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ATAL TUNNEL, ROHTANG

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σ3	σ1
7	276
8	280
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18	364
60	538
61	545
65	582
65	586

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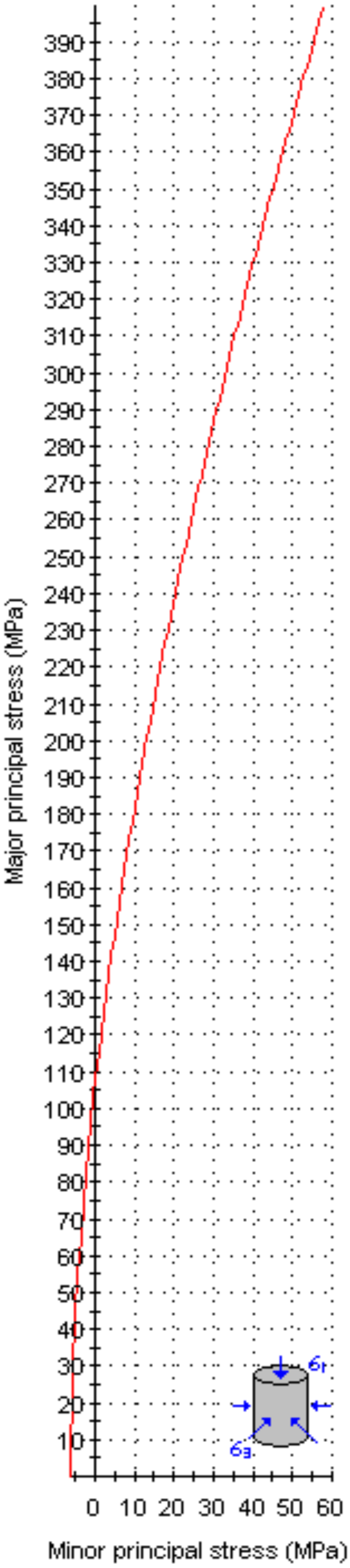
Analysis of Rock Strength using RocLab



Hoek-Brown Classification

intact uniaxial comp. strength (sigci) = 232.278 MPa
GSI = 88 mi = 13.588 Disturbance factor (D) = 0.4
intact modulus (Ei) = 87104.3 MPa
modulus ratio (MR) = 375

Hoek-Brown Criterion

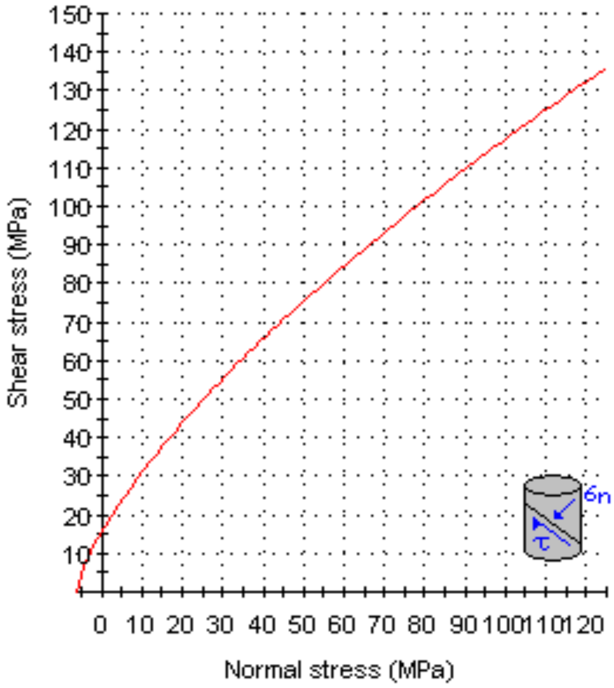
mb = 7.816 s = 0.2083 a = 0.500

Mohr-Coulomb Fit

cohesion = 25.602 MPa friction angle = 42.86 deg

Rock Mass Parameters

tensile strength = -6.191 MPa
uniaxial compressive strength = 105.976 MPa
global strength = 117.367 MPa
deformation modulus = 60705.06 MPa



Introduction-

Rohtang Pass is a high mountain pass on the Eastern Pir Panjal Range of the Himalayas around 51 km from Manali on the Leh – Manali highway in Himachal Pradesh. Owing to its high altitude, the Rohtang Pass gets sudden heavy snowfall each year which is risky for vehicular traffic. The proposal for the construction of a tunnel across Rohtang Pass was conceived in 1942 by Dr. JB Auden, Geological Survey of India (GSI) who at that time visited this pass intending to divert the water of Chandra river to Beas.

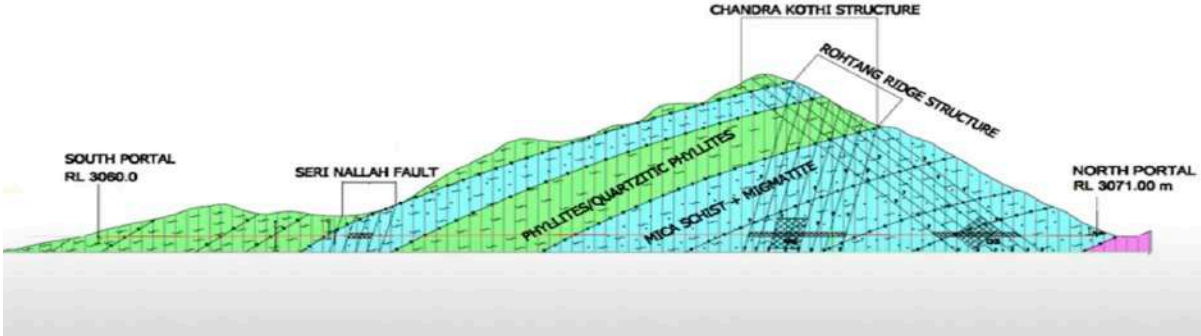
The length of the tunnel is 9.02 Km, which is the world's longest tunnel above an altitude of 10,000 feet. The tunnel is a 10.5 m wide single tube bi-lane tunnel having an overhead clearance of 5.525 m.

Geological Interpretation-

- The area is away from the seismic and volcanic zone.
- The area is away from the "Benioff Zone" and away from plate collision suture.
- Rock strata comprising of Quartz-mica Schist.
- Relationships between geological structures and tunnel alignment.
- The flow of Seri Nala.
- Major geological structures in the area are Seri Nala fault, Chandra-Kothi, Rohtang ridge structure, palchan fault and sundar nagar fault

Geotechnical Parameters-

The rock type assumed for MR value is - **Quartzite (375 +- 75)**
Values obtained from the rocklab software are as follows-
Cohesion (C) = **25.602MPa**
Friction Angle (phi) = **42.86 deg**
Tensile Strength (sigt) = **-6.191MPa**
Poission's ratio (nu) = **0.27**
Young's Modulus for rock mass (E or Deformation Modulus) = **87104.3 MPa**



K.K.Sharma/Study of Roof Collapse in Rohtang Tunnel during Construction/JRMTT 22(1), 2016, 11–20

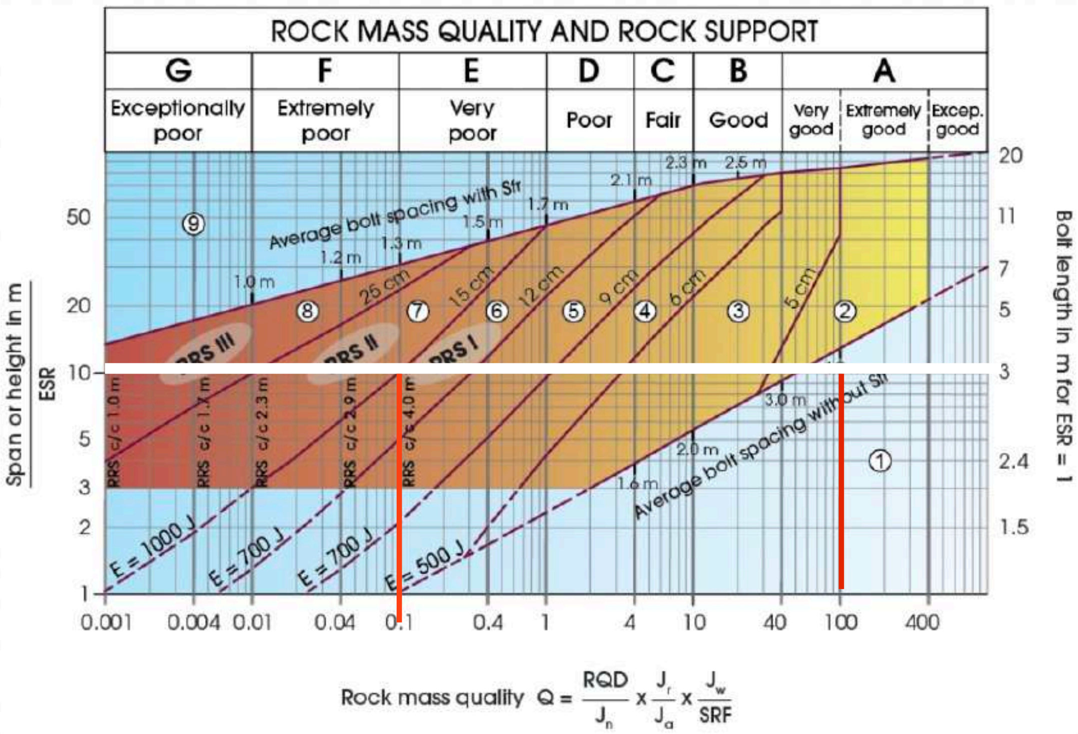
Anticipated Rock Types and Strength-

Rocks were determined using a combination of Qinsituand depth of Overburden, keeping in mind the Stress Reduction Factor constant (SRF=1). Based on these factors, the excavation classes were divided into 09 Rock Classes (RC) viz RC1, 2, 3, 3M, 4M, 4S, 5, 6, 7. These 09 Rock Class were later modified into 07 Rock Class namely 1, 2, 3, 4M, 5, 6, and 7.

Table 2: Rock Mass Assessment

Category	Q_{insitu} Values (SRF = 1)*
Good	>10
Fair	4-10
Poor	1-4
Very Poor	0.4-1
Very Poor	0.1-0.4
Extremely Poor	0.01-0.1

Range of Q-values present in the tunnel-



Class	Q	RMR	GSI	C(MPa)	phi(deg)	σt(Mpa)	nu	E(GPa)
1	**0.01**	3	20	5.177	17.65	-0.020	0.2	87.1043
2	**0.1**	23	25	6.070	19.53	-0.030	0.22	87.1043
3	**0.3**	33	28	6.598	20.63	-0.039	0.24	87.1043
4	**1**	44	39	8.530	24.68	-0.098	0.26	87.1043
5	**3**	54	49	10.381	28.41	-0.228	0.33	87.1043
6	**30**	75	70	15.535	36.43	-1.349	0.31	87.1043
7	**40**	77	72	16.231	37.18	-1.598	0.32	87.1043

In-situ Stresses—

Depth= 450m

Gamma= 2730 kg/m^3 (Quartzite schist)

K= 1.5

σv= 1.59975MPa
σh= 1.0665 MPa

Tunnel Exacavation and Support—

Exacavation-

The tunnel was excavated with a **horizontal excavation sequence**. The tunnel face was divided into **top heading** and **bench**. To reach the breakthrough of the tunnel as soon as possible, the **highest priority was given to the top heading excavation**. Therefore, in case of any machinery or labour induction, all available resources were shifted to the top heading face, even at the cost of interruption to benching works which was excavated more than 1 km behind the top heading.

Support—

Primary support consisted of **shotcrete or steel fibre-reinforced shotcrete** lining with lattice girders and wire meshes. **Self-drilling and/or Swellex rock bolts** were used for radial rock bolting, spiles in the crown area as required. The final lining was made of cast-in-situ plain concrete, except the Seri Nala section and locations around large niches, where reinforced concrete was used. Construction activities was divided into the excavation, primary lining support works and final lining support works.

Description—

Excavation-

The tunnel should be excavated by drilling and blasting technology.

Tunnel boring machines cannot be used because of the inability to see inside the mountain.

Process to excavation-

1. Firstly, the drill holes are marked on the face of the tunnel based on the blasting pattern. Thereafter, the holes are drilled using manual excavators if the face is soft soil/rock, or with boomer machines if the face is hard rock.
2. Further, the explosives are inserted into the drilled holes and connected to detonators which are connected to one prime connection.
3. The prime connection where all the detonators are connected is detonated, which creates a chain reaction of explosions.
4. After the complete removal of the dust and harmful gases suffused due to the blast, the loose materials are removed from the face of the tunnel.
5. After the removal of loose material, primary supports are installed on the tunnel periphery. Shotcrete or rock bolts are used as primary supports.
6. Water ingress inside the tunnel is a major concern as it may lead to the failure of the structure. To avoid this situation, waterproofing membranes are provided after the installation of the primary support system.
7. If the strata demand more support and structural stability, supports in the form of lattice girder, steel ribs, and a second layer of shotcrete can be provided.
8. Finally, the precast concrete linings are installed throughout the periphery of the tunnel section.

Support-

Rockbolt-

Rockbolts and dowels have been used for many years for the support of underground excavations and a wide variety of bolt and dowel types have been developed to meet different needs which arise in mining and civil engineering.

Rockbolts generally consist of plain steel rods with a mechanical or chemical anchor at one end and a face plate and nut at the other. They are always tensioned after installation. For short term applications the bolts are generally left ungrouted. For more permanent applications or in rock in which corrosive groundwater is present, the space between the bolt and the rock can be filled with cement or resin grout.

Types-
1. Mechanically anchored rockbolts
2. Resin anchored rockbolts

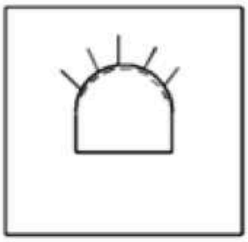
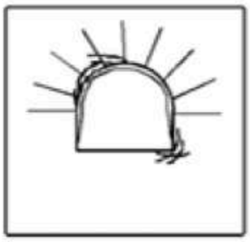
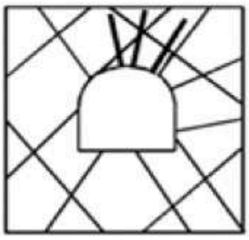
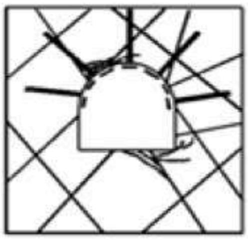
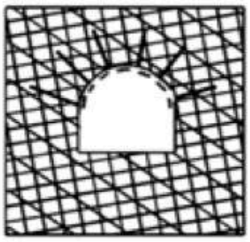
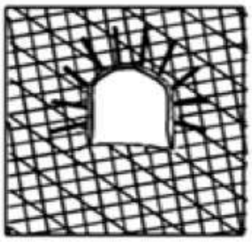
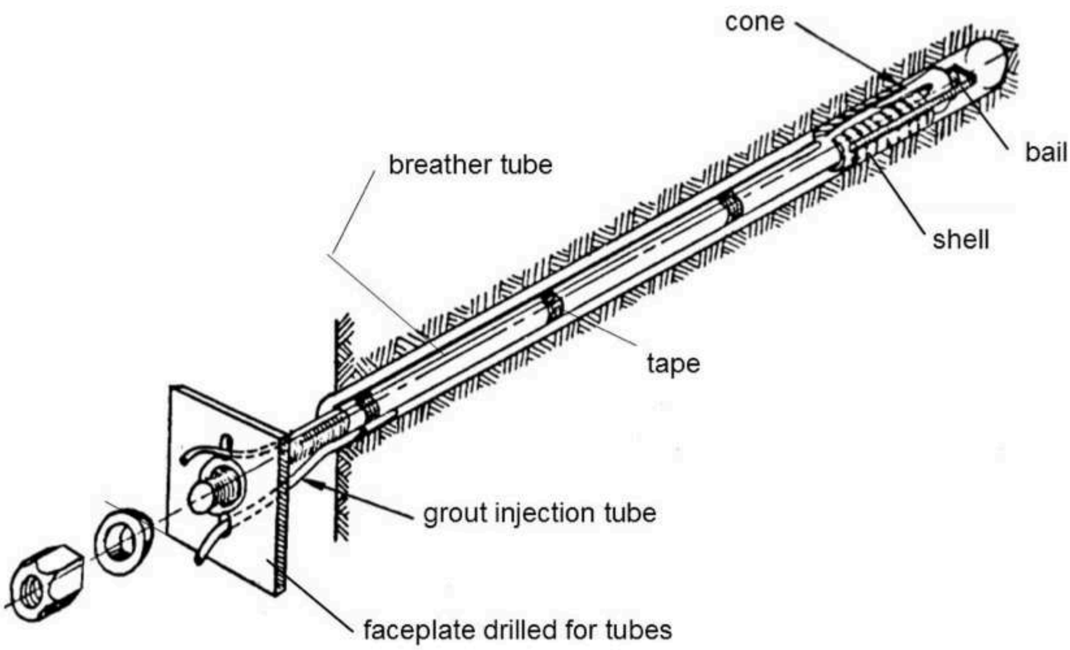
	Low stress levels	High stress levels
Massive rock	 Massive rock subjected to low in situ stress levels. No permanent support. Light support may be required for construction safety.	 Massive rock subjected to high in situ stress levels. Pattern rockbolts or dowels with mesh or shotcrete to inhibit fracturing and to keep broken rock in place.
Jointed rock	 Massive rock with relatively few discontinuities subjected to low in situ stress conditions. 'Spot' bolts located to prevent failure of individual blocks and wedges. Bolts must be tensioned.	 Massive rock with relatively few discontinuities subjected to high in situ stress conditions. Heavy bolts or dowels, inclined to cross rock structure, with mesh or steel fibre reinforced shotcrete on roof and sidewalls.
Heavily jointed rock	 Heavily jointed rock subjected to low in situ stress conditions. Light pattern bolts with mesh and/or shotcrete will control ravelling of near surface rock pieces.	 Heavily jointed rock subjected to high in situ stress conditions. Heavy rockbolt or dowel pattern with steel fibre reinforced shotcrete. In extreme cases, steel sets with sliding joints may be required. Invert struts or concrete floor slabs may be required to control floor heave.

Figure 1: Typical rockbolt and dowel applications to control different types of rock mass failure during tunnel driving.

Rockbolts and cables



Shotcrete-

Shotcrete, also called **Gunite**, concrete applied by spraying. It is a mixture of aggregate and portland cement, conveyed by compressed air to the nozzle of a spray gun, where water is added. The wet mixture is then sprayed in place and may be carved or troweled almost immediately. For structural uses, it is usually applied over a framework of reinforcing bars and steel mesh. Because it can take any shape, is easily coloured, and can be sculptured after application, It is used for a variety of fancy concrete structures, including artificial rock walls, zoo enclosures, canopy roofs, refractory linings, pools, and dams. It is sometimes used in tunneling to bind the walls of the tunnel to prevent leaks and fragmentation.

Shotcrete is the generic name for cement, sand and fine aggregate concretes which are applied pneumatically and compacted dynamically under high velocity.

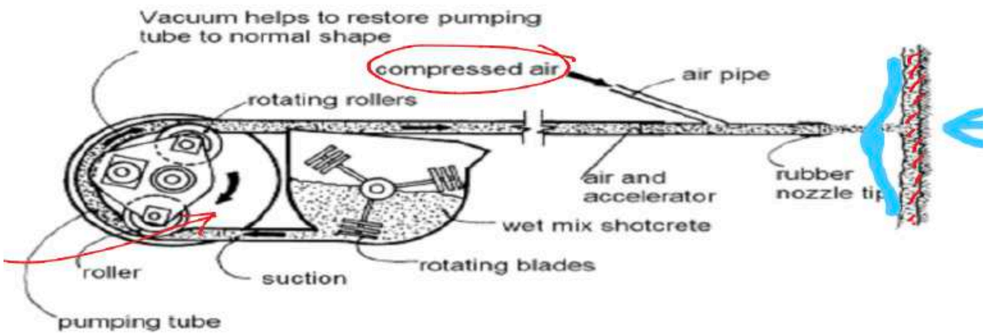


Figure 2: One typical type of wet mix shotcrete machine. After Mahar et al (1975).

Design Methodology For Initial Support—

Rock Mass Classification- Rock Mass Classification is to establish the quality of a particular rock mass (or part of a rock mass) by assigning rating values to a set of rock parameters which, under a particular set of engineering constraints, will behave in a similar way.

Major Engineering Rock Mass Classifications (18)

Classification	Originator/ Year	Country	Applications
Rock Load Theory	Terzaghi,1946	USA	Tunnels with steel support Unsuitable for modern tunneling
Stand-up time	Lauffer,1958	Austria	Tunneling; Conservative
New Austrian Tunneling method (NATM)	Rabcewicz, 1964/65 and 1975	Austria	Tunneling in incompetent (overstresses) ground; unutilized in squeezing ground condition
Rock Quality Designation (RQD)	Deere et al., 1967	USA	Tunneling; Sensitive to orientation effects
Rock structure rating (RSR)	Wickham et al., 1972	USA	Tunnels with steel support Not useful with steel fiber shotcrete
RMR	Bieniawski, 1973 (last modified, 1989 – USA)	South Africa	Tunnels, mines, Slopes foundations
NGI/Q-system	Barton et al., 1974 (modified 2002)	Norway	Tunnels and Wide openings
Mining RMR	Laubscher, 1975		Mining
The typological classification	Matula and Holzer, 1978		For use in communication

Q- Classification-

Barton et. al. (1974)

$$Q = \overset{\text{Block size}}{\boxed{\frac{RQD}{J_n}}} \times \overset{\text{Interblock shear strength}}{\boxed{\frac{J_r}{J_a}}} \times \overset{\text{Active stress}}{\boxed{\frac{J_w}{SRF}}}$$

RQD = Rock Quality Designation

J_n = Joint set number

J_r = Joint roughness

J_a = Joint alteration

J_w = Joint water condition

SRF = Stress reduction factor

Numerators with higher value reflects better quality rock, whereas denominators reflects better quality with their lower values

Block size

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

Interblock shear strength

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

Joint roughness number

Joint alteration number

J_w (Joint water reduction factor) measure of ground water pressure. (1 – 0.05) : dry to water under pressure.

SRF (stress reduction factor) is a measure of rock stress in a competent rock [UCS/major principal stress]. (0.5 – 20): low stress & favourable orientation to high stress)

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

Barton defined equivalent dimension D_e to relate **Q** to the behaviour and the support requirements of an underground excavation.

✓ D_e = equivalent dimension

$$D_e = \frac{\text{Excavation span, diameter, or height of the opening (stope), m}}{\text{Excavation Support Ratio (ESR)}}$$

✓ ESR (excavation support ratio)

– *f* (the tunnel use & **level of risk** chosen)

– indicates the length of safe unsupported span

Equivalent Support Ratio (ESR) Values
(Barton et. al., 1974)

Excavation Category	ESR
Temporary mine opening	3 – 5
Permanent mine opening	1.6
Storage rooms, water treatment plant, access tunnels etc.	1.3
Power stations, major road and railway tunnels, civil, defense chambers, portals etc	1.0
Underground nuclear power stations, public facility	0.75

ESR is roughly analogous to inverse of Factor of Safety

RMR/Geomechanics/CSIR classification-

- Prof. Z. T. Bieniawski developed in 1976 and modified in 1989. Spend 15 years and reported 351 case histories.
- Original (1976) classification has eight (8) parameters whereas in modified (1989) only six (6) parameters

1976	1989
1. Uniaxial Compressive Strength (UCS) of rock material	1. UCS (15-0)*
2. Rock Quality Designation (*RQD*)	2. *RQD* (20 – 3)
3. State of weathering	Not included
4. Spacing of joints and bedding plane	3. Spacing of discontinuities (20 – 5)
5. Strike and dip orientation	4. Orientation of discontinuities (20 – 5)
6. Separation of joints	5. Condition of discontinuities (30 – 0)
7. Continuity of joints	
8. Ground water inflow	6. Ground water condition (20 – 5)

- **Spacing of discontinuities** - mean distance between the plane of weakness in the rock mass in the direction perpendicular to the discontinuity planes.
- **Orientation of discontinuities** – Refers to strike and Dip; Strike of discontinuities is recorded with reference to magnetic north.
- **Condition of discontinuities** - includes roughness, separation, their length or continuity (persistence), weathering of the wall rock, and the infilling (gouge) material.
- **Ground water condition** - rate of inflow of groundwater categorized as completely dry, damp, wet, dripping, and flowing.

$$\text{RMR} = \sum(\text{classification parameters}) + \text{discontinuity orientation adjustment}$$

Parameter			Range of values						
1	Strength of intact rock material	Point-load strength index (MPa)	>10	4–10	2–4	1–2	For this low range uniaxial compressive test is preferred		
		Uniaxial compressive strength (MPa)	>250	100–250	50–100	25–50	5–25	1–5	< 1
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD (%)		90–100	75–90	50–75	25–50	< 25		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities (mm)		> 2000	600–2000	200–600	60–200	< 60		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See Table 3.7E)		Very rough surfaces; Not continuous; No separation; Unweathered wall rock	Slightly rough surfaces; Separation < 1 mm; Slightly weathered walls	Slightly rough surfaces; Separation < 1 mm; Highly weathered walls	Slicken sided surfaces; Gouge < 5 mm thick; Separation 1–5 mm; Continuous	Soft gouge >5 mm thick; Separation > 5 mm; Continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10–25	25–125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1–0.2	0.2 – 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

Rock Quality determined from total ratings

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good	Good	Fair	Poor	Very poor

Meaning of Rock Class

Class number	I	II	III	IV	V
Average stand–up time	20 years for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 1 m span
Cohesion of rock mass (kPa)	> 400	300–400	200–300	100–200	< 100
Friction angle of rock mass (deg)	> 45	35–45	25–35	15–25	< 15

Effect of Discontinuity Strike and Dip Orientation in Tunneling

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		
Drive with dip		Drive against dip		Dip 45–90°	Dip 20–45°	Dip 0–20° irrespective of strike
Dip 45–90°	Dip 20–45°	Dip 45–90°	Dip 20–45°			
Very favourable	Favourable	Fair	Unfavourable	Very unfavourable	Fair	Fair

Table 3.7 E: Guideline for Discontinuity Condition

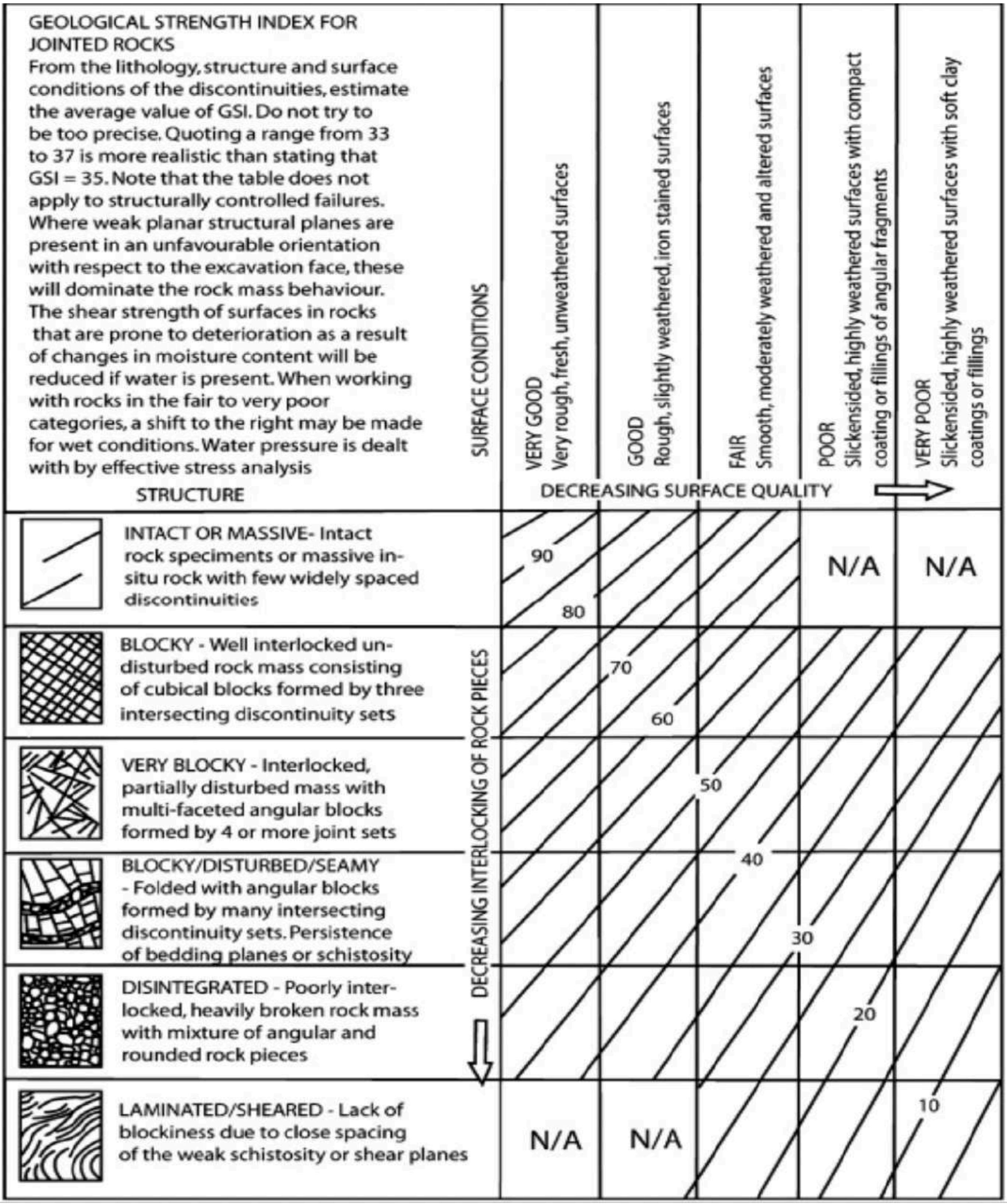
Discontinuity length (persistence), m	< 1	1 – 3	3 – 10	10 – 20	> 20
Rating	6	4	2	1	0
Aperture (mm)	None	< 0.1	0.1 – 1.0	1 – 5	> 5
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Rating	6	5	3	1	0

Rating adjustment for discontinuity Orientation

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Ratings	Tunnels and mines	0	–2	–5	–10	–12
	Foundations	0	2	–7	–15	–25
	Slopes	0	–5	–25	–50	

Geological Strength Index (GSI)-

Hoek & Brown (1997) devised a simple chart for estimating GSI based on rock mass and discontinuity surface condition.



UNWEDGE ANALYSIS—

UnWedge is a 3D stability analysis and visualization program for underground excavations in rock containing intersecting structural discontinuities. Safety factors are calculated for potentially unstable wedges and support requirements can be modeled using various types of pattern and spot bolting and shotcrete. Use UnWedge to quickly create a model, perform a safety factor analysis, place reinforcement and interpret the results. The graphical data interpreter provides a rich set of tools, including 3D animation, for the convenient display of wedges surrounding the excavation.

In addition to allowing for simple point and click geometry input/editing, UnWedge provides enhanced support models for bolts, shotcrete and support pressures, the ability to optimize tunnel orientation and an option to look at different combinations of three joint sets based on a list of more than three joint sets. UnWedge uses a new analysis engine based on Goodman and Shi's block theory, which includes the ability to incorporate induced stress around the excavation and the effect on stability, new strength models such as Barton-Bandis and Power Curve, and the ability to improve the scaling and sizing of wedges.

Numerical Modelling—

About-

A numerical model is a combination of a large number of mathematical equations that depends upon computers to find an approximate solution to the underlying physical problem.

Applications-

Numerical modelling has been used to investigate a variety of problems in underground mining and tunnelling: subsidence induced by longwall coal mining; stresses generated when an open stope is filled cemented backfill and the stability of exposures created during subsequent mining of adjacent stopes; the interaction of two tunnels; and the effects of under-mining a pre-existing tunnel and shaft. In each case, results from nonlinear stress analyses can be used to guide the design of excavations and rock support mechanisms.

Working-

A mathematical model is often described in systems of (partial) differential equations. Numerical modeling tries to solve these using not only well known and established numerical methods but also tries to conserve some physical properties like conservation of (discretized) mass or (discretized) momentum.

A typical example is the 2D staggered grid approximation of the continuity equation (as part of the Navier Stokes or Euler equations) that preserves the discretized mass across volume boundaries.

Tunnel Support Design—

INITIAL ESTIMATE OF SUPPORT BASED ON RMR & Q METHOD -

Since we are designing a tunnel so taking the **ESR** = **1 (as mentioned in above table for road tunnel)**

Rockbolt System/ Shotcrete-

Class	Q	RMR	GSI	Rockbolt spacing(m)	Rockbolt Length(m)	Shotcrete Thickness(cm)
1	**0.01**	3	20	1.5	3	25
2	**0.1**	23	25	1.7	3	15
3	**0.3**	33	28	2.2	3	12
4	**1**	44	39	2.5	3	9
5	**3**	54	49	N/A	N/A	6
6	**30**	75	70	N/A	N/A	5
7	**40**	77	72	N/A	N/A	N/A

*N/A means that support is not required

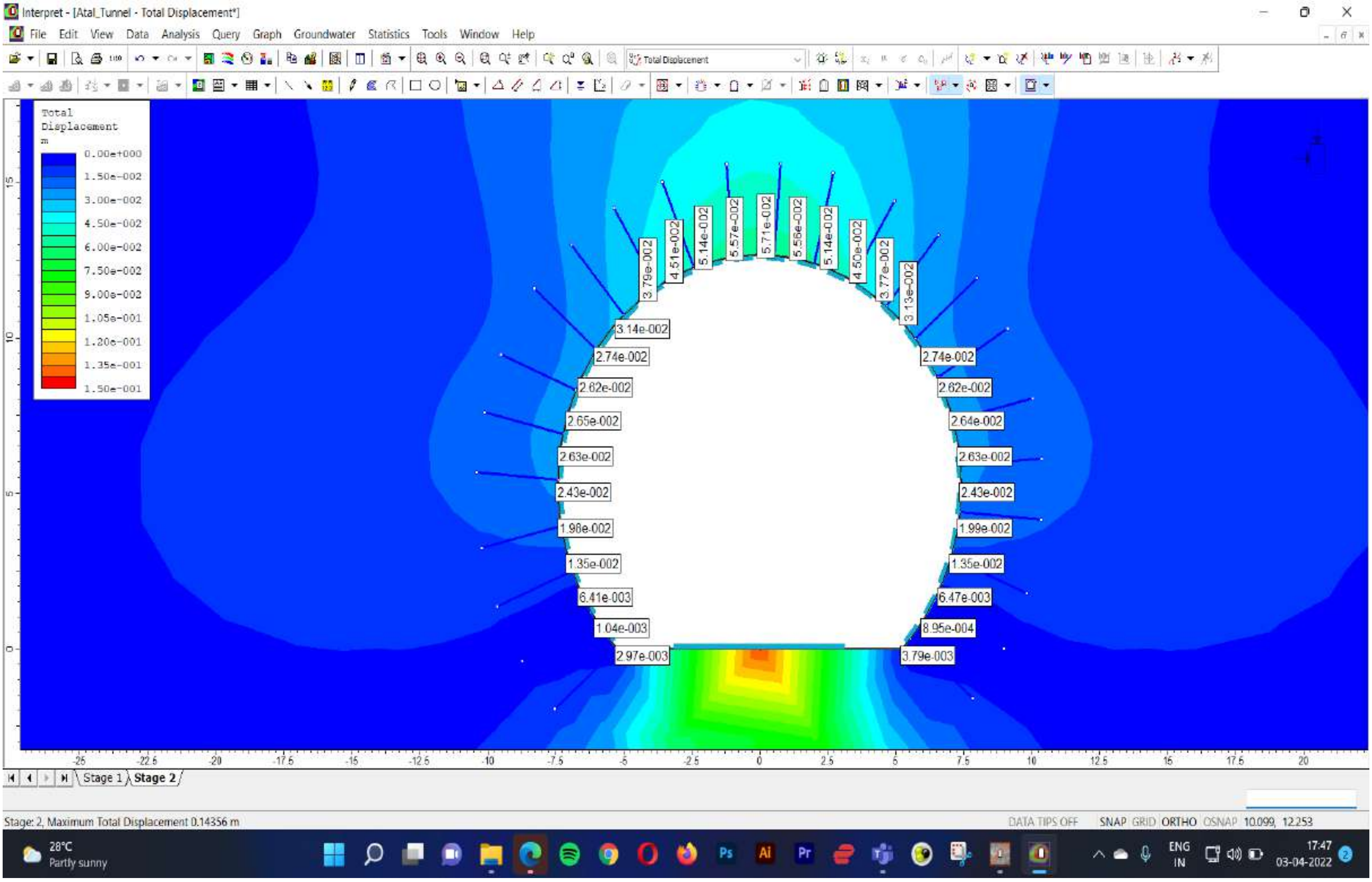
FEM ANALYSIS REPORT -

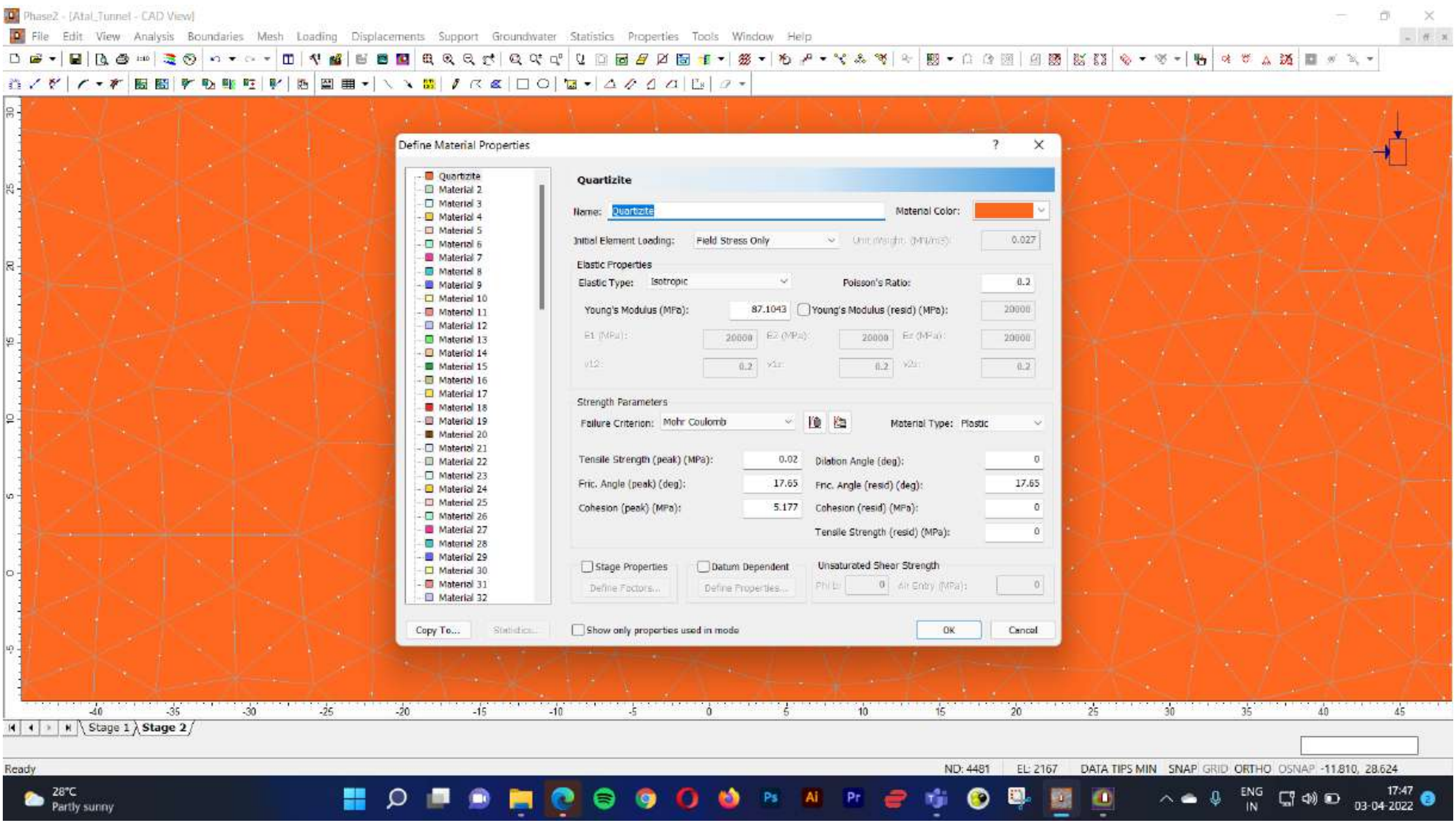
Class-1-

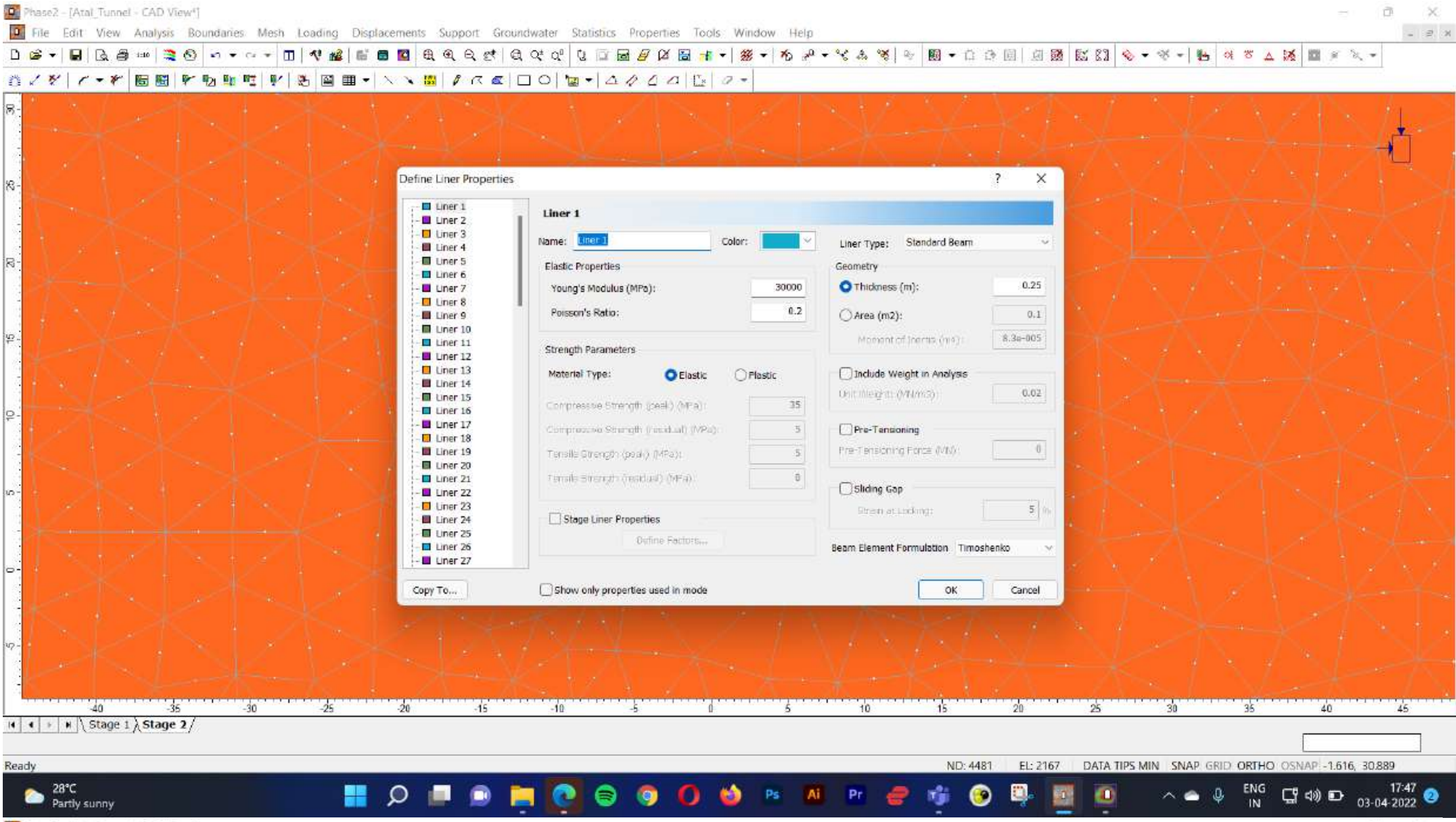
The Image are sequenced as follows for every class-

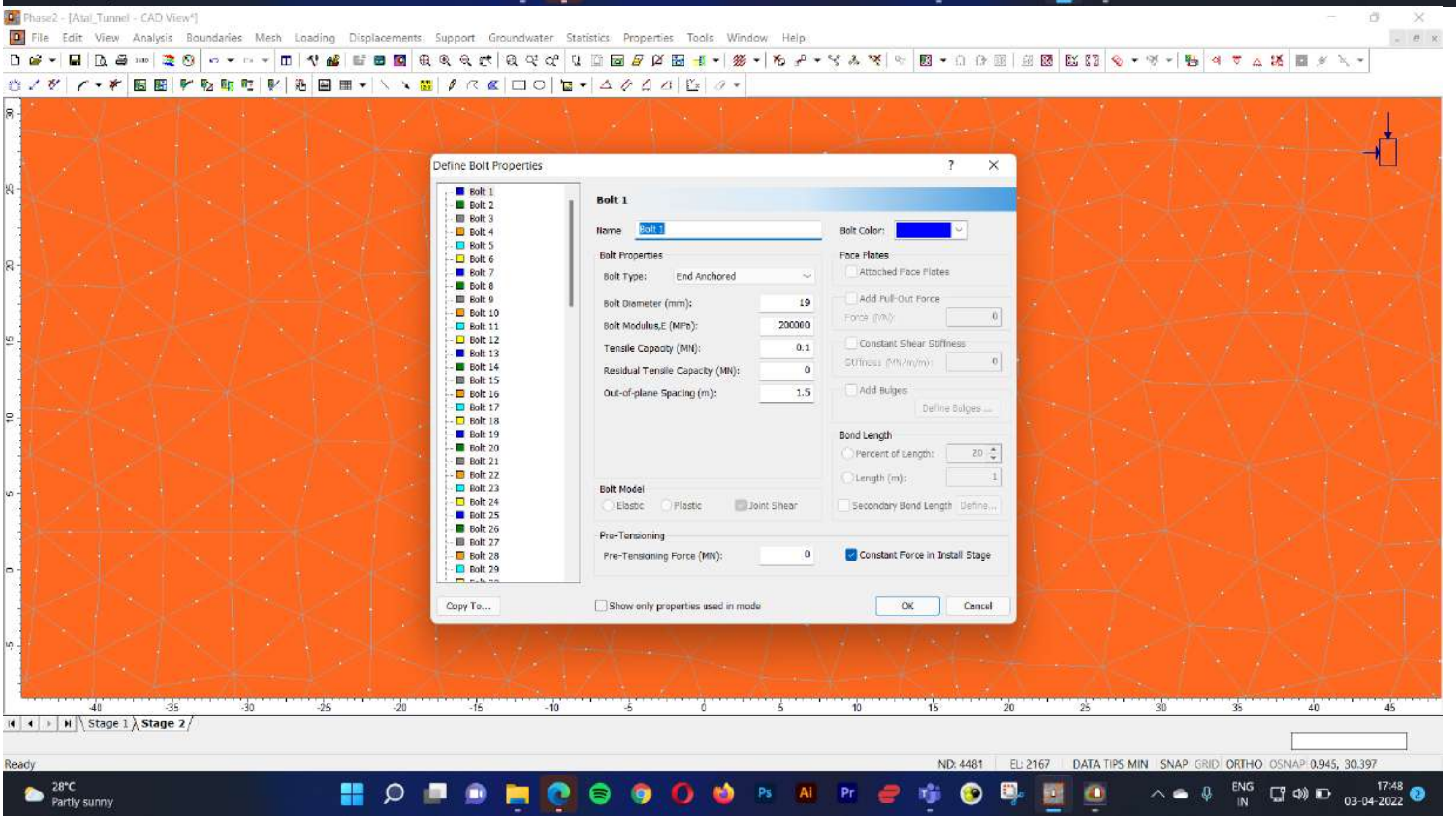
1. **Shows total displacement and failure zones**
2. **Material Properties**
3. **Rock Bolts properties**
4. **Shotcrete Properties**
5. **Rockbolt length and spacing**

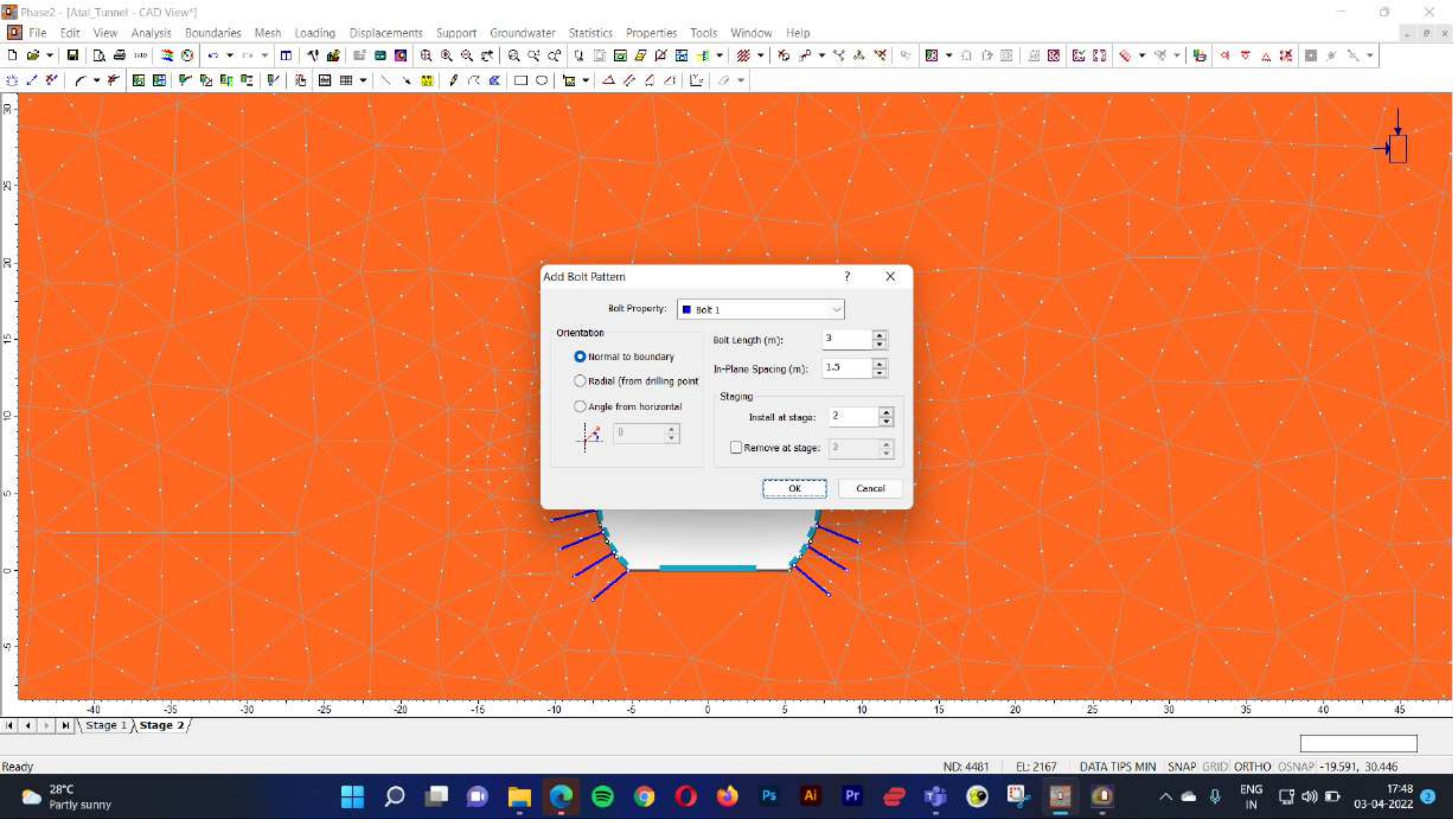
* If any of them are not present in any class, that means that support was not added in that support was not added in analysis of that class.


Interpret - [Atal_Tunnel - Total Displacement*]
Total Displacement
m
0.00e+000
1.50e-002
3.00e-002
4.50e-002
6.00e-002
7.50e-002
9.00e-002
1.05e-001
1.20e-001
1.35e-001
1.50e-001
Stage 1
Stage 2
Stage: 2, Maximum Total Displacement 0.14356 m

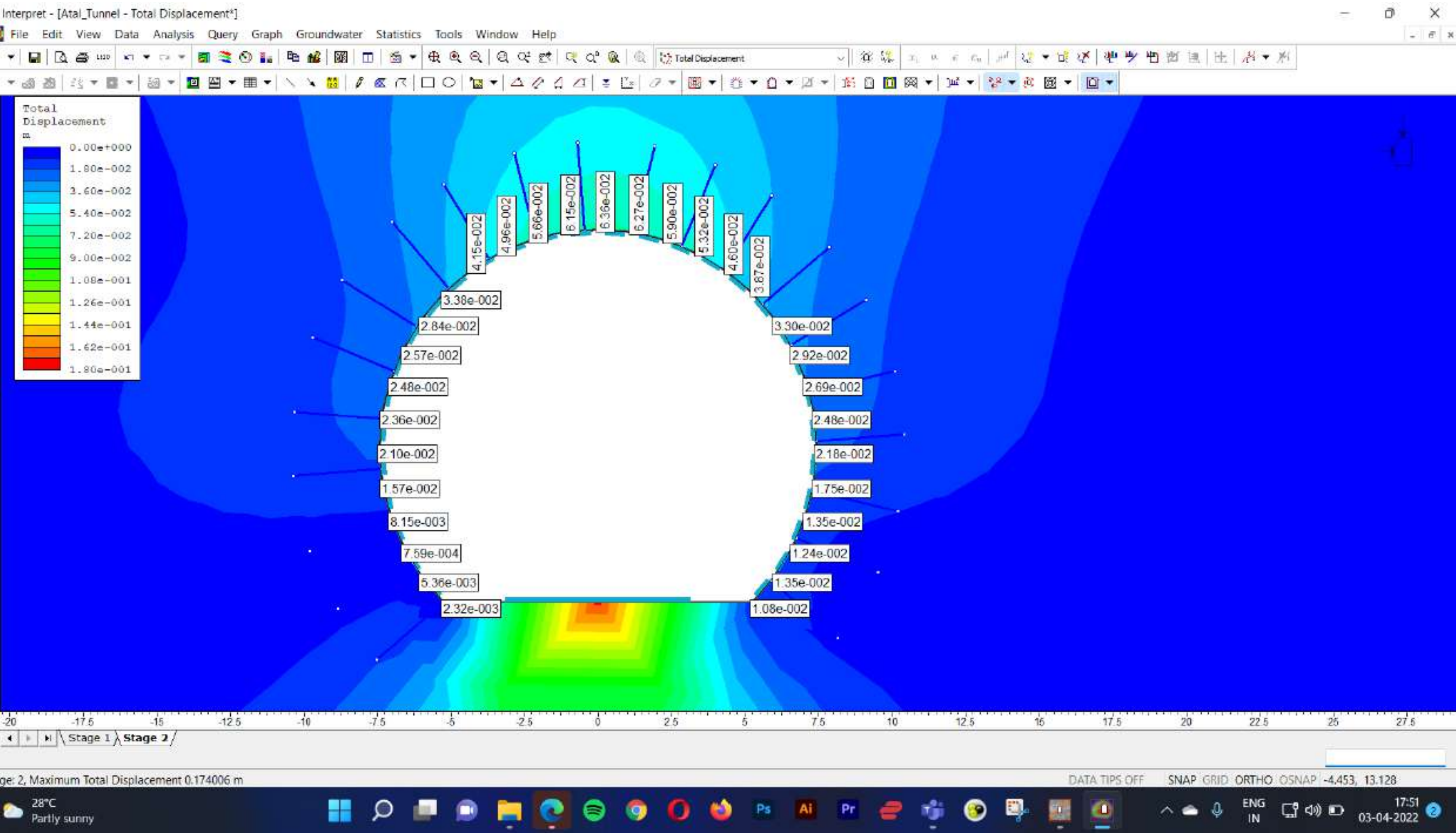

Phase2 - [Atal_Tunnel - CAD View]
Define Material Properties
Quartzite
Name: Quartzite
Material Color:
Initial Element Loading: Field Stress Only
Unit Weight (MN/m3): 0.027
Elastic Properties
Elastic Type: Isotropic
Poisson's Ratio: 0.2
Young's Modulus (MPa): 87.1043
Young's Modulus (resid) (MPa): 20000
Strength Parameters
Failure Criterion: Mohr Coulomb
Material Type: Plastic
Tensile Strength (peak) (MPa): 0.02
Fric. Angle (peak) (deg): 17.65
Cohesion (peak) (MPa): 5.177
Dilation Angle (deg): 0
Fric. Angle (resid) (deg): 17.65
Cohesion (resid) (MPa): 0
Tensile Strength (resid) (MPa): 0
Stage Properties
Datum Dependent
Unsaturated Shear Strength
Copy To...
Show only properties used in model
OK
Cancel
Stage 1
Stage 2

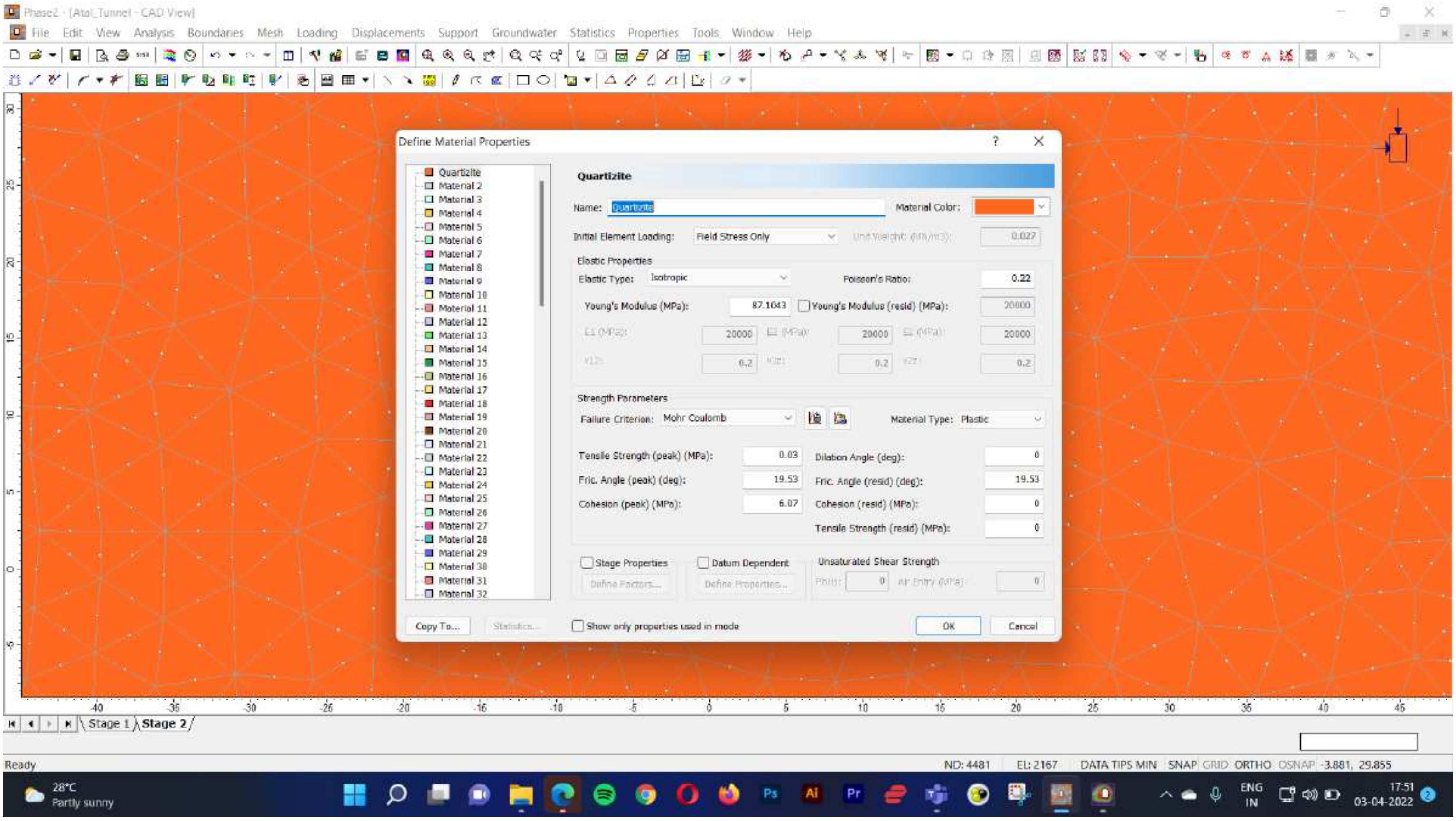

Phase2 - [Atal_Tunnel - CAD View*]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Liner Properties
Liner 1
Name: Liner 1
Color:
Liner Type: Standard Beam
Elastic Properties
Young's Modulus (MPa): 30000
Poisson's Ratio: 0.2
Geometry
Thickness (m): 0.25
Area (m2): 0.1
Moment of Inertia (m4): 8.3e-005
Strength Parameters
Material Type: Elastic Plastic
Compressive Strength (peak) (MPa): 35
Compressive Strength (residual) (MPa): 5
Tensile Strength (peak) (MPa): 5
Tensile Strength (residual) (MPa): 0
Include Weight in Analysis
Unit Weight (MN/m3): 0.02
Pre-Tensioning
Pre-Tensioning Force (MN): 0
Sliding Gap
Strain at Locking: 5
Stage Liner Properties
Define Factors...
Beam Element Formulation Timoshenko
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1 Stage 2
Ready
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP -1.616, 30.889
28°C Partly sunny
17:47 03-04-2022

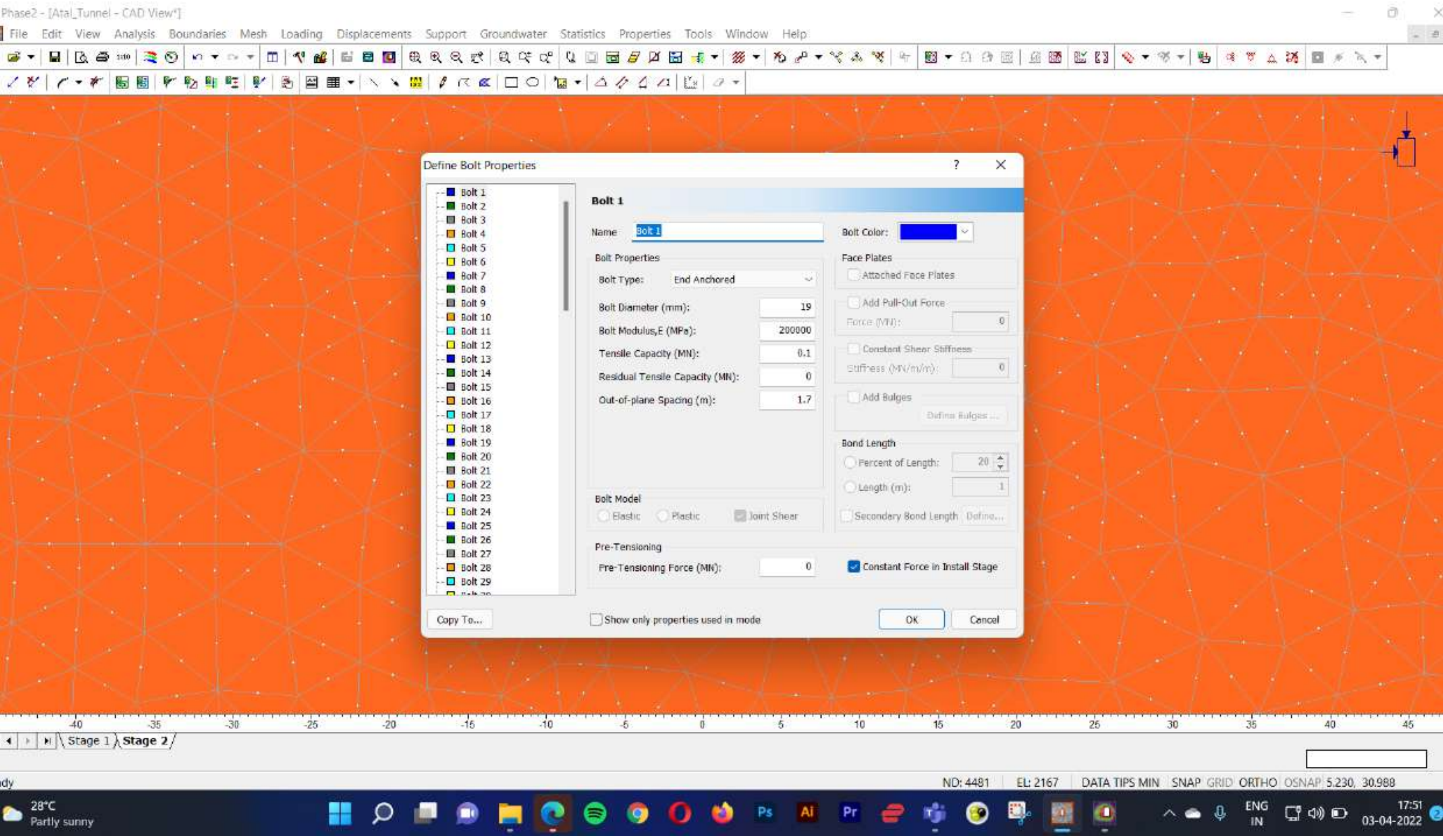

Phase2 - [Atal_Tunnel - CAD View*]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Bolt Properties
Bolt 1
Name Bolt 1
Bolt Color:
Bolt Properties
Bolt Type: End Anchored
Bolt Diameter (mm): 19
Bolt Modulus,E (MPa): 200000
Tensile Capacity (MN): 0.1
Residual Tensile Capacity (MN): 0
Out-of-plane Spacing (m): 1.5
Face Plates
Attached Face Plates
Add Pull-Out Force
Force (MN): 0
Constant Shear Stiffness
Stiffness (MN/m/m): 0
Add Bulges
Define Bulges ...
Bond Length
Percent of Length: 20
Length (m): 1
Bolt Model
Elastic Plastic Joint Shear
Secondary Bond Length Define...
Pre-Tensioning
Pre-Tensioning Force (MN): 0
Constant Force in Install Stage
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1 Stage 2
Ready
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP 0.945, 30.397
28°C Partly sunny
17:48 03-04-2022

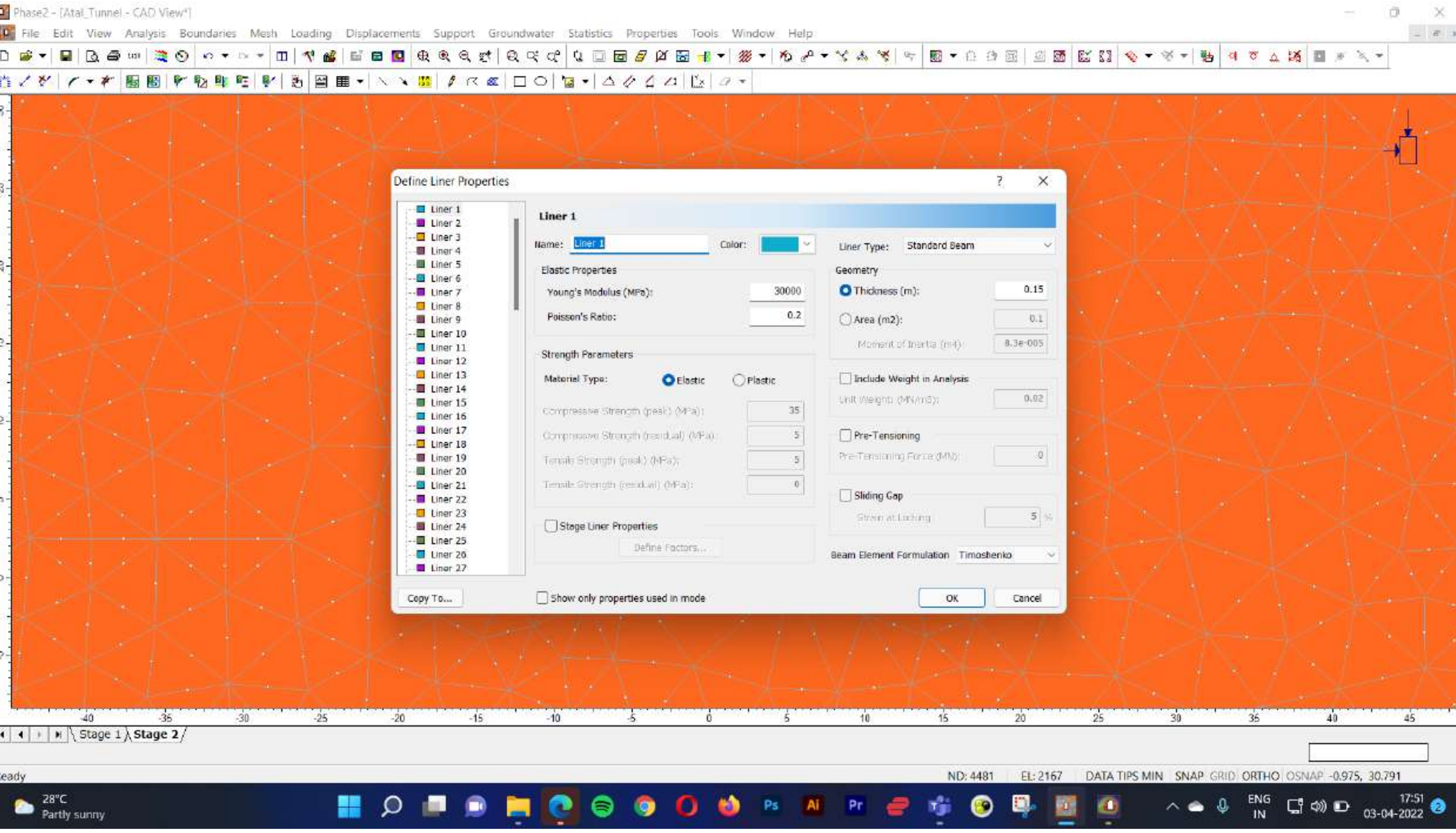


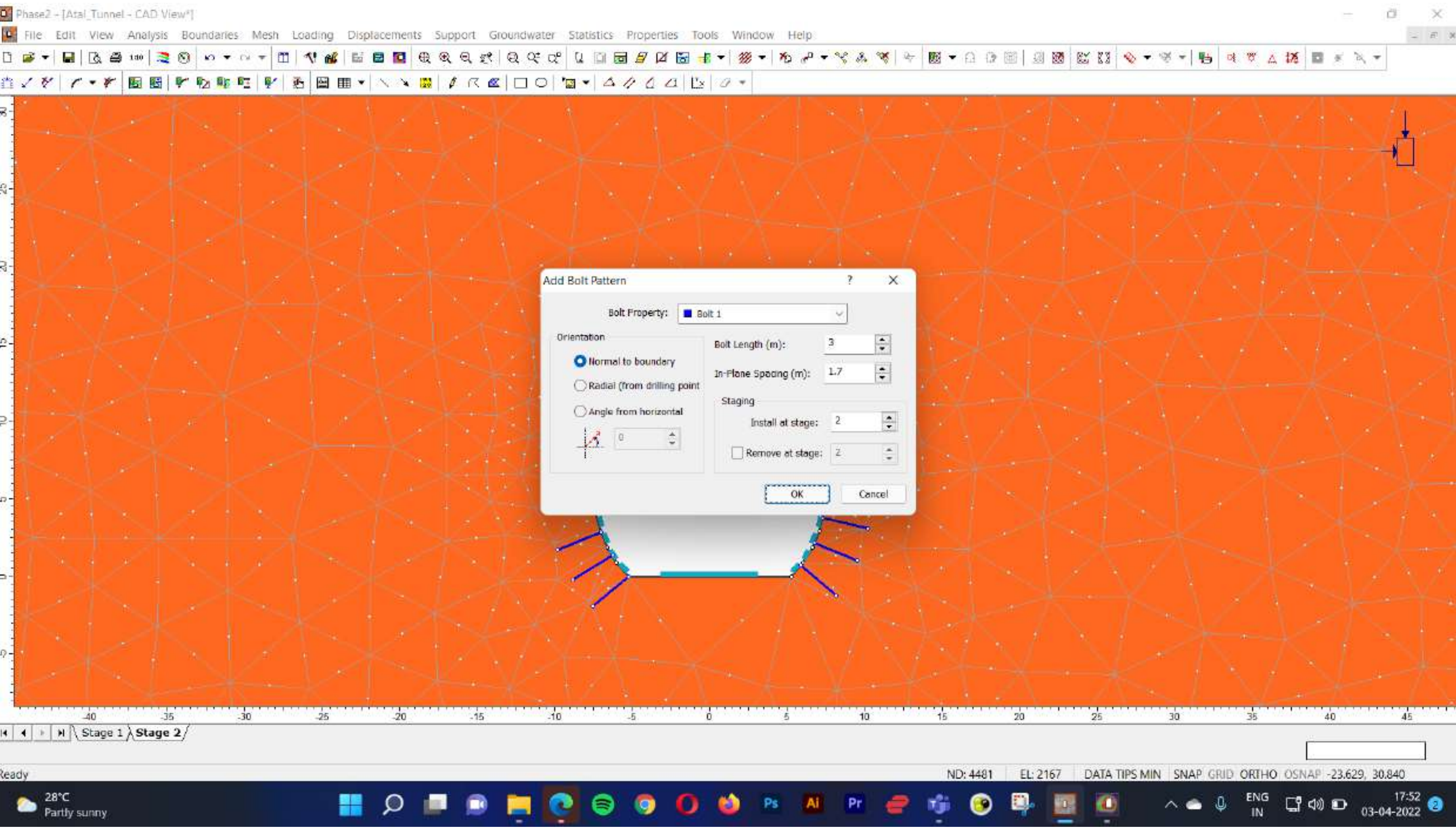
Class-2-



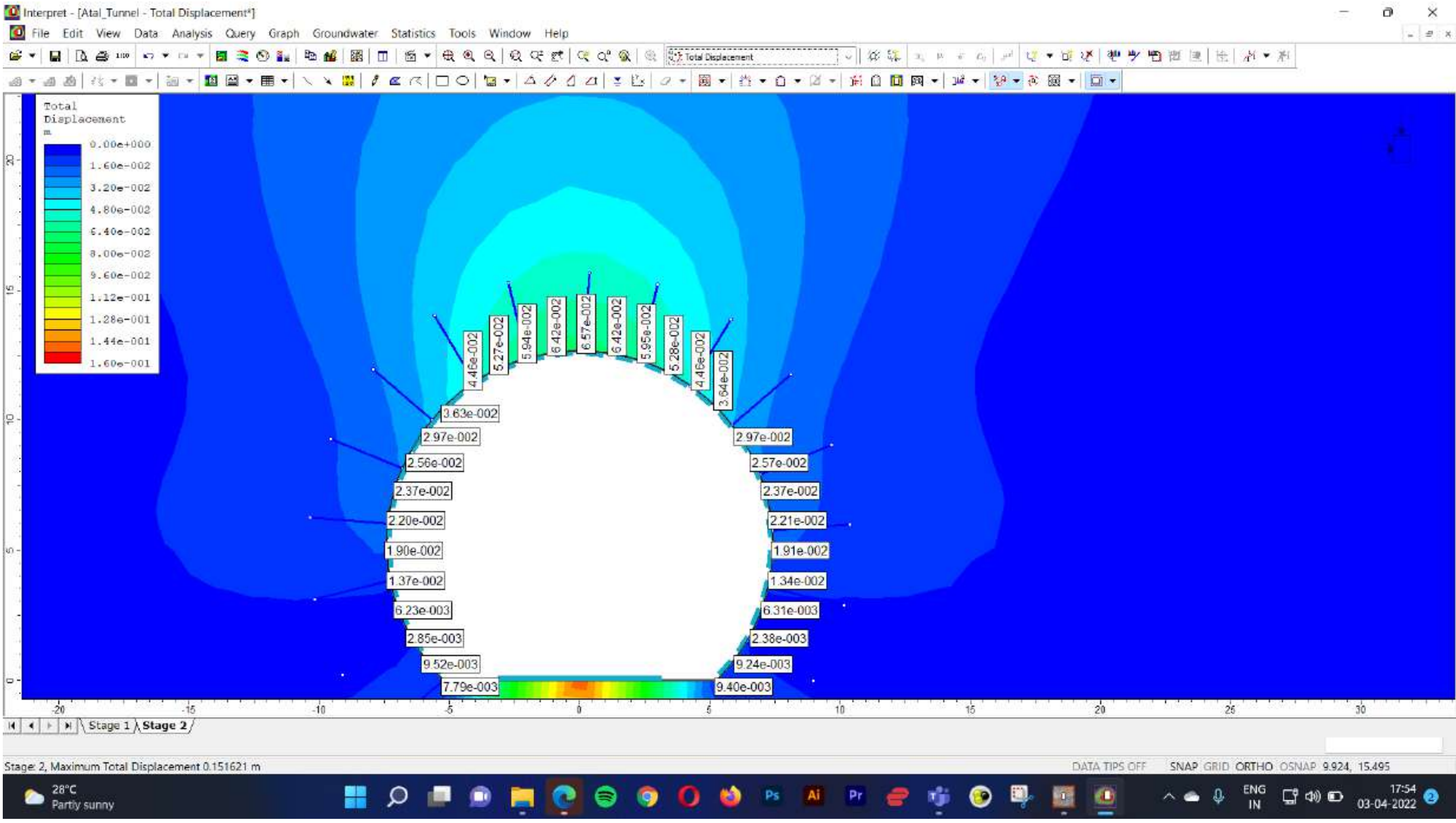

Phase2 - [Atal_Tunnel - CAD View]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Material Properties
Quartzite
Name: Quartzite
Material Color:
Initial Element Loading: Field Stress Only
Elastic Properties
Elastic Type: Isotropic
Poisson's Ratio: 0.22
Young's Modulus (MPa): 87.1043
Young's Modulus (resid) (MPa):
Strength Parameters
Failure Criterion: Mohr Coulomb
Material Type: Plastic
Tensile Strength (peak) (MPa): 0.03
Dilation Angle (deg): 0
Fric. Angle (peak) (deg): 19.53
Fric. Angle (resid) (deg): 19.53
Cohesion (peak) (MPa): 6.07
Cohesion (resid) (MPa): 0
Tensile Strength (resid) (MPa): 0
Stage Properties
Datum Dependent
Unsaturated Shear Strength
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1
Stage 2
Ready
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP -3.881, 29.855
28°C
Partly sunny
17:51
03-04-2022

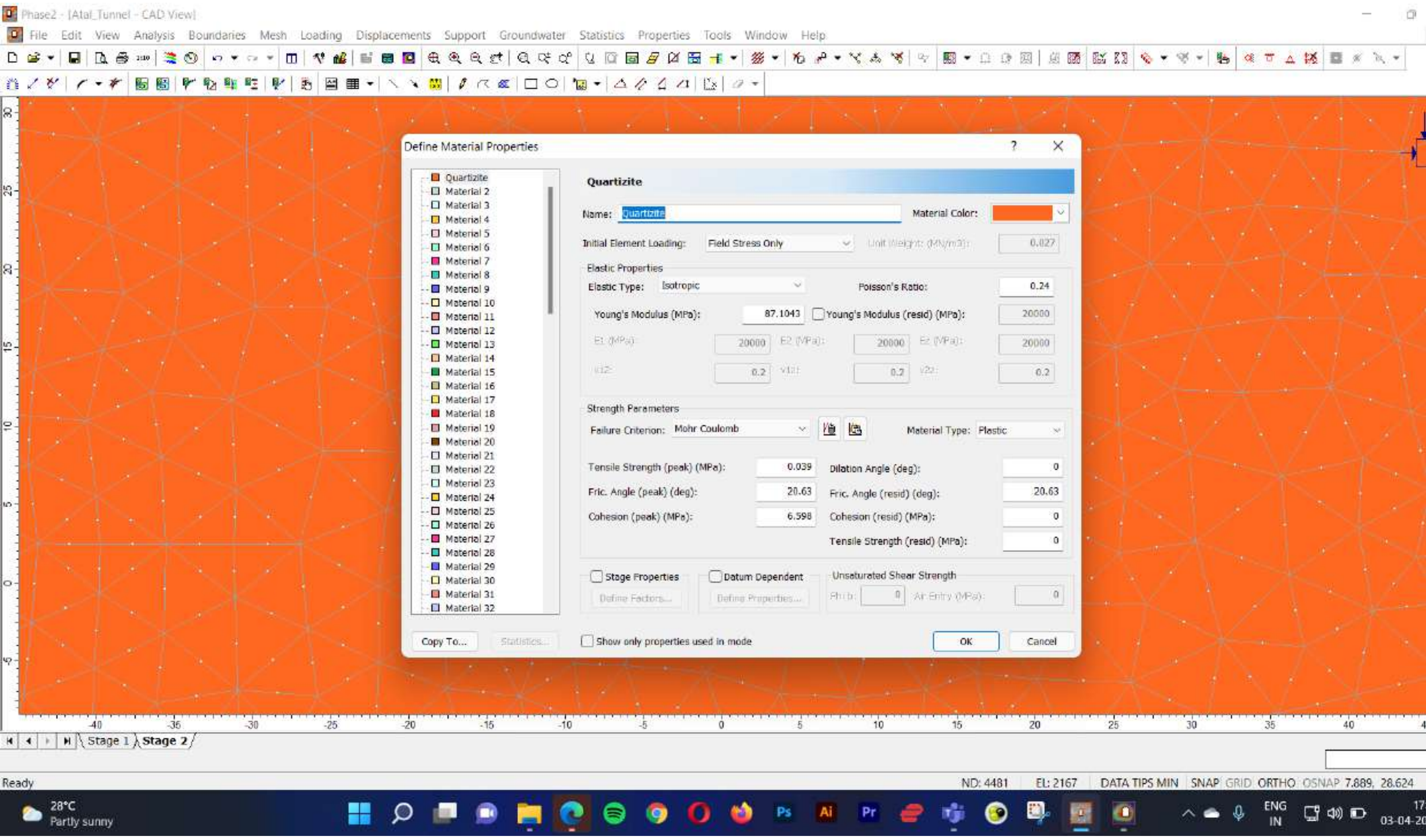

Phase2 - [Atal_Tunnel - CAD View*]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Bolt Properties
Bolt 1
Name: Bolt 1
Bolt Color:
Bolt Properties
Bolt Type: End Anchored
Bolt Diameter (mm): 19
Bolt Modulus,E (MPa): 200000
Tensile Capacity (MN): 0.1
Residual Tensile Capacity (MN): 0
Out-of-plane Spacing (m): 1.7
Face Plates
Attached Face Plates
Add Pull-Out Force
Constant Shear Stiffness
Add Bulges
Bond Length
Percent of Length: 20
Length (m): 1
Bolt Model
Elastic
Plastic
Joint Shear
Secondary Bond Length
Pre-Tensioning
Pre-Tensioning Force (MN): 0
Constant Force in Install Stage
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1
Stage 2
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP 5.230, 30.988
28°C
Partly sunny
17:51
03-04-2022

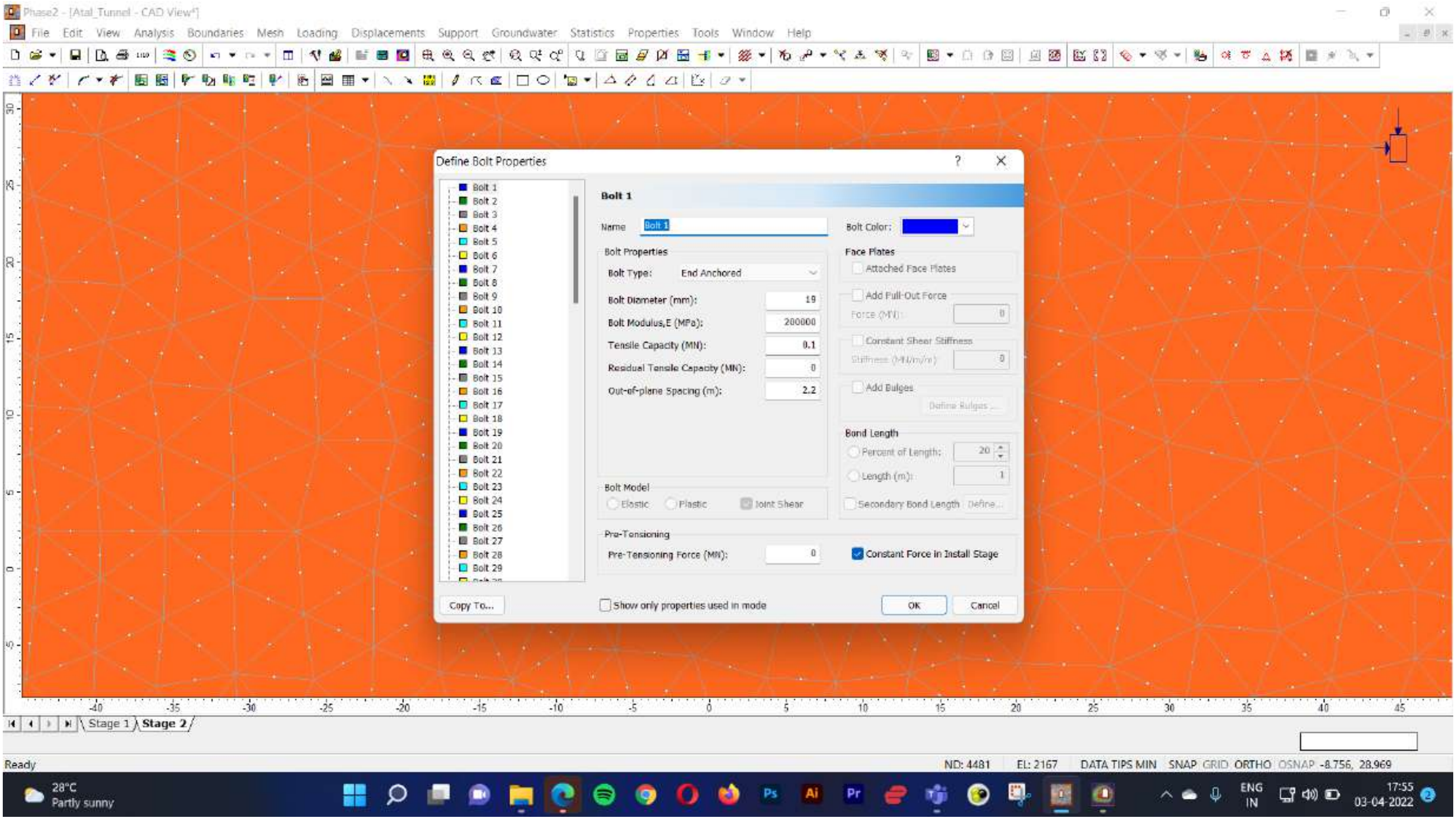

Phase2 - [Atal_Tunnel - CAD View*]
Define Liner Properties
Liner 1
Name: Liner 1
Color:
Liner Type: Standard Beam
Elastic Properties
Young's Modulus (MPa): 30000
Poisson's Ratio: 0.2
Geometry
Thickness (m): 0.15
Area (m2): 0.1
Strength Parameters
Material Type: Elastic Plastic
Include Weight in Analysis
Pre-Tensioning
Sliding Gap
Stage Liner Properties
Beam Element Formulation Timoshenko
Copy To...
Show only properties used in model
OK
Cancel
Stage 1 Stage 2
Ready
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP -0.975, 30.791
28°C Partly sunny
17:51 03-04-2022

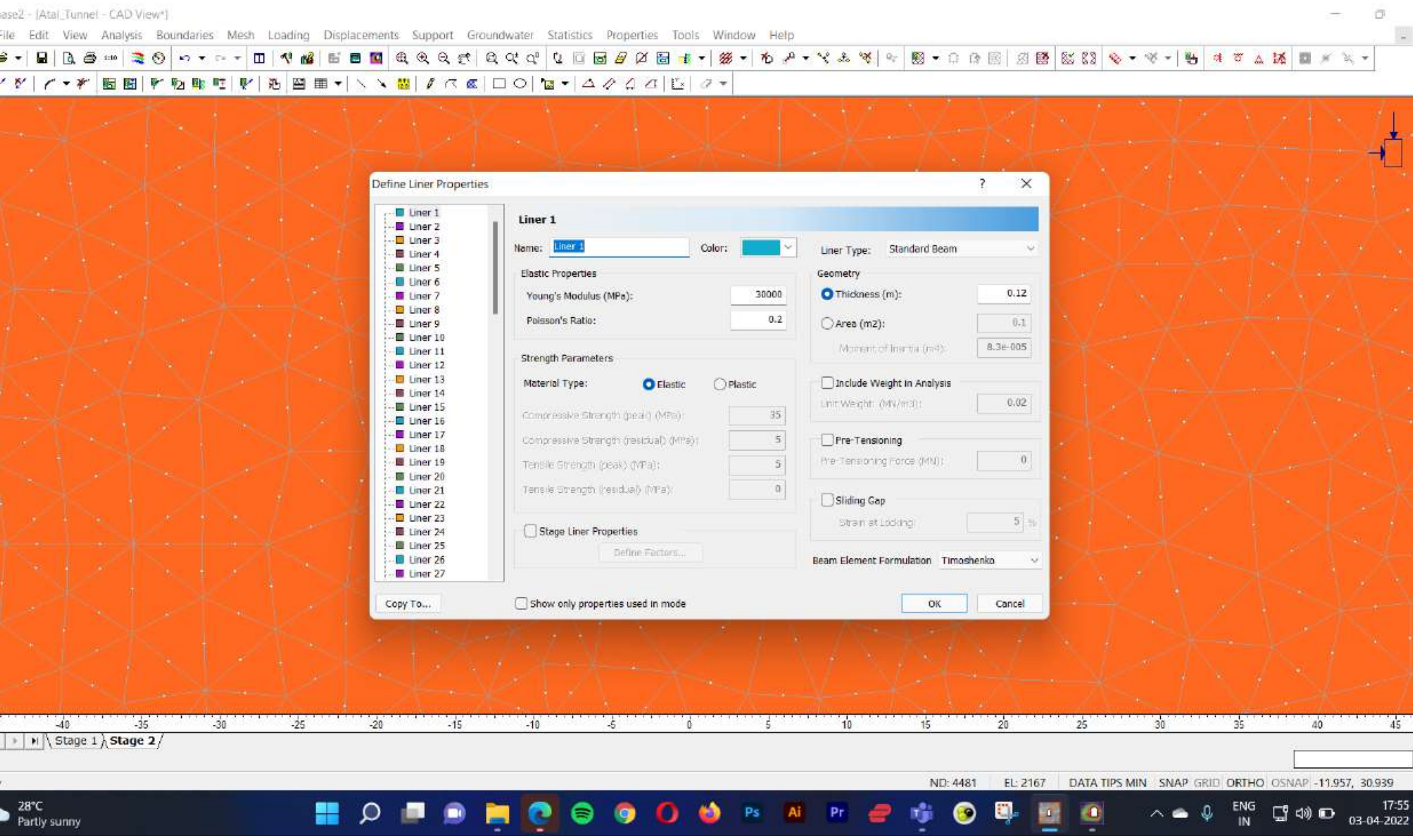

Phase2 - [Atal_Tunnel - CAD View*]
Add Bolt Pattern
Bolt Property: Bolt 1
Orientation
Normal to boundary
Radial (from drilling point
Angle from horizontal
Bolt Length (m): 3
In-Plane Spacing (m): 1.7
Staging
Install at stage: 2
Remove at stage: 2
OK
Cancel
Stage 1 Stage 2
Ready
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP -23.629, 30.840
28°C Partly sunny
17:52 03-04-2022

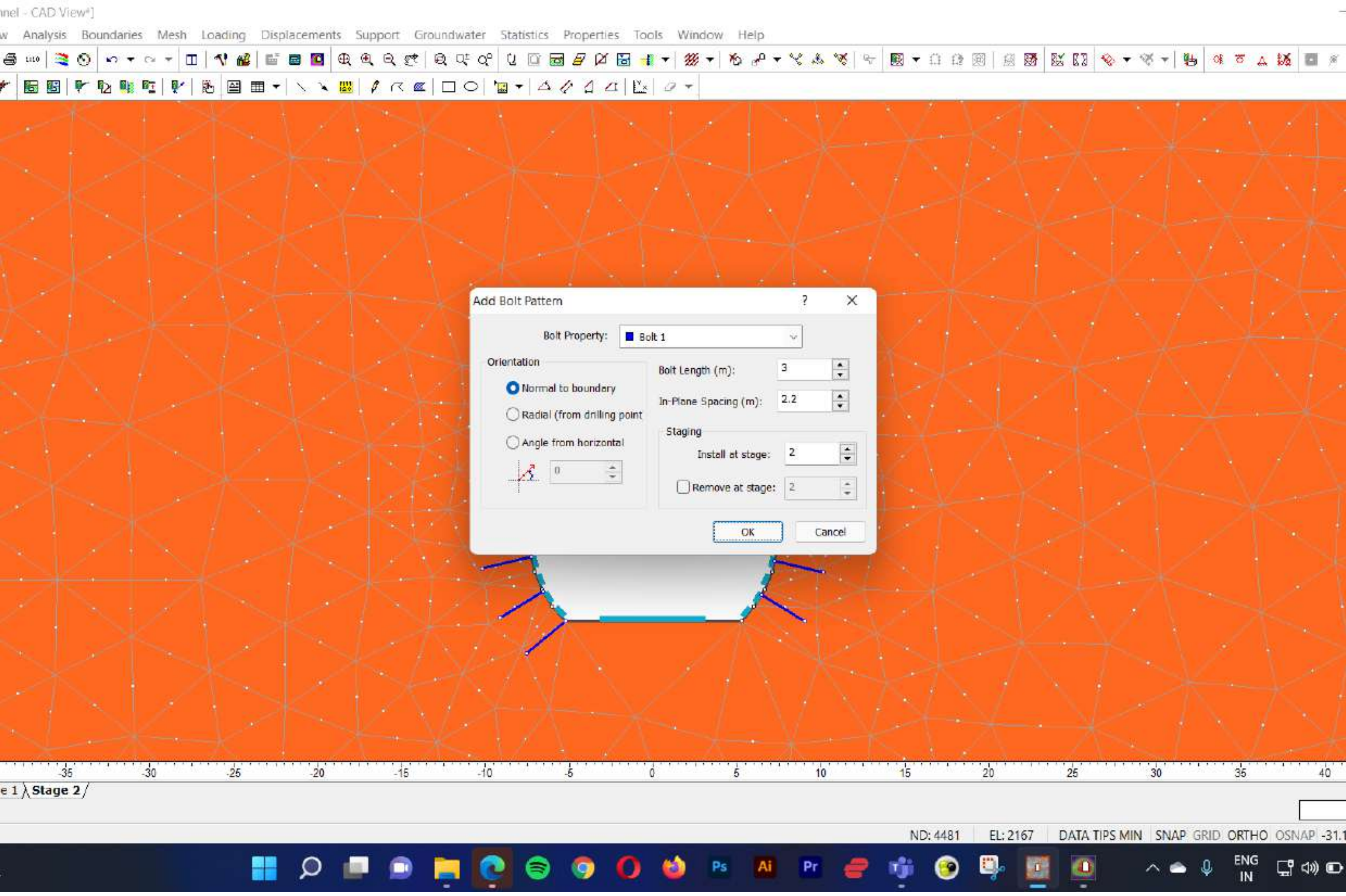
Class-3-


Interpret - [Atal_Tunnel - Total Displacement*]
File Edit View Data Analysis Query Graph Groundwater Statistics Tools Window Help
Total Displacement
Total Displacement m
0.00e+000
1.60e-002
3.20e-002
4.80e-002
6.40e-002
8.00e-002
9.60e-002
1.12e-001
1.28e-001
1.44e-001
1.60e-001
4.46e-002
5.27e-002
5.94e-002
6.42e-002
6.57e-002
6.42e-002
5.95e-002
5.28e-002
4.45e-002
3.64e-002
3.63e-002
2.97e-002
2.56e-002
2.37e-002
2.20e-002
1.90e-002
1.37e-002
6.23e-003
2.85e-003
9.52e-003
7.79e-003
2.97e-002
2.57e-002
2.37e-002
2.21e-002
1.91e-002
1.34e-002
6.31e-003
2.38e-003
9.24e-003
9.40e-003
Stage 1
Stage 2
Stage: 2, Maximum Total Displacement 0.151621 m
DATA TIPS OFF
SNAP GRID ORTHO OSNAP 9.924, 15.495
28°C
Partly sunny
ENG IN
17:54
03-04-2022

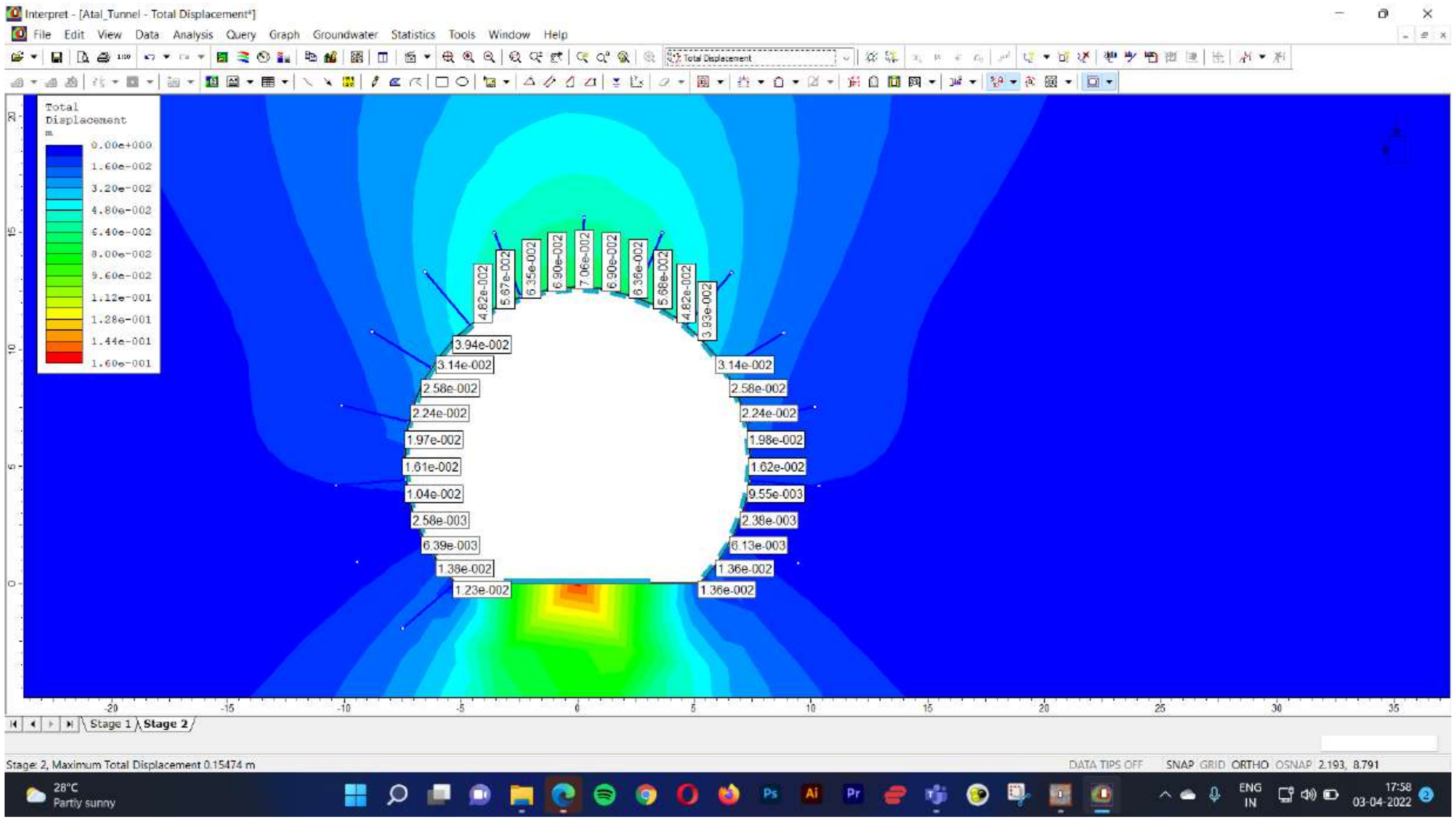

Phase2 - [Atal_Tunnel - CAD View]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Material Properties
Quartzite
Name: Quartzite
Material Color:
Initial Element Loading: Field Stress Only
Unit Weight (MN/m3): 0.027
Elastic Properties
Elastic Type: Isotropic
Poisson's Ratio: 0.24
Young's Modulus (MPa): 87.1043
Young's Modulus (resid) (MPa): 20000
Strength Parameters
Failure Criterion: Mohr Coulomb
Material Type: Plastic
Tensile Strength (peak) (MPa): 0.039
Dilation Angle (deg): 0
Fric. Angle (peak) (deg): 20.63
Fric. Angle (resid) (deg): 20.63
Cohesion (peak) (MPa): 6.598
Cohesion (resid) (MPa): 0
Tensile Strength (resid) (MPa): 0
Stage Properties
Datum Dependent
Unsaturated Shear Strength
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1
Stage 2
Ready
ND: 4481
EL: 2167
DATA TIPS MIN
SNAP GRID ORTHO OSNAP 7.889, 28.624
28°C
Partly sunny

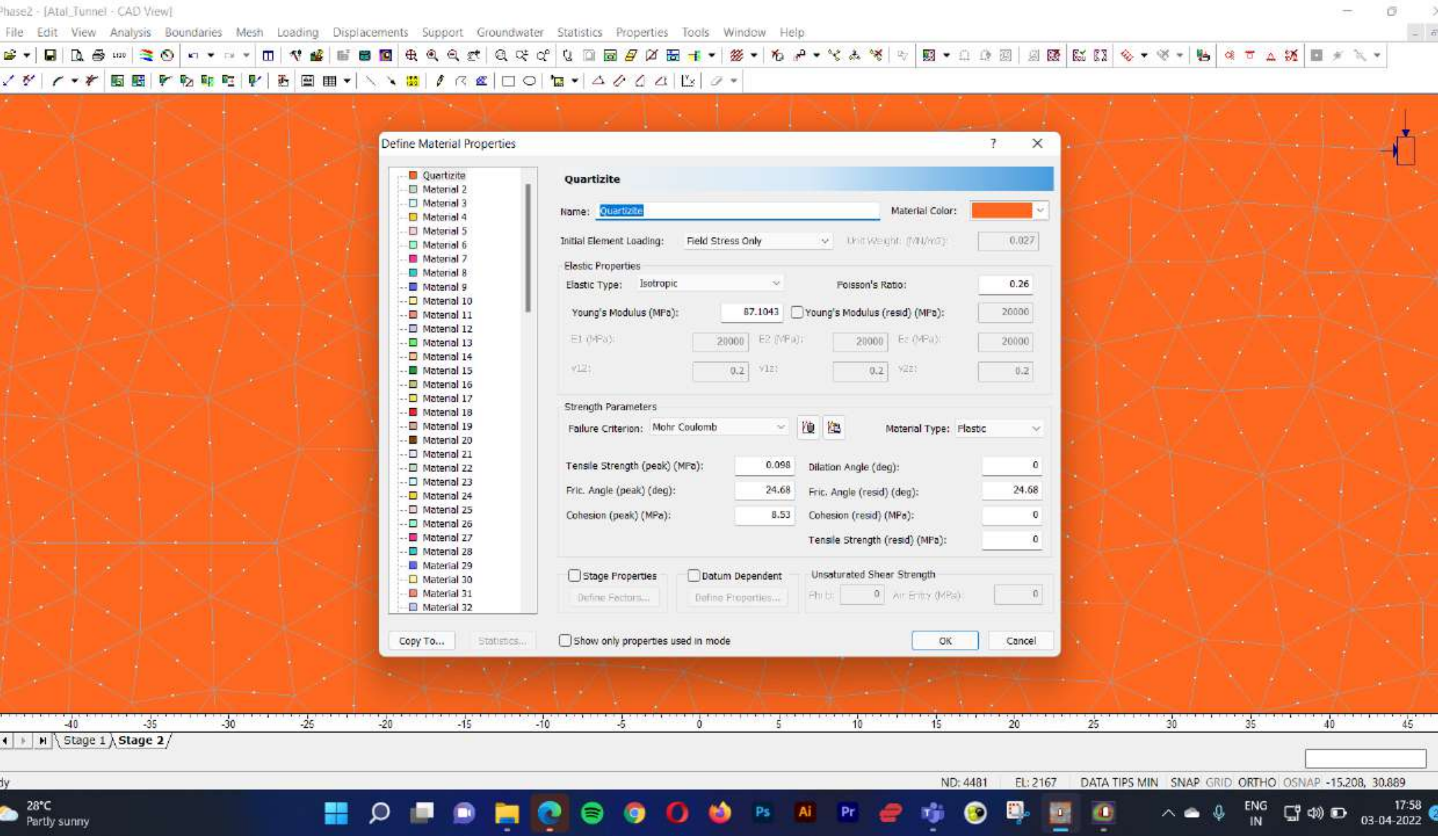

Phase2 - [Atal_Tunnel - CAD View*]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Bolt Properties
Bolt 1
Name Bolt 1
Bolt Color:
Bolt Properties
Bolt Type: End Anchored
Bolt Diameter (mm): 19
Bolt Modulus,E (MPa): 200000
Tensile Capacity (MN): 0.1
Residual Tensile Capacity (MN): 0
Out-of-plane Spacing (m): 2.2
Face Plates
Attached Face Plates
Add Pull-Out Force
Force (MN): 0
Constant Shear Stiffness
Stiffness (MN/m/m): 0
Add Bulges
Define Bulges...
Bond Length
Percent of Length: 20
Length (m): 1
Bolt Model
Elastic Plastic Joint Shear
Secondary Bond Length Define...
Pre-Tensioning
Pre-Tensioning Force (MN): 0
Constant Force in Install Stage
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1 Stage 2
Ready
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP -8.756, 28.969
28°C
Partly sunny
ENG IN
17:55
03-04-2022

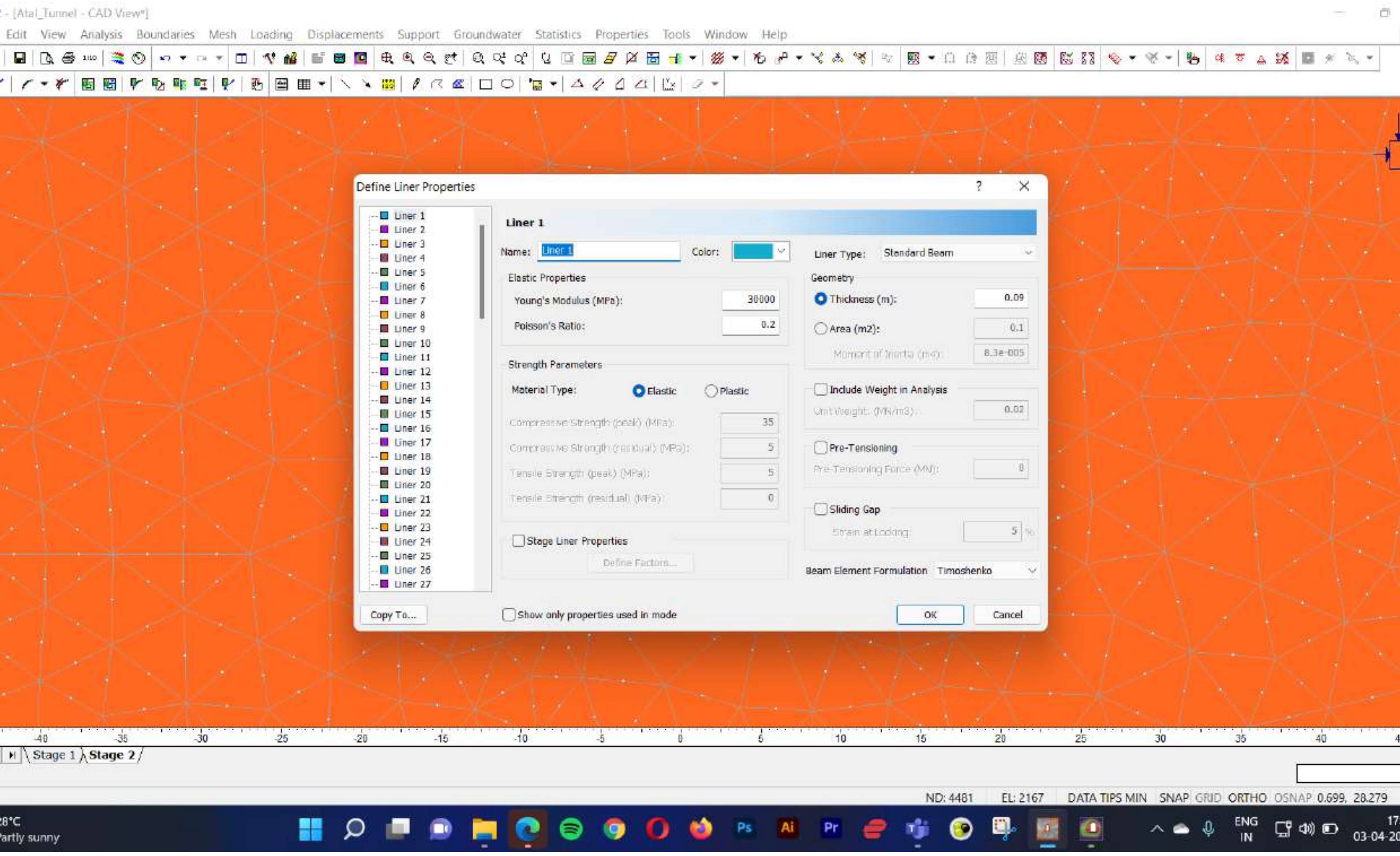

Phase2 - [Atal_Tunnel - CAD View*]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Liner Properties
Liner 1
Name: Liner 1
Color:
Liner Type: Standard Beam
Elastic Properties
Young's Modulus (MPa): 30000
Poisson's Ratio: 0.2
Geometry
Thickness (m): 0.12
Area (m2): 0.1
Moment of Inertia (m4): 8.3e-005
Strength Parameters
Material Type: Elastic Plastic
Compressive Strength (peak) (MPa): 35
Compressive Strength (residual) (MPa): 5
Tensile Strength (peak) (MPa): 5
Tensile Strength (residual) (MPa): 0
Include Weight in Analysis
Unit Weight (MN/m3): 0.02
Pre-Tensioning
Pre-Tensioning Force (MN): 0
Sliding Gap
Strain at Locking: 5 %
Stage Liner Properties
Define Factors...
Beam Element Formulation Timoshenko
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1 Stage 2
ND: 4481 EL: 2167 DATA TIPS MIN SNAP GRID ORTHO OSNAP -11.957, 30.939
28°C
Partly sunny
ENG IN
17:55
03-04-2022

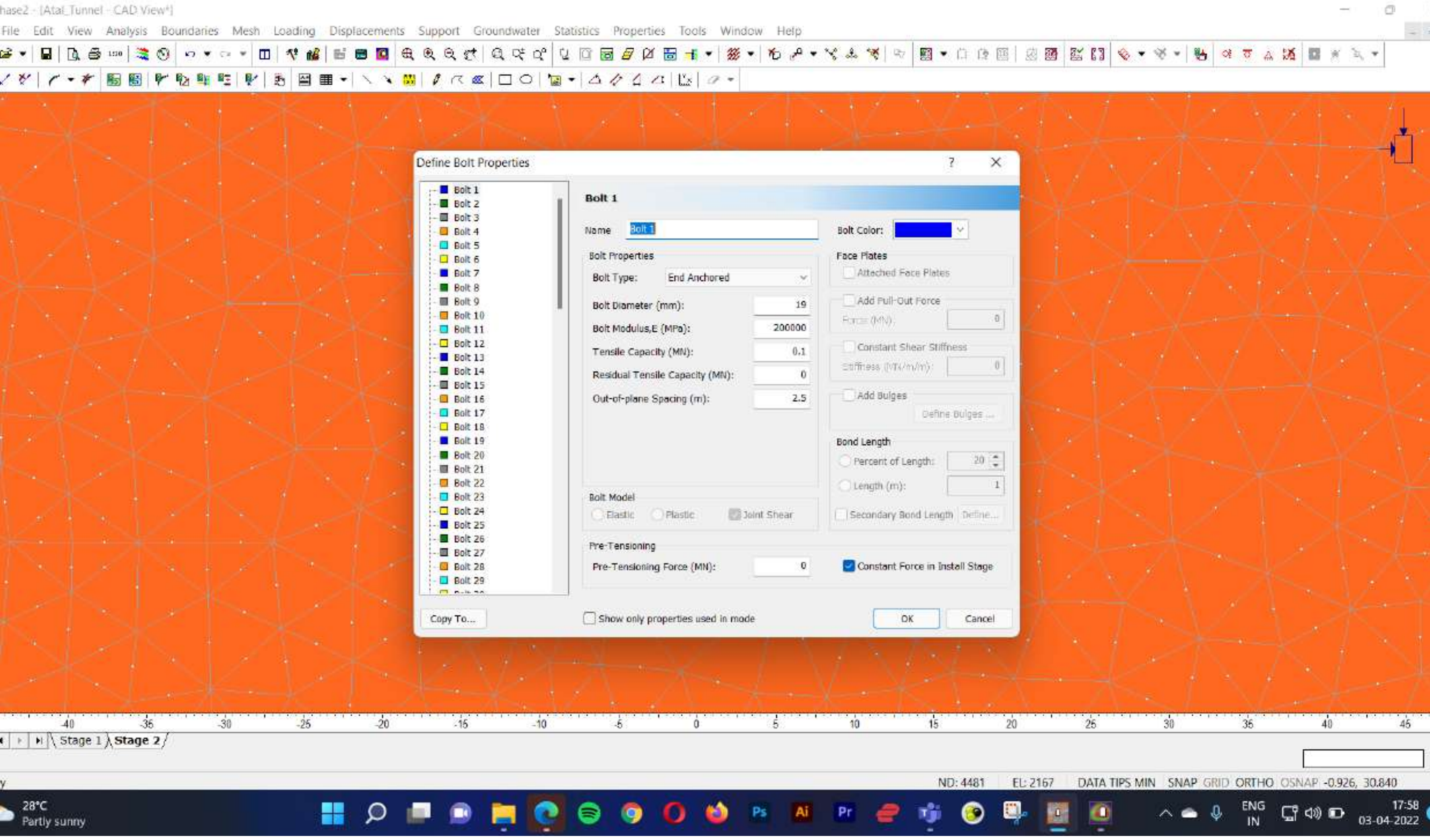

Add Bolt Pattern
Bolt Property:
Bolt 1
Orientation
Normal to boundary
Radial (from drilling point
Angle from horizontal
Bolt Length (m):
3
In-Plane Spacing (m):
2.2
Staging
Install at stage:
2
Remove at stage:
OK
Cancel
Stage 2
ND: 4481
EL: 2167

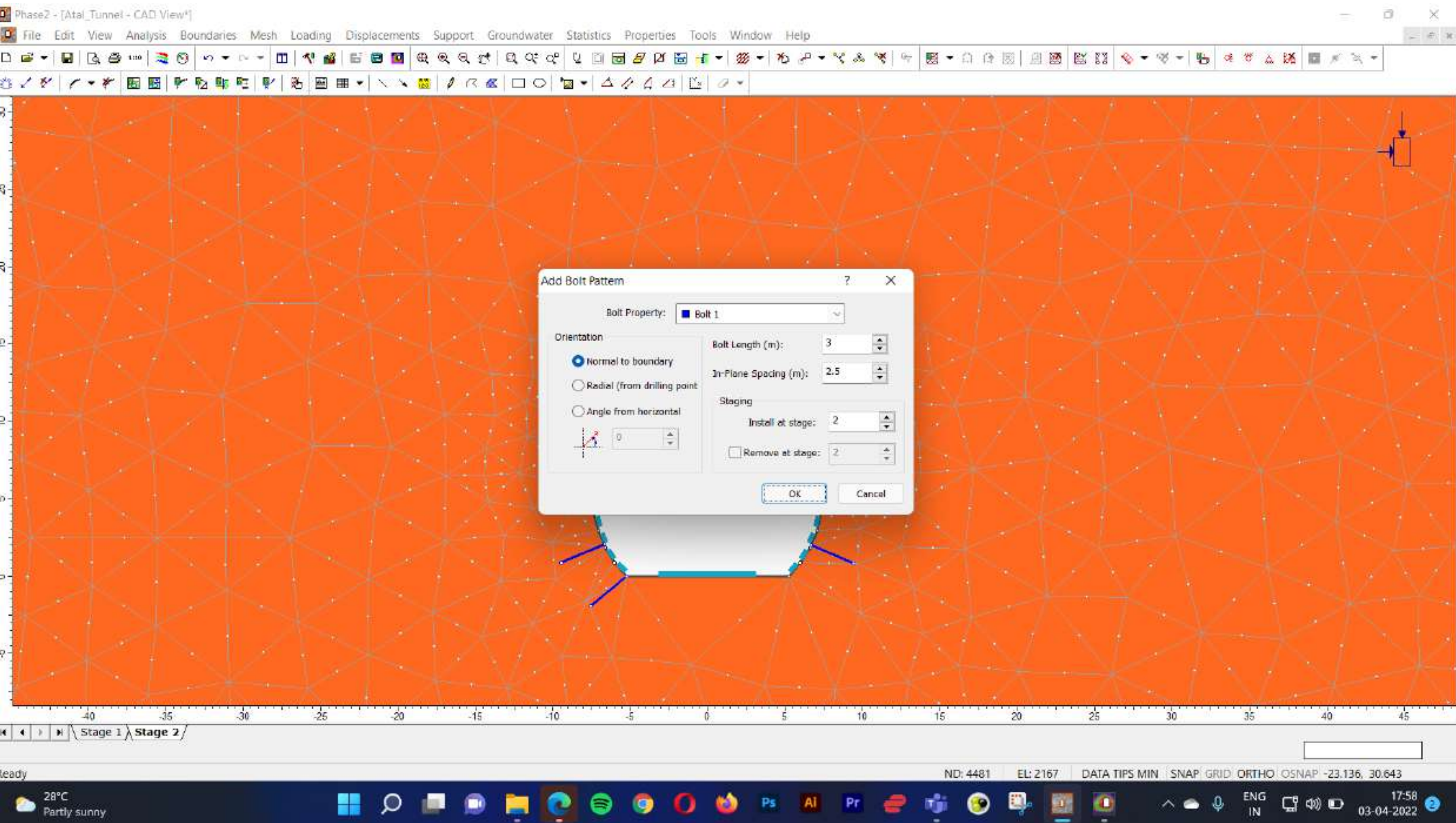
Class-4-


Interpret - [Atal_Tunnel - Total Displacement*]
Total Displacement
m
0.00e+000
1.60e-002
3.20e-002
4.80e-002
6.40e-002
8.00e-002
9.60e-002
1.12e-001
1.28e-001
1.44e-001
1.60e-001
Stage 1
Stage 2
Stage: 2, Maximum Total Displacement 0.15474 m

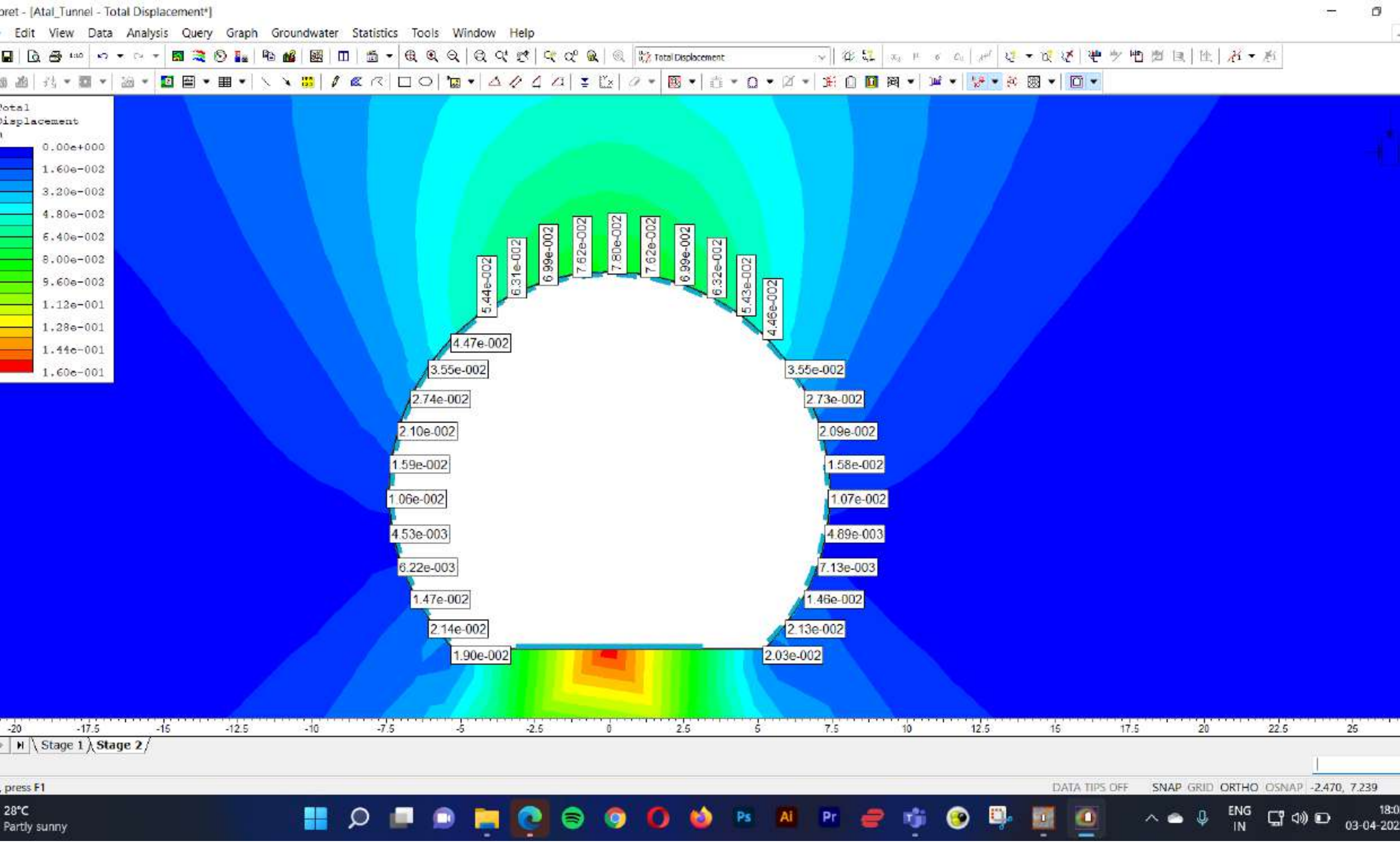

Phase2 - [Atal_Tunnel - CAD View]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Material Properties
Quartzite
Material 2
Material 3
Material 4
Material 5
Material 6
Material 7
Material 8
Material 9
Material 10
Material 11
Material 12
Material 13
Material 14
Material 15
Material 16
Material 17
Material 18
Material 19
Material 20
Material 21
Material 22
Material 23
Material 24
Material 25
Material 26
Material 27
Material 28
Material 29
Material 30
Material 31
Material 32
Quartzite
Name: Quartzite
Material Color:
Initial Element Loading: Field Stress Only
Unit Weight (MN/m3): 0.027
Elastic Properties
Elastic Type: Isotropic
Poisson's Ratio: 0.26
Young's Modulus (MPa): 87.1043
Young's Modulus (resid) (MPa): 20000
E1 (MPa): 20000
E2 (MPa): 20000
Ez (MPa): 20000
v12: 0.2
v1z: 0.2
v2z: 0.2
Strength Parameters
Failure Criterion: Mohr Coulomb
Material Type: Plastic
Tensile Strength (peak) (MPa): 0.098
Dilation Angle (deg): 0
Fric. Angle (peak) (deg): 24.68
Fric. Angle (resid) (deg): 24.68
Cohesion (peak) (MPa): 8.53
Cohesion (resid) (MPa): 0
Tensile Strength (resid) (MPa): 0
Stage Properties
Datum Dependent
Unsaturated Shear Strength
Define Factors...
Define Properties...
Phi b: 0
Air Entry (MPa): 0
Copy To...
Statistics...
Show only properties used in mode
OK
Cancel
Stage 1
Stage 2
ND: 4481
EL: 2167
DATA TIPS MIN SNAP GRID ORTHO OSNAP -15.208, 30.889
28°C
Partly sunny
ENG
IN
17:58
03-04-2022

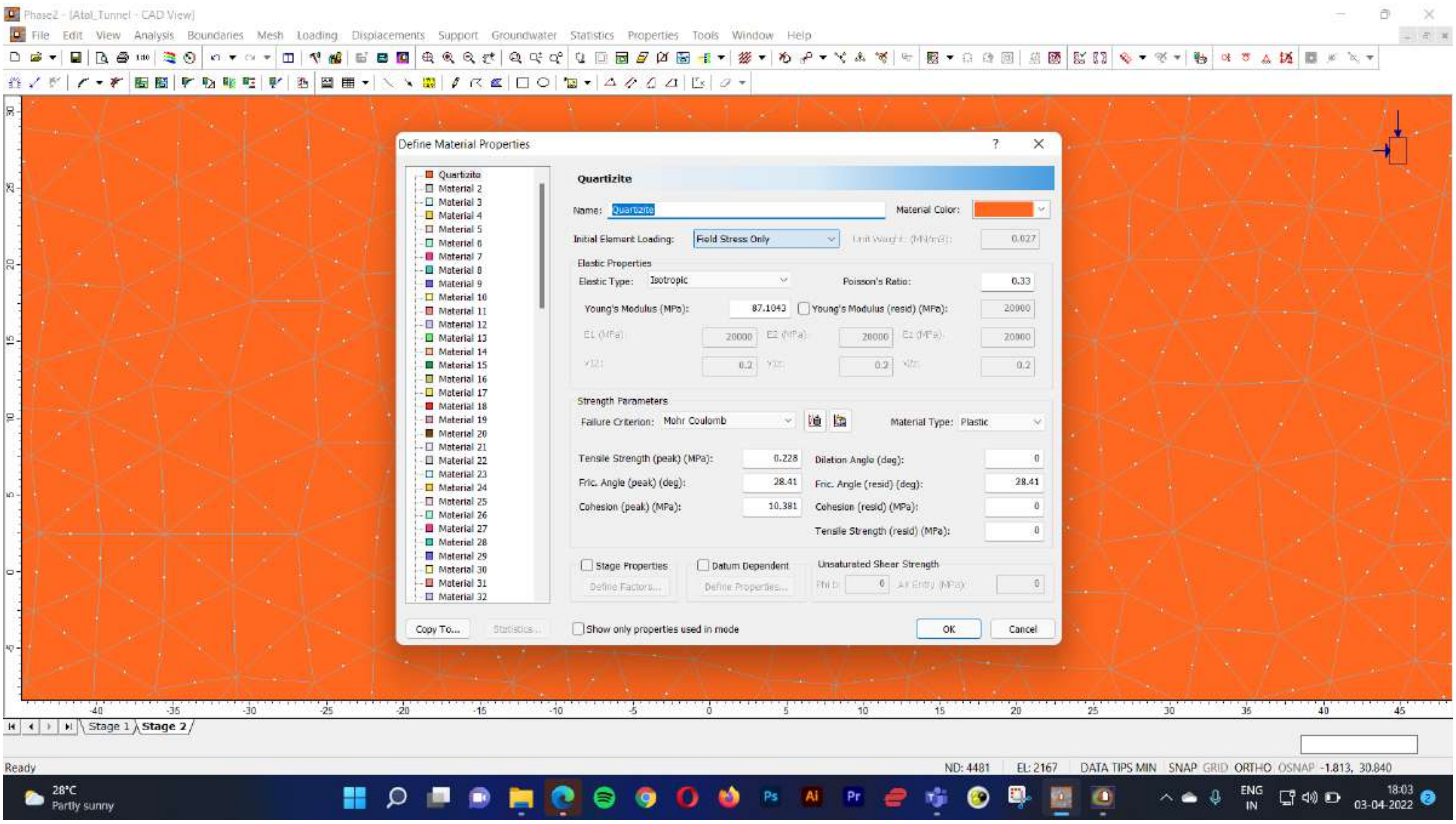

[Atal_Tunnel - CAD View*]
Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Liner Properties
Liner 1
Liner 2
Liner 3
Liner 4
Liner 5
Liner 6
Liner 7
Liner 8
Liner 9
Liner 10
Liner 11
Liner 12
Liner 13
Liner 14
Liner 15
Liner 16
Liner 17
Liner 18
Liner 19
Liner 20
Liner 21
Liner 22
Liner 23
Liner 24
Liner 25
Liner 26
Liner 27
Liner 1
Name: Liner 1
Color:
Liner Type: Standard Beam
Elastic Properties
Young's Modulus (MPa): 30000
Poisson's Ratio: 0.2
Geometry
Thickness (m): 0.09
Area (m2): 0.1
Moment of Inertia (m4): 8.3e-005
Strength Parameters
Material Type: Elastic Plastic
Compressive Strength (peak) (MPa): 35
Compressive Strength (residual) (MPa): 5
Tensile Strength (peak) (MPa): 5
Tensile Strength (residual) (MPa): 0
Include Weight in Analysis
Unit Weight (MN/m3): 0.02
Pre-Tensioning
Pre-Tensioning Force (MN): 0
Sliding Gap
Strain at Locking: 5 %
Stage Liner Properties
Define Factors...
Beam Element Formulation Timoshenko
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1
Stage 2
ND: 4481
EL: 2167
DATA TIPS MIN SNAP GRID ORTHO OSNAP 0.699, 28.279
28°C
Partly sunny
ENG
IN
03-04-20

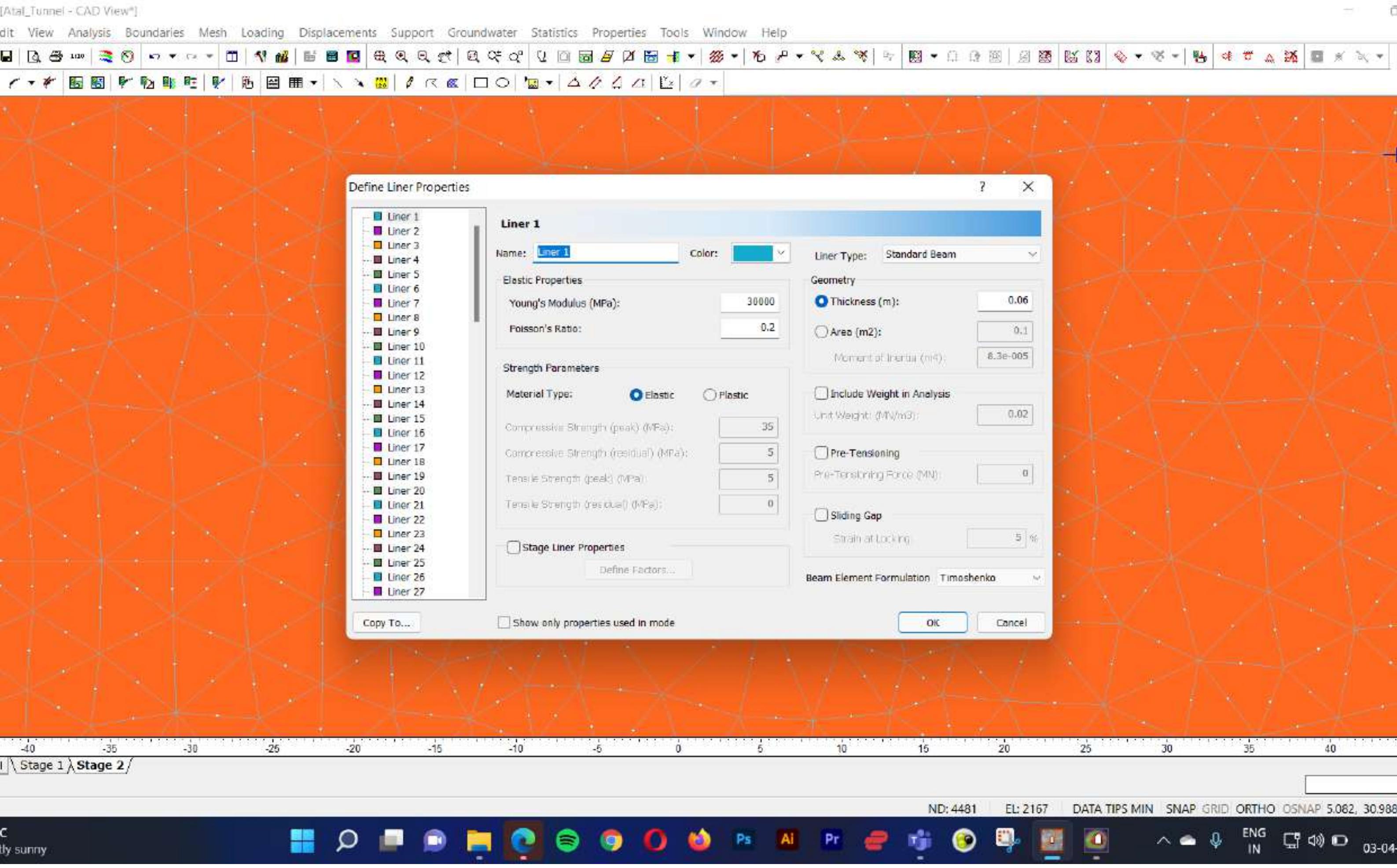

Define Bolt Properties
Bolt 1
Name
Bolt 1
Bolt Color:
Bolt Properties
Bolt Type:
End Anchored
Bolt Diameter (mm):
19
Bolt Modulus,E (MPa):
200000
Tensile Capacity (MN):
0.1
Residual Tensile Capacity (MN):
0
Out-of-plane Spacing (m):
2.5
Face Plates
Attached Face Plates
Add Pull-Out Force
Constant Shear Stiffness
Add Bulges
Define Bulges ...
Bond Length
Percent of Length:
20
Length (m):
1
Bolt Model
Elastic
Plastic
Joint Shear
Secondary Bond Length
Pre-Tensioning
Pre-Tensioning Force (MN):
0
Constant Force in Install Stage
Copy To...
Show only properties used in model
OK
Cancel
Stage 1
Stage 2


Add Bolt Pattern
Bolt Property:
Bolt 1
Orientation
Normal to boundary
Radial (from drilling point
Angle from horizontal
Bolt Length (m):
3
In-Plane Spacing (m):
2.5
Staging
Install at stage:
2
Remove at stage:
2
OK
Cancel
Stage 1
Stage 2

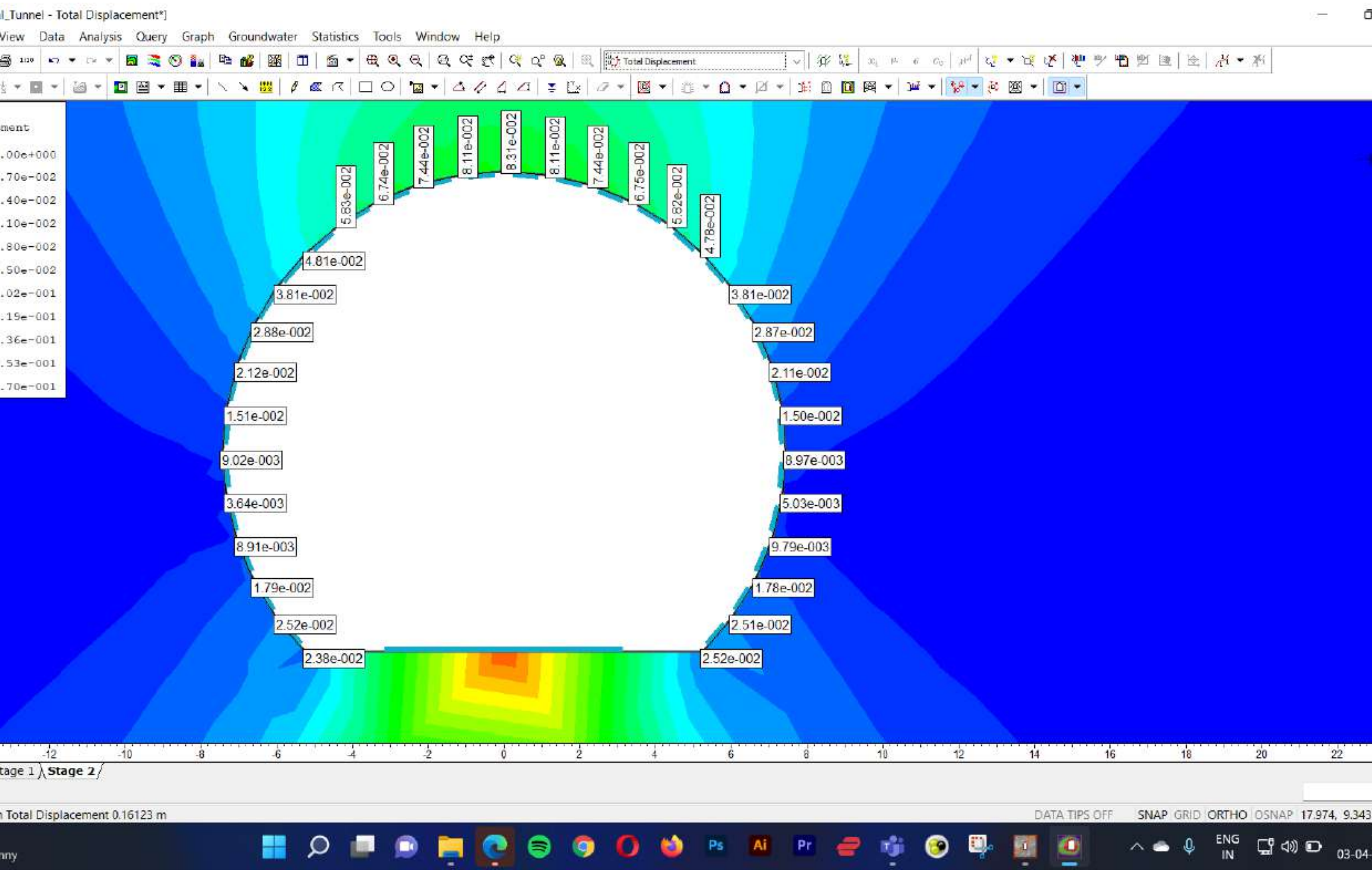
Class-5-

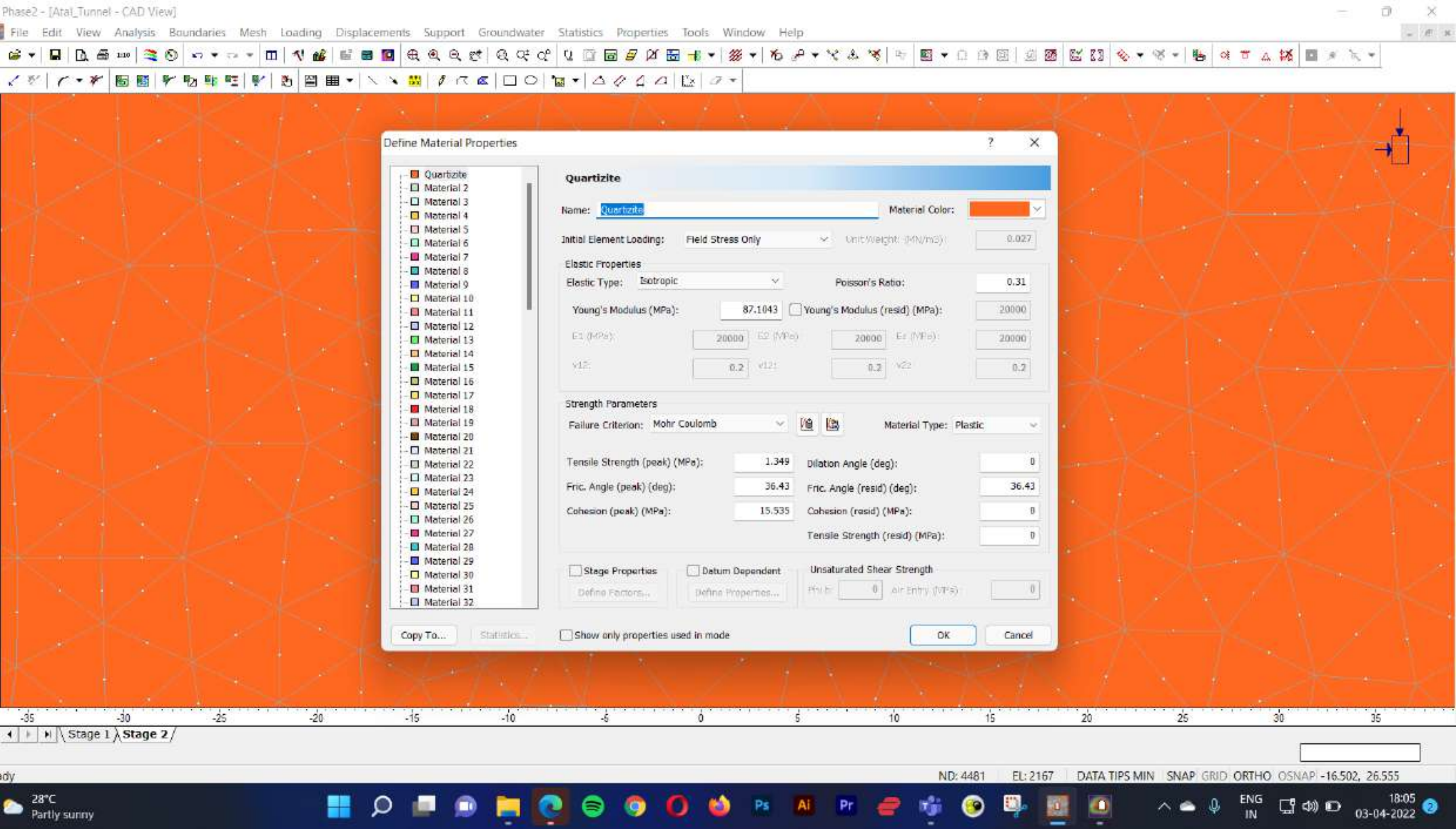


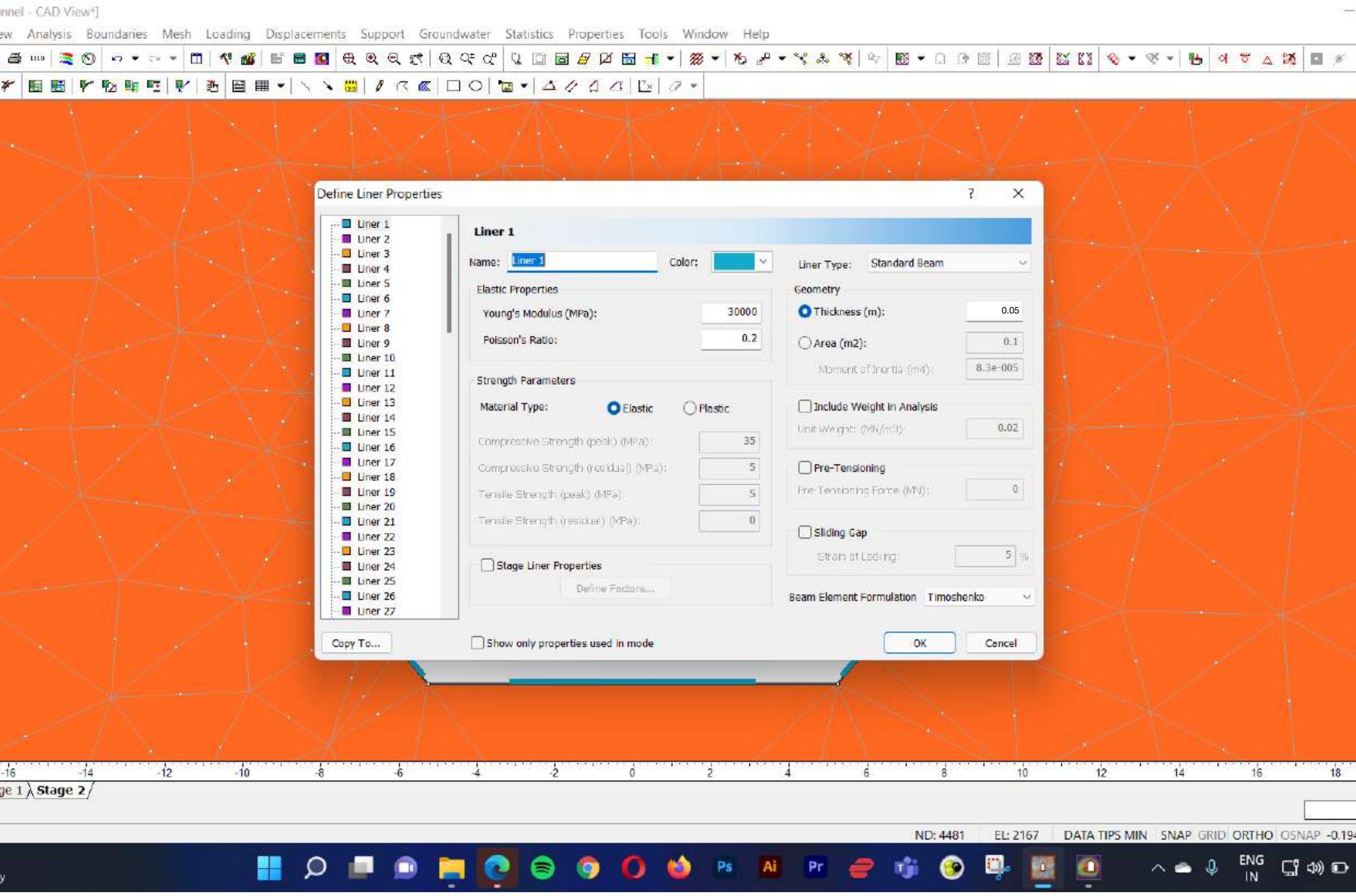




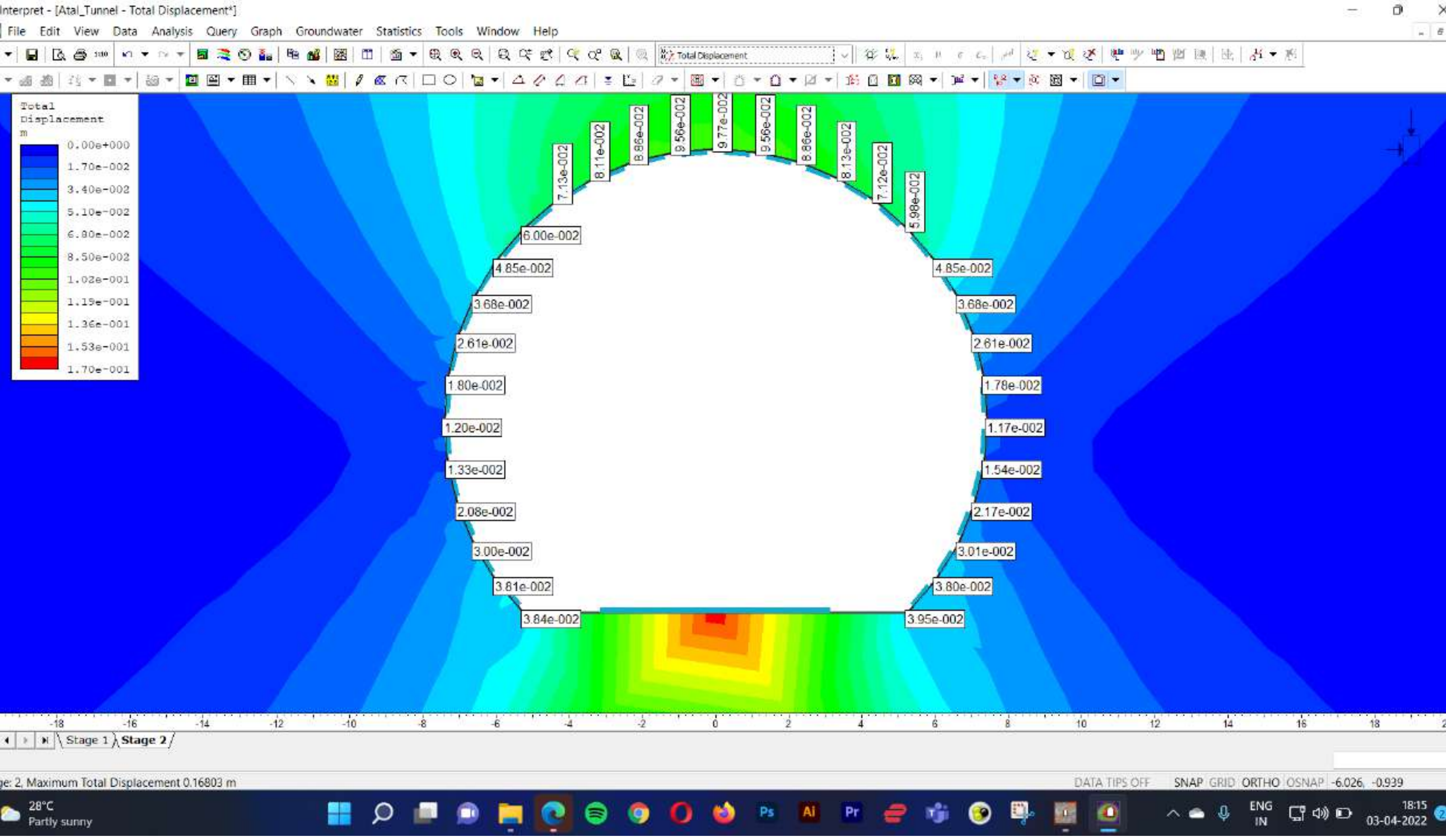
Class-6-

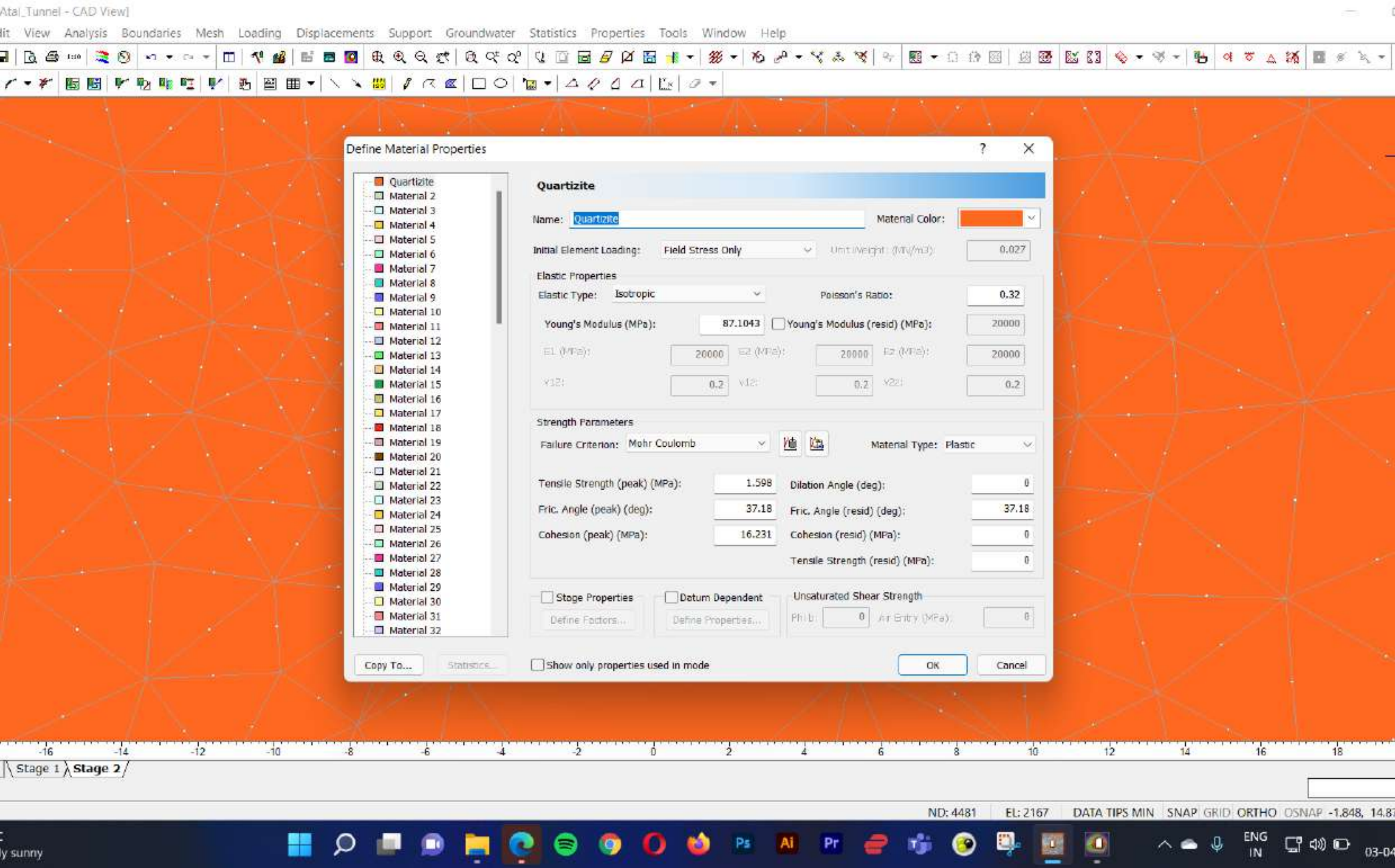


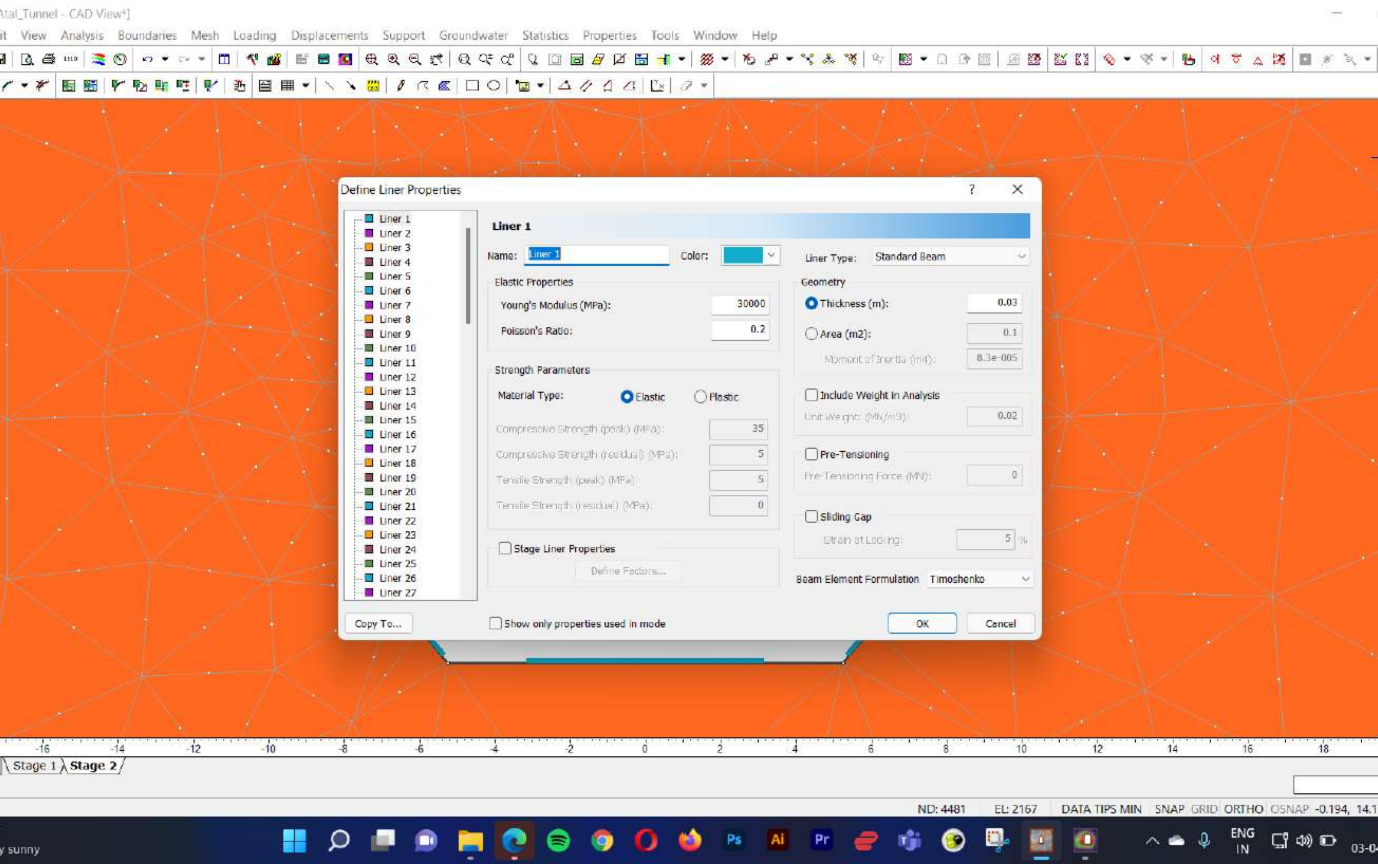

Phase2 - [Atal_Tunnel - CAD View]
File Edit View Analysis Boundaries Mesh Loading Displacements Support Groundwater Statistics Properties Tools Window Help
Define Material Properties
Quartzite
Name: Quartzite
Material Color:
Initial Element Loading: Field Stress Only
Unit Weight (MN/m3): 0.027
Elastic Properties
Elastic Type: Isotropic
Poisson's Ratio: 0.31
Young's Modulus (MPa): 87.1043
Young's Modulus (resid) (MPa): 20000
Strength Parameters
Failure Criterion: Mohr Coulomb
Material Type: Plastic
Tensile Strength (peak) (MPa): 1.349
Dilation Angle (deg): 0
Fric. Angle (peak) (deg): 36.43
Fric. Angle (resid) (deg): 36.43
Cohesion (peak) (MPa): 15.535
Cohesion (resid) (MPa): 0
Tensile Strength (resid) (MPa): 0
Stage Properties
Datum Dependent
Unsaturated Shear Strength
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1
Stage 2


Define Liner Properties
Liner 1
Name: Liner 1
Color:
Liner Type: Standard Beam
Elastic Properties
Young's Modulus (MPa): 30000
Poisson's Ratio: 0.2
Geometry
Thickness (m): 0.05
Area (m2): 0.1
Moment of Inertia (m4): 8.3e-005
Strength Parameters
Material Type: Elastic Plastic
Compressive Strength (peak) (MPa): 35
Compressive Strength (residual) (MPa): 5
Tensile Strength (peak) (MPa): 5
Tensile Strength (residual) (MPa): 0
Include Weight in Analysis
Unit Weight (MN/m3): 0.02
Pre-Tensioning
Pre-Tensioning Force (MN): 0
Sliding Gap
Strain at Locking: 5 %
Stage Liner Properties
Define Factors...
Beam Element Formulation Timoshenko
Copy To...
Show only properties used in mode
OK
Cancel
Stage 1
Stage 2

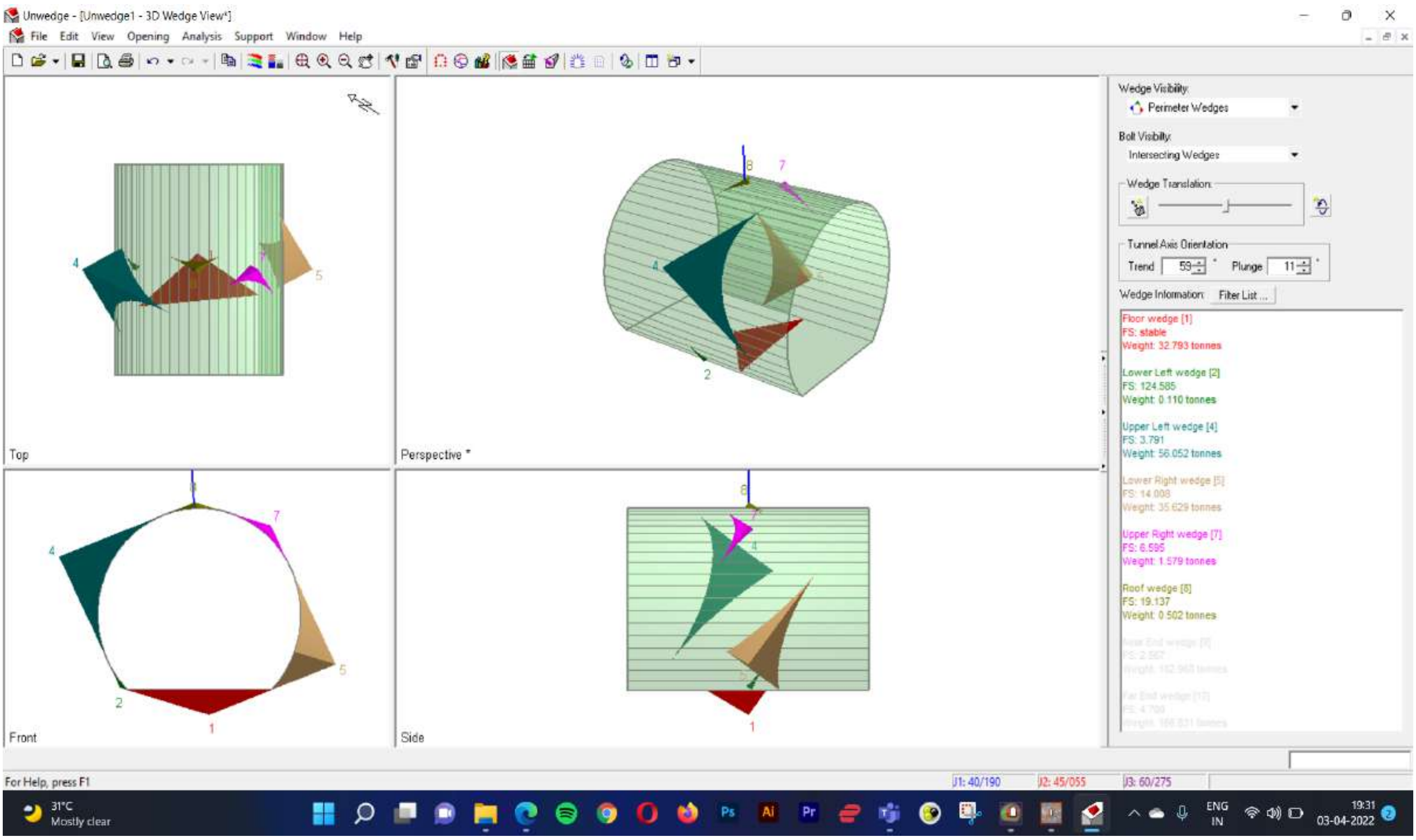
Class-7-


Interpret - [Atal_Tunnel - Total Displacement*]
Total Displacement m
0.00e+000
1.70e-002
3.40e-002
5.10e-002
6.80e-002
8.50e-002
1.02e-001
1.19e-001
1.36e-001
1.53e-001
1.70e-001
Stage 1
Stage 2
Maximum Total Displacement 0.16803 m

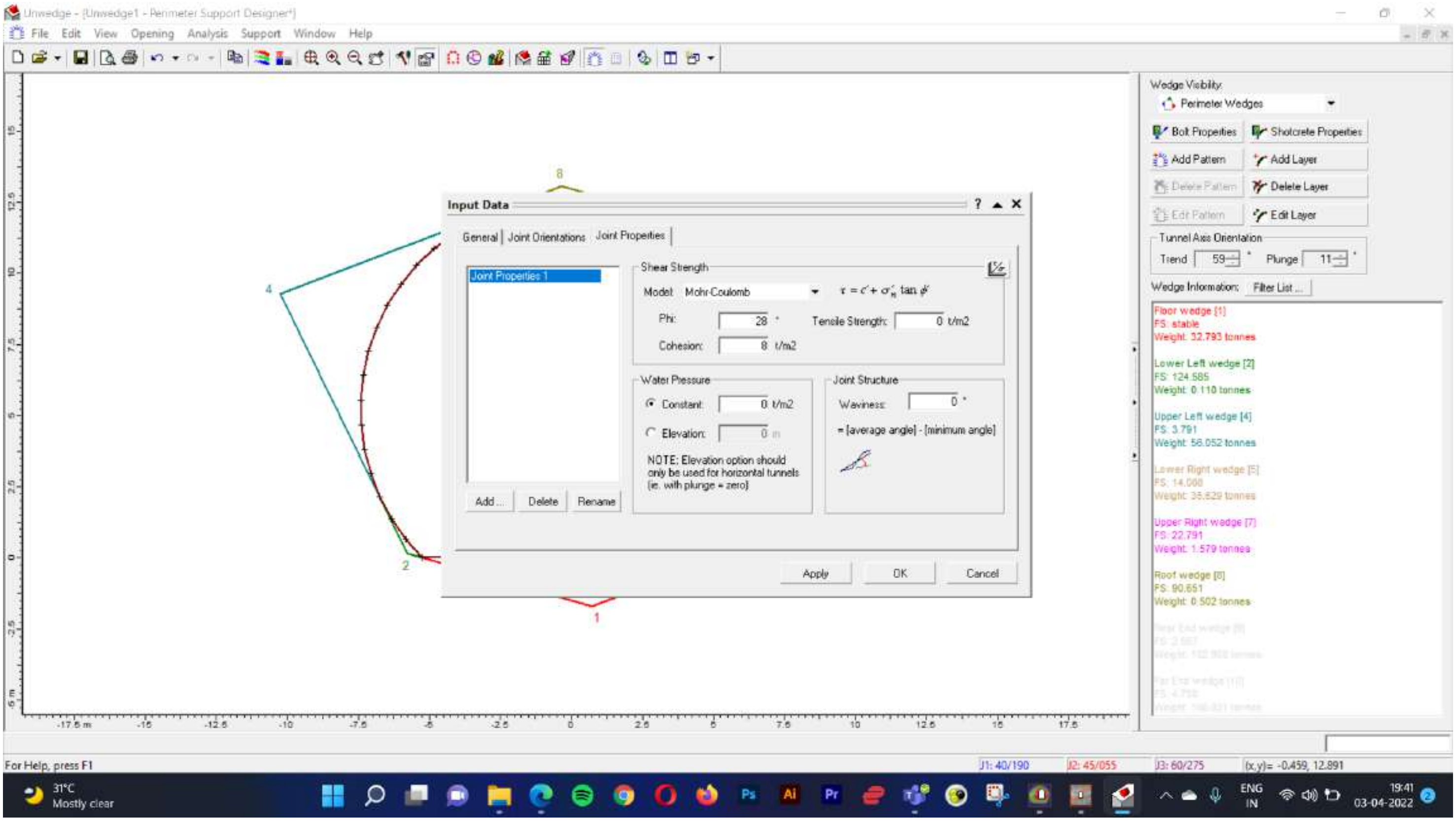

Define Material Properties
Quartzite
Name: Quartzite
Material Color:
Initial Element Loading: Field Stress Only
Unit Weight (MN/m3): 0.027
Elastic Properties
Elastic Type: Isotropic
Poisson's Ratio: 0.32
Young's Modulus (MPa): 87.1043
Young's Modulus (resid) (MPa): 20000
Strength Parameters
Failure Criterion: Mohr Coulomb
Material Type: Plastic
Tensile Strength (peak) (MPa): 1.598
Dilation Angle (deg): 0
Fric. Angle (peak) (deg): 37.18
Fric. Angle (resid) (deg): 37.18
Cohesion (peak) (MPa): 16.231
Cohesion (resid) (MPa): 0
Tensile Strength (resid) (MPa): 0
Stage Properties
Datum Dependent
Unsaturated Shear Strength
Copy To...
Show only properties used in model
OK
Cancel

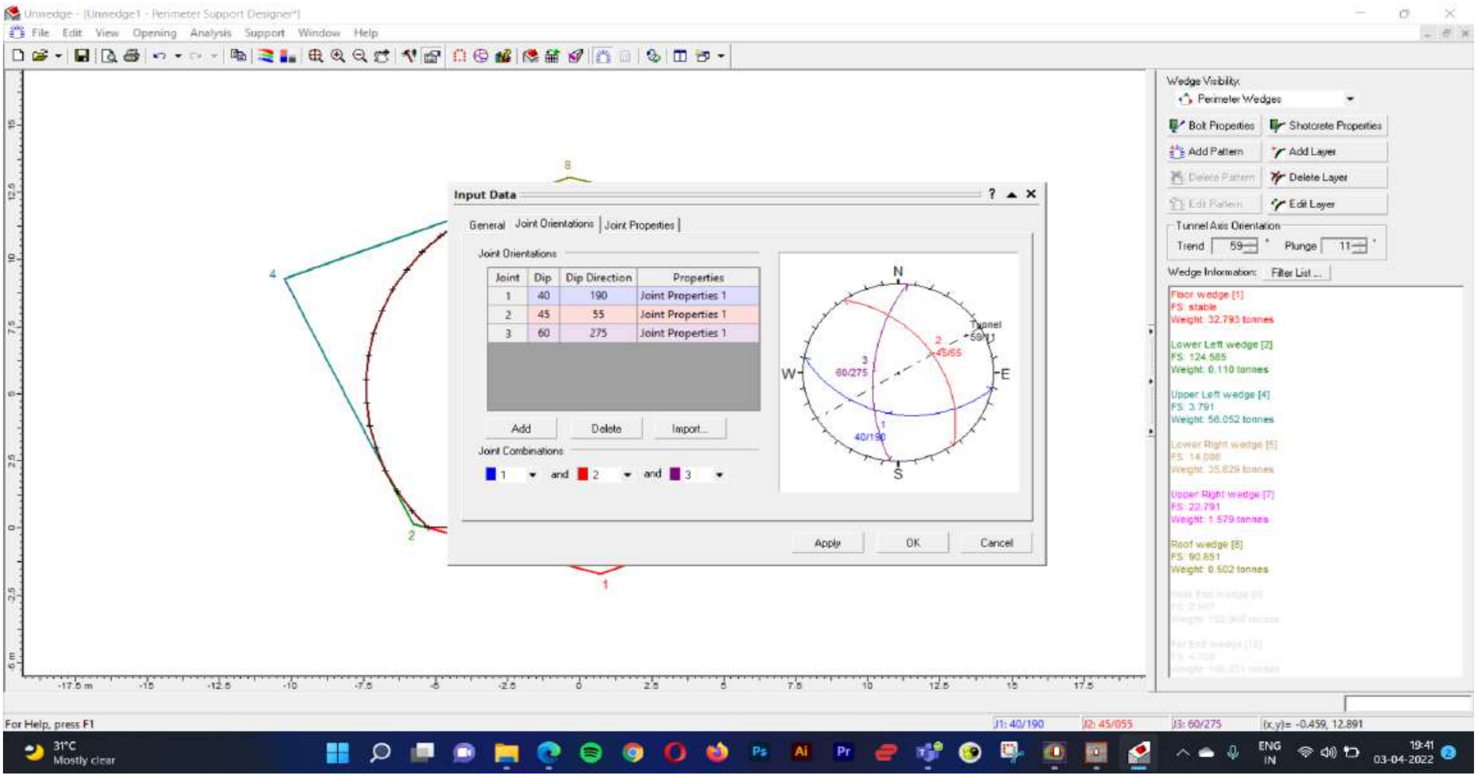


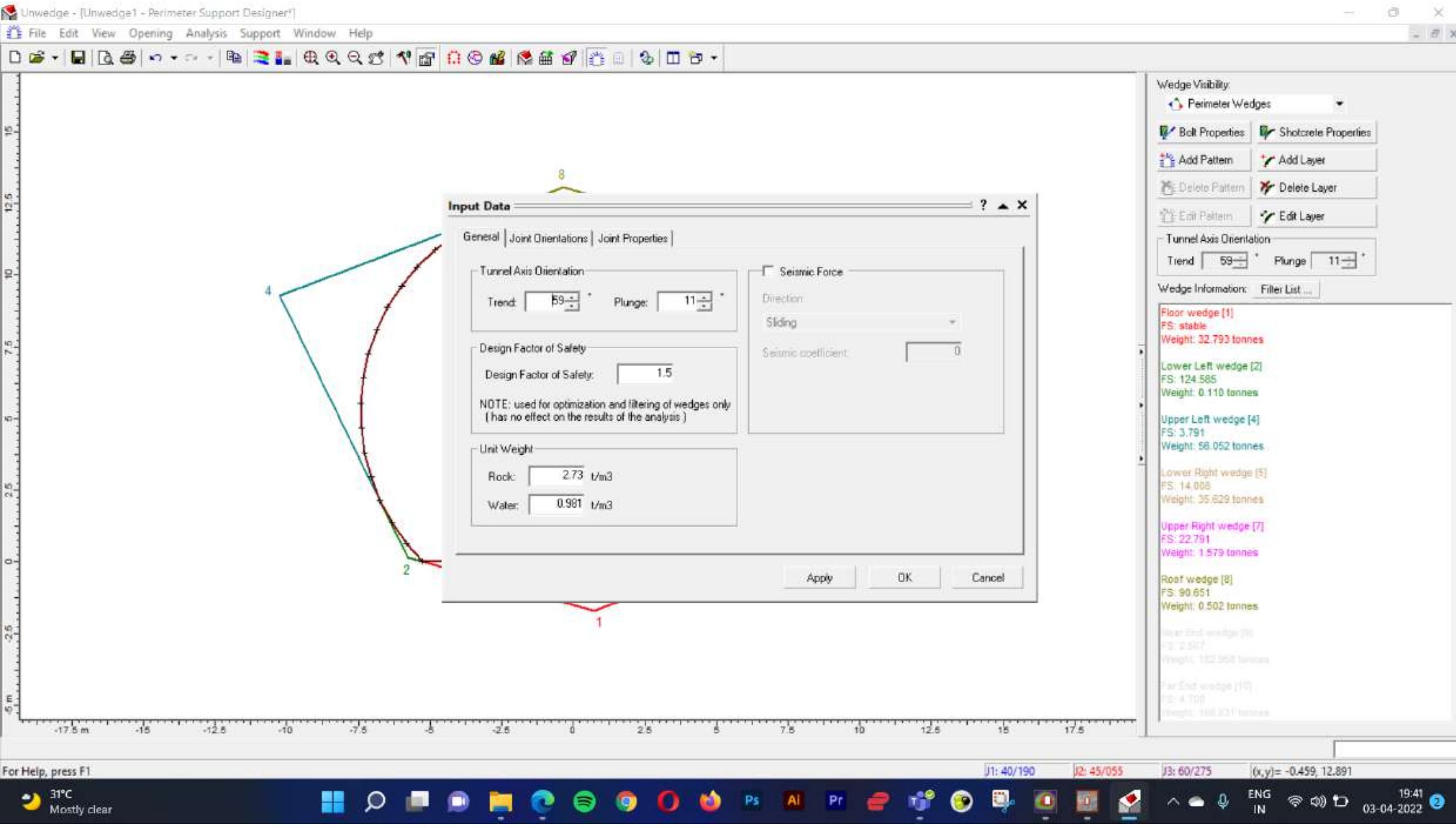
Unwedge Analysis-



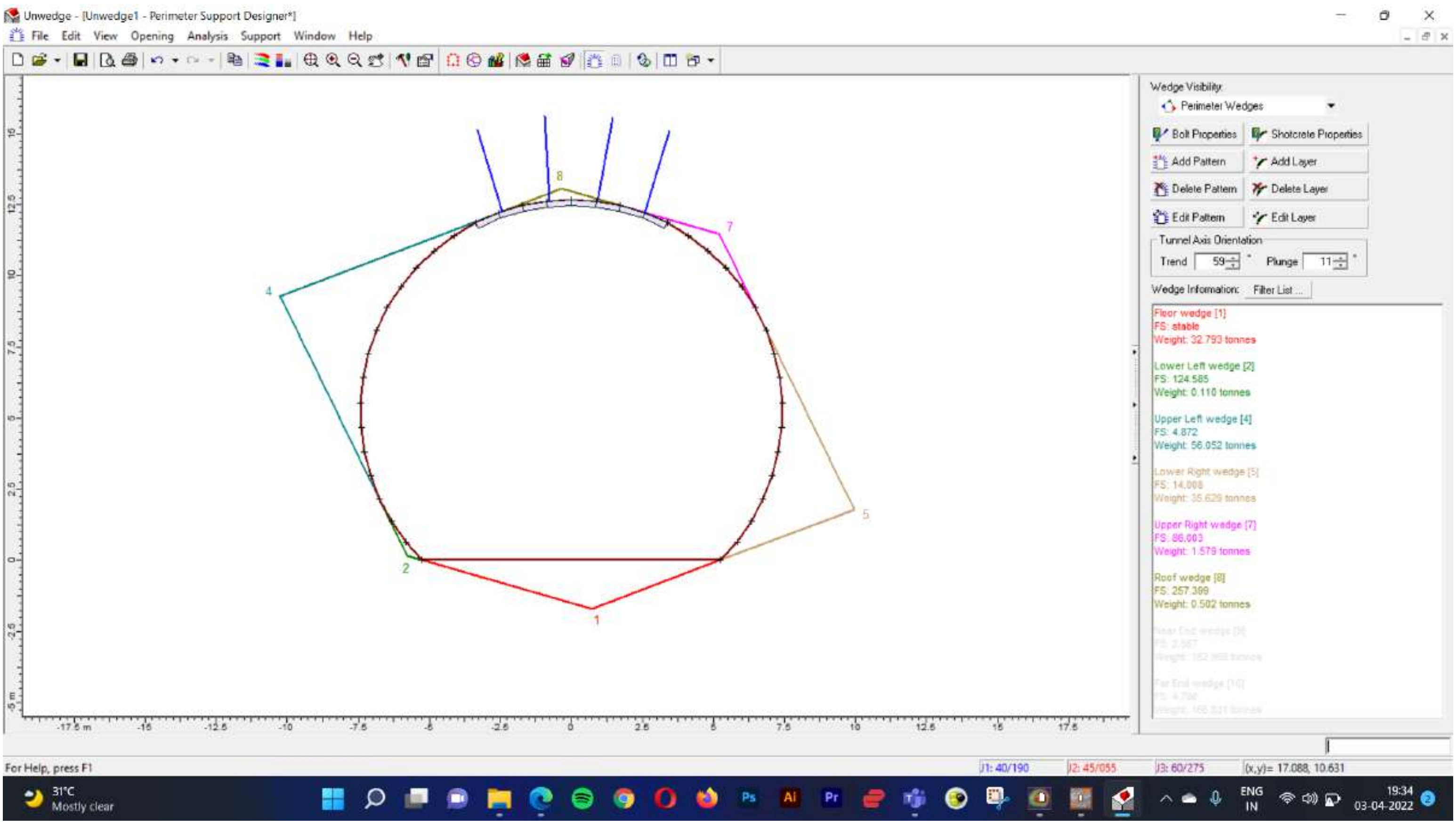
Properties Used for Analysis-



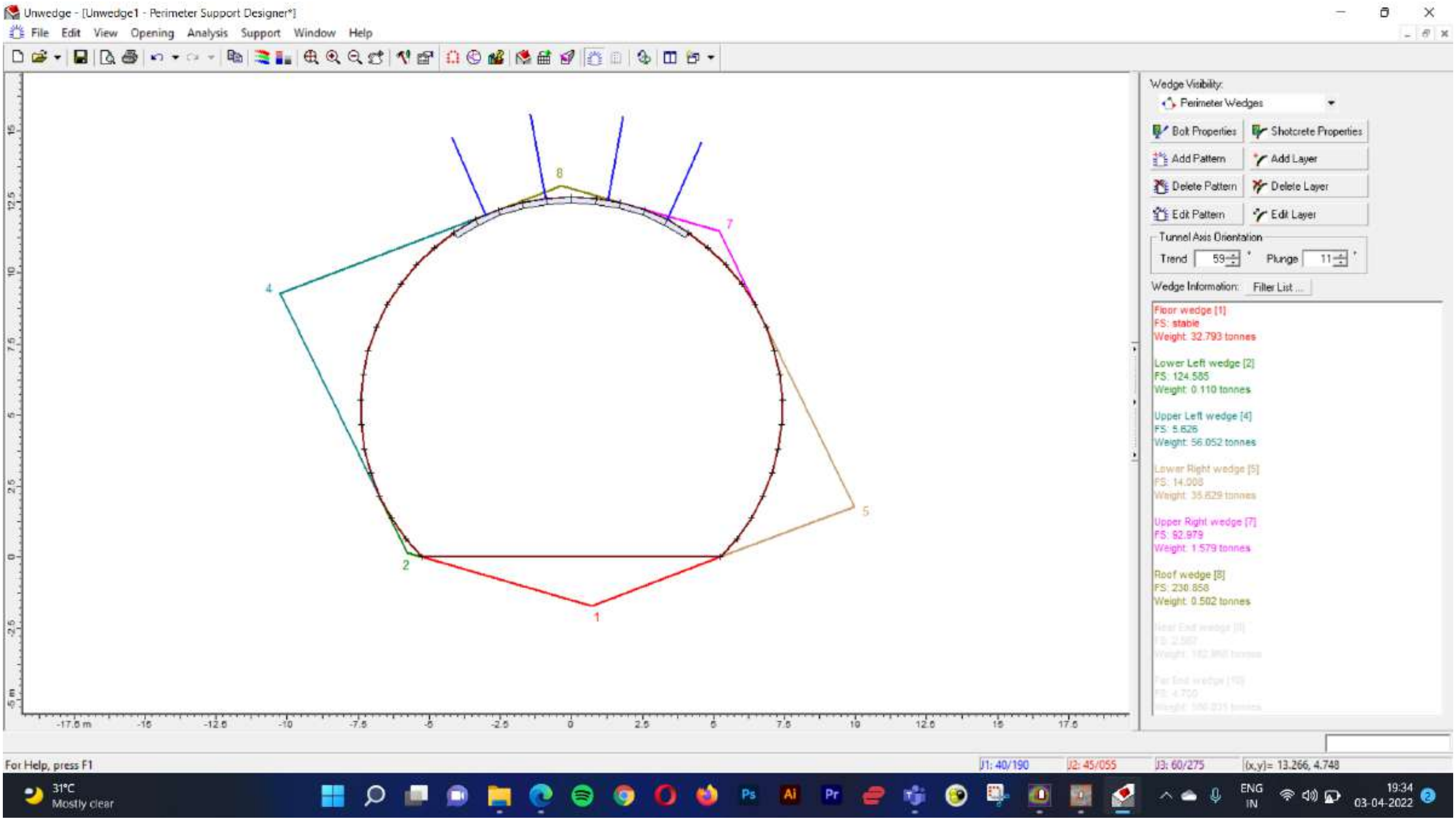




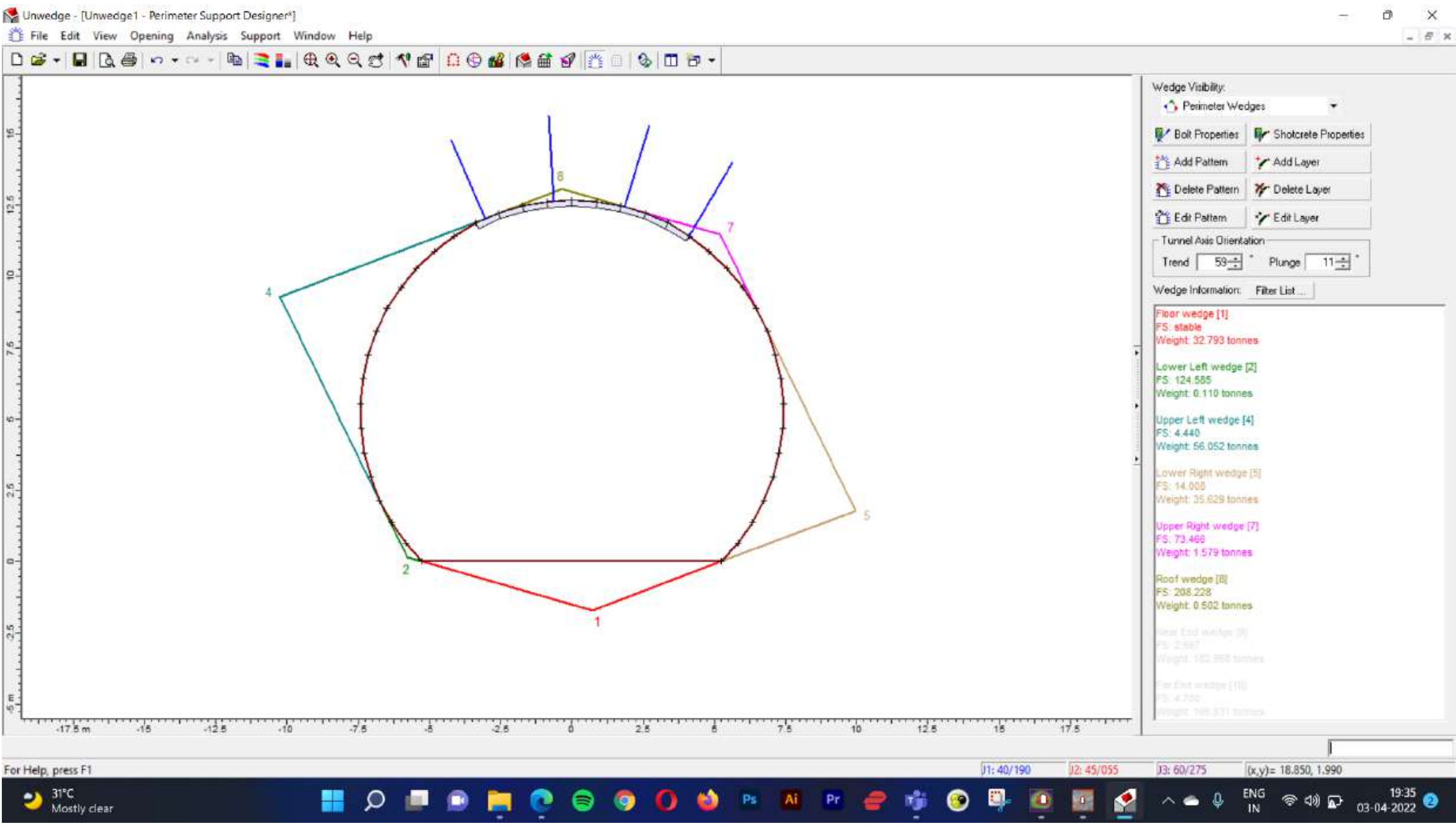
Class 1 Analysis-



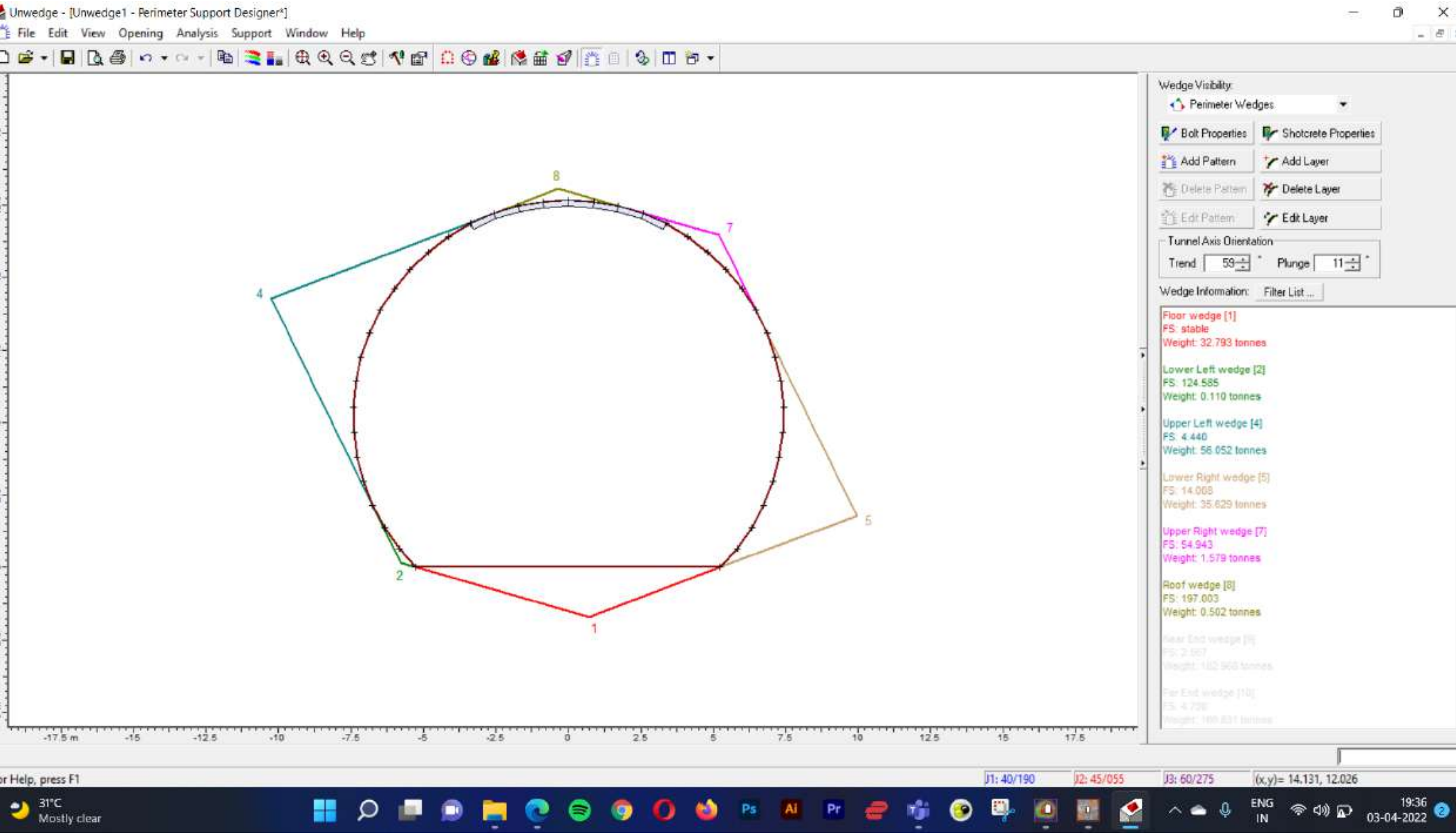
Class 2 Analysis-



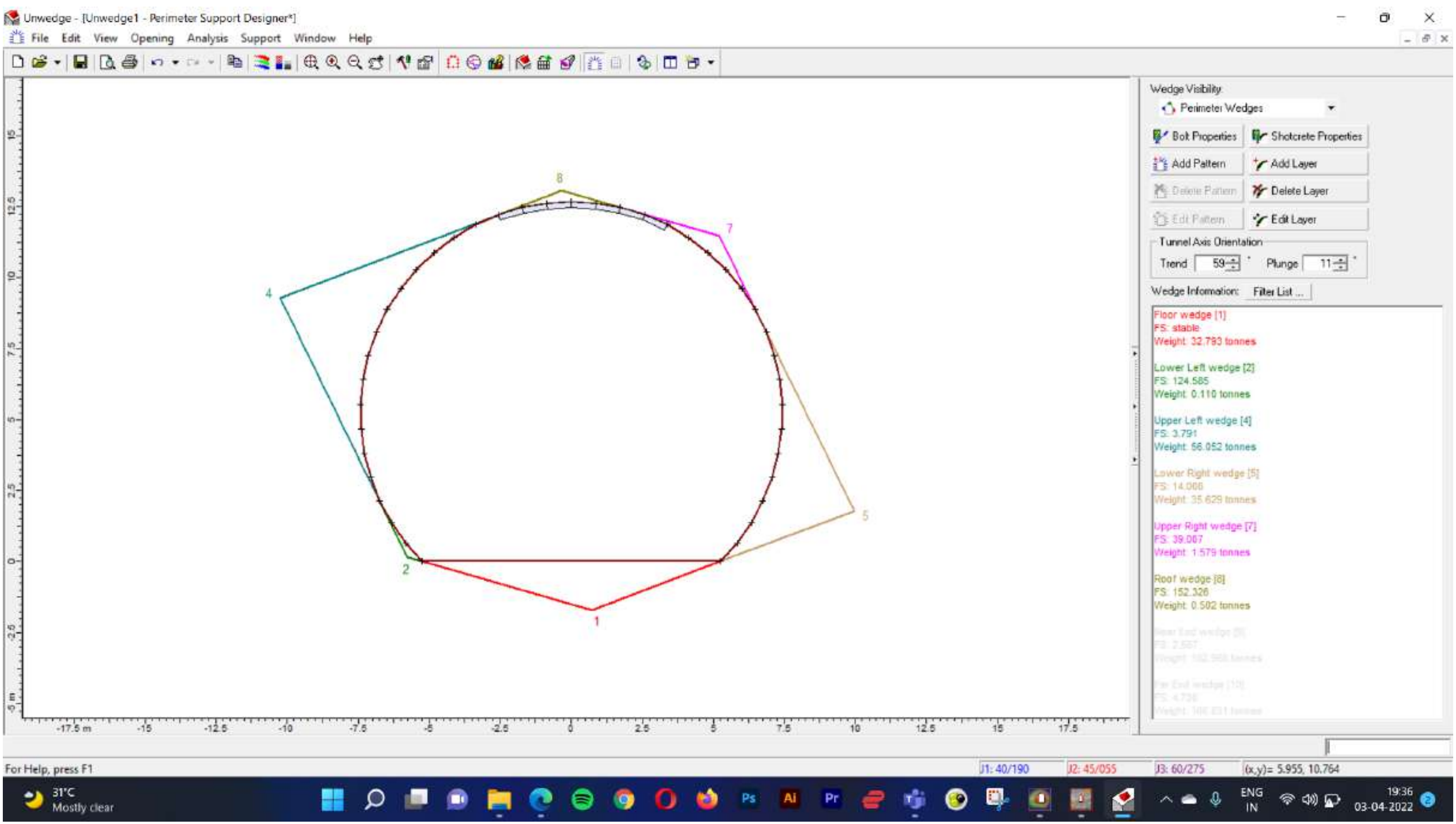
Class 3 Analysis-



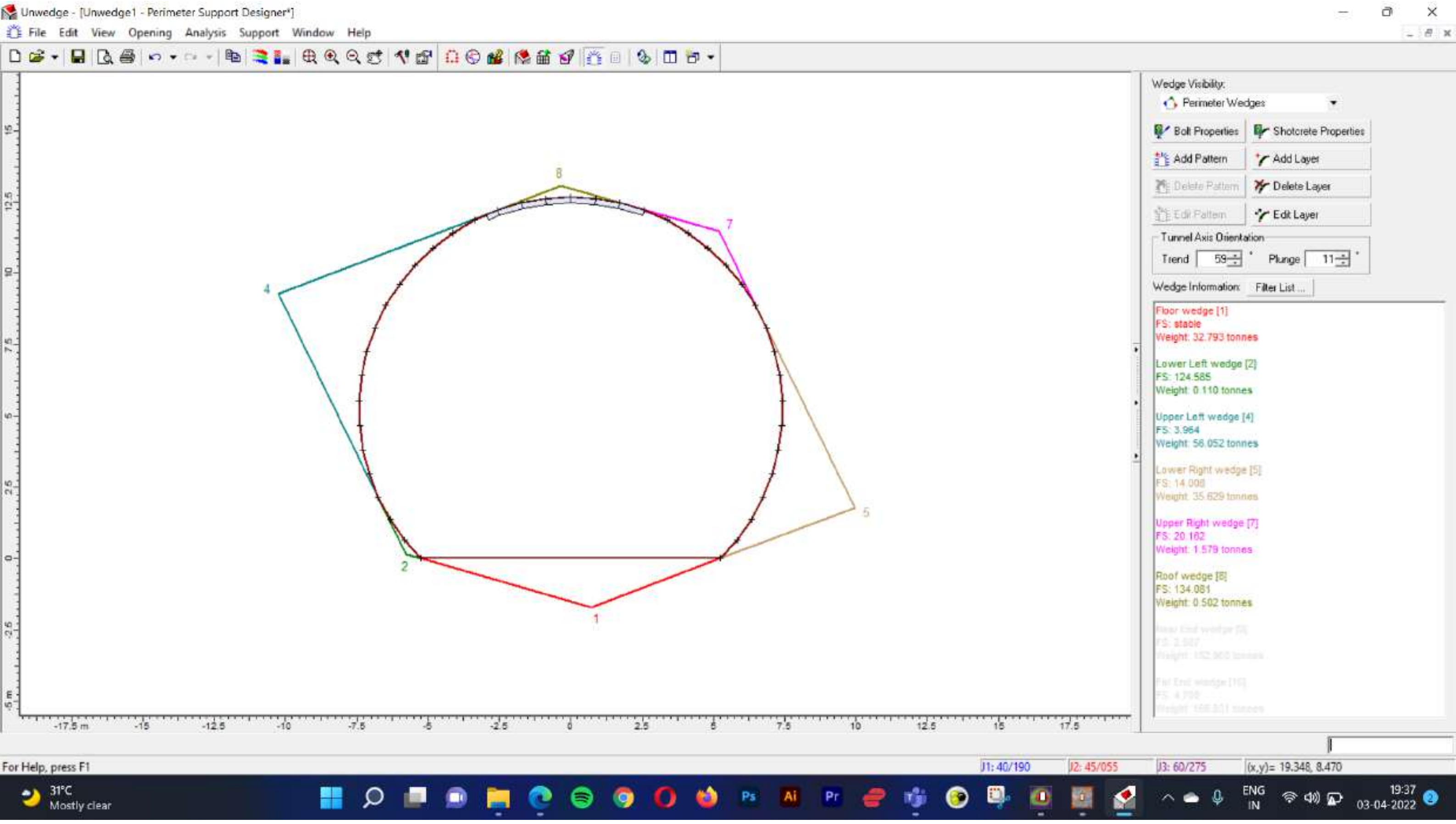
Class 4 Analysis-



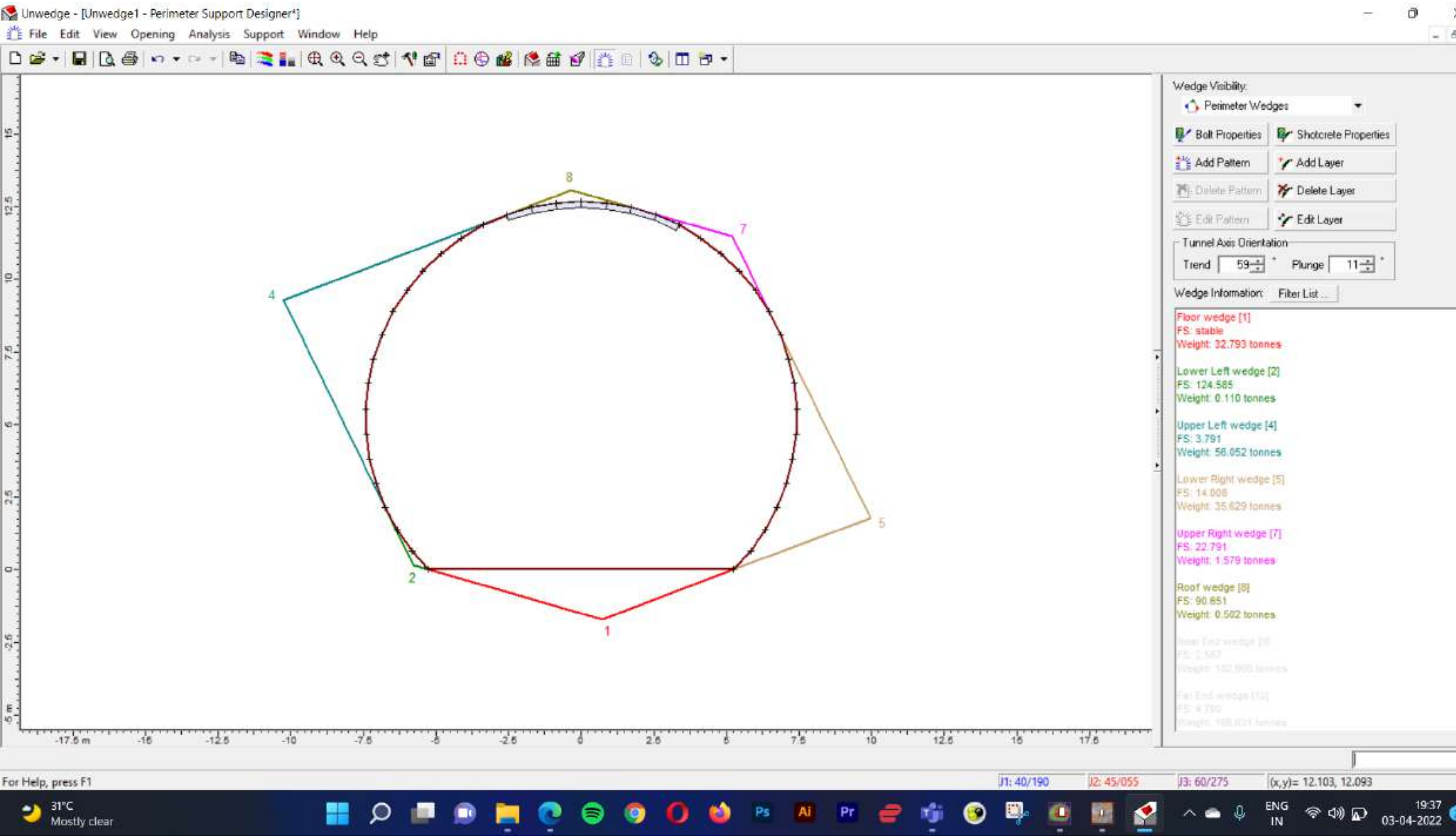
Class 5 Analysis-



Class 6 Analysis-



Class 7 Analysis-



SUMMARY & RECOMMENDATION of SUPPORT SYSTEM

Class	Support on the basis of Rock Mass Classification			FEM Support			Recommended		
	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness
1	3	1.5	25	3	1.5	25	3	1.5	25
2	3	1.7	15	3	1.7	15	3	1.7	15
3	3	2.2	12	3	2.2	12	3	2.2	12
4	3	2.5	9	3	2.5	9	3	2.5	9
5	3	N/A	6	3	N/A	6	3	N/A	9
6	3	N/A	5	3	N/A	5	3	N/A	9
7	3	N/A	N/A	3	N/A	3	3	N/A	9

REFERENCES

1. Compendium on Atal Tunnel, Rohtang- Brig Birendra Singh (2021) Planning and Construction of Tunnel : 30-67

2. Technical Brochure on Atal Tunnel Rohtang- Brig Birendra Singh (2021) Introduction and Geology of Project Area : 12-13

3. Engineering classification of rock masses for the design of tunnel support- Barton, N.R., Lien, R. and Lunde, J. (1974) Rock Mech. 6(4), 189-239.

FINITE ELEMENT ANALYSIS

ANNEXURE-1

PHASE 2 ANALYSIS AND RESULT FOR DIFFERENT ROCK CLASSES-

Class	Support by Q classification			Deformation in %	Support after FEM Analysis		
	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness	(Deformation)/ 12.675	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness

Class	Support by Q classification			Deformation in %	Support after FEM Analysis		
	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness	(Deformation)/ 12.675	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness
2	3	1.7	15	<1%	3	1.7	15
3	3	2.2	12	<1%	3	2.2	12
4	3	2.5	9	<1%	3	2.5	9
5	3	N/A	6	<1%	3	N/A	6
6	3	N/A	5	<1%	3	N/A	5
7	3	N/A	N/A	>1%	3	N/A	3

ANNEXURE-2

FINITE ELEMENT ANALYSIS

PHASE 2- INPUT DATA FILE FOR ALL CLASSES-

https://drive.google.com/drive/folders/1cSM5RTBE2PHr9SzliK3wunBONhAFs4_x?usp=sharing

ANNEXURE-3

FINITE ELEMENT ANALYSIS

PHASE 2- AXIAL FORCE IN ROCK BOLT

Class	FEM Support			Axial Force on Rock Bolt (MN)	
	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness	Max Value	Min Value
1	3	1.5	25	0.0901152	-0.9006391
2	3	1.7	15	0.085212	-0.075202

Class	FEM Support			Axial Force on Rock Bolt (MN)	
	Rock Bolt Length	Rock Bolt Spacing	Shotcrete Thickness	Max Value	Min Value
3	3	2.2	12	0.091234	-0.0341068
4	3	2.5	9	0.0912659	-0.0949089
5	3	N/A	6	N/A	N/A
6	3	N/A	5	N/A	N/A
7	3	N/A	3	N/A	N/A