[J-II Class - 24 Hr Strength]
Radius	=	5.200	[m]	
Outer Radius of tunnel	=	5.5	[m]	
Overburden above tunnel axis	=	17.000	[m]	
Surcharge	=	0.00	[kPa]	
Unit Weight	=	18.00	[kN/m^3]	
Total vertical stress at tunnel axis	=	306.00	[kPa]	
Avg. unit weight including surcharge	=	18.00	[kN/m^3]	
Young's Modulus of ground	=	25.00	[MPa]	
Poisson's ratio of ground	=	0.30		
Horizontal earth pressure coefficient	=	0.58		
Young's Modulus of concrete lining	=	7500.00	[MPa]	
Cross-sectional area of Lining	=	0.30	[m^2]	b = 1.00 [m]
Moment of Inertia	=	0.00225	[m^4]	
Average tunnel radius	=	5.35	[m]	

Stiffness ratio coefficients

Ratio of soil stiffness over the compressibility stiffness of the lining	Ratio of soil stiffness over the bending stiffness of the lining
246.5	0.061111111

Shear bond between lining and ground, basic specific values for sectional forces					
n0	n2	m2	N0	N2	M2
-	-	-	[kN]	[kN]	[kN-m]
0.955	0.747	0.023	1234.95	256.874657	41.83

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
978.07	1491.82	978.07	41.83	-41.83	41.83

Basic Specific values for lining deformations			Basic values for lining deformations		
w0	w2	x2	W0	W2	V2
[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[m.kN^{-1}.s^2]	[mm]	[mm]	[mm]
0.00001284	0.00041111	0.00021042	3.10	26.42	13.52

Shear bond between lining and ground, Lining deformations		
rdc	rdb	rdi
[mm]	[mm]	[mm]
29.52	-23.31	29.52

NOTE: The above calculation is based on the geometry of a full circle.

Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn

Tunnel:	**NATM Regular Section 2 Lane**
Object:	**SC-III (CW-Soil)**
Constr. Stage	**Final Stage / Primary Lining**
Chainage:	**Low overburden**

Structure: *Temporary Shotcrete Lining*

Steel

Characteristic strength of steel	=	500	[N/mm^2]
Partial safety factor for steel	=	1.15	
E-modulus of steel	=	200000	[N/mm^2]

Concrete

Characteristic strength of concrete	=	25	[N/mm^2]
Partial safety factor for concrete	=	1.500	
Width of sections	=	1000	[mm]
Depth of sections	=	300	[mm]
Distance from compression / tension face to centroid of steel	=	50	[mm]
Effective depth of sections	=	250	[mm]

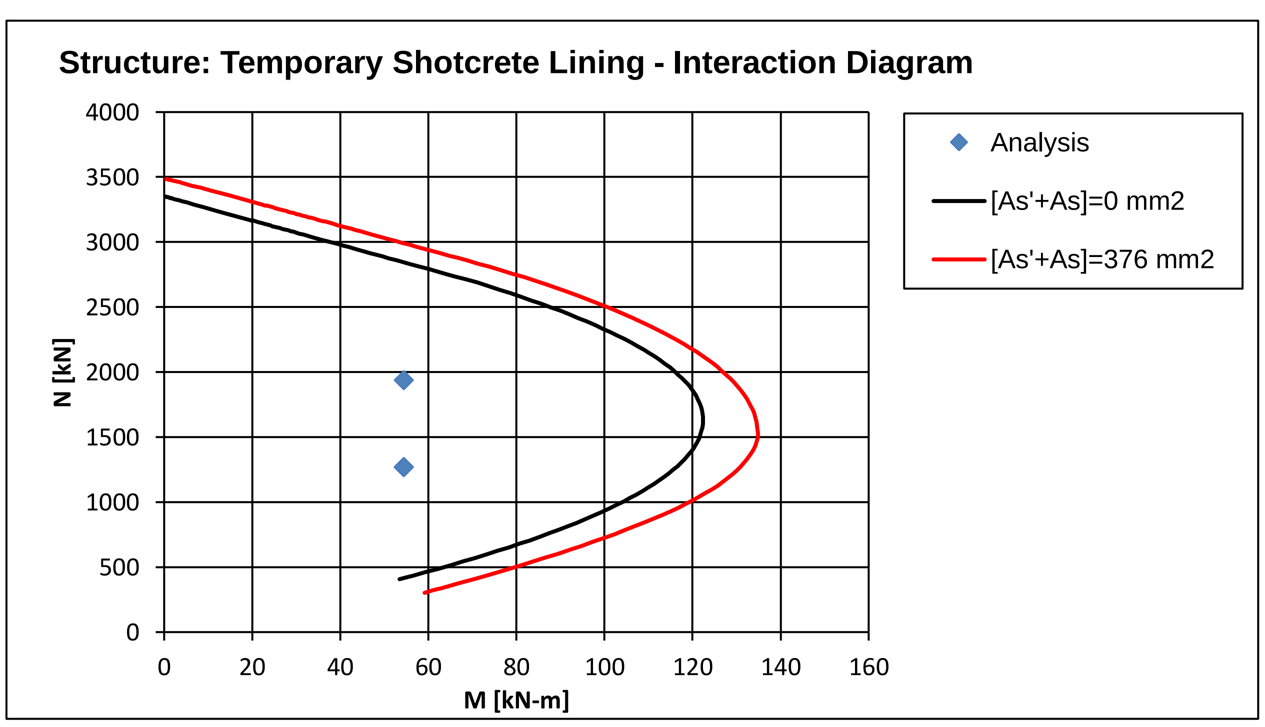
Load factor for N	1.3
Load factor for M	1.3

ANALYSIS

Location	N	M	N/bh	M/bh^2	N (To account for Load Factors)	M (To account for Load Factors)
	[kN]	[kNm]	[N/mm^2]	[N/mm^2]	[kN]	[kNm]
Main Tunnel - Crown	978.07	41.83	4.24	0.60	1271.50	54.38
Main Tunnel - Bench	1491.82	-41.83	6.46	0.60	1939.37	54.38
Main Tunnel - Invert	978.07	41.83	4.24	0.60	1271.50	54.38
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00

Draw Curves for …

	Reinforcement			
	1st layer [As']	2nd layer [As]	As'	As
	[mm^2]	[mm^2]	[%]	[%]
Curve 1 (Unreinforced)	0	0	0	0
Curve 2 (Reinforced)	188	188	0.063	0.063



Project:	I40172				
Job No.:	I40172	Date:	02.09.2024	Made by:	NGn
Tunnel:	NATM Regular Section 2 Lane				
Object:	SC-III (CW-Soil)				
Constr. Stage	Final Stage / Primary Lining				
Chainage:	Low overburden				

LINING CALCULATIONS - DISTRIBUTION OF MOMENTS AND SHEAR FORCES

Structure: *Temporary Shotcrete Lining*

Distribution of Shear Forces

Normal Forces due to earth pressure			Bending Moments due to earth pressure		
Crown	Bench	Invert	Crown	Bench	Invert
[kN]	[kN]	[kN]	[kN-m]	[kN-m]	[kN-m]
978.07	1491.82	978.07	41.83	-41.83	41.83

Shear Forces (V) at sections				
Crown 0^0	45^o	Bench 90^0	135^o	Invert 180^0
0	-15.639	0	15.639	0

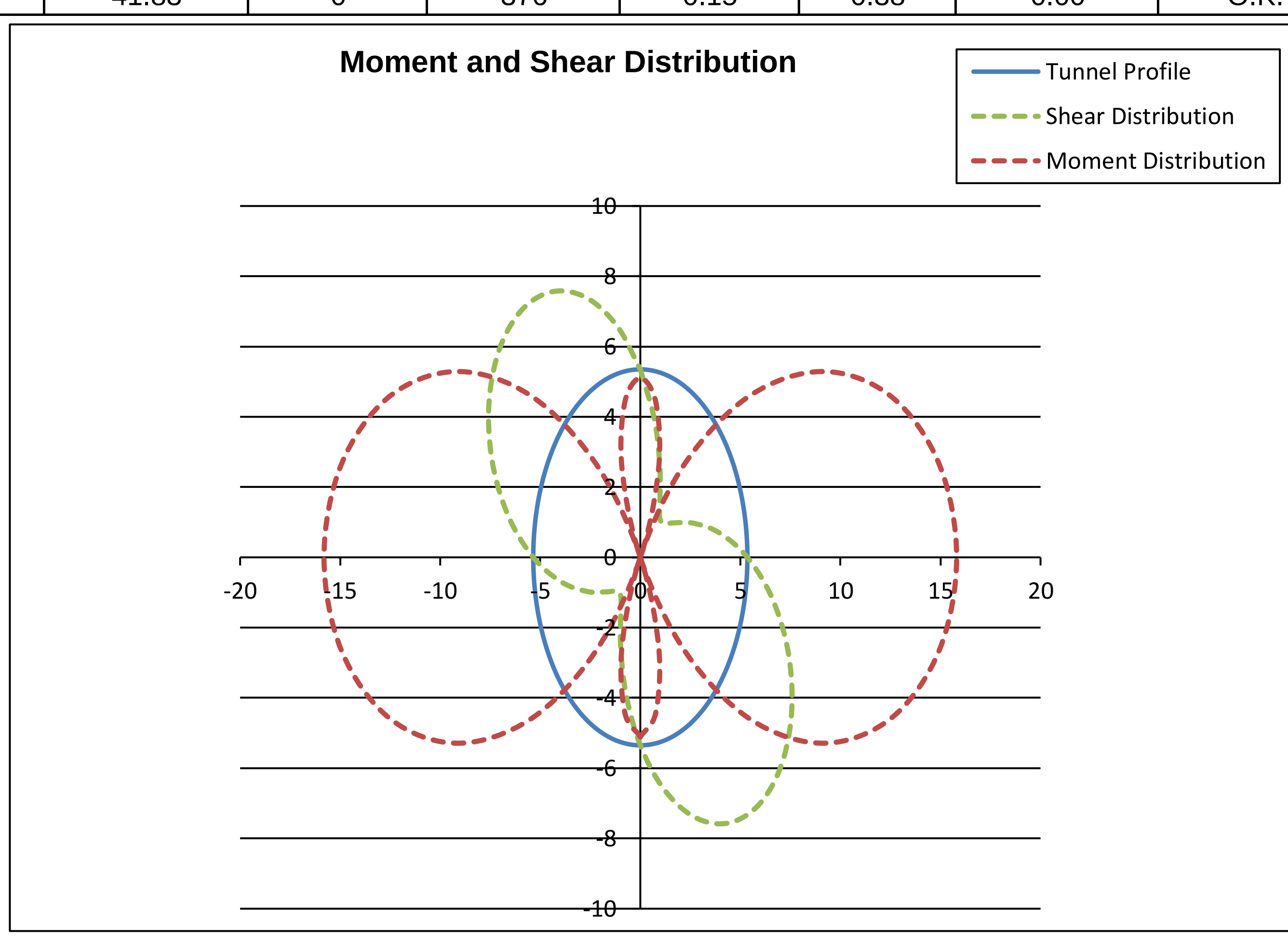
Distribution of Bending Moments and Shear Forces

Average Tunnel Radius = 5.35 m

Load Factor = 1.3

As = 376

Location	M	V	As	100 As / bd	Vc	Actual V	Check	Utilisation
[^{0}]	[kN-m/m]	[kN/m]	[mm^2]	[-]	[N/mm^2]	[N/mm^2]		[%]
0	41.83	0	376	0.15	0.38	0.00	O.K.	0.00
10	39.31	-5.35	376	0.15	0.38	0.03	O.K.	7.38
20	32.05	-10.05	376	0.15	0.38	0.05	O.K.	13.87
30	20.92	-13.54	376	0.15	0.38	0.07	O.K.	18.68
40	7.26	-15.40	376	0.15	0.38	0.08	O.K.	21.24
50	-7.26	-15.40	376	0.15	0.38	0.08	O.K.	21.24
60	-20.92	-13.54	376	0.15	0.38	0.07	O.K.	18.68
70	-32.05	-10.05	376	0.15	0.38	0.05	O.K.	13.87
80	-39.31	-5.35	376	0.15	0.38	0.03	O.K.	7.38
90	-41.83	0	376	0.15	0.38	0.00	O.K.	0.00
100	-39.31	5.35	376	0.15	0.38	0.03	O.K.	7.38
110	-32.05	10.05	376	0.15	0.38	0.05	O.K.	13.87
120	-20.92	13.54	376	0.15	0.38	0.07	O.K.	18.68
130	-7.26	15.40	376	0.15	0.38	0.08	O.K.	21.24
140	7.26	15.40	376	0.15	0.38	0.08	O.K.	21.24
150	20.92	13.54	376	0.15	0.38	0.07	O.K.	18.68
160	32.05	10.05	376	0.15	0.38	0.05	O.K.	13.87
170	39.31	5.35	376	0.15	0.38	0.03	O.K.	7.38
180	41.83	0	376	0.15	0.38	0.00	O.K.	0.00



ANNEXURE – 5
PIPE ROOF CHECK

Project ID	I40172
Project Description	NATM REGULAR SECTION 2 LANE

CONSULTANCY SERVICES FOR PREPRATION OF DPR FOR THE WORK OF CONSTRUCTION OF UNDERGROUND VEHICULAR TUNNELFROM HEBBAL ESTEEM MALL JUNCTION TO SILK BOARD KSRP JUNCTION

OVERVIEW

Cross Section		**Regular Section -2 Lanes**	
Material above Crown		**Soil**	
Material in Face		**Soil**	
max. Overburden	[m]	**11**	H
Surface Load	[kN/m2]	**60**	[-]

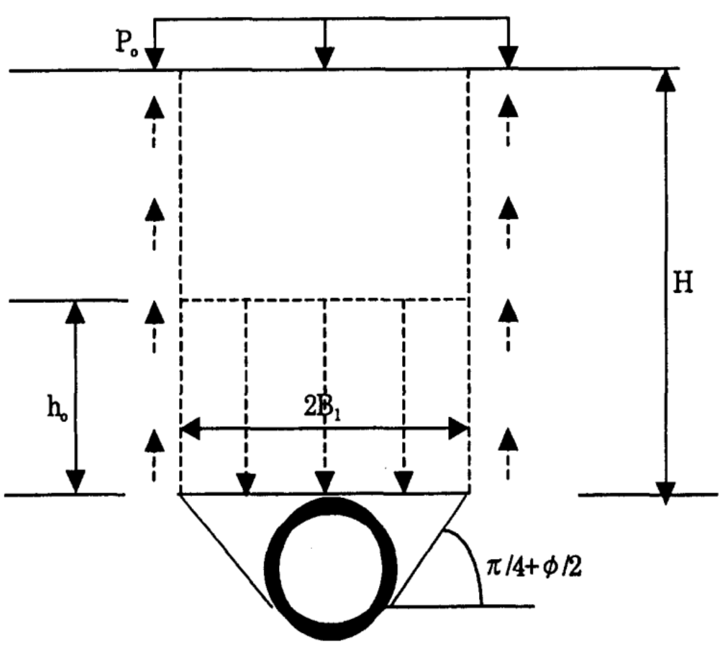
Soil Properties			
dry weight	[kN/m3]	**17**	γdry
wet weight	[kN/m3]	**18**	γwet
angle of friction	[°]	**25**	Φ
cohesion	[kPa]	**2**	C
Coeff. Lateral press.	[-]	**0.58**	Ko
Coeff. Lateral press.	[-]	**0.58**	Ko

Cross Section				
equ. Radius	[m]	**3.94**	R0	*circular Cross Section assumed*
Height of Face	[m]	**5.5**	hf	Top Heading only
ass. Wedge Width	[m]	**8.9**	bf	

Vertical Loading acc. to Terzaghi

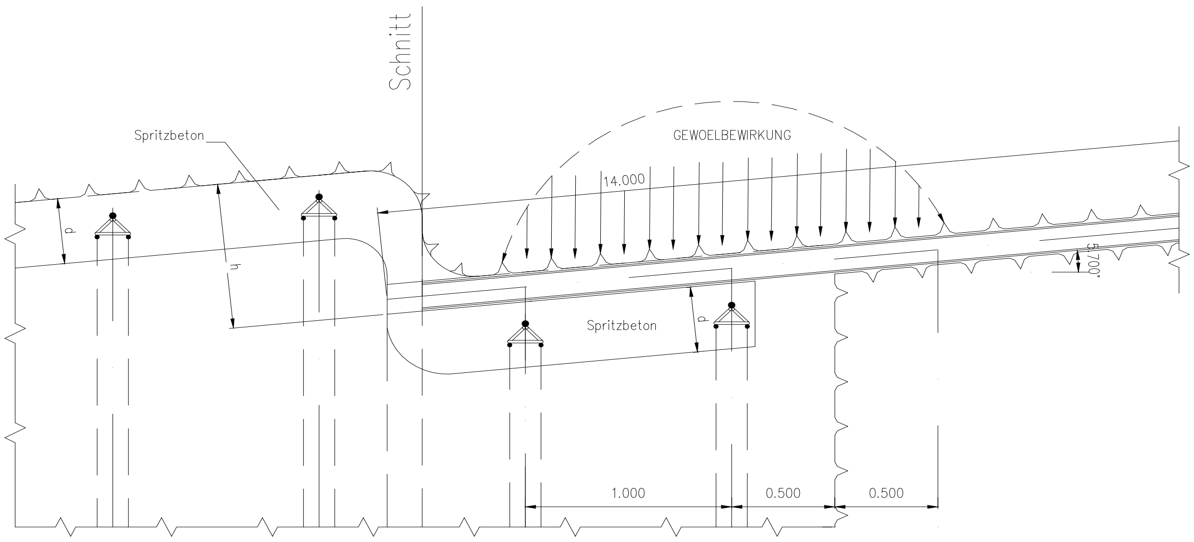
B1	[m]	7.2
weight, wet		
h0	[m]	11.1
Pe1	**[kPa]**	**199.4**
weight, dry		
h0	[m]	11.2
Pe1	**[kPa]**	**188.3**

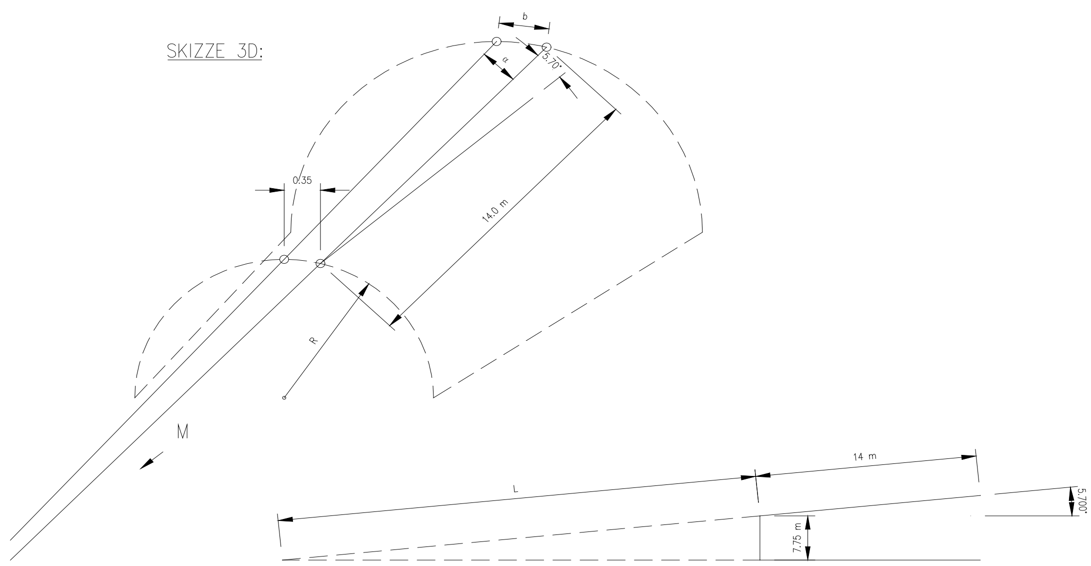
load to be taken by liner		
B1	[m]	7.2
Pe1	[kPa]	199.4
Plin	[kN/m]	1435.5
d_lin	[m]	0.3
s_lin	[MPa]	**4.8**



$$h_0 = B_1 \{1 - C/B_1 \gamma)\} \{1 - \exp(-k_0 \tan(\phi) H/B_1)\}/K_0 \tan(\phi) + P_0 \exp\{-K_0 \tan(\phi) H/B_1\}/\gamma$$

PIPE ROOF UMBRELLA





Note: The sketches above are of a typical example

Angle of Inclination β= 7.00 [°]

R= 3.94 [m]

$$L = \frac{R}{\sin \beta}$$

L= 32.33 [m]

S= 0.3 [m]

$$\alpha = \frac{s * 180}{L * \pi}$$

where s is c/c piperoof spacing

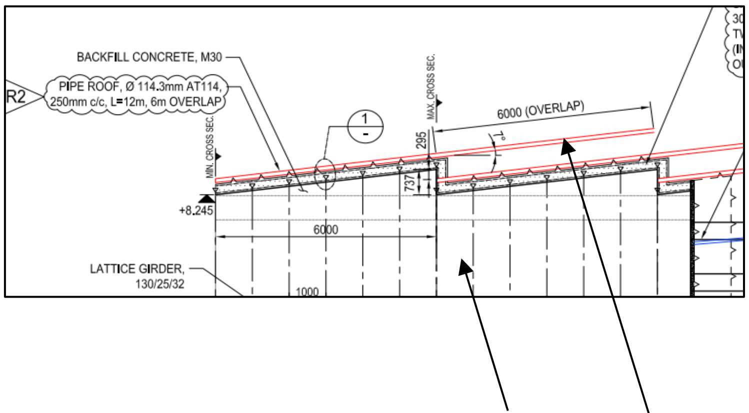
α = 0.53 [°]

$$b = \frac{(L + L1) * \pi * \alpha}{180}$$

L1 is 12m, i.e.pipe roof length

b= 0.41 [m]

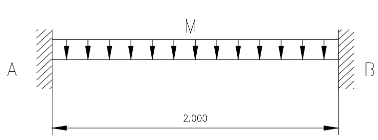
width of influence at the end of umbrella 41 [cm]
(c/c distance between drillholes at start of umbrella = 25 [cm])



Lattice Girder Pipe roof

Outer diameter of pipe	d_a=	11.43	[cm]	(AT114 PipeRoof, 6.3mm wall thickness
Thickness of wall	s=	0.63	[cm]	(As per Dywidag specs, has effective external dia 114.3mm and internal dia 101.7mm; S355, Fy-355 MPa)
perm tensile stress	β_s:=	35.50	[kN/cm²]	
compressive strength of concrete inside pipe	β_d=	2.0	[kN/cm²]	
	σ_{V3D}=	181.6	[kN/m²]	(siehe Anlage C2/8)
	n=	1	no of pipe rows	
Loading per pipe	P=	74.70	[kN/m]	

1.) Analysis in respect to bending:



$$\min M = M_A = M_B = -\frac{P.l^2}{12}$$

Note: The sketches above are of a typical example

l= 1.00 [m]

M= -6.23 [kNm]

Bending moment permissible for the steel pipe:

$$W_{Stahlrohr} = \frac{\pi}{32} * \frac{d_a^4 - d_i^4}{d_a}$$

d_a= 11.43 [cm]
d_i= 10.17 [cm]

W_S= 54.72 [cm³]

Permissible moment: $M_{auf.}$= -1942.49 [kNcm] > $M_{vorh.}$ = -622.514 [kNcm]

2.) Ultimate load state:

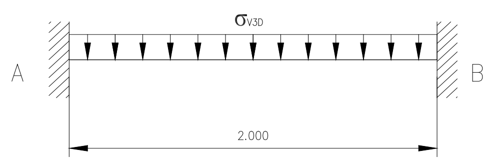
Pipe is loaded up to yield load of steel

St37 => β= 350 [N/mm²]

r_a= 57.15 [mm]
r_i= 50.85 [mm]

$$M = \frac{\pi}{4} * \frac{r_a^4 - r_i^4}{r_a} * \beta$$

M= 19.15 [kNm]



$$M_A = M_B = -\frac{\sigma_{V3D} . l^2}{12} * b$$

$$b_{erf.} = -\frac{12 . M}{\sigma_{V3D} * l^2}$$

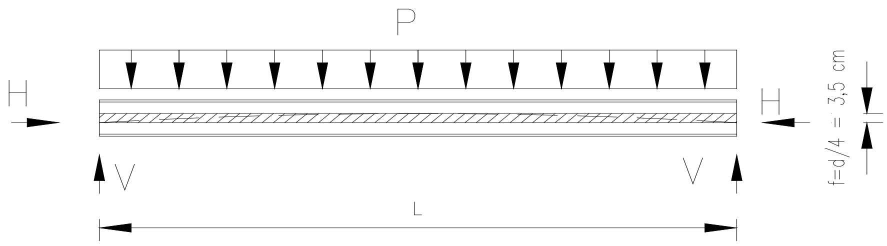
Note: The sketches above are of a typical example

$b_{erf.}$= 1.27 [m] >$b_{vorh.}$= 0.41 [m]

3.) It is assumed that due to the beginning arch effect the load transfer occurs through the core area of the cross section.

Circular section: $k = \frac{d}{8}$

Area outside the circular cross section which might have been improved are not taken into account for the load transfer.



Note: The sketches above are of a typical example

$$H = \frac{\sigma_V * l_{Sb.}^2}{8 * f}$$

	H=	326.78	[kN]
Area Pipe	A_R=	21.38	[cm²]
Area concrete	A_B=	81.23	[cm²]

$F_{zul.}$= 921.29 [kN] >$F_{vorh.}$= 326.78 [kN]

ANNEXURE – 6
FACE STABILITY

Project ID	I40172	
Project Description	NATM REGULAR SECTION 2 LANE	

CONSULTANCY SERVICES FOR PREPRATION OF DPR FOR THE WORK OF CONSTRUCTION OF UNDERGROUND VEHICULAR TUNNELFROM HEBBAL ESTEEM MALL JUNCTION TO SILK BOARD KSRP JUNCTION

OVERVIEW

Cross Section		Regular Section -2 Lanes	
Material above Crown		Soil	
Material in Face		Soil	
max. Overburden	[m]	11	H
Surface Load	[kN/m2]	60	[-]

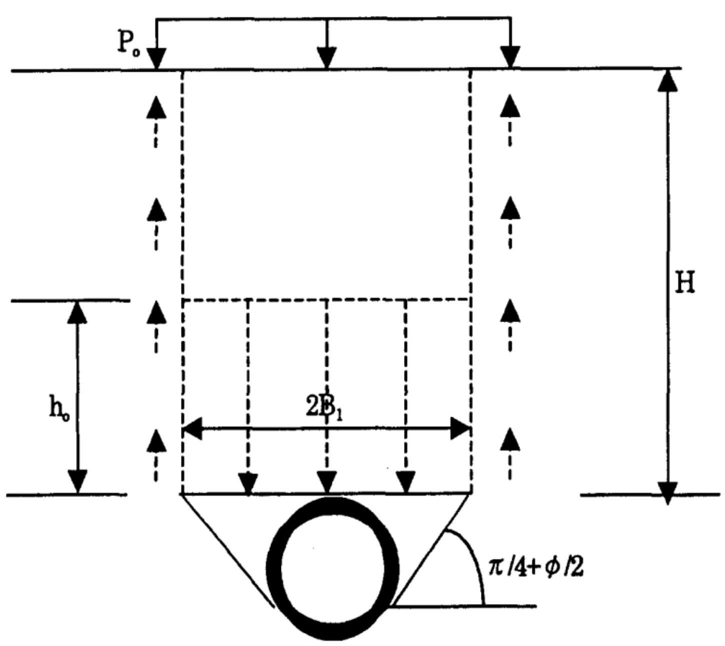
Soil Properties			
dry weight	[kN/m3]	17	γdry
wet weight	[kN/m3]	18	γwet
angle of friction	[°]	25	Φ
cohesion	[kPa]	2	C
Coeff. Lateral press.	[-]	0.58	Ko
Coeff. Lateral press.	[-]	0.58	Ko

Cross Section				
equ. Radius	[m]	3.94	R0	*circular Cross Section assumed*
Height of Face	[m]	5.5	hf	Top Heading only
ass. Wedge Width	[m]	8.9	bf	

Vertical Loading acc. to Terzaghi

B1	[m]	7.2
weight, wet		
h0	[m]	11.1
Pe1	**[kPa]**	**199.4**
weight, dry		
h0	[m]	11.2
Pe1	**[kPa]**	**188.3**

load to be taken by liner		
B1	[m]	7.2
Pe1	[kPa]	199.4
Plin	[kN/m]	1435.5
d_lin	[m]	0.3
s_lin	[MPa]	**4.8**



$$h_0 = B_1 \{1 - C/B_1 \gamma)\} \{1 - \exp(-k_0 \tan(\phi) H/B_1)]/K_0 \tan(\phi) + P_0 \exp\{-K_0 \tan(\phi) H/B_1\}/\gamma$$

Face Stability Check

Surface Load	P0	kN/m2	60	
Overburden	H	[m]	11	
Diametre	D	[m]	7.9	
Angle of friction	ϕ	[°]	25	
Cohesion	c	HWR	2	
weight, wet	γ	MWR	18	
Coefficient of lateral pressure	K0	[-]	0.6	
Pull length	lp	[m]	1.0	
height of face	hf	[m]	5.5	
wedge width	bf	[m]	8.9	

Angle of failure at face	β	[Deg]	47.5	57.5
wedge length	lf	[Deg]	5.0	3.5
Wedge length + 2 pulls	b	[m]	7.0	5.5
one maximum dia	a	[m]	7.9	7.9
equ. Radius Silo (rectangular)	b1_equ	[m]	3.7	3.2

Earth Pressure (Silo)

equivalent height	h0	[m]	8.8	8.3
vertical stress (pressure)	σv3d	[kN/m2]	159.2	149.1

Wedge

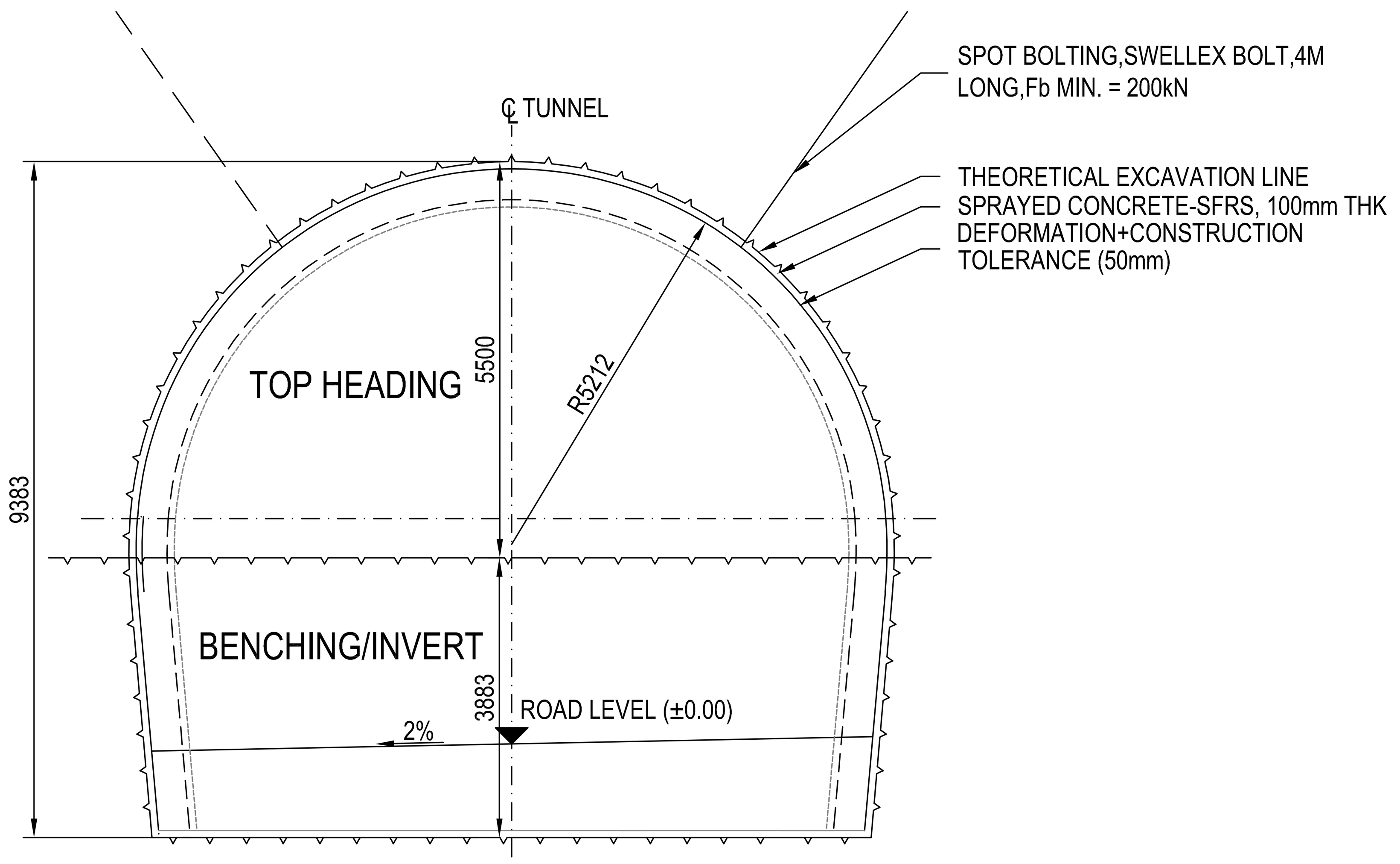
Weight of the wedge	G1	[kN]	2220.3	1543.6
Vertical Force / Weight silo	G2	[kN]	7139.3	4648.7
Total Weight	G	[kN]	9359.6	6192.3
Length of Sliding plane	ls	[m]	7.5	6.5
Area of Sliding plane	As	[m2]	66.4	58.0
Resistance	R	[kN]	3081.4	1667.5
Stress	1.1	[kN]	6900.6	5222.5
Factor of Safety w/o support	η	[-]	0.4	0.3
required Factor of safety	erf η	[-]	1.15	1.15
Required Support Action	Areq	[kN]	4762.0	4662.0

Face Bolting

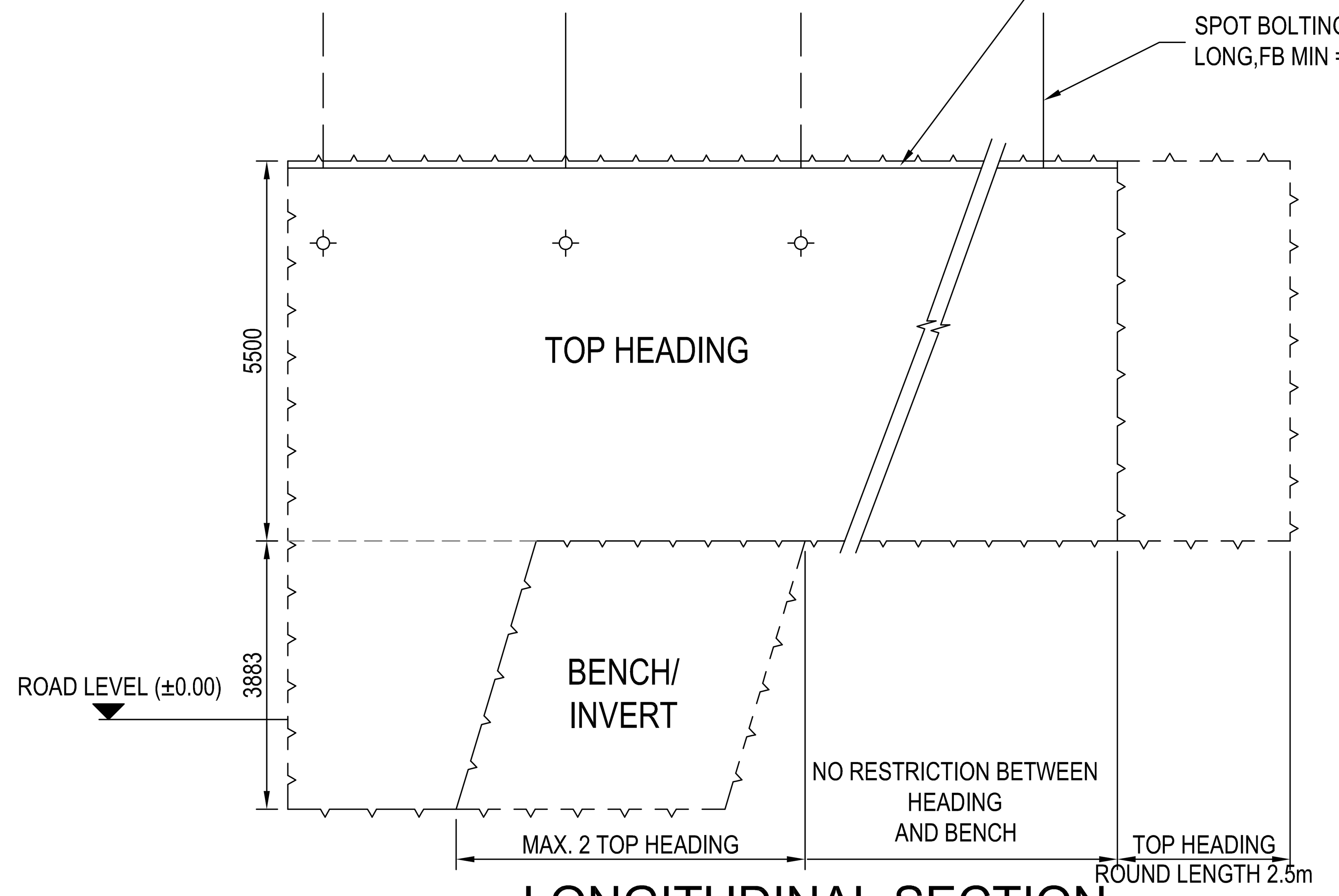
allowable bolt force	Azul	[kN]	560	560
required number of bolts	n	[-]	**9**	**9**

ANNEXURE - 7
DRAWINGS

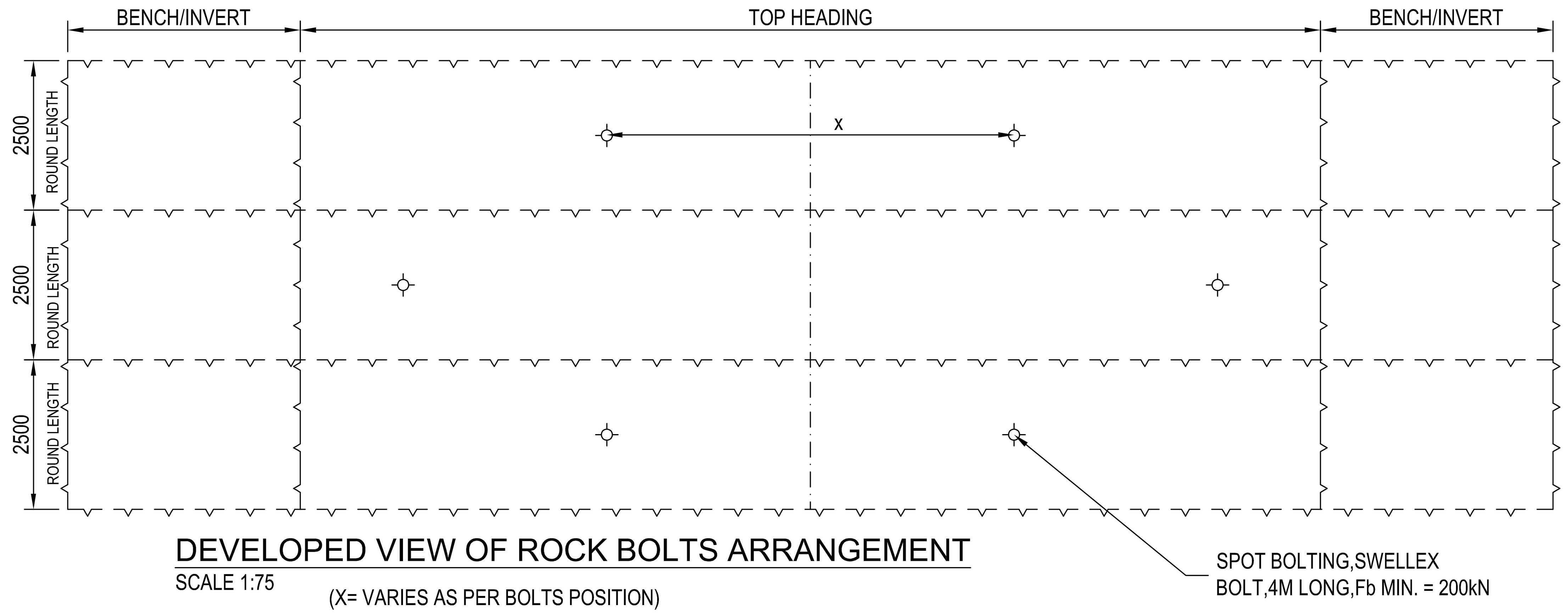
Original Drawing Size A1



SUPPORT CLASS I
NATM TUNNEL-2 LANE
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. 2.5m
		Theoretical Excavation Volume	46.32 m³
		Theoretical Excavation Circumference(excluding invert)	17.06 m
	Support	Sprayed Concrete 100mm Thick - SFRS	1.79 m²
		Spot Bolting,Swellex Bolt,4M Long,Fb MIN = 200kN	spot bolting as required
BENCH/INVERT	Excavation	Round Length	Avg. 5.0 m
		Theoretical Excavation Volume	40.09 m³
		Theoretical Excavation Circumference (excluding invert)	17.78 m
	Support	Sprayed Concrete 100mm Thick - SFRS	0.76 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).
4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.
5. DEFORMATION ALLOWANCE + CONSTRUCTION TOLERANCE OF 50MM IS CONSIDERED AND INCLUDED, WHEREAS IN INVERT NO CONSTRUTION TOLERANCE IS INCLUDED

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

(PRELIMINARY)

REVISION	DATE	AMENDMENT \ ISSUE DESCRIPTION
R0	11.09.24	PRELIMINARY

CLIENT
GOVERNMENT OF KARNATAKA
GOVERNMENT OF KARANATAKA
Bruhat Bangalore Mahanagara Palike

CONSULTANT:
RODIC CONSULTANTS PVT. LTD.
1, JAI SINGH MARG (FIRST FLOOR), YMCA CULTURAL CENTRE BUILDING
NEW DELHI - 110001 (INDIA)

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Fluidyn India
#15, 4th Floor, Outer Ring Road JP Nagar 6th Phase Bengaluru, Karnataka 560078 India

DRAFT PROJECT REPORT

Designed:	GCI
Drawn:	GCI
Checked:	GCI
Approved:	GCI

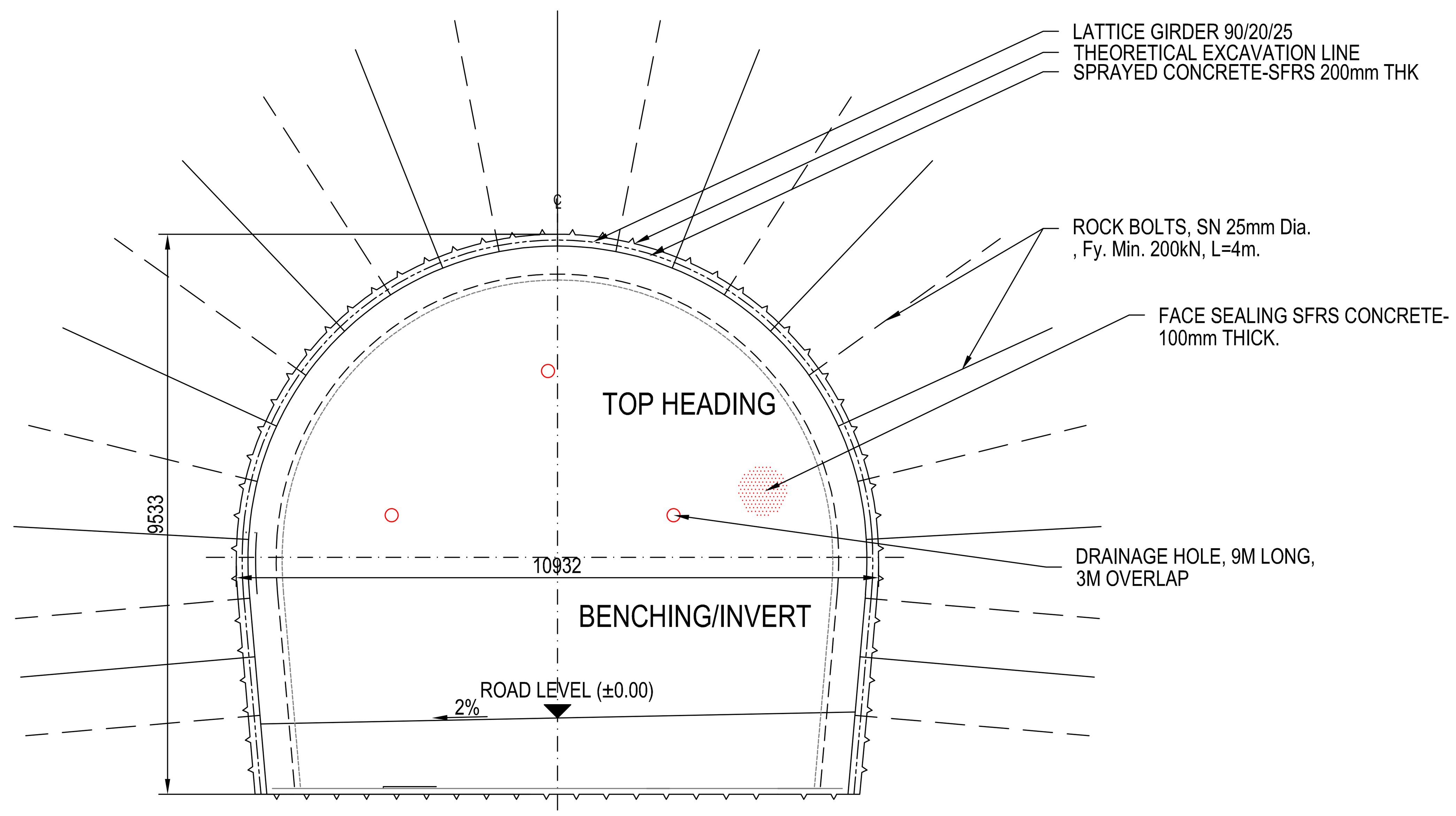
Scale :- 1:75
Sheet size: A1

Project: "Consultancy services for preparation of DPR for the work of Construction of Underground Vehicular Tunnel from Hebbal Esteem mall junction to Silk Board KSRP junction"

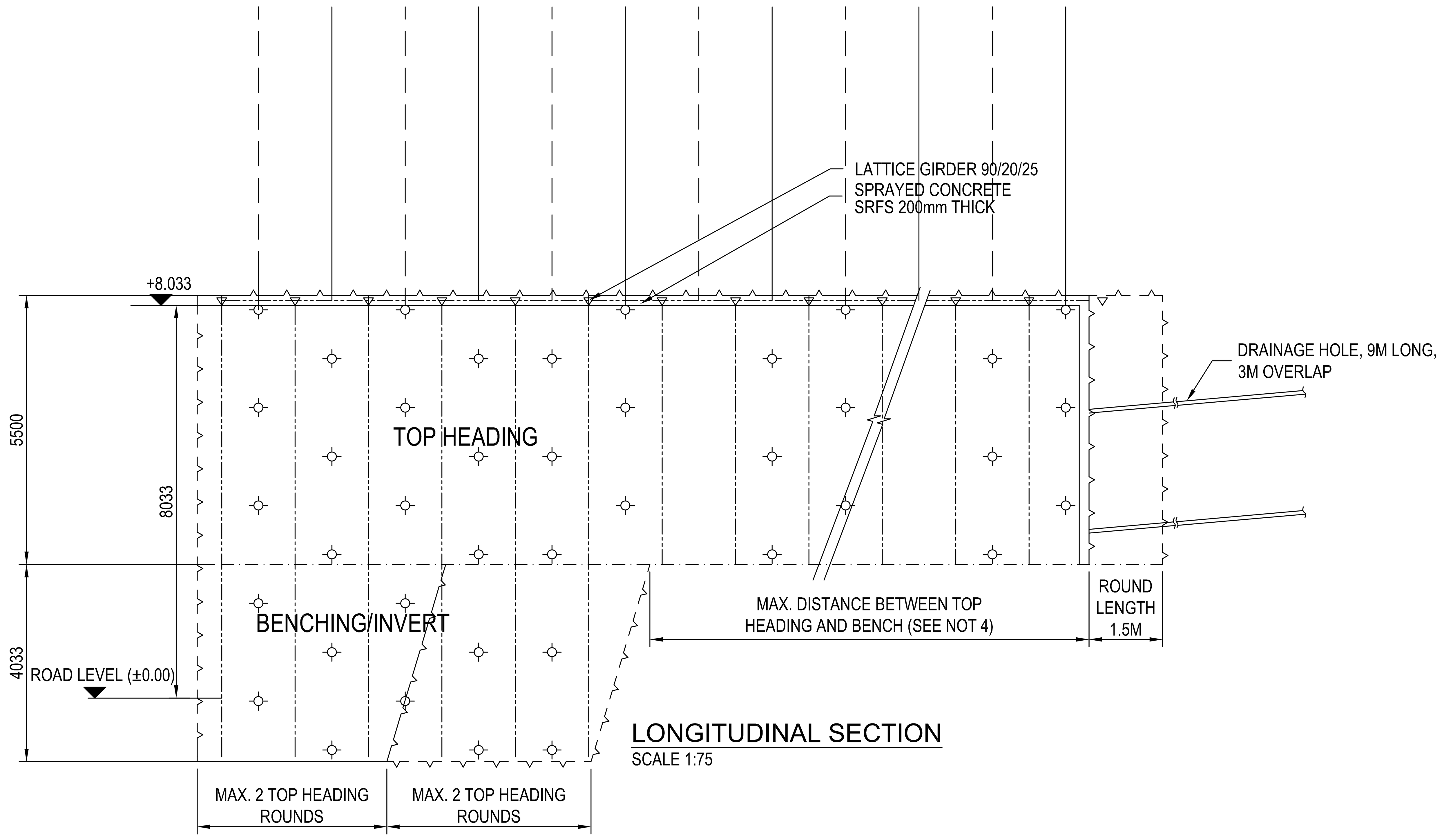
Drawing Title: NATM TUNNEL 2-LINE REGULAR CROSS SECTION SUPPORT CLASS-I

Drawing No.: RC/1640/HO/HBT/TU/DWG/NT/SUP/406/R0

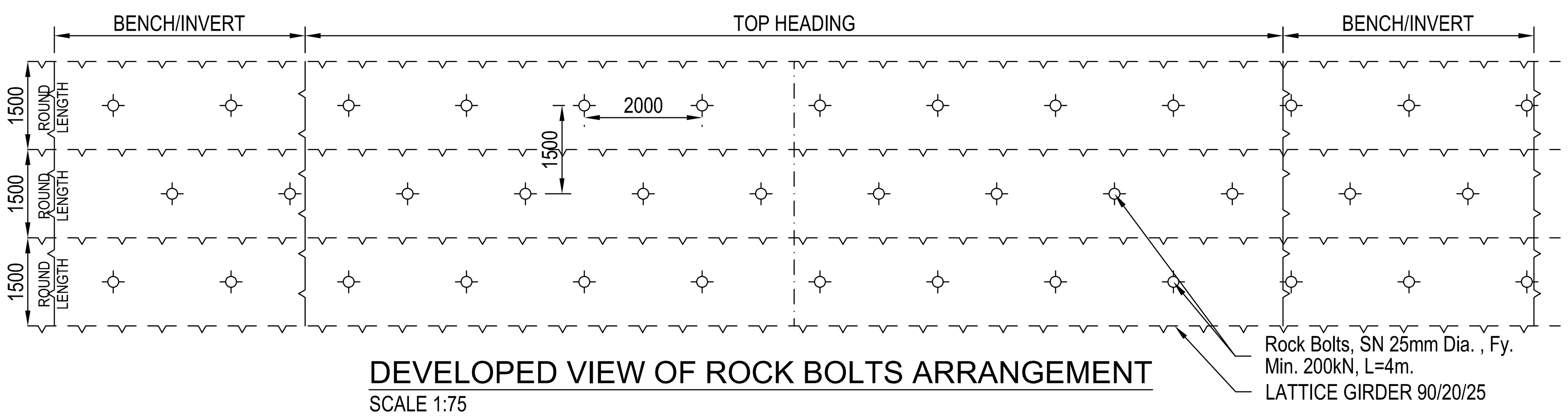
Original Drawing Size A1



SUPPORT CLASS II
NATM TUNNEL-2 LANE
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. 1.5m
		Theoretical Excavation Volume	47.28 m³
		Theoretical Excavation Circumference(excluding invert)	17.23 m
	Support	Sprayed Concrete 200mm Thick - SFRS	3.38 m²
		Rock Bolts, SN 25mm Dia. , Fy. Min. 200kN, L=4m.	5.66 no.
		LATTICE GIRDER 90/20/25	16.92 m
		Face sealing SFRS, 100mm thk (min. section)	47.28 m²
BENCH/INVERT	Excavation	Round Length	Avg. 3 m
		Theoretical Excavation Volume	42.90 m³
		Theoretical Excavation Circumference (excluding invert)	18.38 m
	Support	Sprayed Concrete 200mm Thick - SFRS	1.60 m²
		Rock Bolts, SN 25mm Dia. , Fy. Min. 200kN, L=4m.	2.0 no.
		Lattice Girder 90/20/25	8.09 m

NOTES :

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4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.
5. DEFORMATION ALLOWANCE + CONSTRUCTION TOLERANCE OF 50MM IS CONSIDERED AND INCLUDED, WHEREAS IN INVERT NO CONSTRUTION TOLERANCE IS INCLUDED

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

(PRELIMINARY)

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DRAFT PROJECT REPORT

Designed:	GCI
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Checked:	GCI
Approved:	GCI

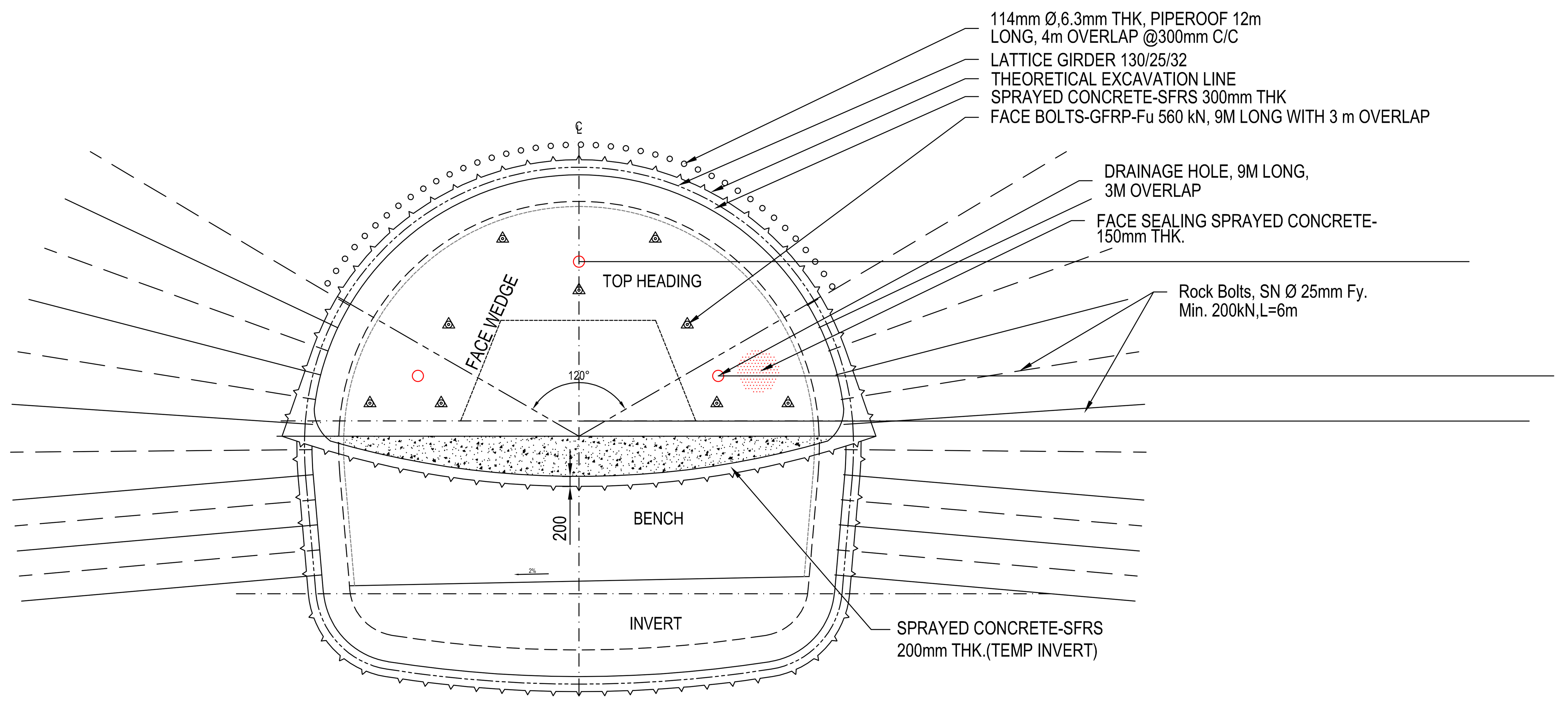
Scale :- 1:75
Sheet size: A1

Project: "Consultancy services for preparation of DPR for the work of Construction of Underground Vehicular Tunnel from Hebbal Esteem mall junction to Silk Board KSRP junction"

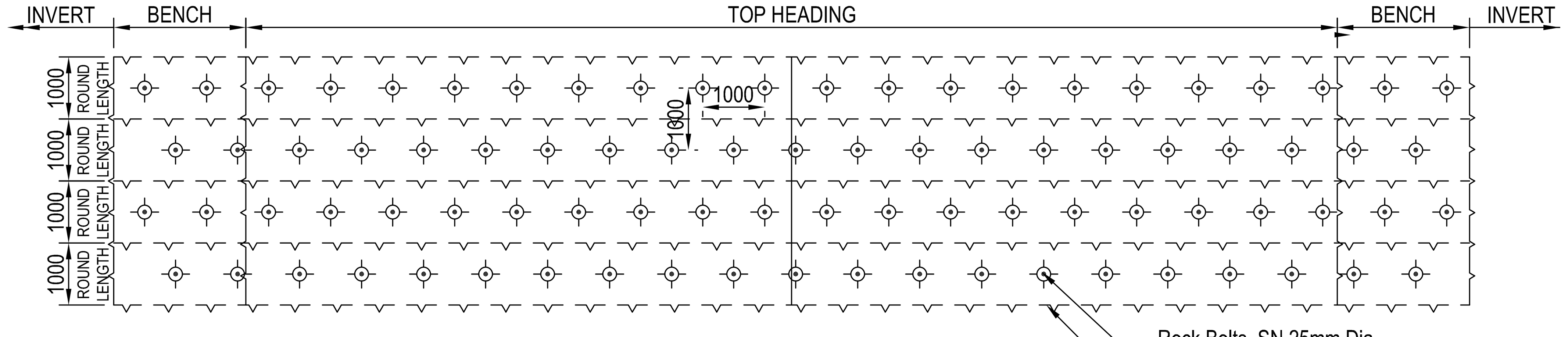
Drawing Title: NATM TUNNEL 2-LINE REGULAR CROSS SECTION SUPPORT CLASS-II

Drawing No.: RC/1640/HO/HBT/TU/DWG/NT/SUP/407/R0

Original Drawing Size A1

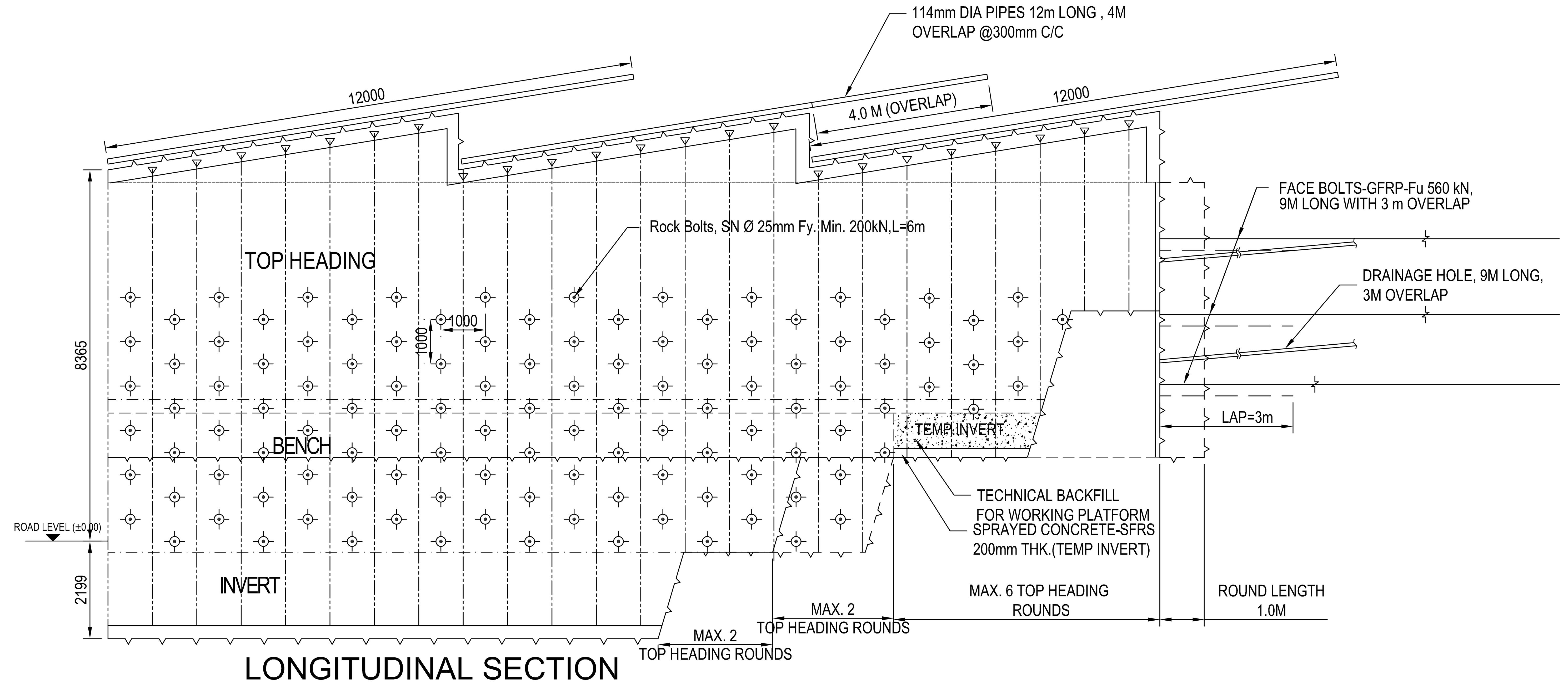


SUPPORT CLASS III
NATM TUNNEL-2 LANE (ARCH INVERT)
SCALE 1:50



DEVELOPED VIEW OF ROCK BOLTS ARRANGEMENT
SCALE 1:75

EXCAVATION AND SUPPORT QUANTITIES/m			
TOP HEADING	Excavation	Round Length	Avg. 1.0 m
		Theoretical Excavation volume (Including temp invert)	48.57 m³
		Theoretical Excavation Circumference(Including temp invert)	17.54 m
	Support	Sprayed Concrete-SFRS, 300mm THK	5.53 m²
		Sprayed Concrete-SFRS, 200mm THK (temp inv)	2.29 m²
		Rock Bolts, SN 25mm Dia. Fy. Min. 200kN, L=6m.	6.0 no.
		Lattice Girder 130/25/32	16.93 m
		Drainage Hole, 9m Long, 3m Overlap	0.5 no.
		114mm Ø,6.3mm THK, Piperoof 12m Long, 4m Overlap @300mm C/C	5.1 no.
		Face sealing SFRS, 150mm thk (min. section)	48.57 m²
		Face Bolts-GFRP-Fu 560 kN, 9m long With 3 m Overlap	1.5 no.
BENCH	Excavation	Round Length	Avg. 2.0 m
		Theoretical Excavation Volume	28.28 m³
		Theoretical Excavation Circumference (side walls only)	26.69 m
	Support	Sprayed Concrete-SFRS, 300mm THK	1.79 m²
		Rock Bolts, SN 25mm Dia. Fy. Min. 200kN, L=6m.	6.0 no.
		Lattice Girder 130/25/32	5.98 m
INVERT	Excavation	Round Length	Avg. 4.0 m
		Theoretical Excavation Volume	17.96 m³
		Theoretical Excavation Circumference (Invert only)	12.58 m
	Support	Sprayed Concrete-SFRS, 300mm THK	3.63 m²
		LATTICE GIRDER 130/25/32	12.14 m



LONGITUDINAL SECTION
SCALE 1:75

NOTES :

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4. MAX. DISTANCE BETWEEN TOP HEADING AND BENCH/INVERT CAN BE ALTERED BY THE ENGINEER-IN-CHARGE ACCORDING TO ENCOUNTERED GEOLOGICAL CONDITIONS.
5. DEFORMATION ALLOWANCE + CONSTRUCTION TOLERANCE OF 150MM IS CONSIDERED AND INCLUDED, WHEREAS IN INVERT NO CONSTRUTION TOLERANCE IS INCLUDED

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

(PRELIMINARY)

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DRAFT PROJECT REPORT

Designed:	GCI
Drawn:	GCI
Checked:	GCI
Approved:	GCI

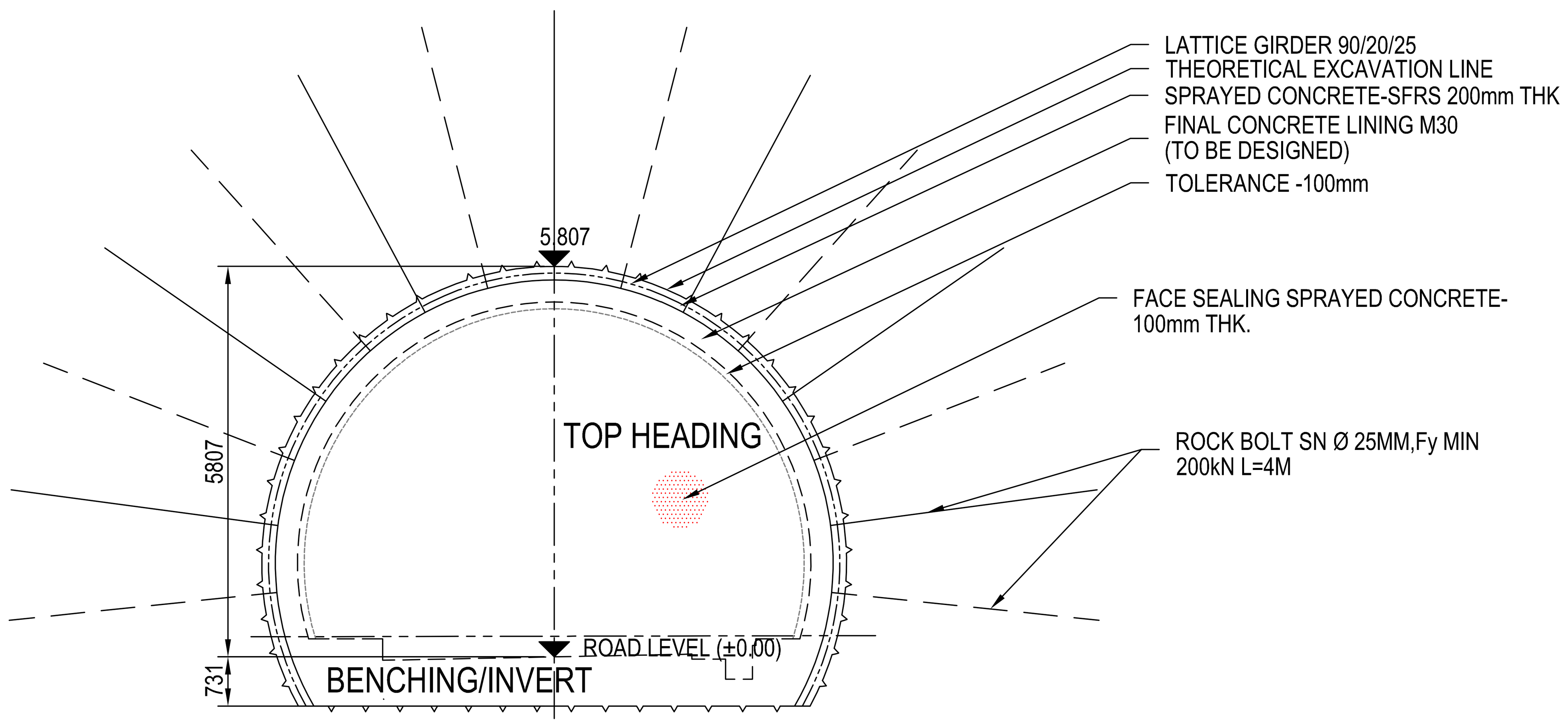
Scale :- 1:75
Sheet size: A1

Project: "Consultancy services for preparation of DPR for the work of Construction of Underground Vehicular Tunnel from Hebbal Esteem mall junction to Silk Board KSRP junction"

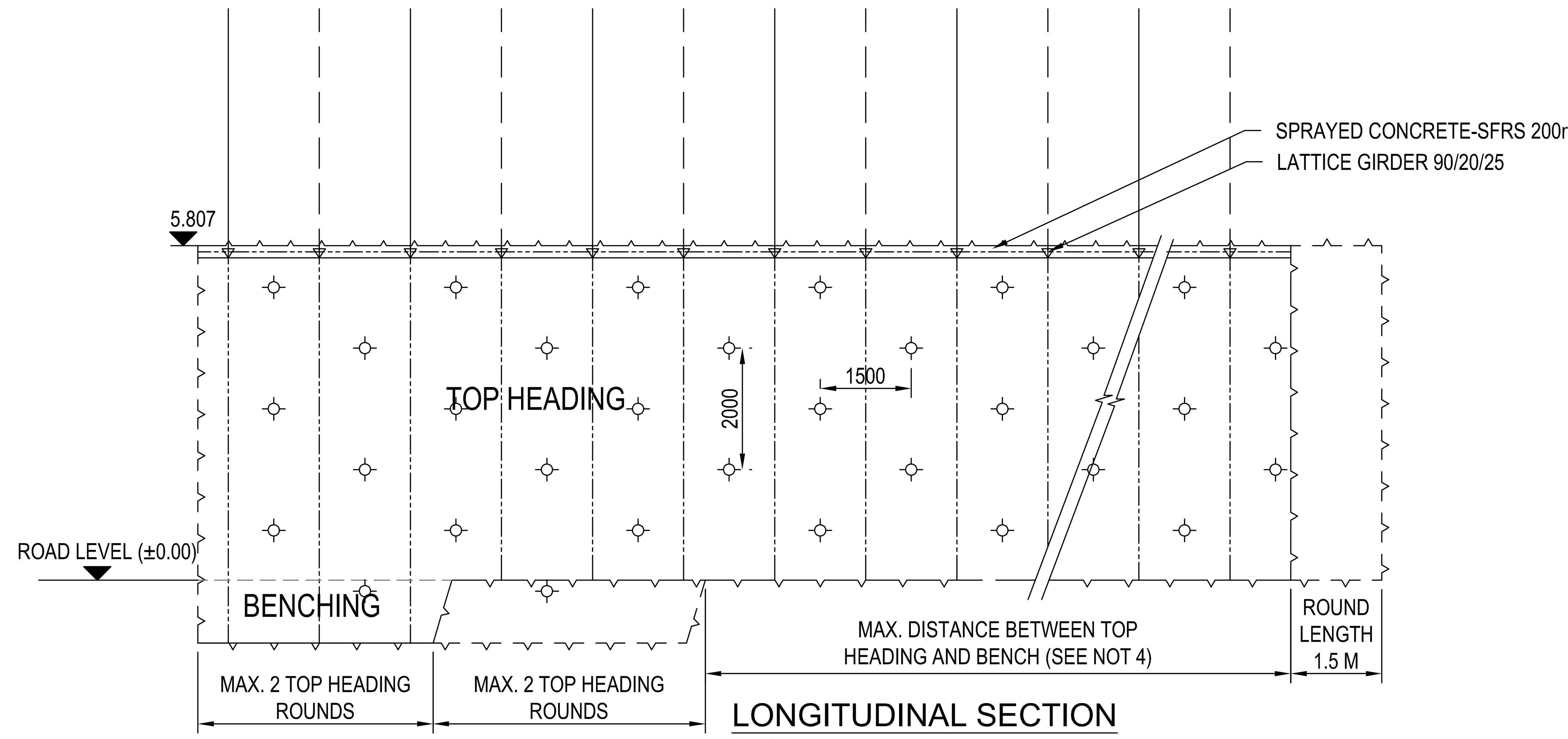
Drawing Title: NATM TUNNEL 2-LINE REGULAR CROSS SECTION SUPPORT CLASS-III

Drawing No.: RC/1640/HO/HBT/TU/DWG/NT/SUP/408/R0

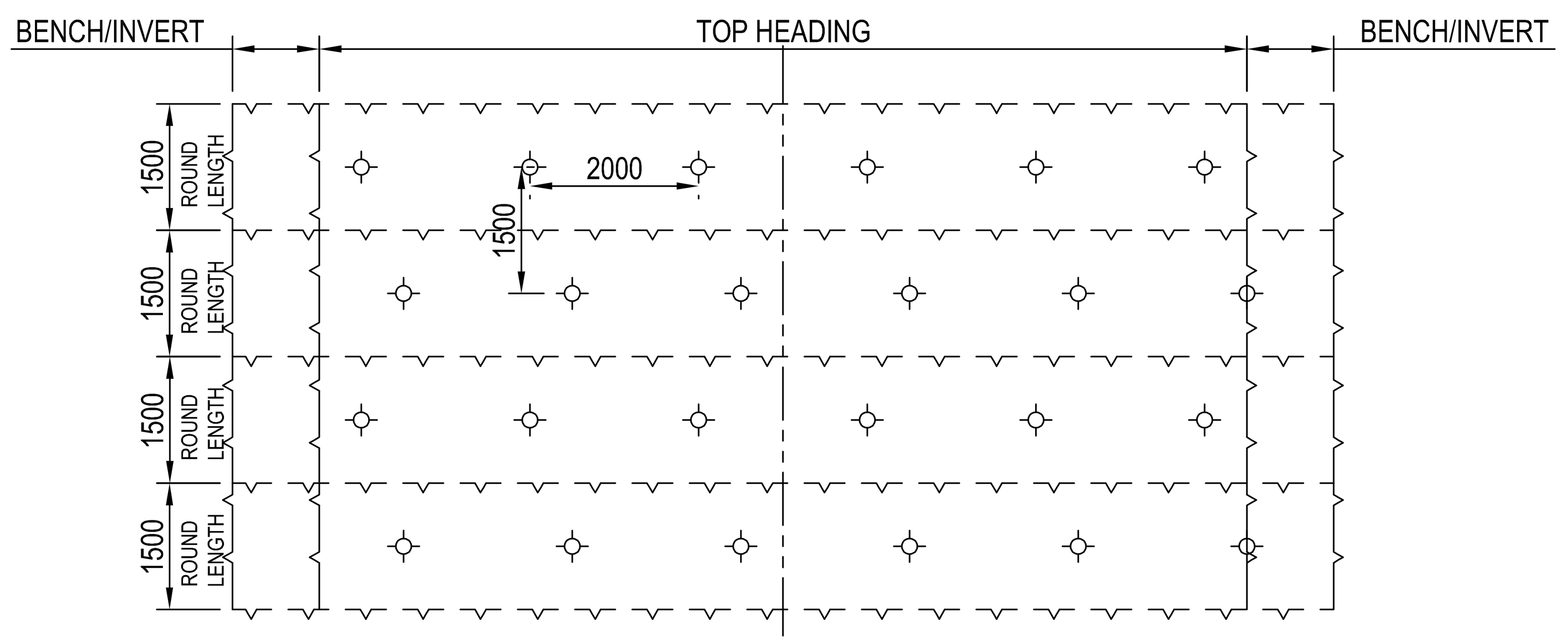
Original Drawing Size A1



SUPPORT CLASS II
CROSS PASSAGE
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. 1.5 m
		Theoretical Excavation Volume	39.53 m³
		Theoretical Excavation Circumference(excluding invert)	15.96 m
	Support	Sprayed Concrete 200mm Thick-SFRS	3.13 m²
		ROCK BOLT SN Ø 25MM,Fy MIN 200kN L=4M	5 no.
		FACE SEALING SPRAYED CONCRETE- 100mm THK.	39.53 m²
		LG 90/20/25	15.65 m.
BENCH	Excavation	Round Length	Avg. 3 m
		Theoretical Excavation Volume	42.90 m³
		Theoretical Excavation Circumference (excluding invert)	9.83 m
	Support	Sprayed Concrete 200mm Thick - SFRS	0.44 m²
		LG 90/20/25	2.24 m.

NOTES :

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

(PRELIMINARY)

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DRAFT PROJECT REPORT

Designed:	GCI	Scale :- 1:75
Drawn:	GCI	
Checked:	GCI	
Approved:	GCI	Sheet size: A1

Project	"Consultancy services for preparation of DPR for the work of Construction of Underground Vehicular Tunnel from Hebbal Esteem mall junction to Silk Board KSRP junction"
Drawing Title	VEHICULAR CROSS PASSAGE SUPPORT CLASS II SINGLE LANE
Drawing No.	RC/1640/HO/HBT/TU/DWG/VCP/SUP/409/R0

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