

Cut and cover tunnel construction – one anchor level (Using permanent cast-in-place diaphragm wall)

Advanced nonlinear tunnel and geotechnical FEA features:

- *Moving traffic load analysis under nonlinear conditions (linear is also performed).*
- *Geotechnical stability ultimate state ("Jordbrott").*
- *Staged construction analysis for excavation, tunnel and anchors.*
- *Mohr–Coulomb nonlinear soil model is used for nonlinear conditions.*
- *Initial horizontal stresses based on Rankine at-rest earth pressure (K_0).*
- *Nonlinear tunnel–soil interface elements to handle slip resistance.*
- *Comparison of linear and nonlinear soil behaviour*

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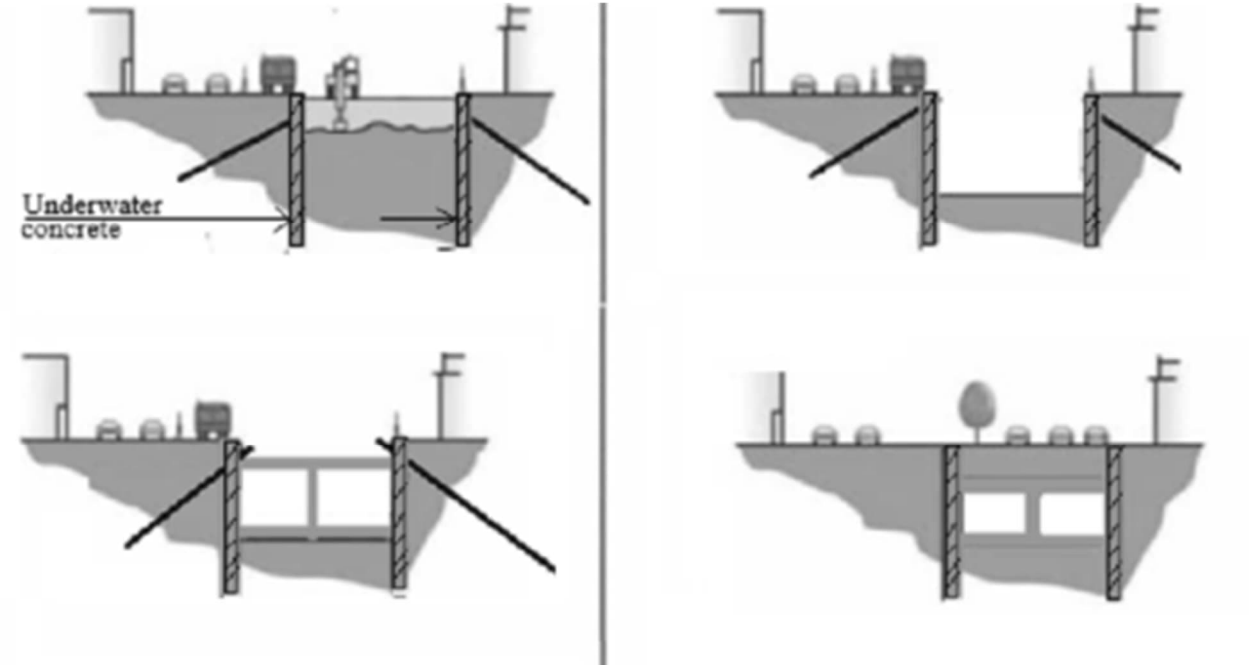
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Appendix

1. Input receipt (FEM-program)

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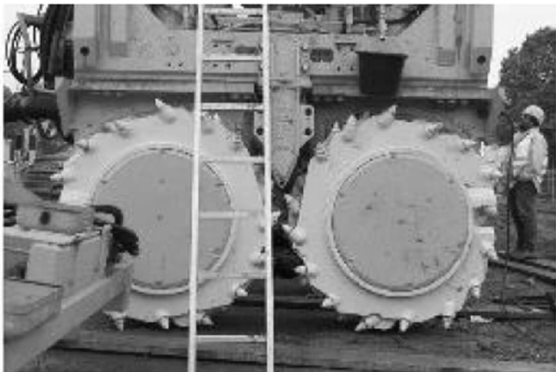
0. PREFACE



Principal sketch
Overview



Excavation
Fine grained soil



Excavation
Bouldery soil

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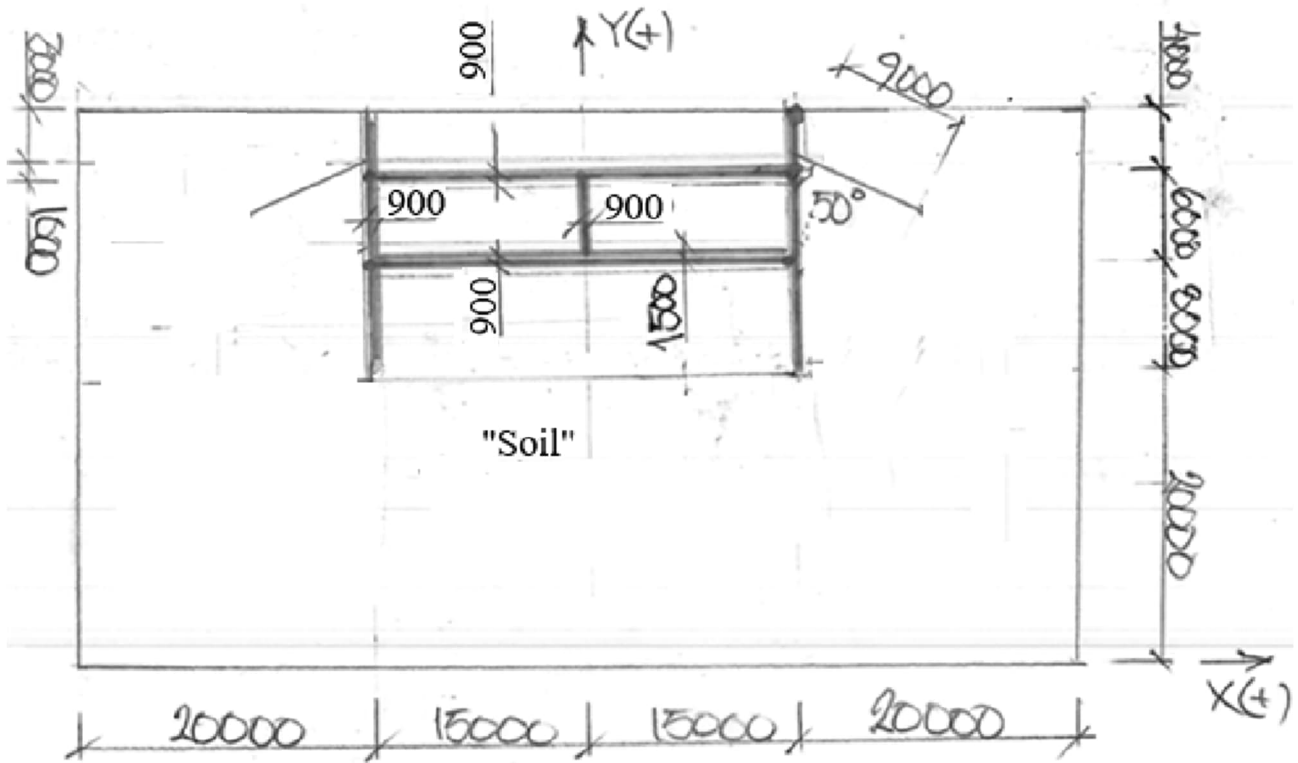
1. GENERAL

Below is a description of varying stages of design.

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 4
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1.1 GEOMETRY

Below are geometries associated to constuction and operational stage.



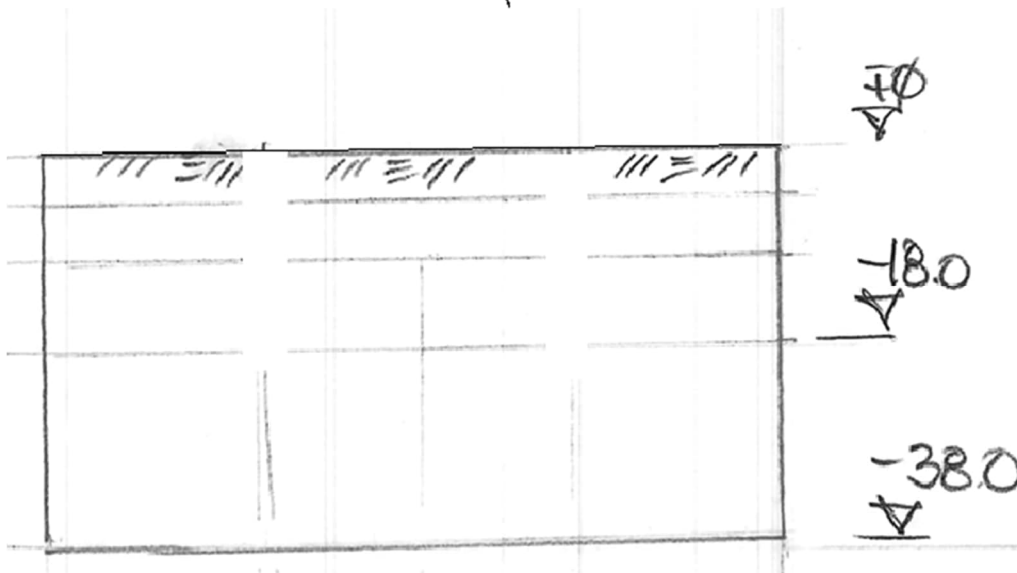
ELEVATION

Overall

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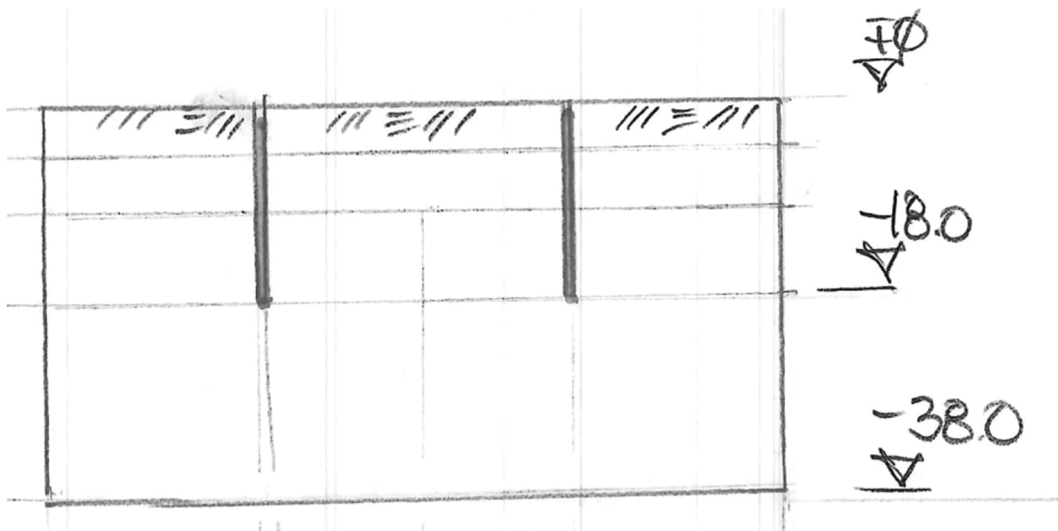
1.1.1 Construction stages

There are a total of 7 construction stages as seen on sketches below.



ELEVATION

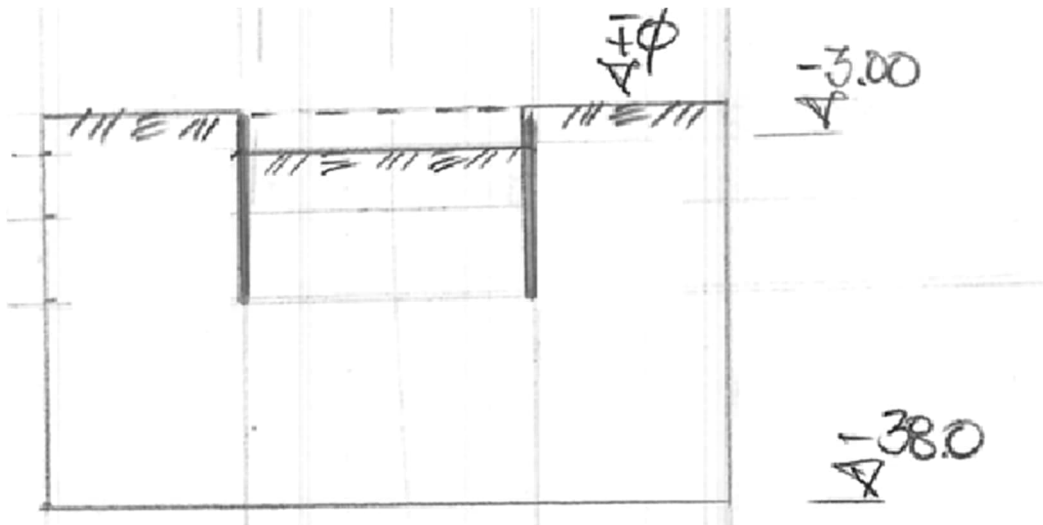
Stage 1: Initial conditions.



ELEVATION

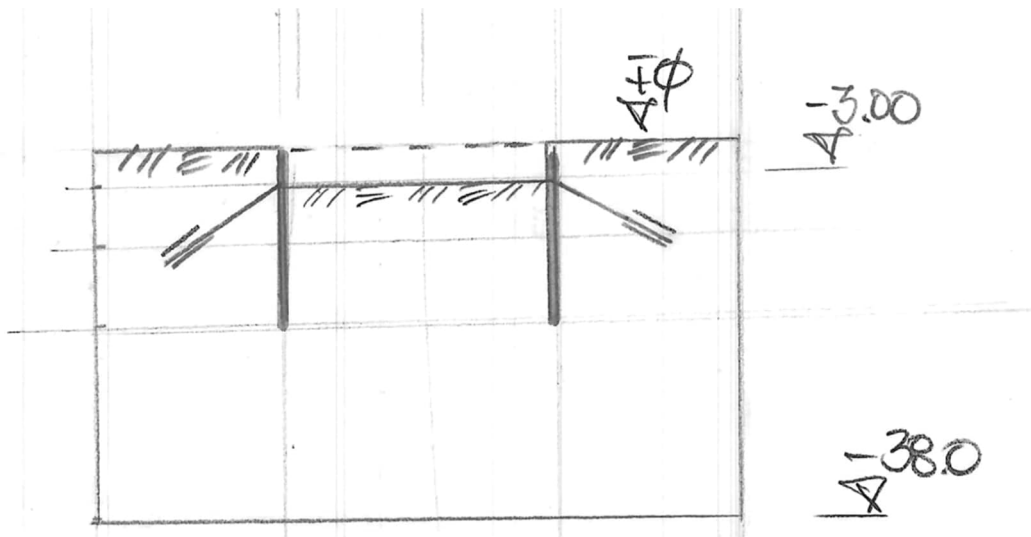
Stage 2: Installation diaphragm-walls.

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ELEVATION

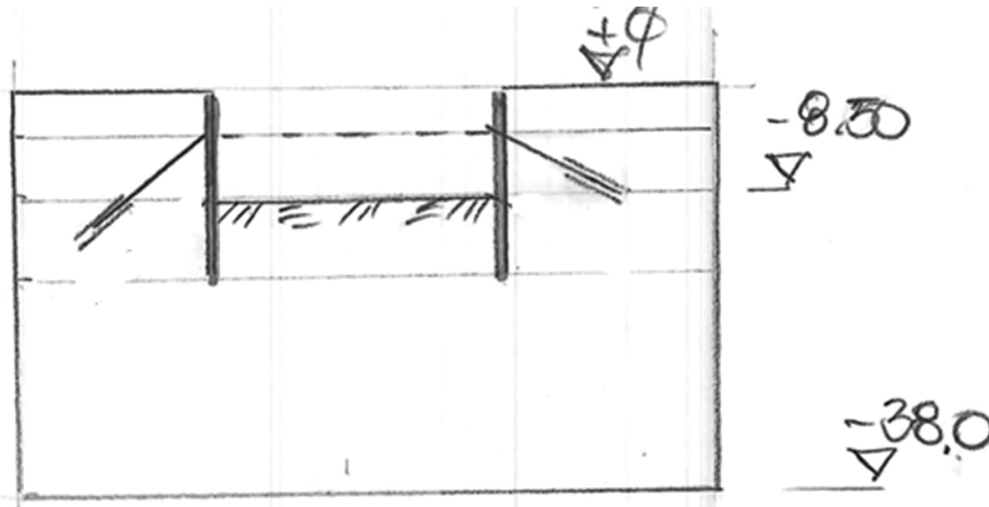
Stage 3: Excavation 1



ELEVATION

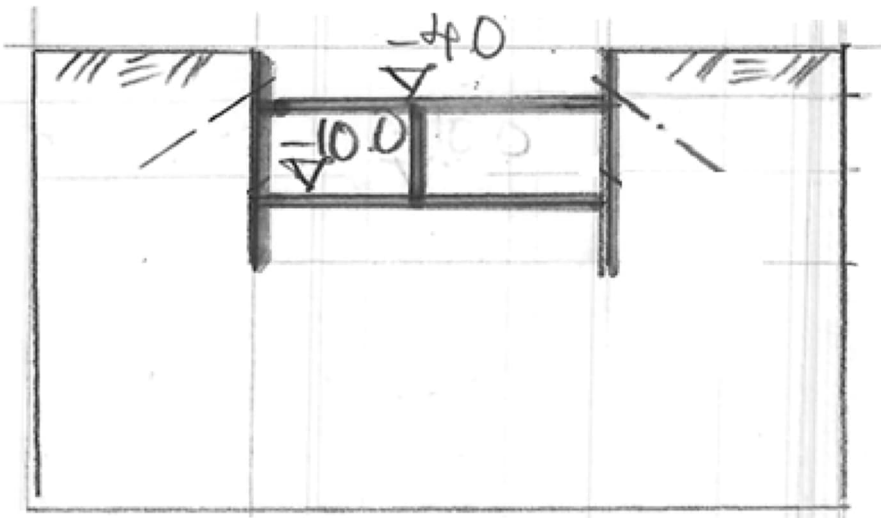
Stage 4: Installation of anchors at level 1.

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ELEVATION

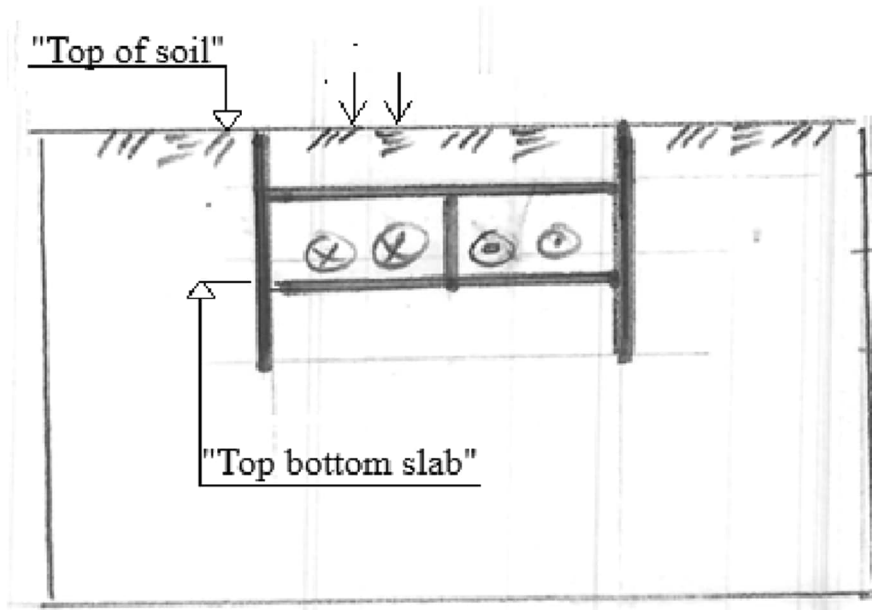
Stage 5: Excavation 2.



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Stage 6: Construction tunnel

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Overall. Stage 7: Filling on top of tunnel

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1.2 SOIL PROPERTIES

1.2.1 Ground water

Ground water level is assumed lower than level ± 0 .

1.2.2 Soil material

Geotechnical parameters:

Material	Level	ρ	ρ'	ϕ_k	E_k
"Soil"	$\pm 0 \rightarrow -38.0$	20	11	30	8
"Rock"	± 0	-	-	-	-
-	m	kN/m ³	kN/m ³	deg	MPa

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2. SYSTEM ANALYSIS

2.1 GENERAL

There are 7 construction stages (∴ Stage 1-7) that are analysed using nonlinear analysis. During each construction stage varying structural parts and soil material is activated or deactivated due to excavation and construction of structure.

The soil material is modelled using a elasto-plastic model *Mohr-Coulomb* (called model 65) that is used for soil and rocks.

Soil is modelled using plain strain surface elements (QNP8).

All structural parts of tunnel including diaphragms are modelled as thick beam elements (BMI3).

Analysis using "branches" (∴ Branch 1-5) is used to perform nonlinear analysis. Each "branch" is a sub-analysis has completed. Using braches means start and end of the previous sub-analysis are indepndent sub-analysis. Every branch is defined using single loadcases, thus load ing occur 'simultaneously', not 'sequentially'.

When applying gravity load at stage 1 (∴ before excavtion") deformations arisies which do not occur since have allready been "consolidated" over time. These are historic deformation are used by resting formations av stage 1 but maintaining stress.

Safety factor analysis is performed using function *Phi-c Reduction* to determine the most dangerous situation. Considered to arise at Stage 5,

.

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 11
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Schematic sketch

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 12
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Analysis 1:

Stage #	Name	Excavation	Loading	Deactivate	Activate
1	Before excavation	Before excavation	Gravity soil *	Tunnel & anchors	-
2	Wall installation	Before excavation	Gravity wall	-	Wall
3	Excavation:1	After excavation 1	-	Excavation:1	-
4	Install anchor:1	After excavation 1	Anchor load:1	-	Anchor:1
5	Excavation:2	After excavation 2	-	Excavation:2**	-
6	Construct tunnel	After excavation 2	Gravity top slab	Anchors	Tunnel
7	Filling at top slab	After filling top slab	Gravity filling top slab	-	Soil top slab

* = Reset deformation is applied to remove historic deformations.

** = Phi-c analysis to determin geotechnical stability ("Jordbrott").

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2.2 NONLINEAR ANALYSIS

Nonlinear analysis is performed using increments using Newton Raphson numerical procedure.

Max number of iterations:

For each load increment if convergence is not achieved.

Residual force norm:

The limit for the sum of the squares of all residual forces as a percentage of the sum of the squares of all external forces, including reactions (rdnrm). By default, only translation degrees of freedom are considered. So for a value of 0.1 the convergence of the solution at each load increment will be achieved when the out of balance forces are as less than 0.1% of the reactions.

Displacement norm:

The limit for the sum of the squares of the iterative displacements as a percentage of the sum of the squares of the incremental displacements (DTNRM). Only translation degrees of freedom are considered

Stage #	LC name	Control	Branch	Incrementation
1	Before excavation	Nonlinear	-	Automatic
2	Wall installation	Nonlinear	-	Automatic
3	Excavation:1	Nonlinear	-	Automatic
4	Install anchor:1	Nonlinear	-	Automatic
5	Excavation:2	Nonlinear	-	Automatic
”	”_”_	”_”_	Branch 1	Automatic
6	Construct tunnel	Nonlinear	-	Automatic
7	Filling at top slab	Nonlinear	-	Automatic
”	”_”_	Nonlinear	Branch 2	Automatic
”	”_”_	Nonlinear	Branch 3	Automatic
”	”_”_	Linear	Branch 4	-
”	”_”_	Linear	Branch 5	-

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Incrementation as chosen to be performed *Automatic* with chosen parameters in dialogue box.

Nonlinear & Transient

Incrementation

☒ Nonlinear

Incrementation
Automatic

Starting load factor
0.1

Max change in load factor
1.0

Max total load factor
1.0

☒ Adjust load based on convergence

Iterations per increment
4

Advanced...

☐ Time domain

Two Phase

Initial time step

Total response time

☐ Automatic time stepping

Advanced...

Solution strategy

☒ Same as previous loadcase

Max number of iterations
12

Residual force norm
0.1

Displacement norm
0.1

Advanced...

Incremental LUSAS file output

☒ Same as previous loadcase

Output file
1

Plot file
1

Restart file
0

Max number of saved restarts
0

Log file
1

History file
1

☐ Save a restart at the end of this control

Common to all

Max time steps or increments
20

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 15
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2.3 SAFETY FACTOR ANALYSIS

A nonlinear safety factor analysis is performed using function *Phi-c Reduction* with starting values seen below. This analysis is performed at stage 5 which is considered most dangerous.

Phi-c Reduction

	Value
Starting value for safety factor	1.1
Minimum change in safety factor	0.01
Maximum number of steps to use	40

Name
Phi-c1
(1)

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2.4 SKETCH SYSTEM ANALYSIS

To describe geometry first POINTS are defined.

Beam elements are defined by applying attributes to LINES.

Shell elements are defined by applying attributes to SURFACES.

All coordinates needed to describe POINTS are found in attachment 1.

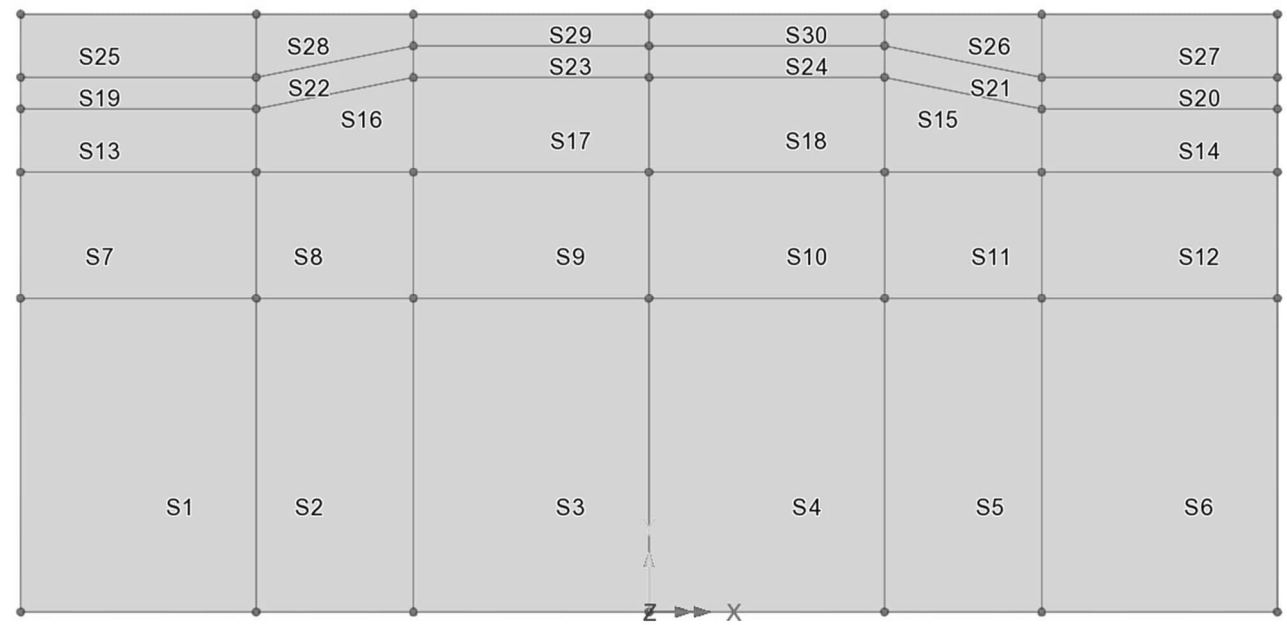
All POINTS needed to describe LINES are found in attachment 1.

All LINES need to describe SURFACE are found in attachment 1.

Sketches are generated by using POINTS, LINES and SURFACES.

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2.4.3 Geometry: Surfaces

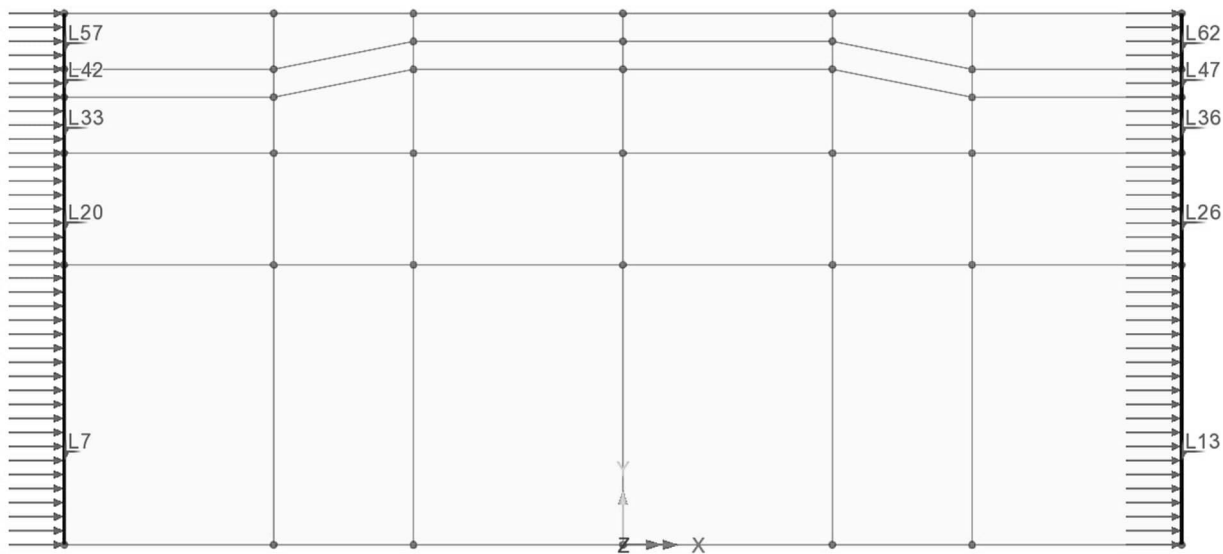


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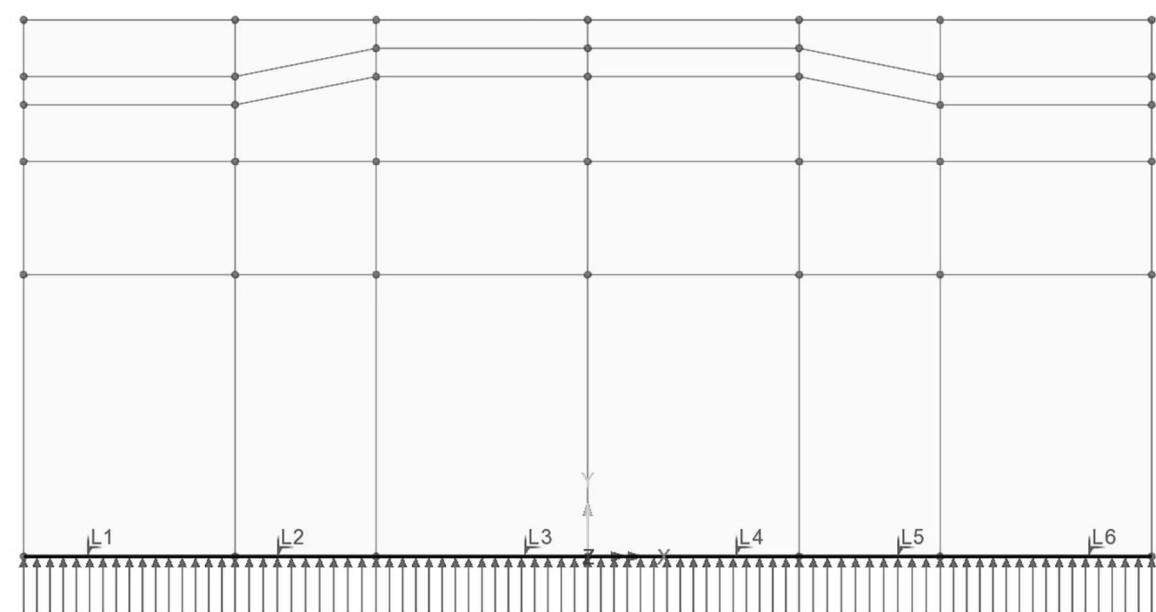
2.5 BOUNDARY CONDITIONS

2.5.1 Horizontal boundary soil: Fixed X



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2.5.2 Vertical boundary soil: Fixed Y



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Overall

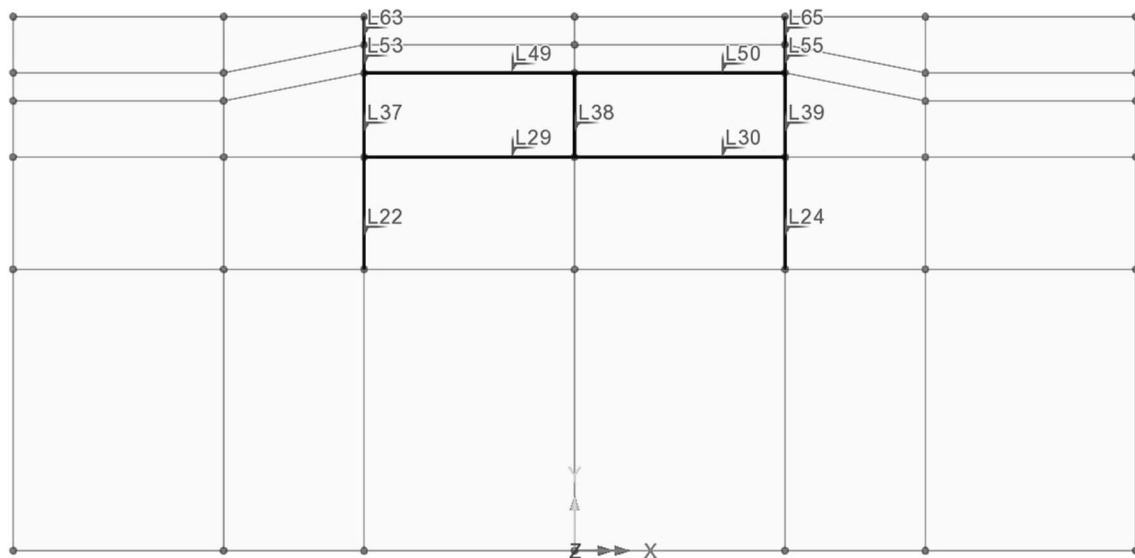
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2.6 MESH

2.6.1 Tunnel: Thick beam (BMI3)

Diaphragms seen below with two dimensional long structures retaining walls for which the plane strain assumption is appropriate.

Name	Element type	Element length	Order element
BMI3	Thick beam	2.0 m	Quadratic



ELEVATION

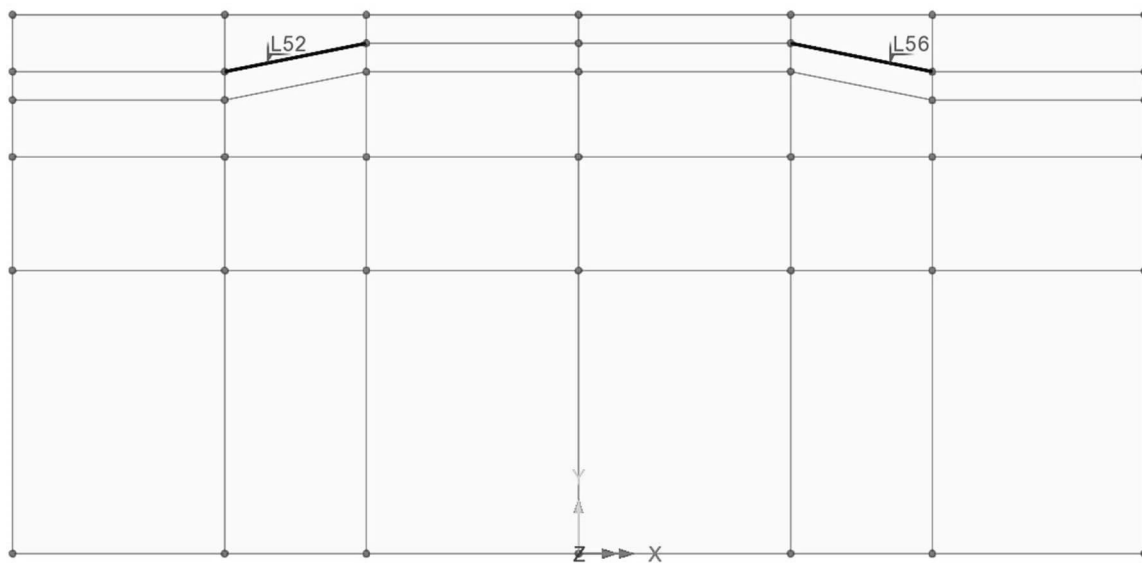
Overall

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2.6.2 Anchor rod: Bar element (BAR3)

Anchor rods are modelled as seen below. This element is connected to nodes in soil thus the rod is defined by same nodes as soil.

Name	Element type	Element length	Order element
BAR3	Bar	2.0 m	Quadratic



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2.6.3 Interface element between tunnel and soil: Interface plain strain (IPN6)

The interface between soil and wall is modelled as seen below.

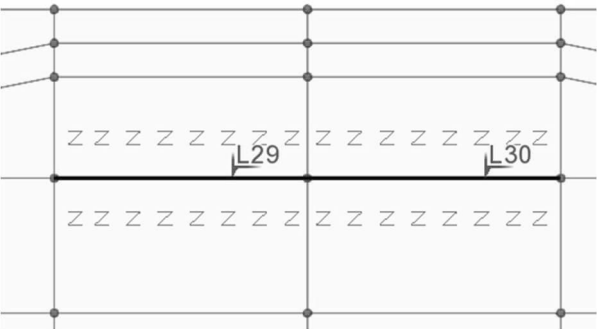
The element is used for modelling standard Mohr-Coulomb friction contact in soil/structure interactions.

Name	Element type	Element length	Assignment type	Order element
IPN6	Interface: vertical	2 m	Single feature (automatic)	Quadratic
IPN6	Interface: horizontal	2 m	Single feature (automatic)	Quadratic



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Interface: vertical



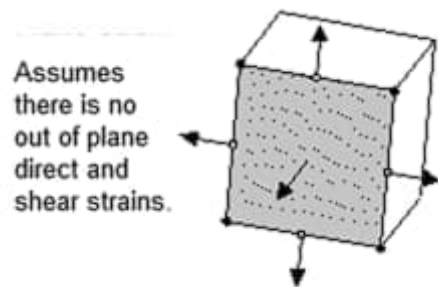
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Interface: horizontal

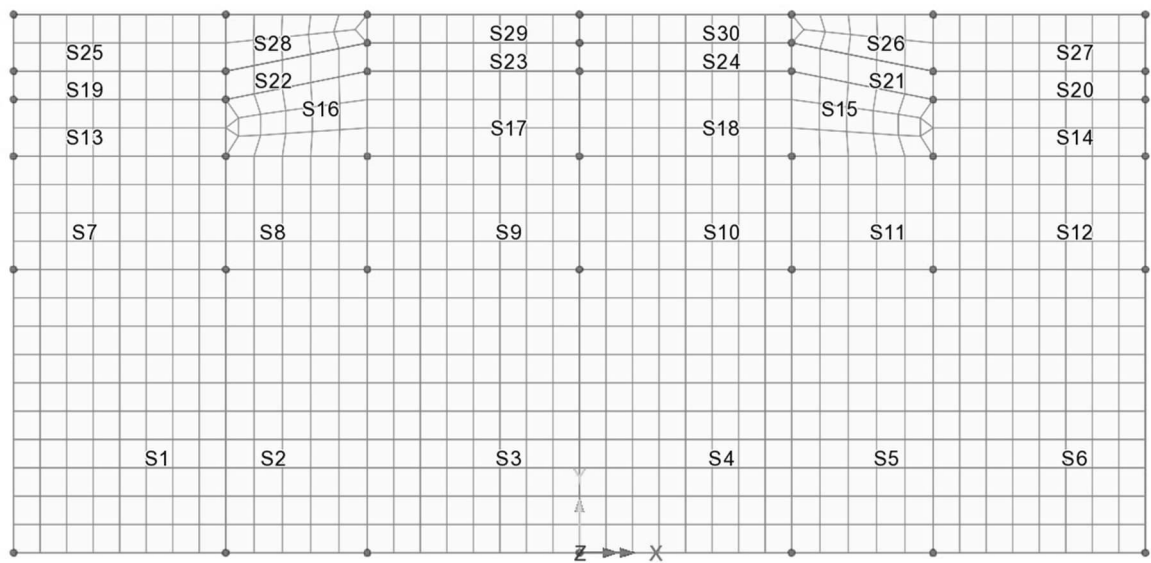
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 23
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2.6.4 Soil: plain strain surface elements (QPN8)

Soil is modelled using surface elements as seen below. The element type plain strain.



Name	Element type	Element size	Order element	Mesh
QPN8	Plain strain surfacde	Automatic	Quadratic	Regular



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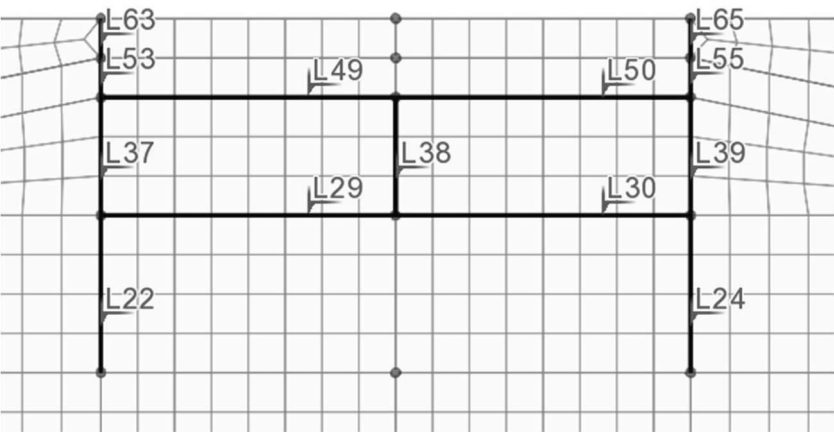
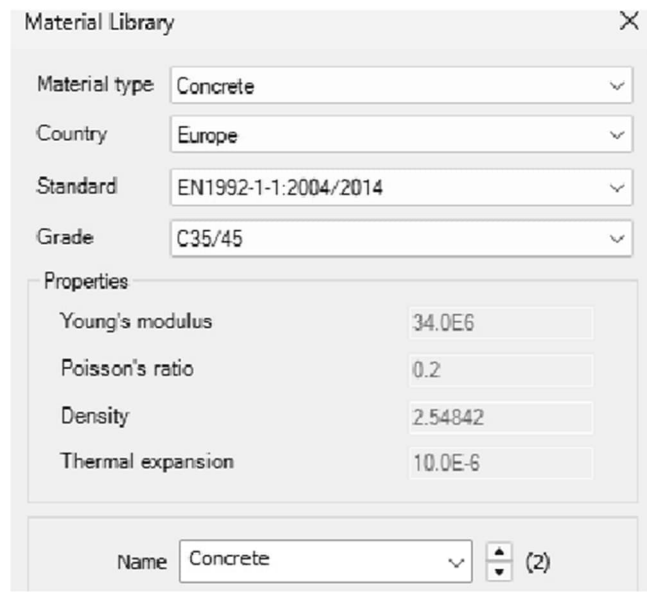
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 24
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2.7 MATERIAL

2.7.1 Linear elastic material: tunnel & anchors

Tunnel:

The retaining wall is assumed to be isotropic concrete C40/50.



ELEVATION
Detail

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Anchors:

Material Library

Material type

Steel - Structural

Country

Europe

Standard

EN1993-1-1:2005

Grade

Ungraded

Properties

Young's modulus

210.0E6

Poisson's ratio

0.3

Density

7.84913

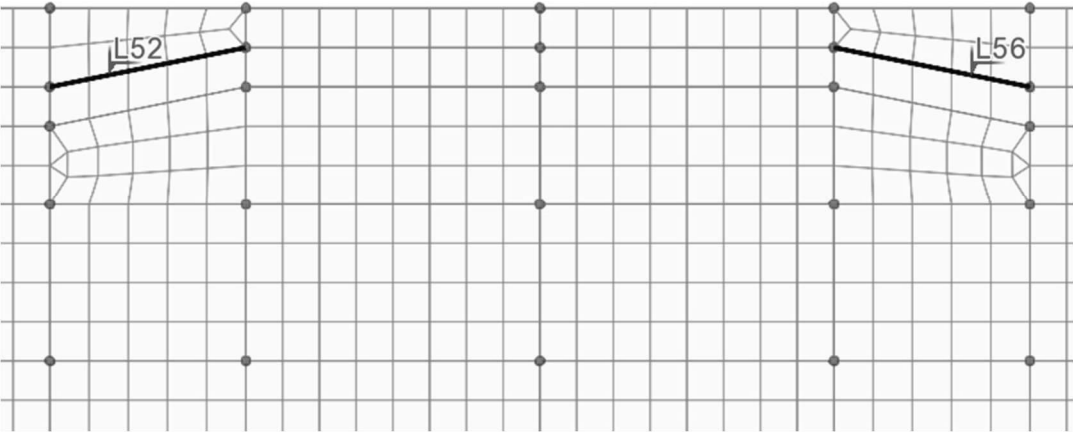
Thermal expansion

12.0E-6

Name

Steel

(3)



ELEVATION
Detail

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2.7.2 Nonlinear material: soil

Soil is modelled modified Mohr-Coulomb (called modell 65).

The above mentioned material assumes:

- Perfectly plastic after the failure criterion is reached.
- Yielding is governed by the Mohr–Coulomb failure formula, which relates shear strength as seen below.

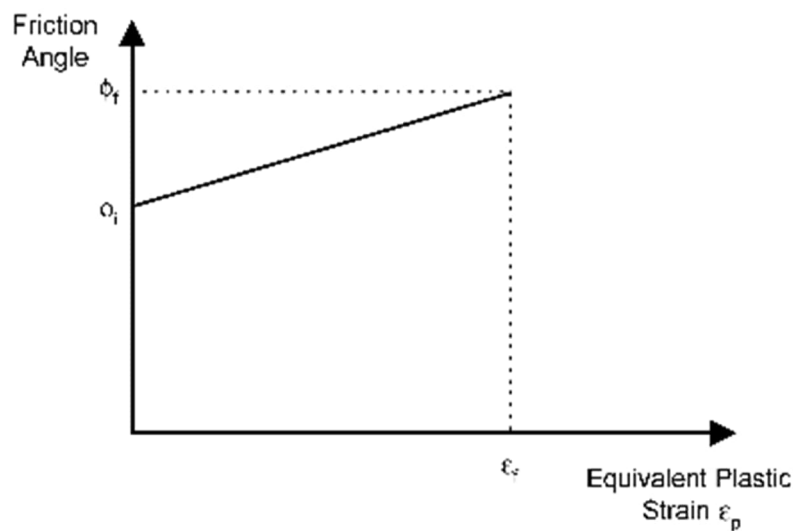
$$\tau_f = c + \sigma_n \tan \phi$$

$$\sigma_1 = \sigma_3 \frac{1+\sin \phi}{1-\sin \phi} + \frac{2c \cos \phi}{1-\sin \phi}$$

where:

σ_1 = major principal stress,

σ_3 = minor principal stress.



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Definition	Parameter	Soil
Elastic	Young's Modulus	8,000 kPa
Elastic	Poisson's ratio	0.3
Elastic	Mass density (Fully Saturated)	2.0
Plastic	Friction angle	30.0°
Plastic	Dilation angle	0 °
Plastic	Cohesion	1.0 kPa
Plastic (Rankine)	Tensile cut-off stress	0 kPa
Plastic (Rankine)	Compressive cut-off stress	1E30 kPa
Plastic (Rankine)	Damping factor	0
Plastic (Rankine)	Coefficient of lateral earth pressure K_0	0.5

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 28
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2.7.3 Nonlinear joint material between retaining tunnel and soil

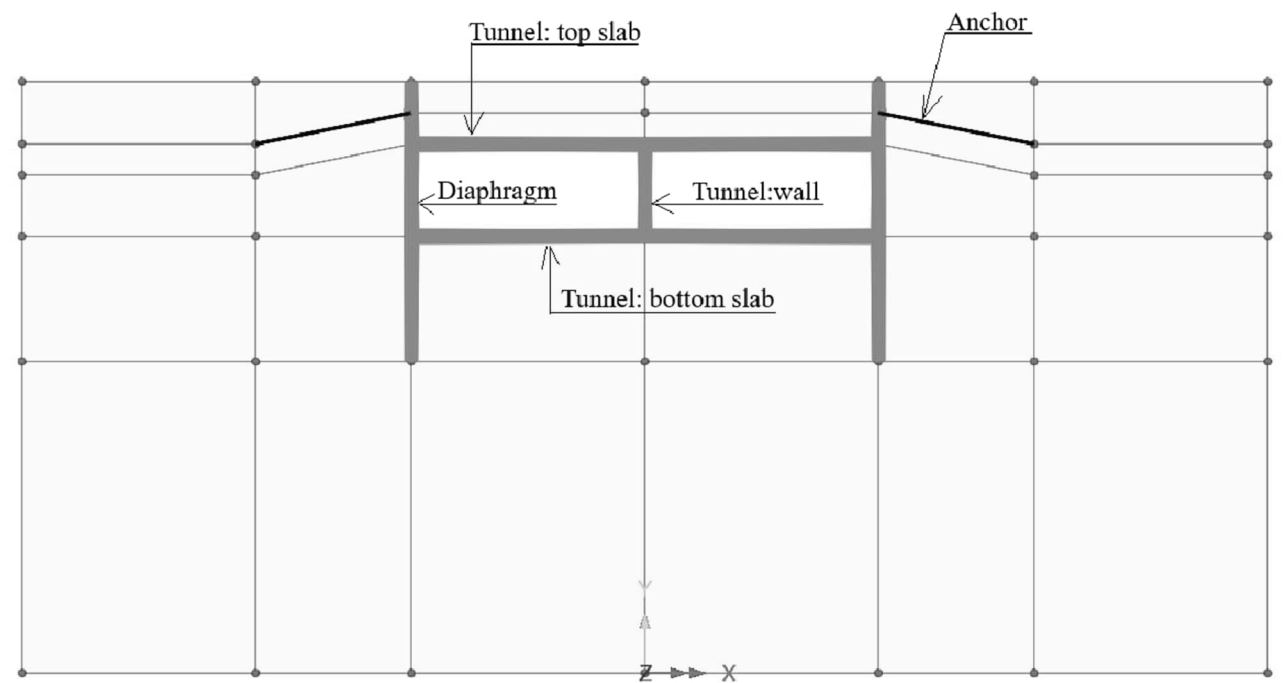
The tangential slip surface is defined as seen below.

Defintion	Parameter	Tunnel/soil
Soil structure interface (tangential slip)	Angle of friction	20°
Soil structure interface (tangential slip)	Dilatency angle	0
Soil structure interface (tangential slip)	Cohesion	0 kPa

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2.8 CROSS SECTIONS

Defined cross section properties.



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Detail

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 30
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2.8.1 Tunnel

Same tunnel section is used for all parts including diaphragm.

Geometric Line

Analysis category
2D Inplane

Definition

☒ From library / calculator
☐ Enter properties

Rotation about centroid
0 °
Mirrored about axis
None

Parametric Sections
Rectangular Sections
1:0.9x1 (RSS D=0.9 B=1)

ey origin
Centroid

	Value
Cross sectional area (A)	0.9
Second moment of area about z axis (Izz)	0.06075
Effective shear area in y direction (Asy)	0.750089
Eccentricity in y direction (ey)	0.0

Visualise...
Section details...

Name
Tunnel cross-section
(1)

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 31
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2.8.2 Rod anchor

Rod area is adapted to c/c 2.5 m of anchor rods.

Geometric Line

Analysis category
2D Inplane

Definition

☒ From library / calculator
☐ Enter properties

Rotation about centroid
0 °
Mirrored about axis
None

Parametric Sections
Circular Sections
2:0.05CSS (CSS D=0.05)

ey origin
Centroid

	Value
Cross sectional area (A)	1.9635E-3
Second moment of area about z axis (Izz)	0.306796E-6
Effective shear area in y direction (Asy)	1.67924E-3
Eccentricity in y direction (ey)	0.0

Visualise...
Section details...

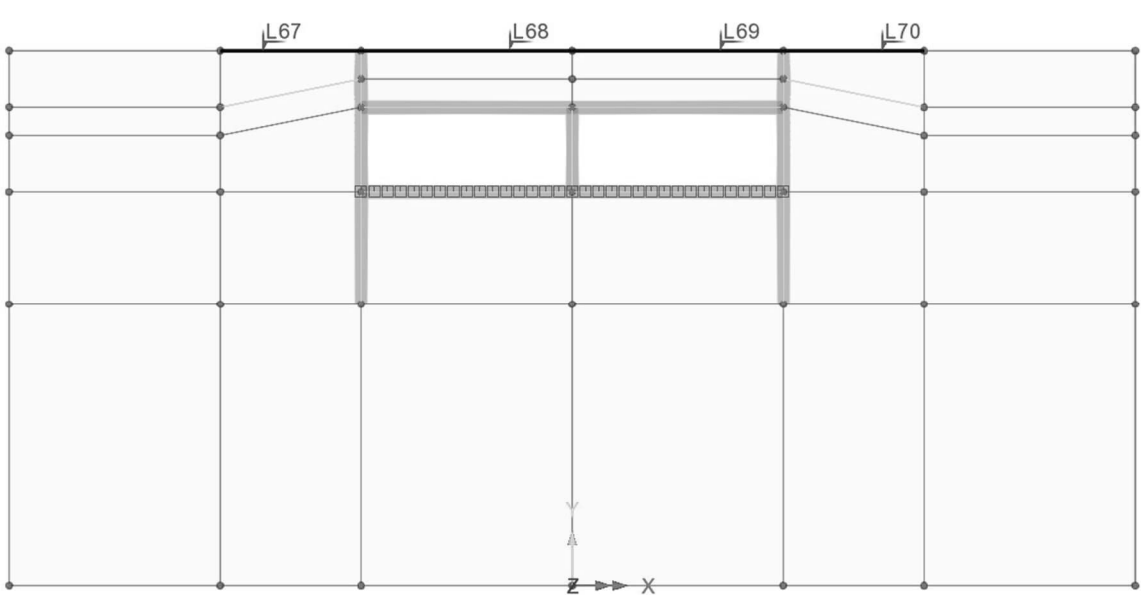
Name
Anchor
(2)

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2.9 SEARCH AREA

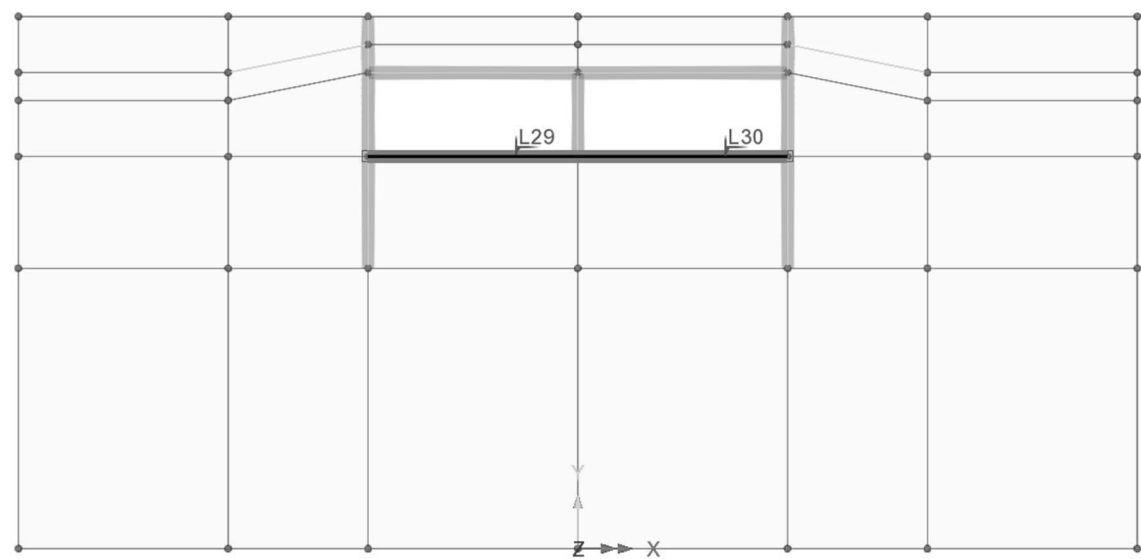
Discrete load can be applied to structure as geometrical load areas. The load areas are termed “Search Area”.

2.9.1 Search area: Fictive beam



ELEVATION

2.9.2 Search area: Bottom slab

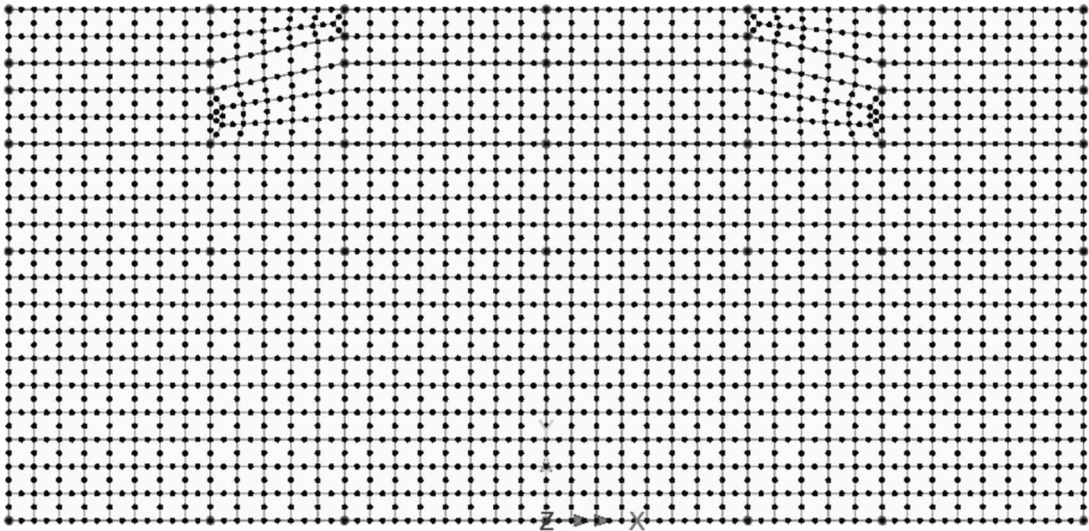
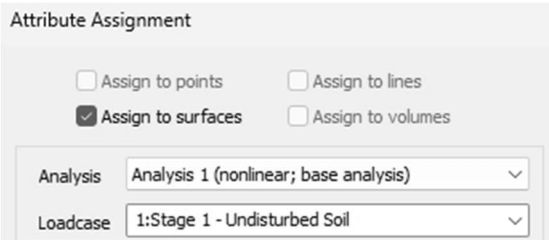
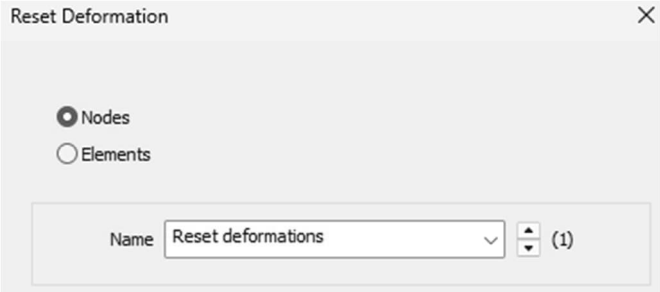


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2.10 RESET DEFORMATIONS

All node deformations at stage 1 are set to zero.



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Overall

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3. LOADS

3.1 Soil weight (Gravity)

Soil weight is determined material density.

Body Force

Analysis category
2D Inplane

Component	Value
Linear acceleration in X	0.0
Linear acceleration in Y	-10.0
Angular velocity about Z axis	0.0
Angular acceleration about Z axis	0.0

Name
Gravity
(2)

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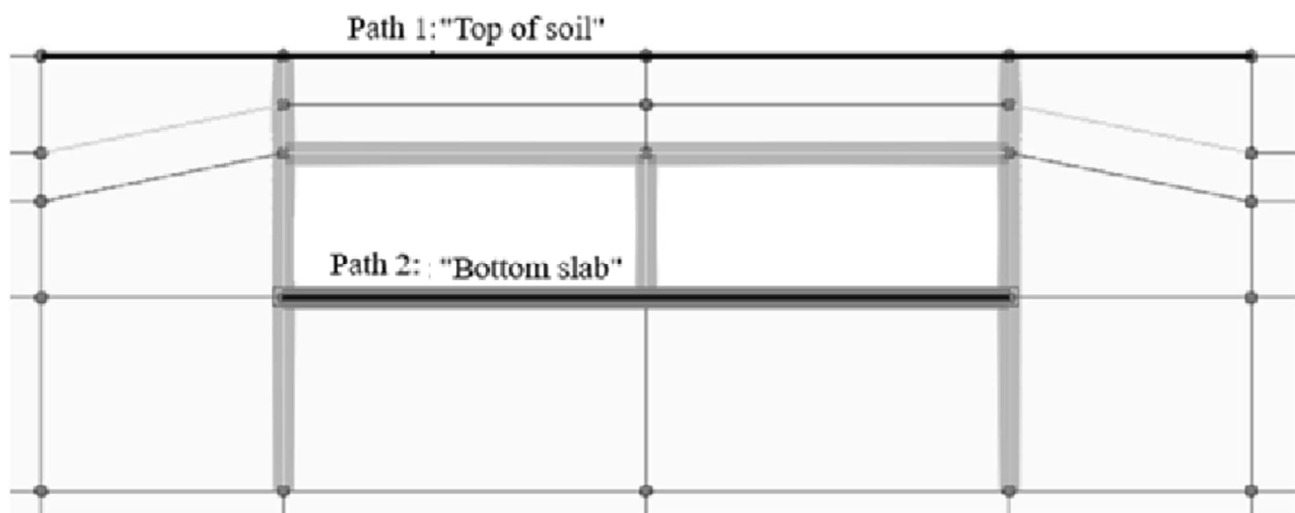
3.2 Traffic load – LM 1

Traffic is applied at two levels, “top of soil” and “bottom slab”.

Since soil is nonlinear analysing moving traffic load is difficult. Another difficulty is principle of load superposition which does not apply.

To verify nonlinear traffic load a linear analysis is also conducted.

Branch #	Level at road	Soil	LC
2	"Top of soil"	Linear	Branch 2: LM 1
3	"Bottom slab"	Linear	Branch 3: LM 1
4	"Top of soil"	Nonlinear	Branch 4: LM 1
5	"Bottom slab"	Nonlinear	Branch 5: LM 1



ELEVATION

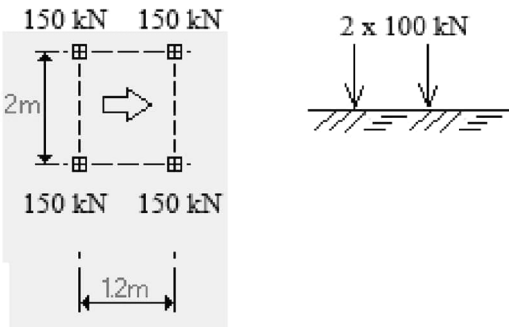
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3.2.1 Road “Top of soil”

3.2.1.1 Traffic load

Axle load (LM 1:P-T):

Distribution width 3.0 m I assumed in transversal traffic direction.



Point

Analysis category2D Inplane

Arbitrary

Grid

x2

y1

Untransformed load direction

X

Y

Z

Surface normal

XYZ global

XYZ transformable

Projection vector

☒

Project in load direction

X component

0.0

Y component

1.0

Z component

0.0

	X	Y	Z	Load
1	-0.6	0.0	0.0	-100.0
2	0.6	0.0	0.0	-100.0

Name

LM 1:P-T

(3)

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 37
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Surface load (LM 1:q):

Patch

Analysis category
2D Inplane

Patch type

☐ 8 node patch
☐ 4 node patch
☐ Multi-patch
☒ Straight
☐ Curve
☐ Multi-straight

Load direction

☐ X
☐ Z
☒ Y
☐ XYZ global

☐ Patch x
☐ Patch y
☐ Surface normal
☐ XYZ transformable

Projection vector

☐ Project in load direction
☐ Project for prestress

X component
0.0

Y component
0.0

Z component
1.0

Patch load divisions

☒ Use default

Number of divisions in x
0

Number of divisions in y
0

	X	Y	Z	Load
1	-15.0	0.0	-1.5	-9.0
2	15.0	0.0	-1.5	-9.0

Name
LM 1:q
(4)

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 38
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3.2.1.2 Linear analysis

Moving Load Analysis (Linear)

Discrete load
LM 1:P-T & LM 1:q

Assignment

☒ Project onto line (2D line beams and frames)

☐ Project over area (grillages, shells, and 3D space frames)

Search area
1: Top of soil

Options for loads outside search area
Exclude All Load

Moments to include
All

Load path definition

Reference path
Path1

Direction of travel
Forward

Path divisions

☒ Move load along path in equal divisions

Divisions
16

☐ Move load by incremental distance along path

Distance
5.5

☒ Create loadcase envelope

Name
Branch 2: LM 1-T

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 39
		Date :	Created :

3.2.1.3 Nonlinear analysis

Moving Load Analysis (Linear)

Discrete load
LM 1-T

Assignment

☒ Project onto line (2D line beams and frames)

☐ Project over area (grillages, shells, and 3D space frames)

Search area
1: Top of soil

Options for loads outside search area
Exclude All Load

Moments to include
All

Load path definition

Reference path
Path1

Direction of travel
Forward

Path divisions

☒ Move load along path in equal divisions

Divisions
16

☐ Move load by incremental distance along path

Distance
5.5

☒ Create loadcase envelope

Name
Branch 2: LM 1-T

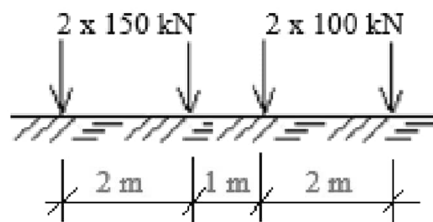
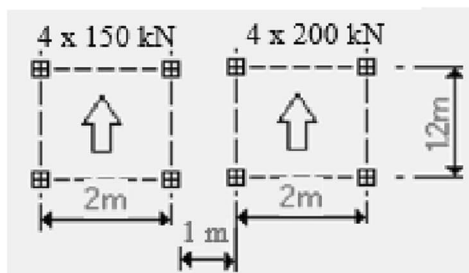
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 40
		Date :	Created :

3.2.2 Road “Bottom slab”

3.2.2.1 Traffic load

Axle load (LM 1:P-B):

Distribution width 2.0 m I assumed in transversal traffic direction.



Point

Analysis category
2D Inplane

☐ Arbitrary

☒ Grid

x
4

y
1

Untransformed load direction

☐ X
☒ Y

☐ Z
☐ Surface normal

☐ XYZ global
☐ XYZ transformable

Projection vector

☒ Project in load direction

X component
0.0

Y component
1.0

Z component
0.0

	X	Y	Z	Load
1	-2.5	0.0	0.0	-150.0
2	-0.5	0.0	0.0	-150.0
3	0.5	0.0	0.0	-100.0
4	2.5	0.0	0.0	-100.0

Name
LM 1:P-B
(5)

Surface load (LM 1:q):

See page 37.

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 41
		Date :	Created :

3.2.2.2 Linear analysis

Moving Load Analysis(Linear)

Discrete load
LM 1:P-B & LM 1:q

Assignment

☒ Project onto line (2D line beams and frames)

☐ Project over area (grillages, shells, and 3D space frames)

Search area
2: Bottom of slab

Options for loads outside search area
Exclude All Load

Moments to include
All

Load path definition

Reference path
Path 2

Direction of travel
Forward

Path divisions

☒ Move load along path in equal divisions

Divisions
8

☐ Move load by incremental distance along path

Distance
5.5

☒ Create loadcase envelope

Name
Branch 3: LM 1-B

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 42
		Date :	Created :

3.2.2.3 Nonlinear analysis

Moving Load Analysis(Nonlinear & transient)

Discrete load
LM 1:P-B & LM 1:q

Assignment

☒ Project onto line (2D line beams and frames)
☐ Project over area (grillages, shells, and 3D space frames)

Search area
2: Bottom of slab

Options for loads outside search area
Exclude All Load

Moments to include
All

Load path definition

Reference path
Path 2

Direction of travel
Forward

Path divisions

☒ Move load along path in equal divisions
Divisions
8

☐ Move load by incremental distance along path
Distance
5.5

☒ Create loadcase envelope

Name
Branch 5: LM 1-B

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 43
		Date :	Created :

4. **RESULTS (FEM-program)**

Summary soil stress (min SY):

Stage #	LC name	Min Sy	Branch	Type
1	Before excavation	-671	-	Nonlinear
2	Wall installation	-684	-	Nonlinear
3	Excavation:1	-672	-	Nonlinear
4	Install anchor:1	-671	-	Nonlinear
5	Excavation:2	-657	-	Nonlinear
6	Construct tunnel	-666	-	Nonlinear
7	Filling at top slab	-667	-	Nonlinear
"	Traffic & gravity	-684	Branch 2	Nonlinear
"	Traffic (linear)	-137	Branch 4	Nonlinear
"	Traffic (nonlinear)	-145	Branch 2	Smart combination
-	-	kPa	-	-

Geotechnical safety factor (SF):

Stage #	LC name	SF	Branch	Type
1	Before excavation	-	-	Nonlinear
2	Wall installation	-	-	Nonlinear
3	Excavation:1	-	-	Nonlinear
4	Install anchor:1	-	-	Nonlinear
5	Excavation:2	1.42	-	Nonlinear
6	Construct tunnel	-	-	Nonlinear
7	Filling at top slab	-	-	Nonlinear

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 44
		Date :	Created :

Summary deformations (max RSLT):

Stage #	LC name	max RSLT	Branch	Type
1	Before excavation	0	-	Nonlinear
2	Wall installation	0	-	Nonlinear
3	Excavation:1	14	-	Nonlinear
4	Install anchor:1	14	-	Nonlinear
5	Excavation:2	77	-	Nonlinear
6	Construct tunnel	61	-	Nonlinear
7	Filling at top slab	43	-	Nonlinear
"	Traffic (linear)	12	Branch 4	Nonlinear
"	Traffic (nonlinear)	69	Branch 2	Smart combination
-	-	mm	-	-

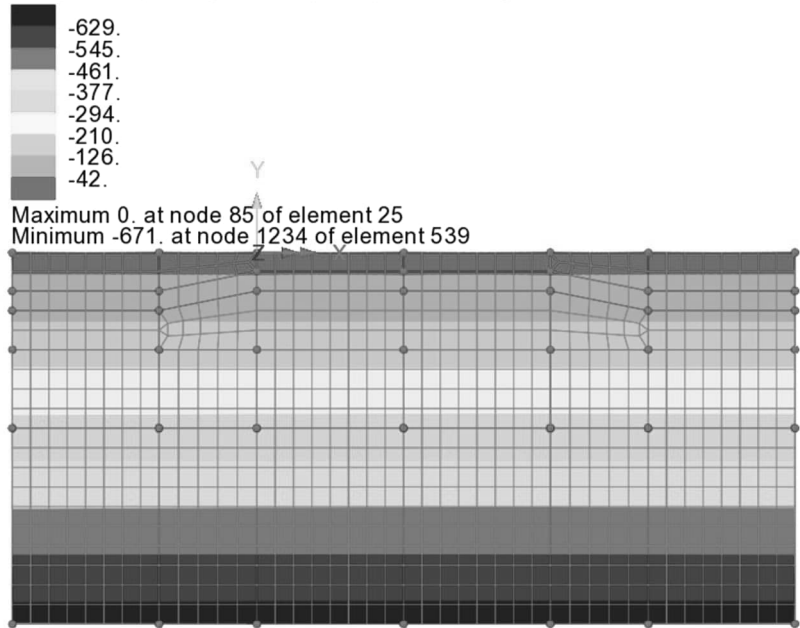
Summary forces tunnel (max/min My):

Stage #	LC name	Max My	Min My	Branch	Type
1	Before excavation	-	-	-	Nonlinear
2	Wall installation	0	0	-	Nonlinear
3	Excavation:1	42	-46	-	Nonlinear
4	Install anchor:1	42	-46	-	Nonlinear
5	Excavation:2	245	-366	-	Nonlinear
6	Construct tunnel	628	-686	-	Nonlinear
7	Filling at top slab	1953	-2125	-	Nonlinear
"	Traffic & gravity	2219	-2620	Branch 2	Nonlinear
"	Traffic (linear)	261	-258	Branch 4	Nonlinear
"	Traffic (nonlinear)	266	-495	Branch 2	Smart combination
-	-	kNm/m	kNm/m	-	-

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 45
		Date :	Created :

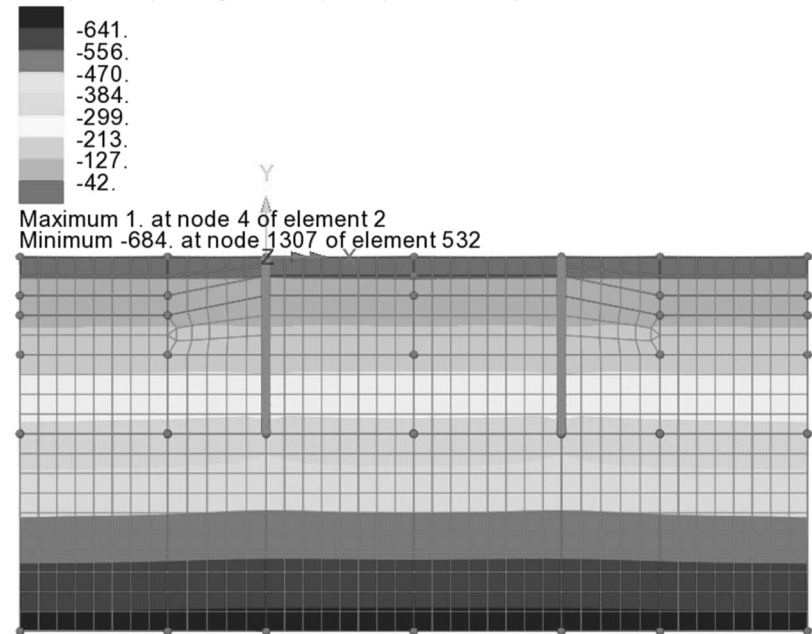
4.1 SOIL STRESS GLOBAY Y-DIRECTION (SY)

Analysis: Analysis 1
 Loadcase: 1:Stage 1 - Undisturbed Soil, 1:Increment 1
 Results file: Tunnel1V1~Analysis 1.mys
 Entity: Stress - Plane Strain
 Component (Averaged nodal): SY (Units: kN/m²)



→ min Sy = -671 kPa

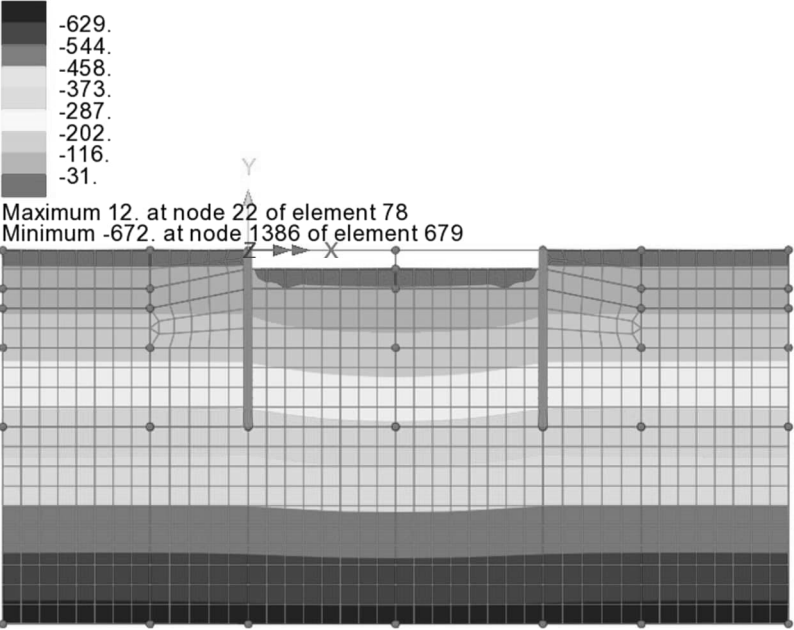
Analysis: Analysis 1
 Loadcase: 2:Stage 2 - pile walls, 2:Increment 2
 Results file: Tunnel1V1~Analysis 1.mys
 Entity: Stress - Plane Strain
 Component (Averaged nodal): SY (Units: kN/m²)



→ min Sy = -684 kPa

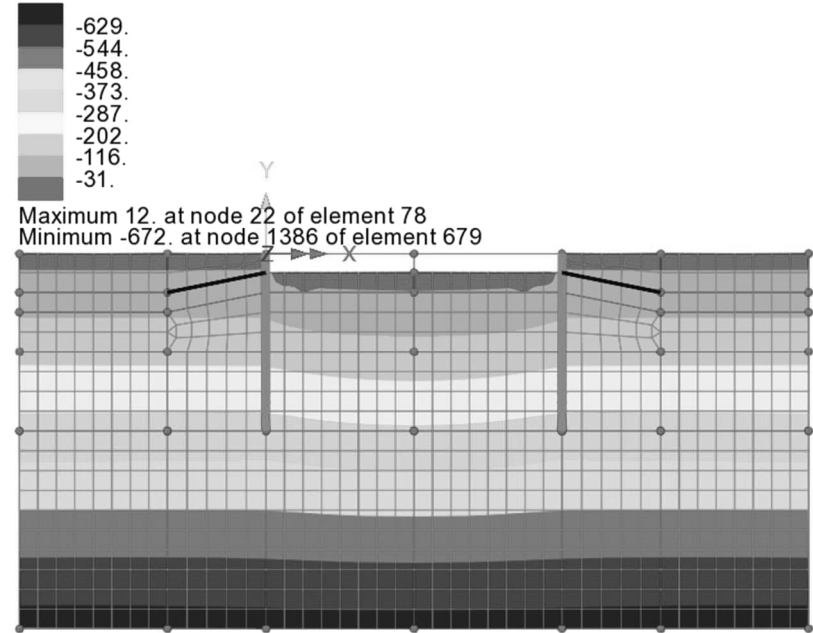
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 46
		Date :	Created :

Analysis: Analysis 1
 Loadcase: 3:Stage 3 - Excavation 1, 3:Increment 3
 Results file: Tunnel1V1~Analysis 1.mys
 Entity: Stress - Plane Strain
 Component (Averaged nodal): SY (Units: kN/m²)



→ min Sy = -672 kPa

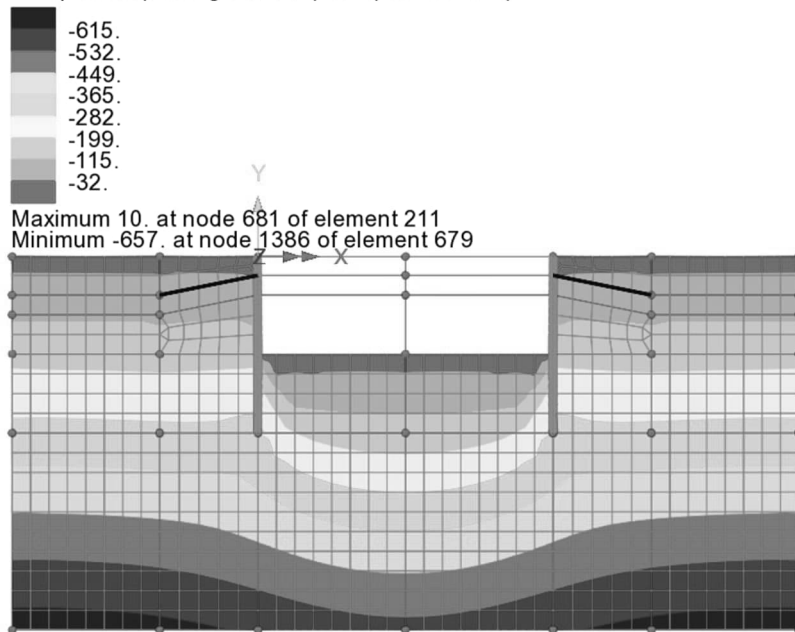
Analysis: Analysis 1
 Loadcase: 4:Stage 4 - Install anchors, 4:Increment 4
 Results file: Tunnel1V1~Analysis 1.mys
 Entity: Stress - Plane Strain
 Component (Averaged nodal): SY (Units: kN/m²)



→ min Sy = -671 kPa

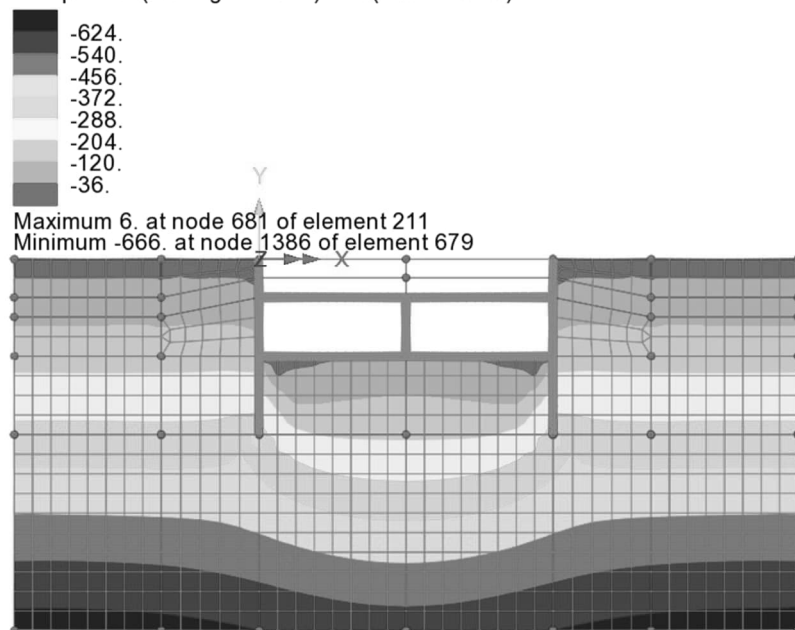
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 47
		Date :	Created :

Analysis: Analysis 1
Loadcase: 5:Stage 5 - Excavation 2, 5:Increment 5
Results file: Tunnel1V1~Analysis 1.mys
Entity: Stress - Plane Strain
Component (Averaged nodal): SY (Units: kN/m²)



→ min Sy = -657 kPa

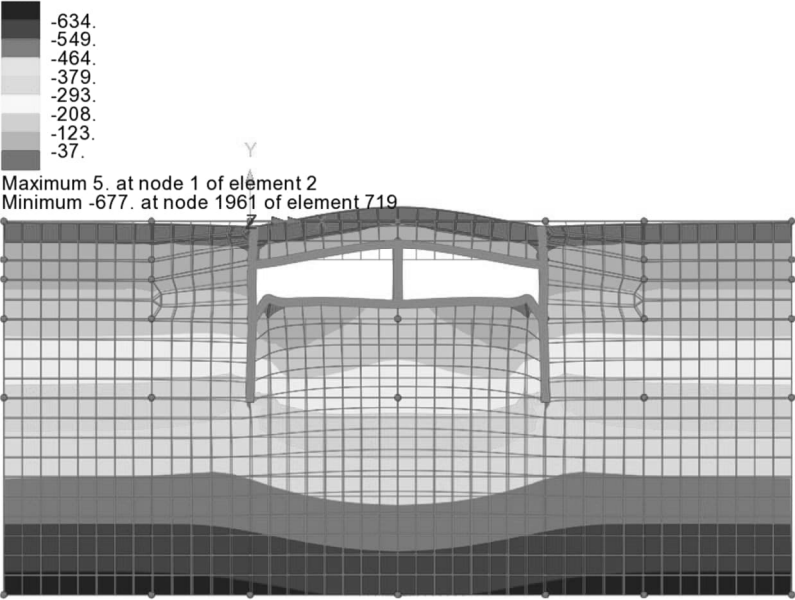
Analysis: Analysis 1
Loadcase: 6:Stage 6 - tunnel, 6:Increment 6
Results file: Tunnel1V1~Analysis 1.mys
Entity: Stress - Plane Strain
Component (Averaged nodal): SY (Units: kN/m²)



→ min Sy = -666 kPa

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 48
		Date :	Created :

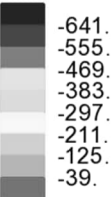
Analysis: Analysis 1
Loadcase: 7:Stage 7 - Filling top of tunnel, 7:Increment 7
Results file: Tunnel1V1~Analysis 1.mys
Entity: Stress - Plane Strain
Component (Averaged nodal): SY (Units: kN/m²)



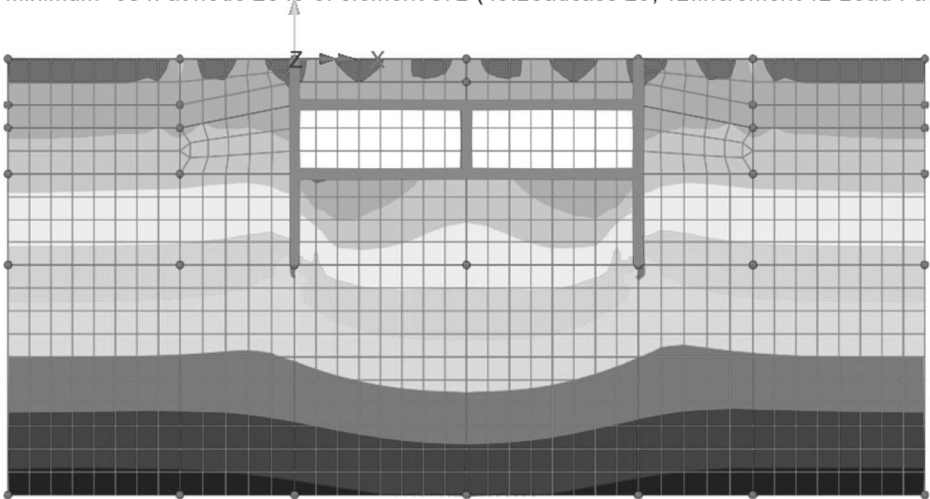
→ min Sy = -667 kPa

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 49
		Date :	Created :

Envelope: 50:Branch 2 - Traffic (nonlinear including gravity) (Min - SY)
 Entity: Stress - Plane Strain
 Component (Averaged nodal): SY (Units: kN/m²)



Maximum 4. at node 1 of element 2 (39:Loadcase 19, 30:Increment 30 Load Factor = 1.00000)
 Minimum -684. at node 2345 of element 872 (45:Loadcase 25, 12:Increment 12 Load Factor = 1.00000)



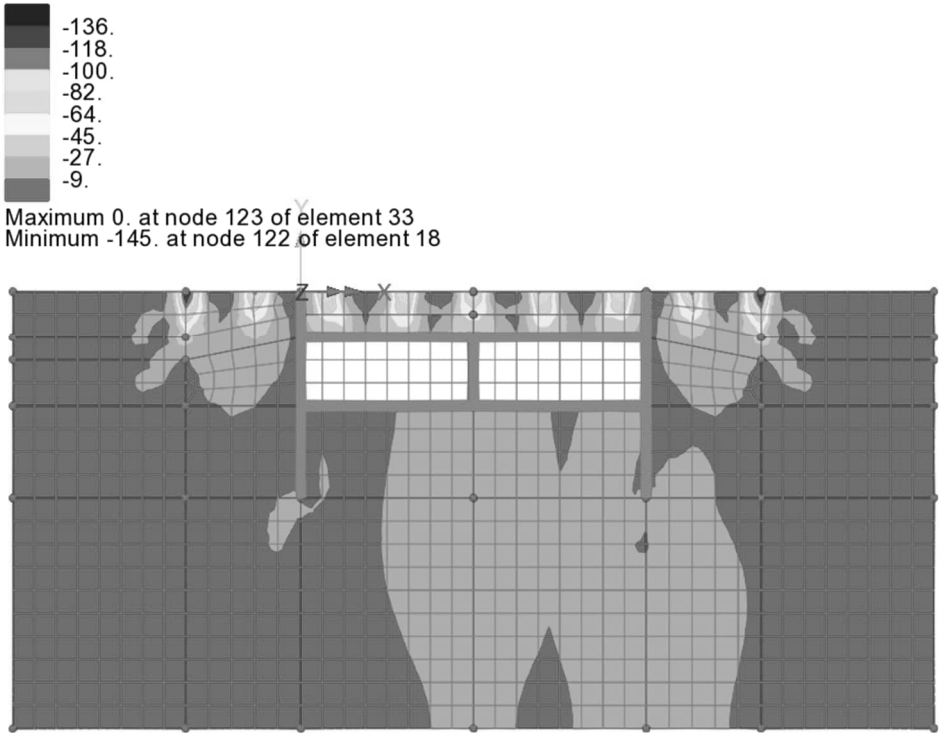
→ min Sy = -684 kPa

Remark

Envelope above contain traffic load (nonlinear) including gravity (soil + tunnel).

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 50
		Date :	Created :

Combination: 62:Traffic (nonlinear) (Min - SY)
 Entity: Stress - Plane Strain
 Component (Averaged nodal): SY (Units: kN/m²)

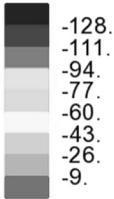


→ min Sy = -145 kPa

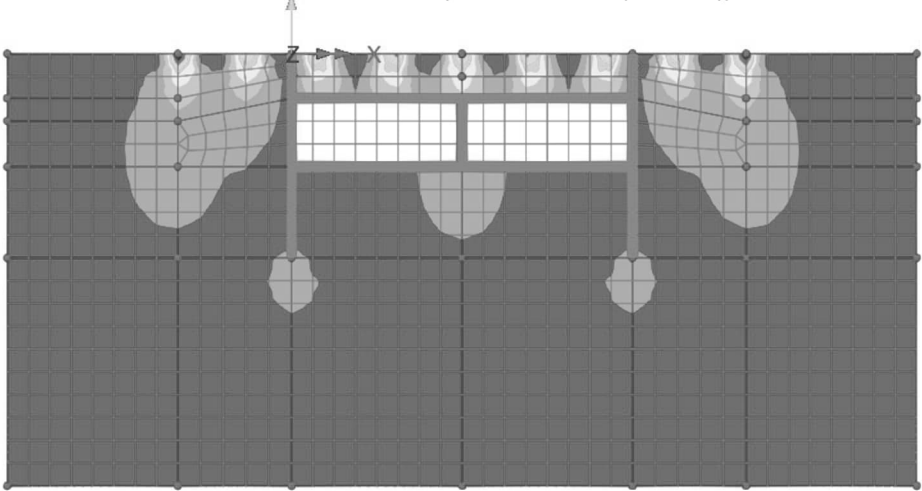
Remark
 Envelope above contain traffic load (nonlinear) excluding gravity. Achieved by subtracting LC 7 from envelope 50.

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 51
		Date :	Created :

Envelope: 61:Branch 4 - Traffic (linear) (Min - SY)
Entity: Stress - Plane Strain
Component (Averaged nodal): SY (Units: kN/m²)



Maximum 0. at node 126 of element 34 (60:Loadcase 36 (s = 50.0m))
Minimum -137. at node 122 of element 18 (17:Loadcase 10 (s = 0.0m))

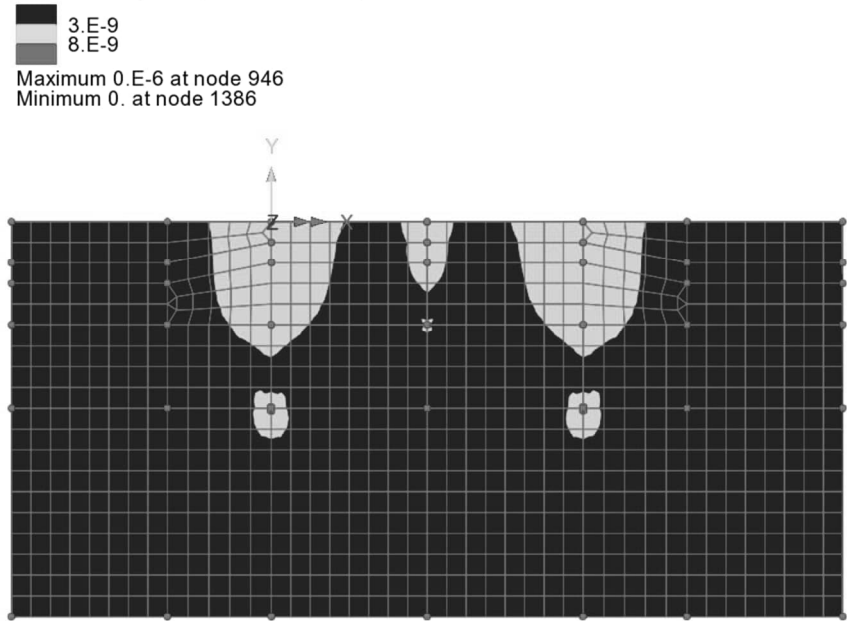


→ min Sy = -137 kPa

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 52
		Date :	Created :

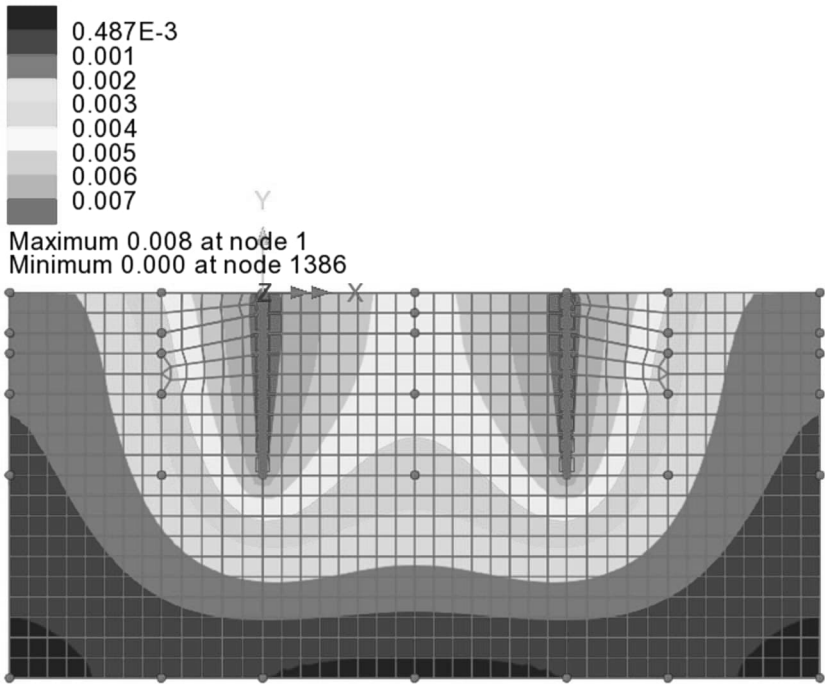
4.2 SOIL DEFORMATIONS

Analysis: Analysis 1
Loadcase: 1:Stage 1 - Undisturbed Soil, 1:Increment 1
Results file: Tunnel1V1~Analysis 1.mys
Entity: Displacement
Component (Nodal): RSLT (Units: m)



→ max RSLT = 0 mm

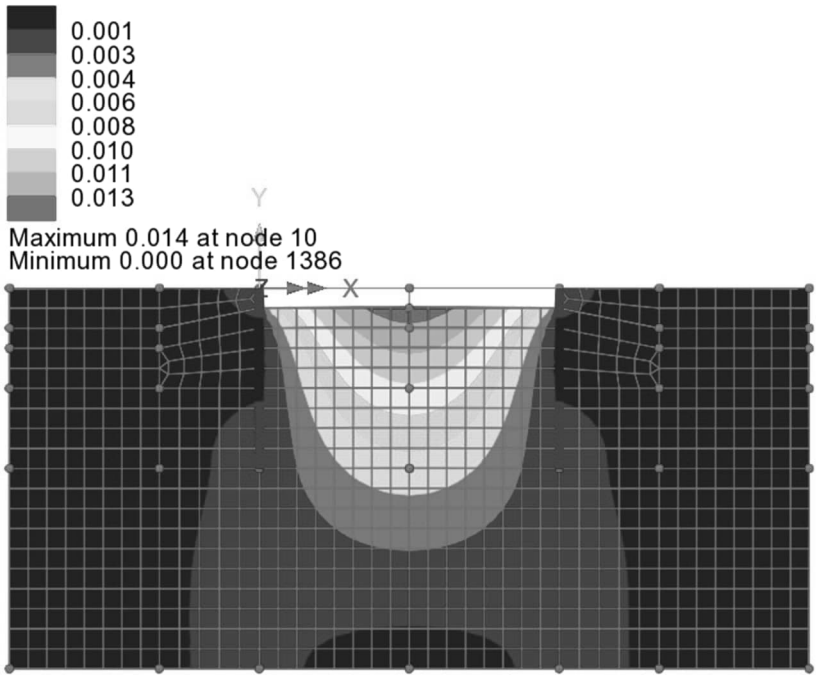
Analysis: Analysis 1
Loadcase: 2:Stage 2 - pile walls, 2:Increment 2
Results file: Tunnel1V1~Analysis 1.mys
Entity: Displacement
Component (Nodal): RSLT (Units: m)



→ max RSLT = 0 mm

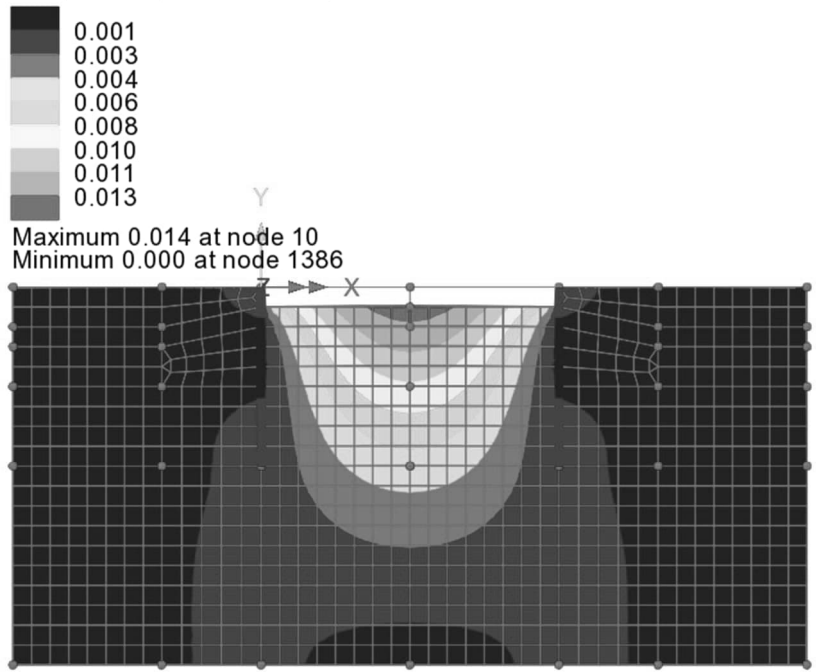
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 53
		Date :	Created :

Analysis: Analysis 1
Loadcase: 3:Stage 3 - Excavation 1, 3:Increment 3
Results file: Tunnel1V1~Analysis 1.mys
Entity: Displacement
Component (Nodal): RSLT (Units: m)



→ max RSLT = 14 mm

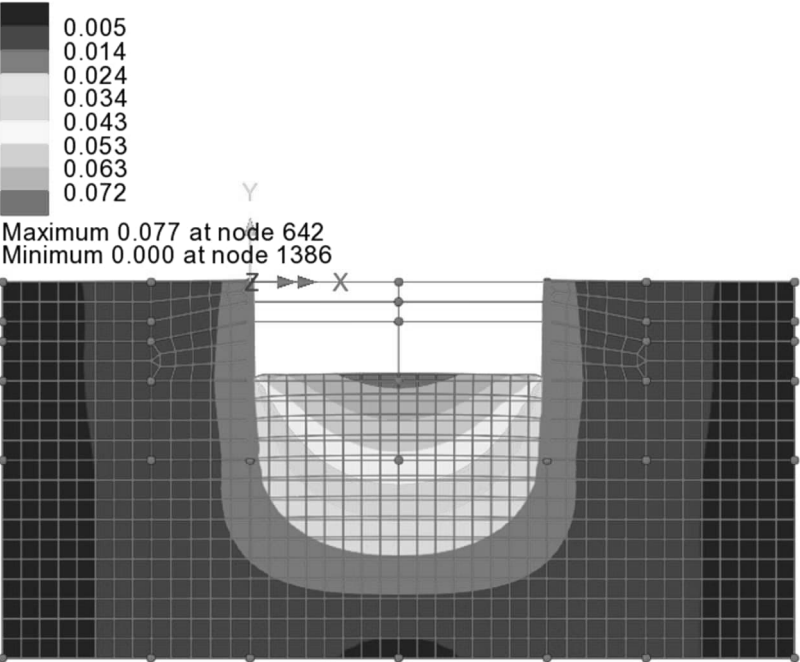
Analysis: Analysis 1
Loadcase: 4:Stage 4 - Install anchors, 4:Increment 4
Results file: Tunnel1V1~Analysis 1.mys
Entity: Displacement
Component (Nodal): RSLT (Units: m)



→ max RSLT = 14 mm

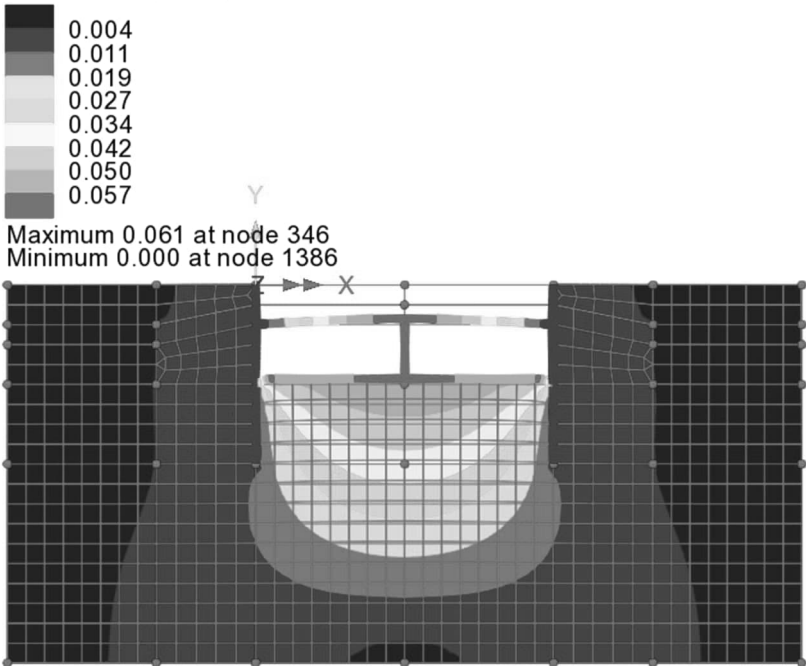
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 54
		Date :	Created :

Analysis: Analysis 1
 Loadcase: 5:Stage 5 - Excavation 2, 5:Increment 5
 Results file: Tunnel1V1~Analysis 1.mys
 Entity: Displacement
 Component (Nodal): RSLT (Units: m)



→ max RSLT = 77 mm

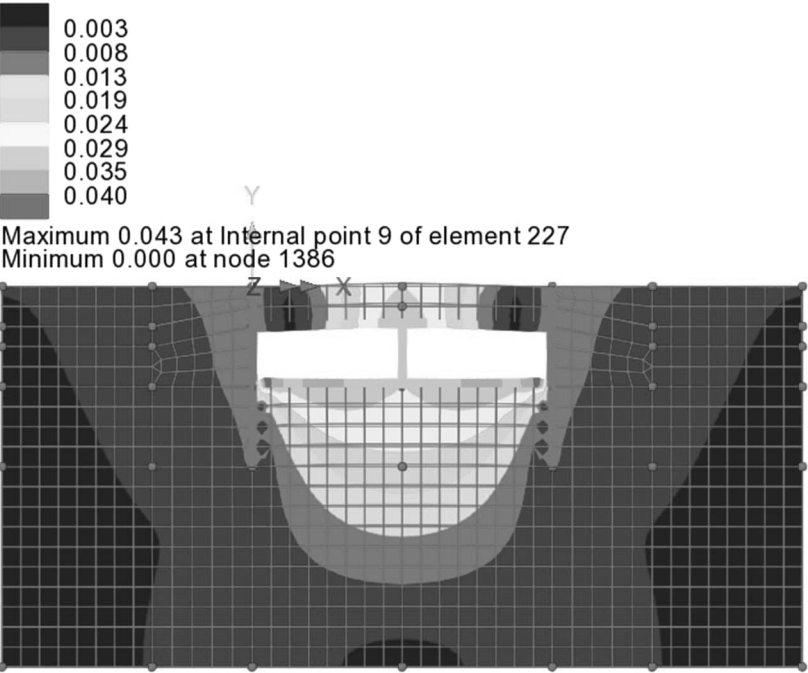
Analysis: Analysis 1
 Loadcase: 6:Stage 6 - tunnel, 6:Increment 6
 Results file: Tunnel1V1~Analysis 1.mys
 Entity: Displacement
 Component (Nodal): RSLT (Units: m)



→ max RSLT = 61 mm

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 55
		Date :	Created :

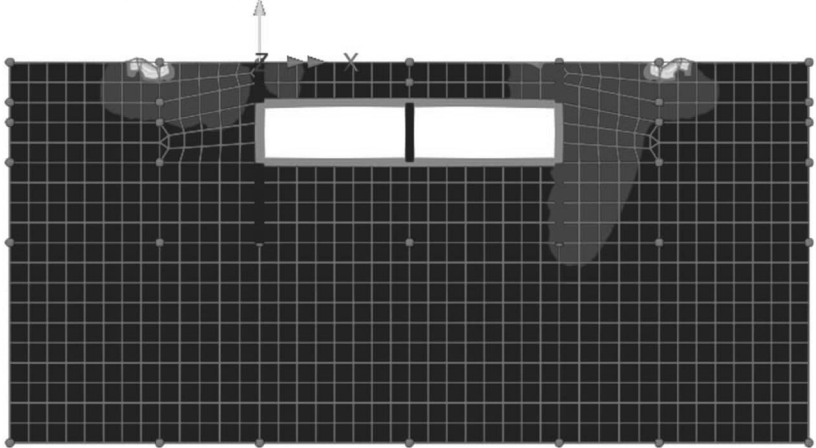
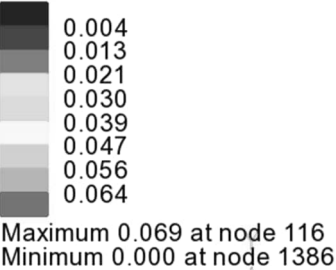
Analysis: Analysis 1
 Loadcase: 7:Stage 7 - Filling top of tunnel, 7:Increment 7
 Results file: Tunnel1V1~Analysis 1.mys
 Entity: Displacement
 Component (Nodal): RSLT (Units: m)



→ max RSLT = 43 mm

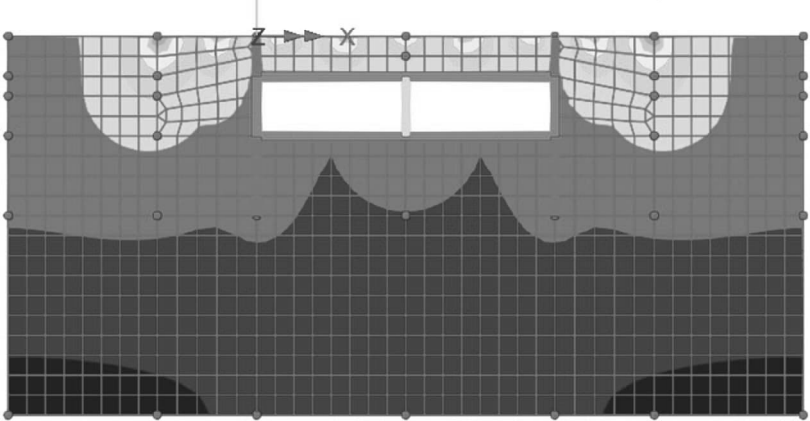
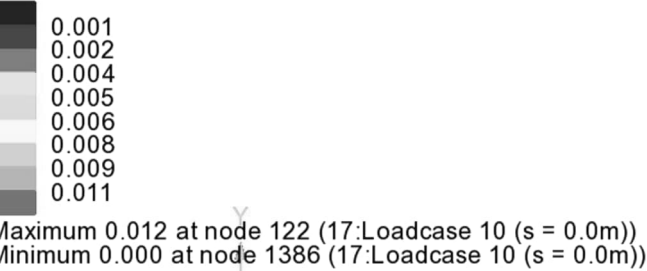
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 56
		Date :	Created :

Combination: 62:Traffic (nonlinear) (Max - RSLT)
 Entity: Displacement
 Component (Nodal): RSLT (Units: m)



→ max RSLT = 69 mm

Envelope: 61:Branch 4 - Traffic (linear) (Max - RSLT)
 Entity: Displacement
 Component (Nodal): RSLT (Units: m)

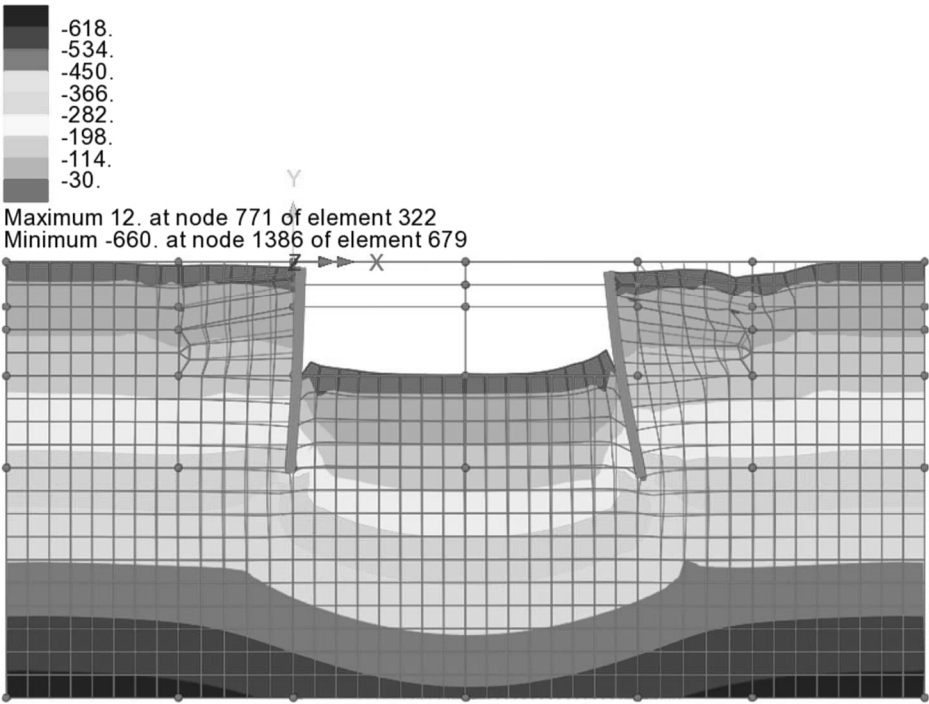


→ max RSLT = 12 mm

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 57
		Date :	Created :

4.3 SAFETY FACTOR SOIL STABILITY (SF)

Analysis: Branch 1
 Loadcase: 38:Stability check, 16:Increment 16 SF=1.418
 Results file: Tunnel1V1~Branch 1.mys
 Entity: Stress - Plane Strain
 Component (Averaged nodal): SY (Units: kN/m²)



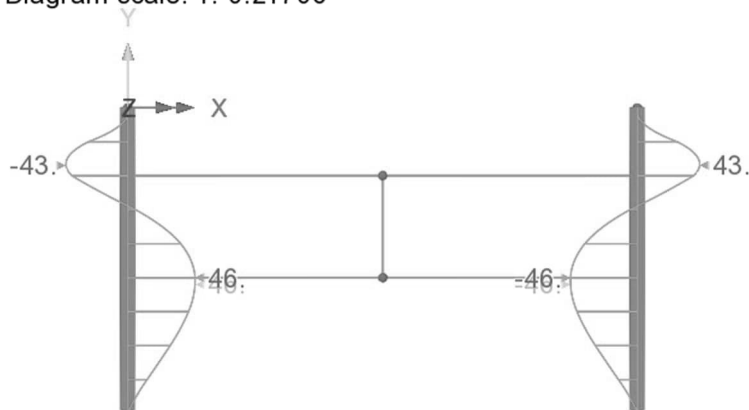
	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 58
		Date :	Created :

4.4 FORCES TUNNEL

4.4.1 Moment (Mz)

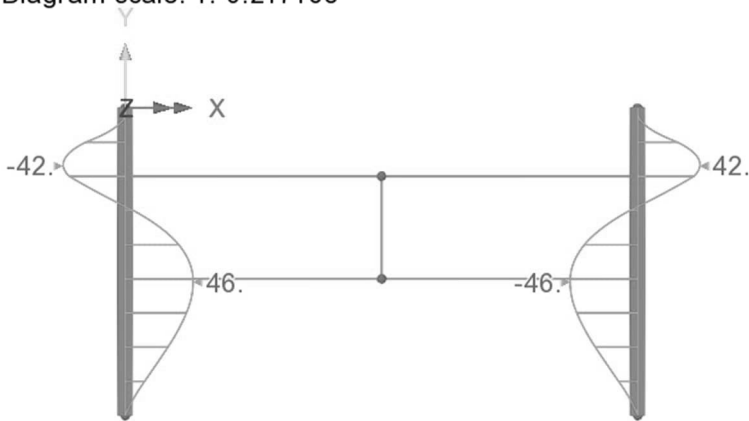
Scale: 1: 200.032
Zoom: 50.6631
Eye: (-9.00435E-3, 4.50227E-3, 0.999949)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 3:Stage 3 - Excavation 1, 3:Increment 3
Results file: Tunnel1V1~Analysis 1.mys

Diagram entity: Force/Moment - Thick 2D Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 46.0702 at node 650 of element 237
Diagram minimum -46.0702 at node 698 of element 264
Diagram scale: 1: 0.21706



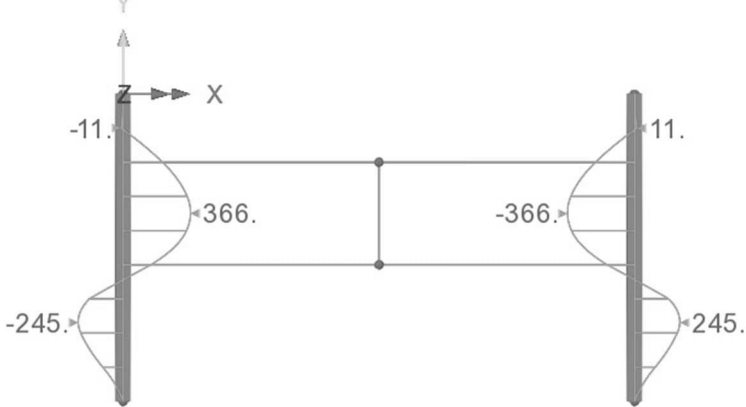
Scale: 1: 200.032
Zoom: 50.6631
Eye: (-9.00435E-3, 4.50227E-3, 0.999949)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 4:Stage 4 - Install anchors, 4:Increment 4
Results file: Tunnel1V1~Analysis 1.mys

Diagram entity: Force/Moment - Thick 2D Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 46.0474 at Internal point 10 of element 237
Diagram minimum -46.0474 at Internal point 10 of element 264
Diagram scale: 1: 0.217168

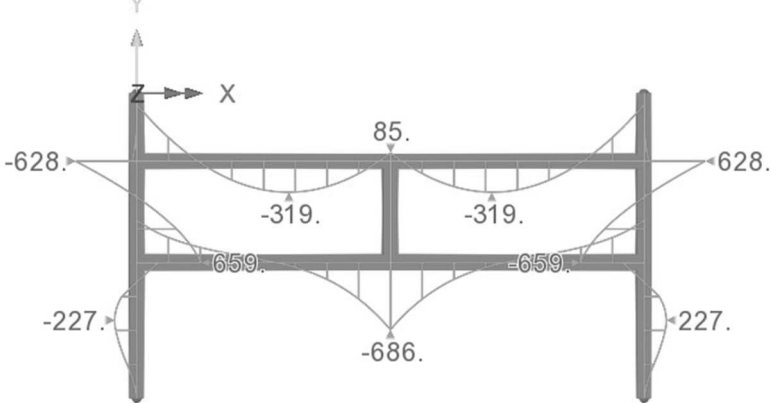


	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 59
		Date :	Created :

Scale: 1: 200.032
 Zoom: 50.6631
 Eye: (-9.00435E-3, 4.50227E-3, 0.999949)
 Nonlinear analysis
 Analysis: Analysis 1
 Loadcase: 5:Stage 5 - Excavation 2, 5:Increment 5
 Results file: Tunnel1V1~Analysis 1.mys
 Diagram entity: Force/Moment - Thick 2D Beam
 Diagram component: Mz (Units: kN.m)
 Diagram maximum 366.333 at Internal point 6 of element 236
 Diagram minimum -366.333 at Internal point 6 of element 263
 Diagram scale: 1: 0.0272976



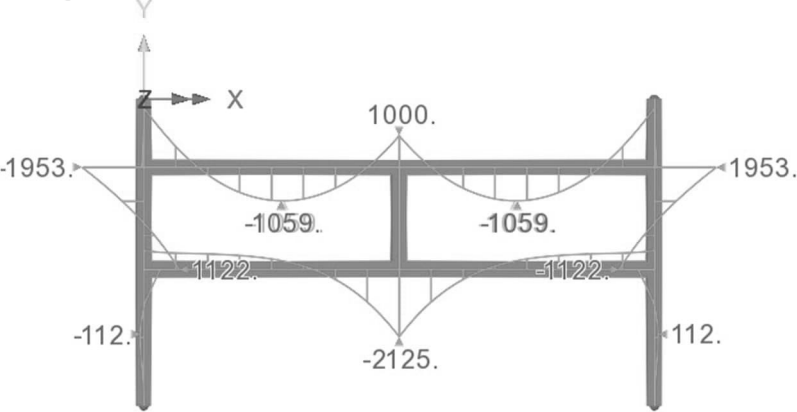
Scale: 1: 200.032
 Zoom: 50.6631
 Eye: (-9.00435E-3, 4.50227E-3, 0.999949)
 Nonlinear analysis
 Analysis: Analysis 1
 Loadcase: 6:Stage 6 - tunnel, 6:Increment 6
 Results file: Tunnel1V1~Analysis 1.mys
 Diagram entity: Force/Moment - Thick 2D Beam
 Diagram component: Mz (Units: kN.m)
 Diagram maximum 659.226 at node 650 of element 237
 Diagram minimum -686.013 at node 642 of element 234
 Diagram scale: 1: 0.014577



	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 60
		Date :	Created :

Scale: 1: 200.032
Zoom: 50.6631
Eye: (-9.00435E-3, 4.50227E-3, 0.999949)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 7:Stage 7 - Filling top of tunnel, 7:Increment 7
Results file: Tunnel1V1~Analysis 1.mys

Diagram entity: Force/Moment - Thick 2D Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 1.95292E3 at node 402 of element 262
Diagram minimum -2.12507E3 at node 642 of element 234
Diagram scale: 1: 4.70572E-3



	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 61
		Date :	Created :

Nonlinear traffic (incl. gravity soil & tunnel) max/min Mz:

Scale: 1: 149.493

Zoom: 55.6272

Eye: (-9.00435E-3, 4.50227E-3, 0.999949)

Envelope: 50:Branch 2 - Traffic (nonlinear including gravity) (Max - All)

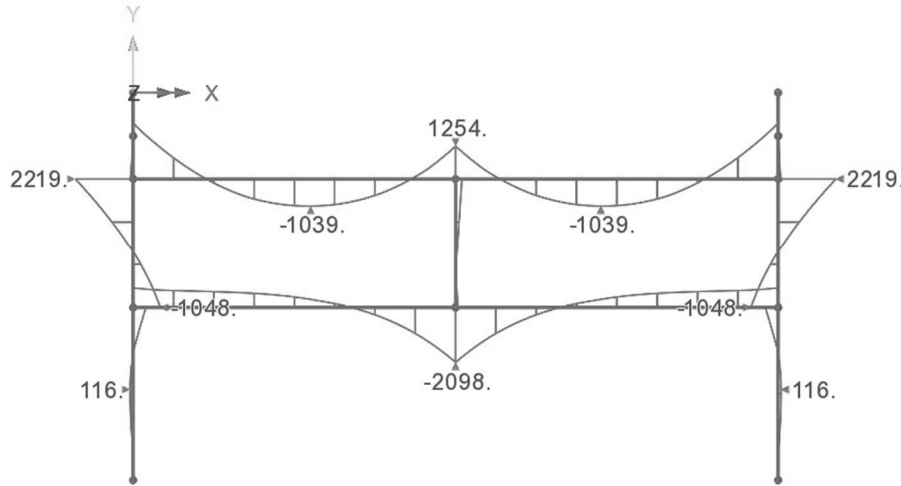
Diagram entity: Force/Moment - Thick 2D Beam

Diagram component: Mz (Units: kN.m)

Diagram maximum 2.21868E3 at node 354 of element 145 (42:Loadcase 22, 12:Increment 12 Load Factor = 1.00000)

Diagram minimum -2.09757E3 at node 642 of element 234 (40:Loadcase 20, 12:Increment 12 Load Factor = 1.00000)

Diagram scale: 1: 4.50719E-3



→ Max Mz = +2219 kNm/m

Scale: 1: 149.493

Zoom: 55.6272

Eye: (-9.00435E-3, 4.50227E-3, 0.999949)

Envelope: 50:Branch 2 - Traffic (nonlinear including gravity) (Min - All)

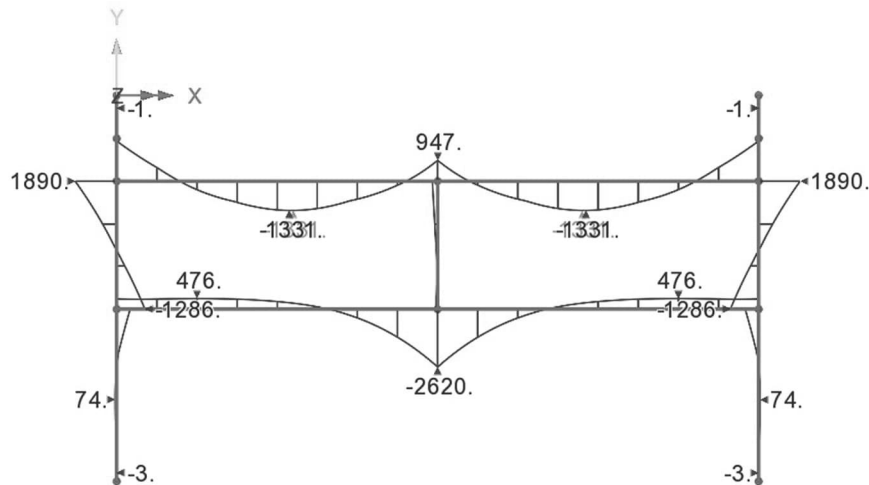
Diagram entity: Force/Moment - Thick 2D Beam

Diagram component: Mz (Units: kN.m)

Diagram maximum 1.89013E3 at node 354 of element 145 (40:Loadcase 20, 12:Increment 12 Load Factor = 1.00000)

Diagram minimum -2.62047E3 at node 642 of element 234 (43:Loadcase 23, 12:Increment 12 Load Factor = 1.00000)

Diagram scale: 1: 3.81611E-3

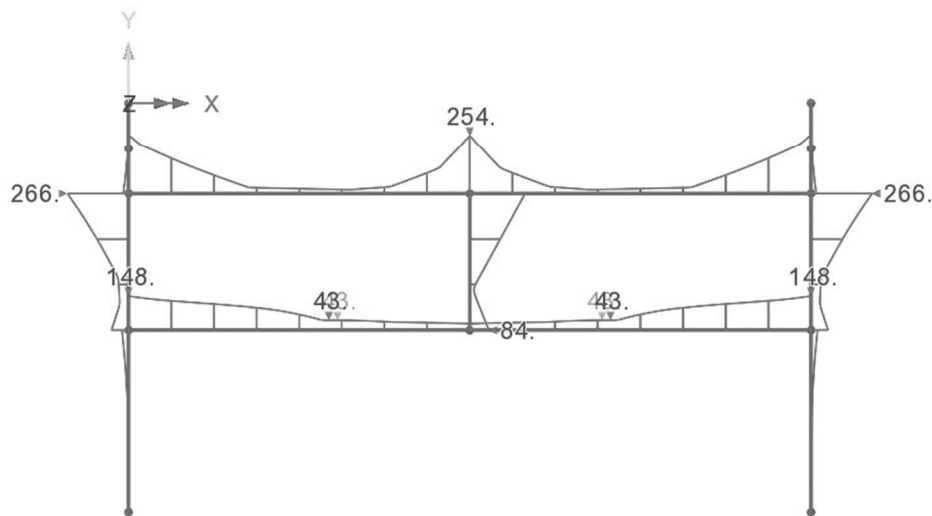


→ Min Mz = -2620 kNm/m

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 62
		Date :	Created :

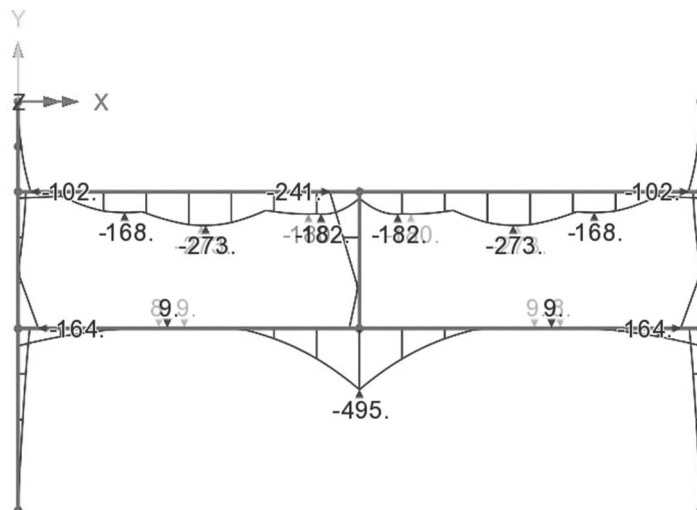
Nonlinear traffic max/min Mz:

Scale: 1: 149.493
Zoom: 55.6272
Eye: (-9.00435E-3, 4.50227E-3, 0.999949)
Combination: 62:Traffic (nonlinear) (Max - All)
Diagram entity: Force/Moment - Thick 2D Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 265.752 at node 354 of element 145
Diagram scale: 1: 0.0376291



→ Max Mz = +266 kNm/m

Scale: 1: 149.493
Zoom: 55.6272
Eye: (-9.00435E-3, 4.50227E-3, 0.999949)
Combination: 62:Traffic (nonlinear) (Min - All)
Diagram entity: Force/Moment - Thick 2D Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 8.52754 at Internal point 5 of element 230
Diagram minimum -495.399 at node 642 of element 234
Diagram scale: 1: 0.0201858



→ Min Mz = -495 kNm/m

	Cut and cover tunnel – one anchor level (Using permanent diaphragm wall)	Status :	Page : 63
		Date :	Created :

Linear traffic max/min Mz:

Scale: 1: 149.493

Zoom: 55.6272

Eye: (-9.00435E-3, 4.50227E-3, 0.999949)

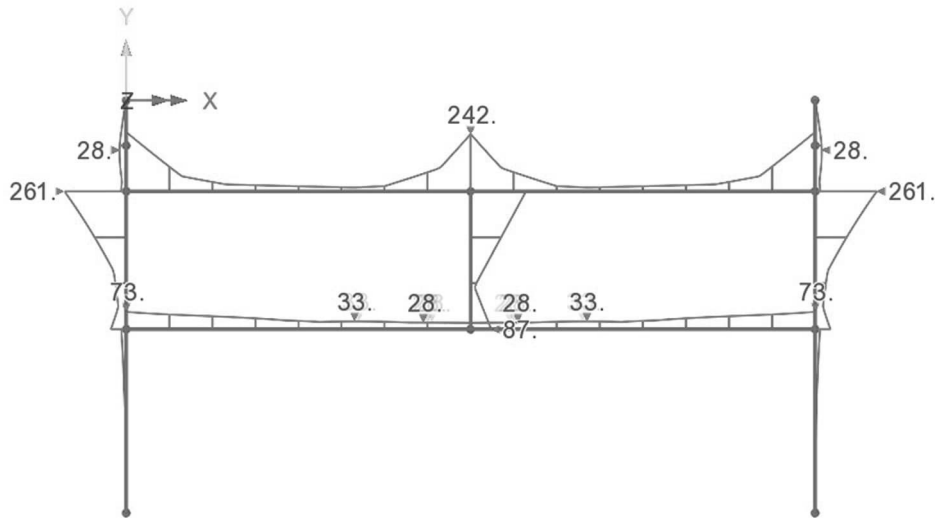
Envelope: 61:Branch 4 - Traffic (linear) (Max - All)

Diagram entity: Force/Moment - Thick 2D Beam

Diagram component: Mz (Units: kN.m)

Diagram maximum 260.848 at node 354 of element 145 (55:Loadcase 31 (s = 18.75m))

Diagram scale: 1: 0.0383366



→ Max Mz = +261 kNm/m

Scale: 1: 149.493

Zoom: 55.6272

Eye: (-9.00435E-3, 4.50227E-3, 0.999949)

Envelope: 61:Branch 4 - Traffic (linear) (Min - All)

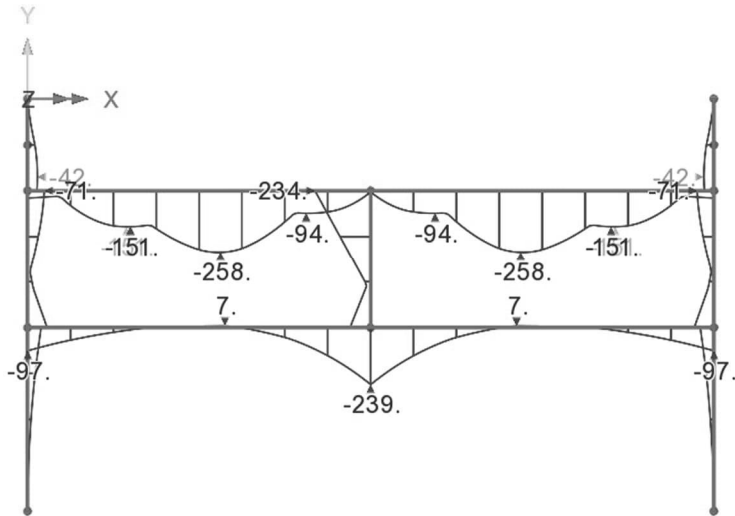
Diagram entity: Force/Moment - Thick 2D Beam

Diagram component: Mz (Units: kN.m)

Diagram maximum 7.06972 at Internal point 6 of element 231 (60:Loadcase 36 (s = 50.0m))

Diagram minimum -258.329 at Internal point 5 of element 111 (55:Loadcase 31 (s = 18.75m))

Diagram scale: 1: 0.0387104



→ Min Mz = -258 kNm/m