Retaining wall with two levels of tie back anchors

Table of content

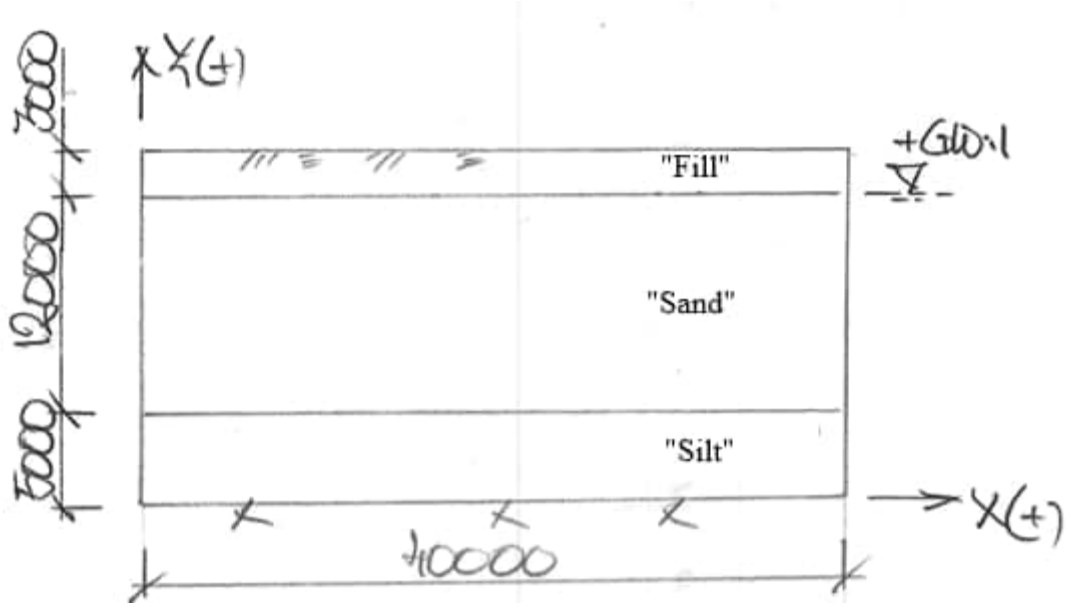
Appendix

1. Input receipt (FEM-program)

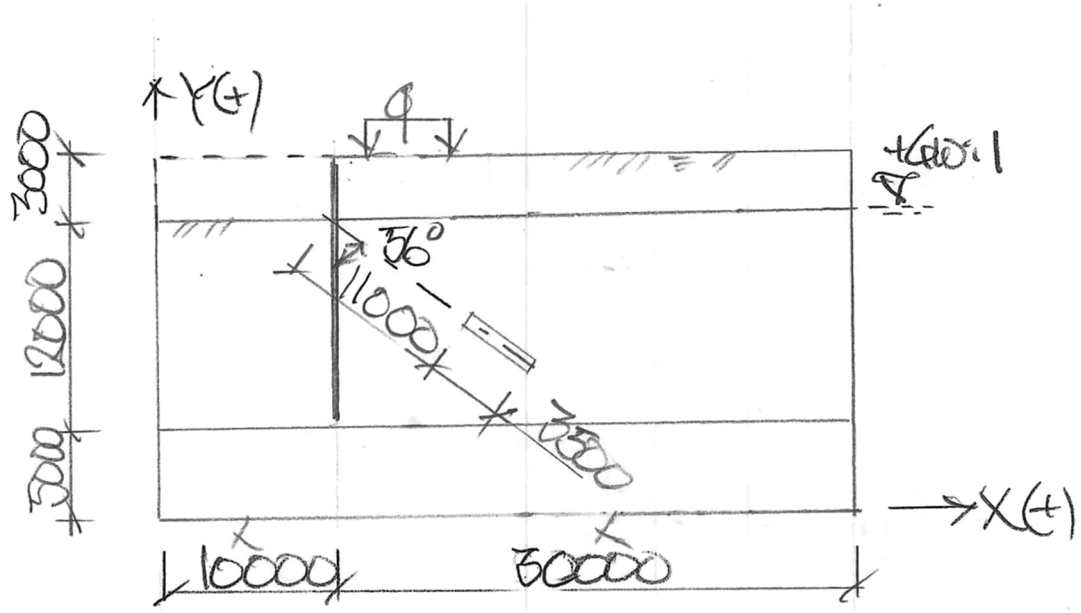
1. GENERAL

The retaining wall is excavated in 3 stages. After excavation 1 "upper" level tie-back anchors are installed. After exaction 2 "lower" level tie back anchors are installed.

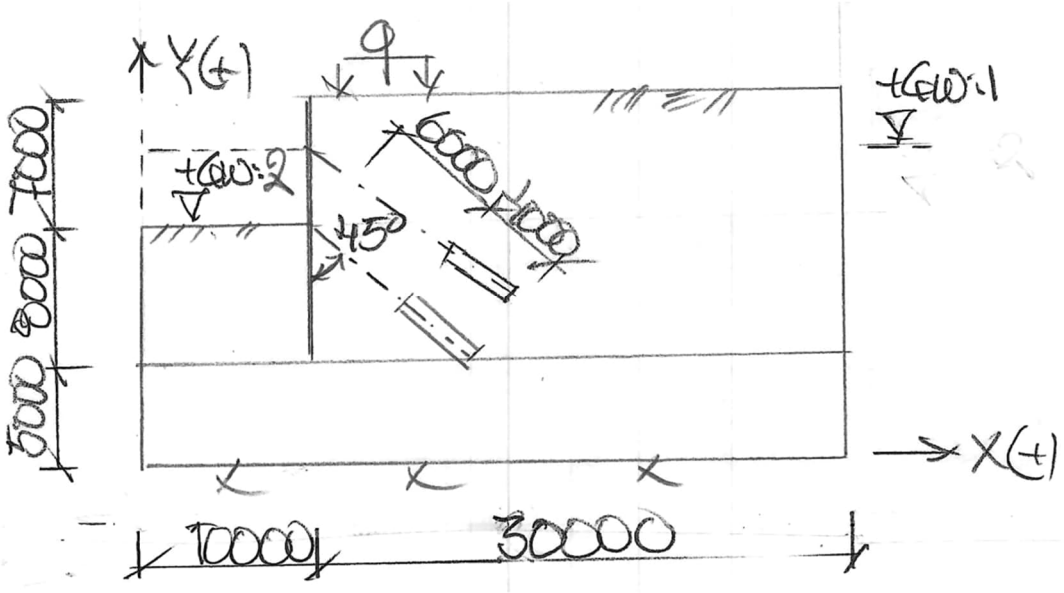
1.1 GEOMETRY



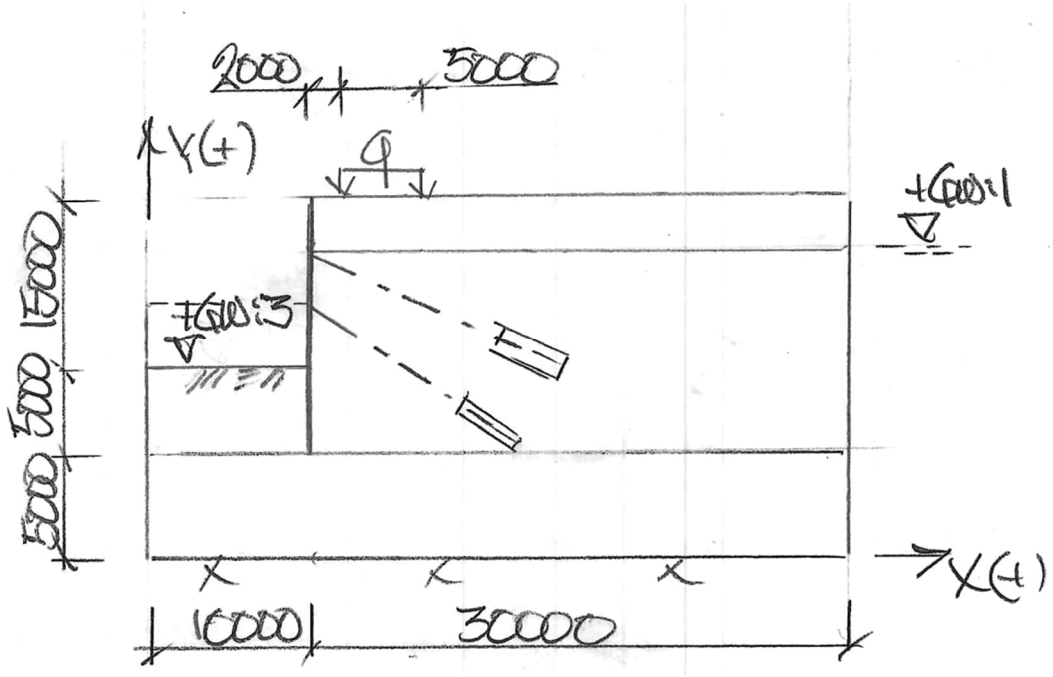
ELEVATION
Before excavation



ELEVATION
After excavation 1



ELEVATION
After excavation 2



ELEVATION
After excavation 3

1.2 SOIL PROPROPETIES

1.2.1 Ground water

Ground water level before excavation is termed GW:1 (= +17.0).

After excavation 1 water level on side from filling lowered to GW:2 (= +13.0).

After excavation 2 water level on side form filling lowered further to GW:3 (= +10.0).

The retaining wall is considered watertight.

1.2.2 Soil material

Geotechnical parameters:

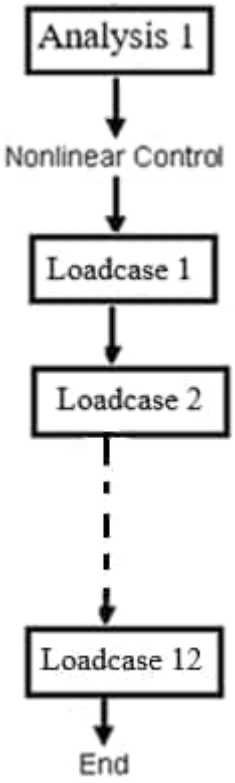
Material	Level	ρ	ρ'	ϕ_k	E_k
"Fill"	+17.0→ +20.0	20	11	30	8
"Sand"	+5.0→ +17.0	20	11	34	30
"Silt"	± 0→ +5.0	19	11	29	20
"Rock"	± 0	-	-	-	-
-	m	kN/m^3	kN/m^3	deg	MPa

2. SYSTEM ANALYSIS

2.1 GENERAL

Below is short description of assumptions used in the analysis. Will be improved shortly.

333A nonlinear analysis is performed with a total of 12 load cases (LC). These have varying parts activated and deactivated as excavation and installation of anchors progress. The load cases also contains the lowering of GW due to exavaction.



Schematic sketch

LC nr	LC name	Excavation	Loading	Deactivate	Activate
1	Before excavation	Before excavation	Water pressure GW:1 & soil gravity	Wall & anchors	-
2	Wall installation	Before excavation	Same as LC 1	-	Wall
3	Surface load	Before excavation	Same as LC 1 & surface load	-	Wall
4	Excavation:1	After excavation 1	Same as LC 3	Soil excavation:1	-
5	Install anchor:1	After excavation 1	Same as LC 3 & anchor load:1	-	Anchor:1
6	Set water level GW:2	After excavation 1	Same as LC 4 & water pressure GW:2	-	-
7	Reduction to GW:2	After excavation 1	Same as LC 6 & reduced pore pressure:1	-	-
8	Excavation:2	After excavation 2	Same as LC 7	Soil excavation:2	-
9	Install anchor:2	After excavation 2	Same as LC 8 & anchor load:2	-	Anchor:2
10	Set water level GW:3	After excavation 2	Same as LC 9 & water pressure GW:3	-	-
11	Reduction to GW:2	After excavation 2	Same as LC 10 & reduced pore pressure:2	-	-
12	Excavation:3	After excavation 3	Same as LC 7	Soil excavation:3	-

2.2 NONLINEAR ANALYSIS

Nonlinear analysis is performed using increments using Newton_Raphson numerial 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.

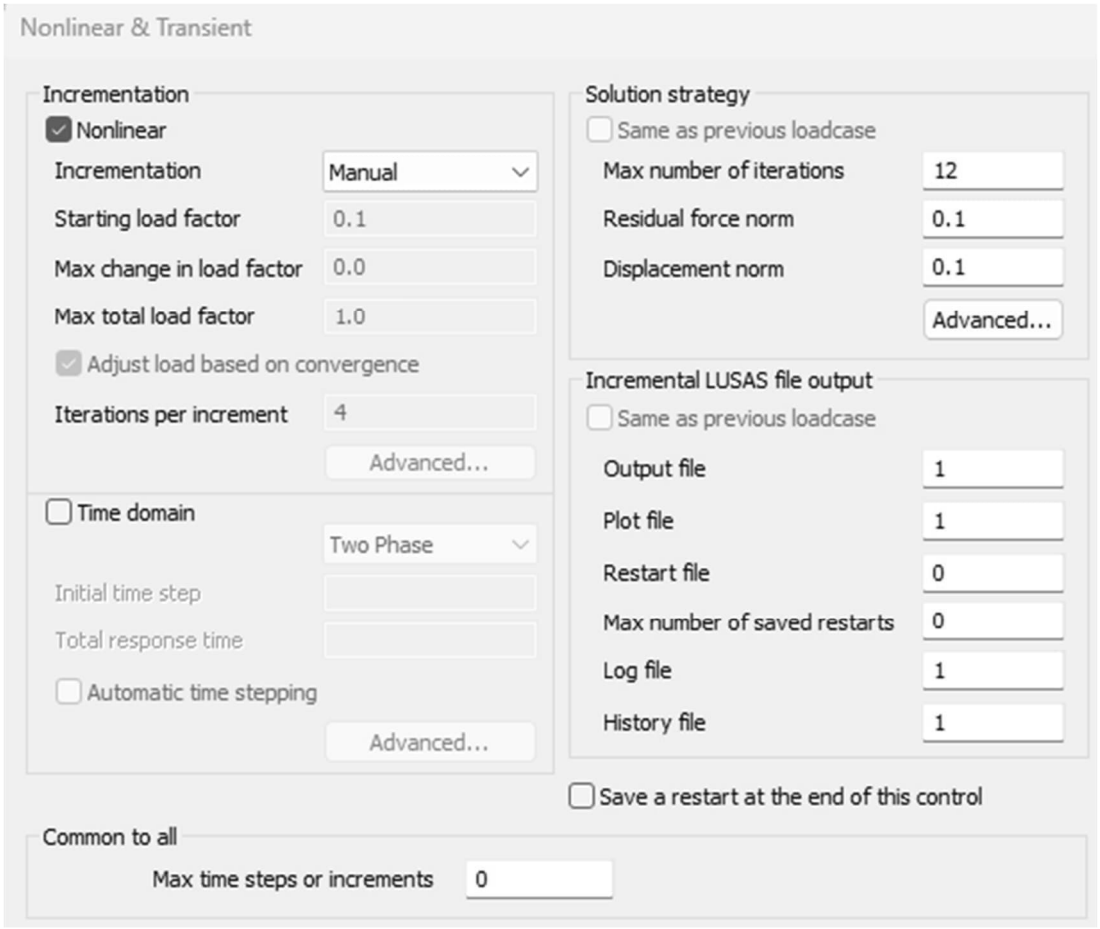
Displacement norm:
The limit for the sum of the squares of the iterative displacements as a percentage of the sum of the squares of the incremental displacements (DTNRM). Only translation degrees of freedom are considered

LC nr	LC name	Type analysis	Incrementation
1	Before excavation	Nonlinear	Manual
2	Wall installation	Linear	-
3	Surface load	Linear	-
4	Excavation:1	Nonlinear	Automatic
5	Install anchor:1	Nonlinear	Automatic
6	Set water level GW:2	Linear	-
7	Reduction to GW:2	Nonlinear	Automatic
8	Excavation:2	Nonlinear	Automatic
9	Install anchor:2	Nonlinear	Automatic
10	Set water level GW:3	Linear	-
11	Reduction to GW:2	Nonlinear	Automatic
12	Excavation:3	Nonlinear	Automatic

2.2.1 Load case: LC1

Incrementation as chosen to be performed *Manual* since generally more stable, see chosen parameters in dialogue box below.

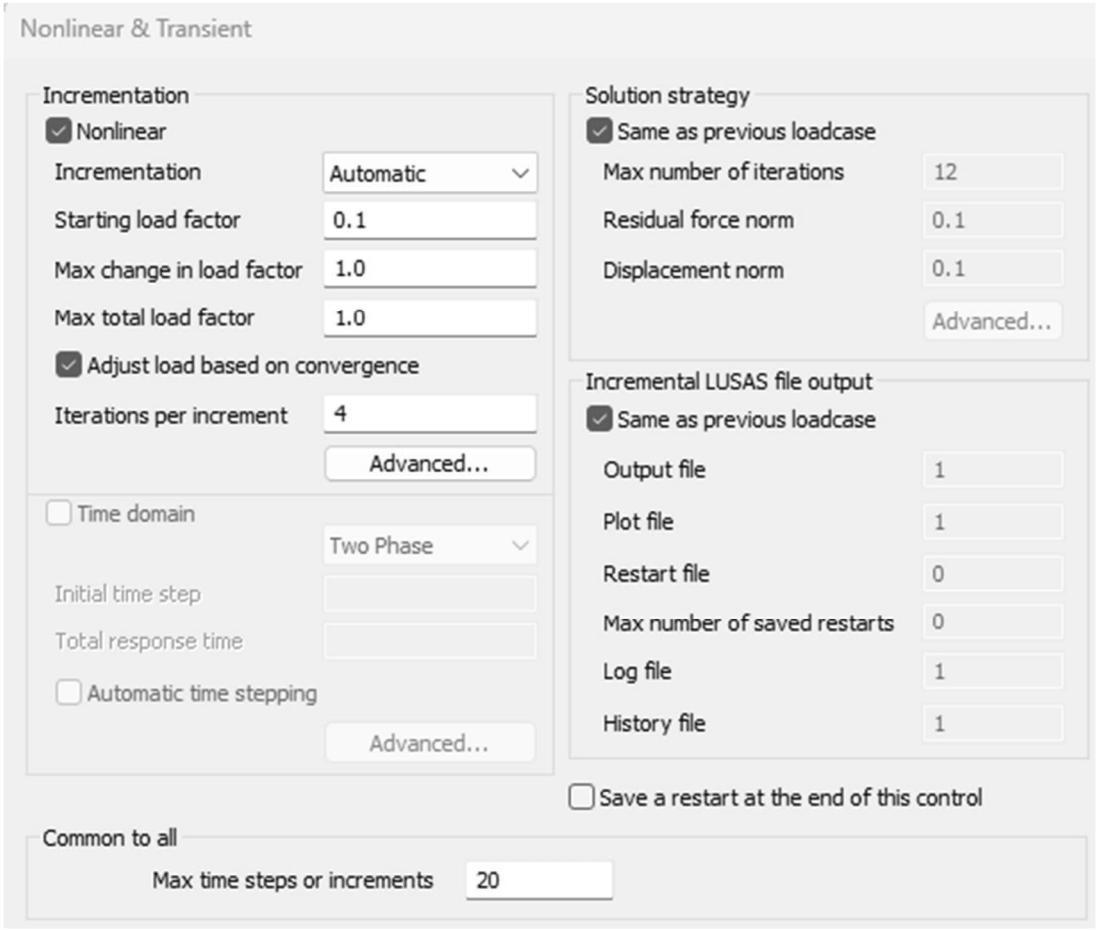
The need of nonlinear analysis is due to nonlinear material properties of soil equivalent joints.



2.2.2 Load cases: LC 4, LC 5, LC 6, LC 7, LC 8, LC 9, LC 11 & LC12

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

The only load is horizontal anchor load that is increased by load factors 1, 2,…. 9 & 10.



2.3 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.

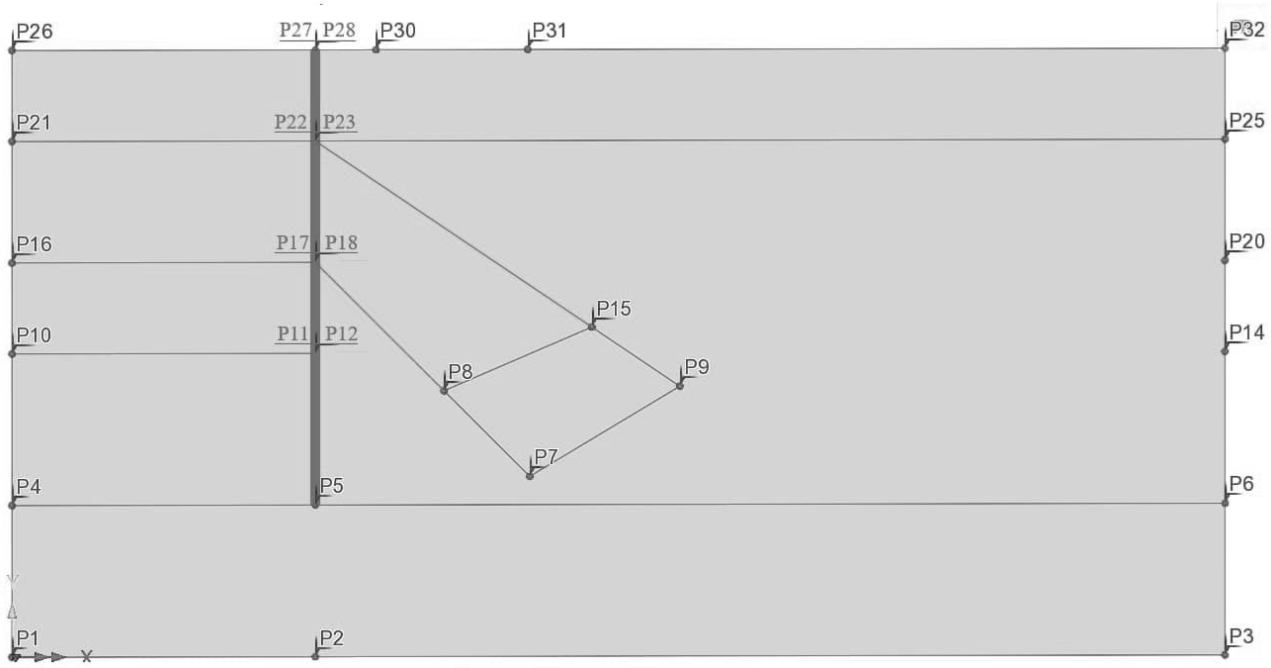
Attached pictures are retrieved from graphical sketches generated by LUSAS of POINTS, LINES and SURFACES.

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

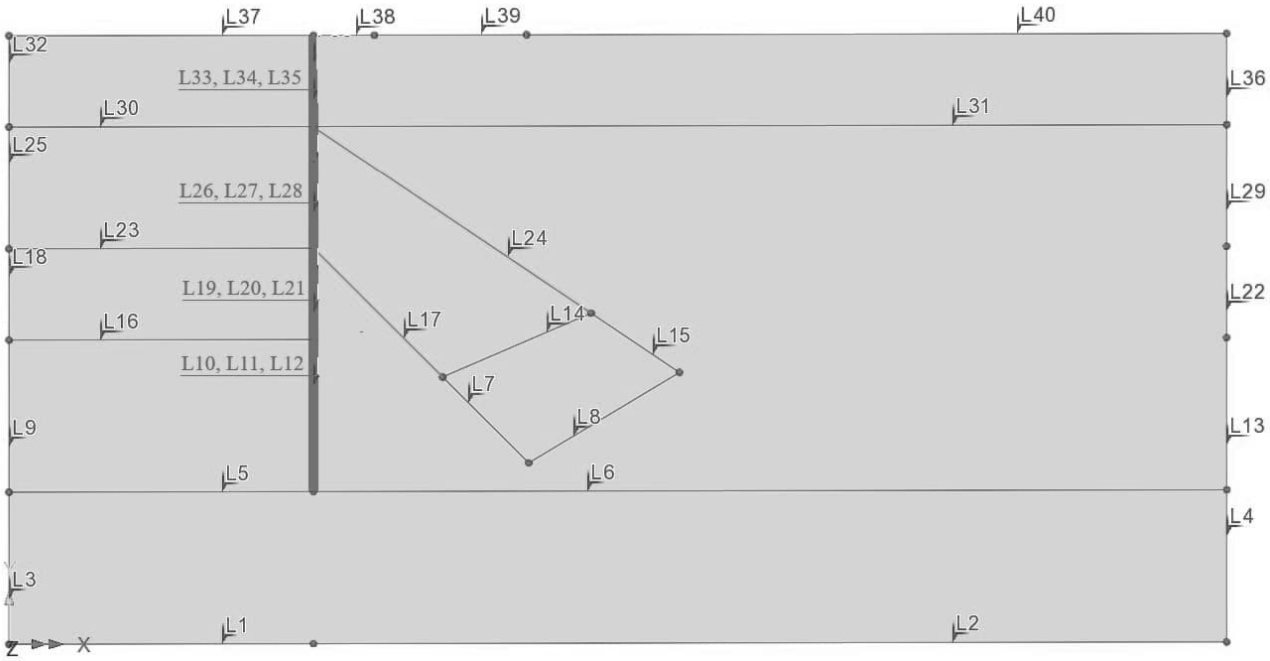
All POINTS needed to describe LINES are found in attachment 1.

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

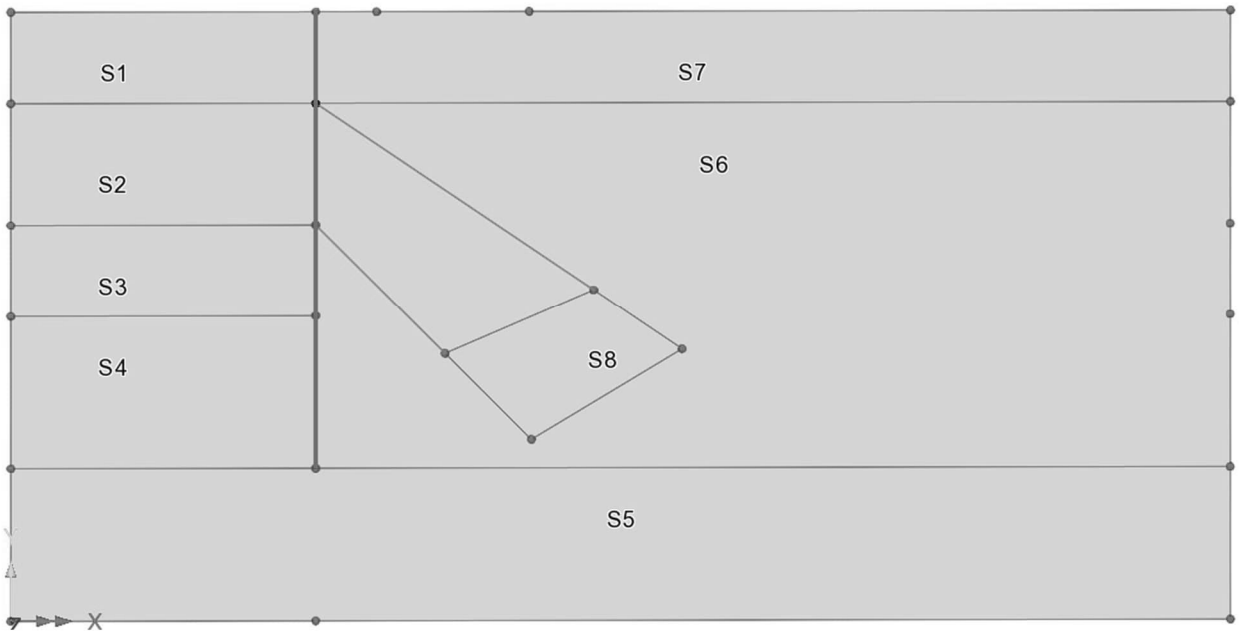
2.3.1 Geometry: Points



2.3.2 Geometry: Lines

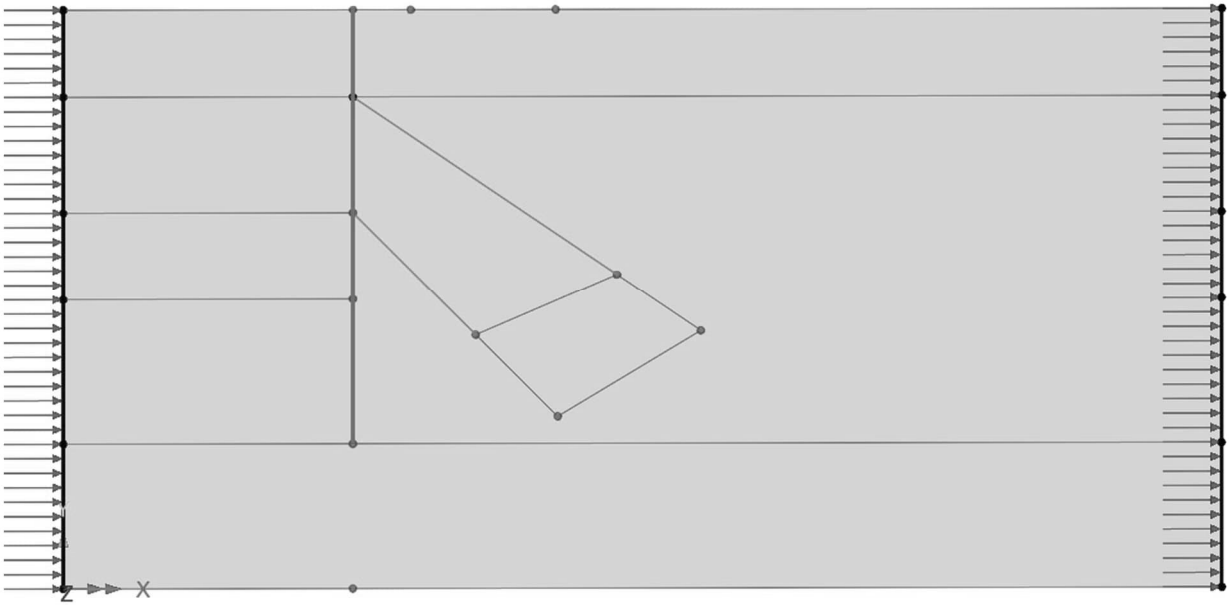


2.3.3 Geometry: Surfaces

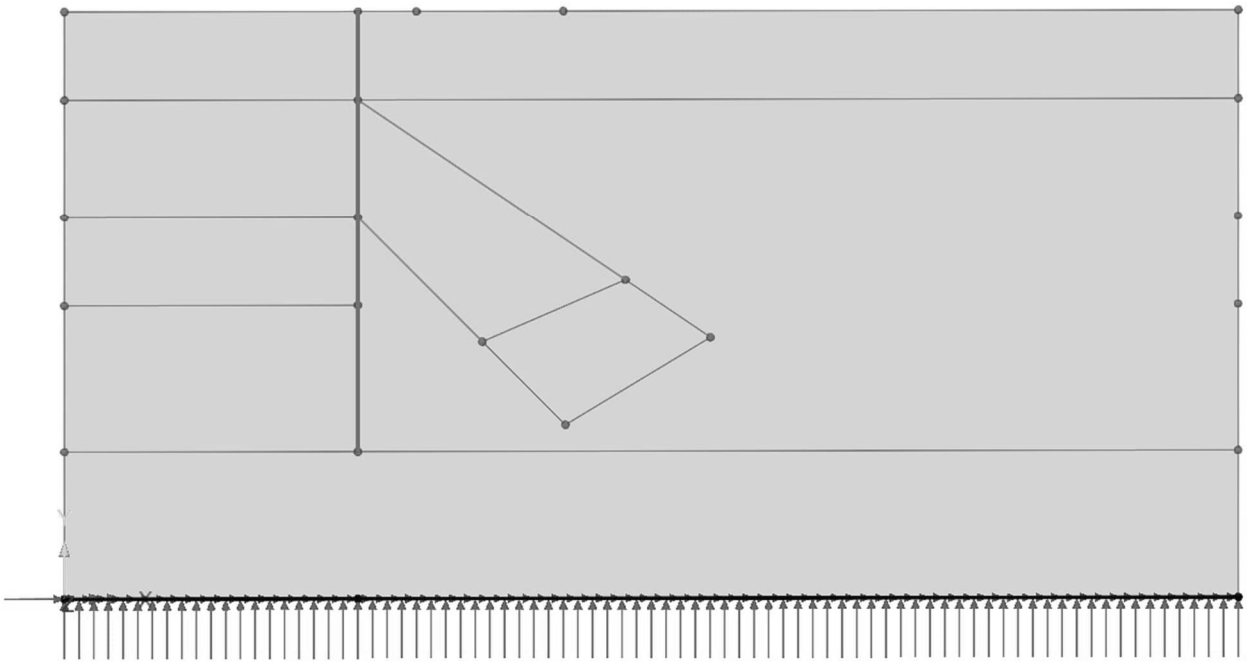


2.4 BOUNDARY CONDITIONS

2.4.1 Horizontal boundary soil: Fixed X



2.4.2 Vertical boundary soil: Fixed Xy

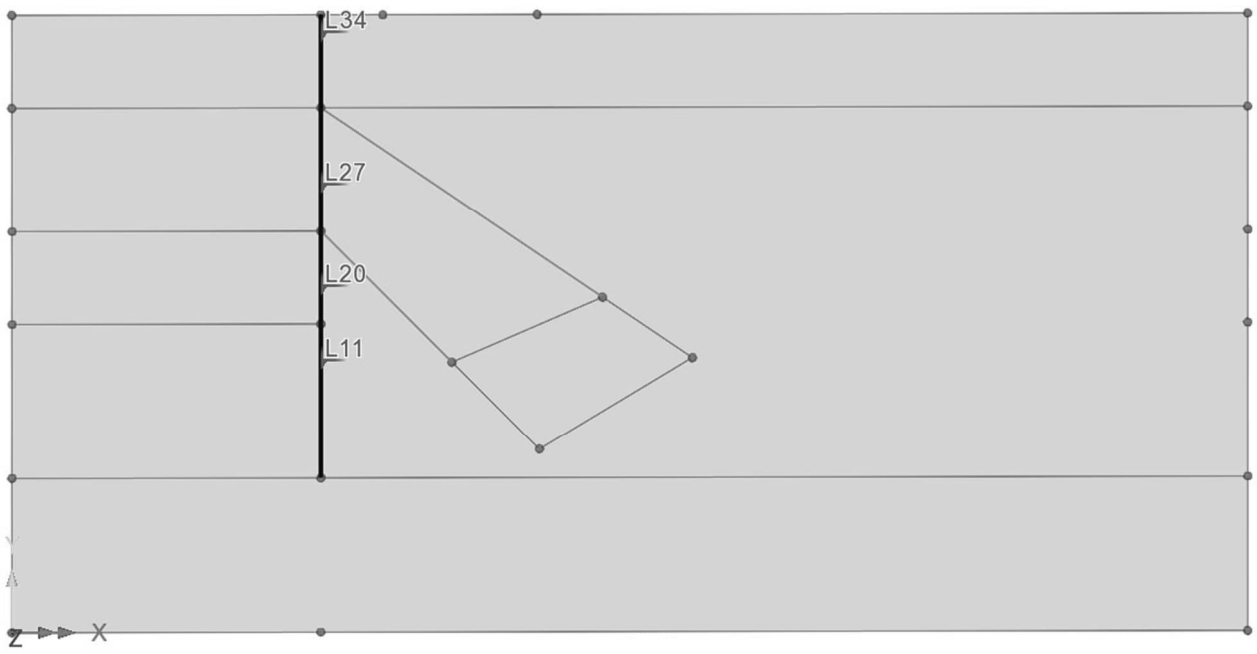


2.5 MESH

2.5.1 Wall: Plain strain beam element (BMI3N)

Retaining wall (L11, L12, L27 and L34) is modelled as seen below. The element is used for linear and nonlinear analysis of two dimensional long structures retaining walls for which the plane strain assumption is appropriate.

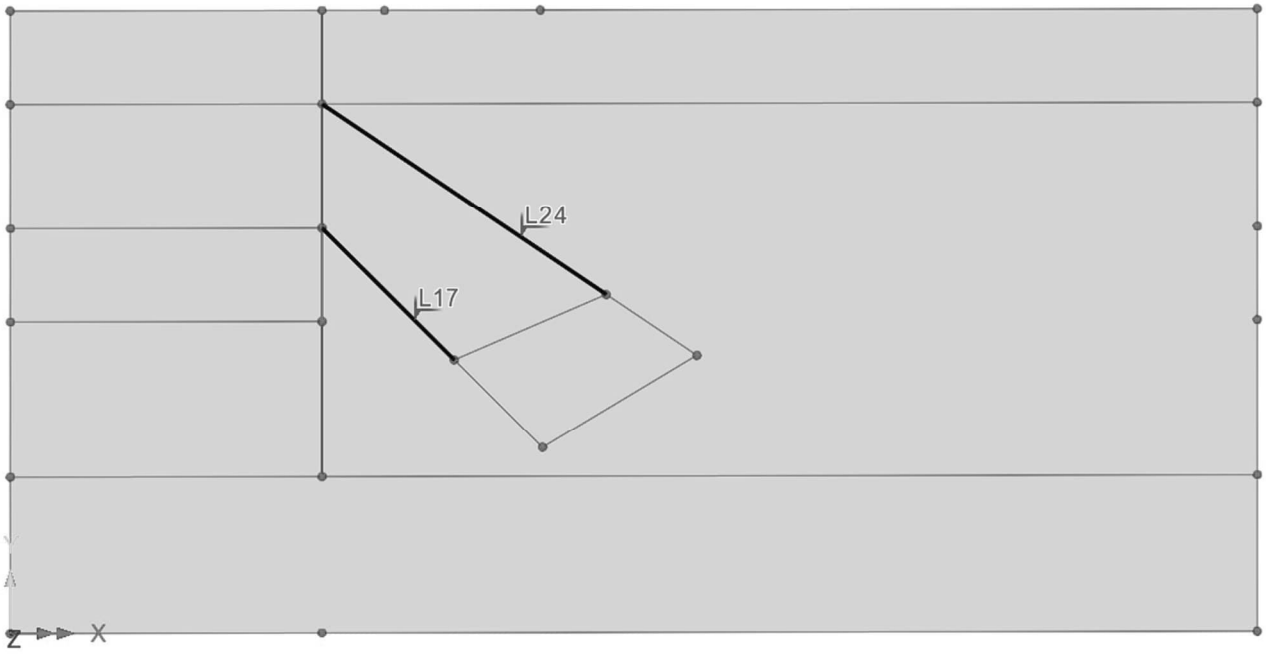
Name	Element type	Element length	Order element
BMI3N	Plain strain beam	1.0	Quadratic



2.5.2 Anchor rod: Bar element (BAR2)

Anchor rods (L17 and L24) is modelled as seen below. This element is not connected to nodes in soil thus the rod is defined by only one element. More elements than one would create a failure due mechanism.

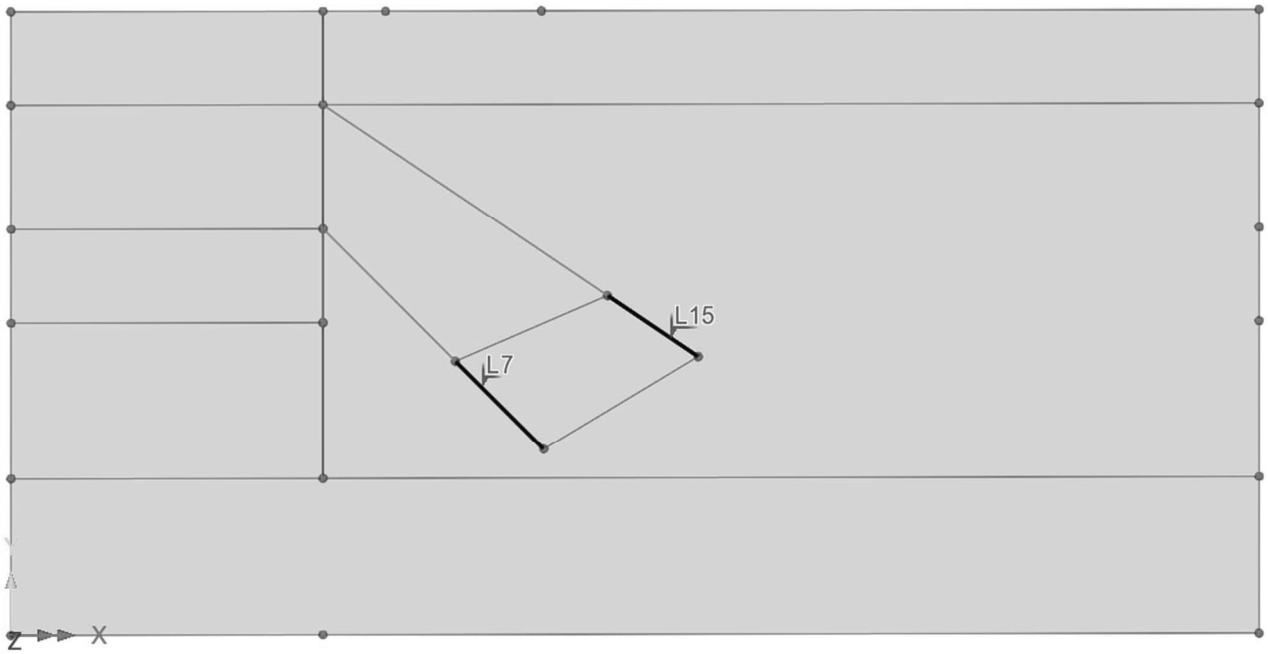
Name	Element type	Number of divisions	Order element
BAR2	Bar	1	Linear



2.5.3 Anchor grout : Bar element (BAR3)

Anchor grouts (L7 and L15) is modelled as seen below. These elements are connected to nodes in soil.

Name	Element type	Element length	Order element
BAR3	Bar	1	Quadratic

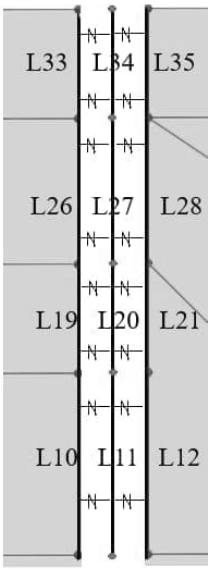


2.5.4 Interface element between wall and soil: Interface element two phase (IPN6P)

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

The element is two phase so can handle undrained and drained analyis. The element is used for modelling standard Mohr-Coulomb friction contact in soil/structure interactions.

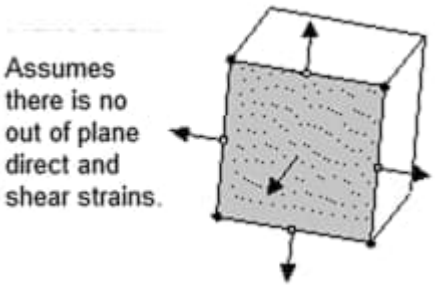
Name	Element type	Element length	Order element
IPN6P	Interface two phase	1 m	Quadratic



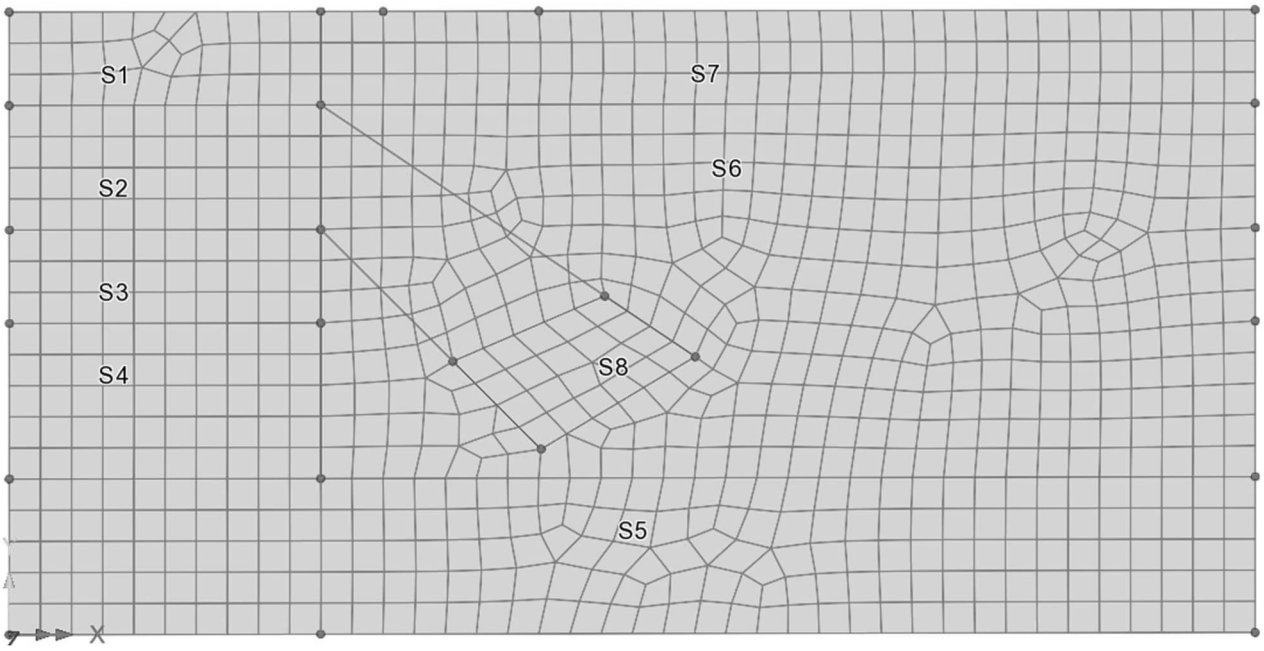
2.5.5 Soil: plain strain two phase surface elements (QPN8P)

Soil is modelled using surface elements applied to S1, S2, S3, S4, S5, S6 and S7.

The element type plain strain “two phase” is used used when undrained and consolidation analysis is performed.



Name	Element type	Element size	Order element	Mesh
QPN8P	Plain strain two phase	1 m	Quadratic	Irregular

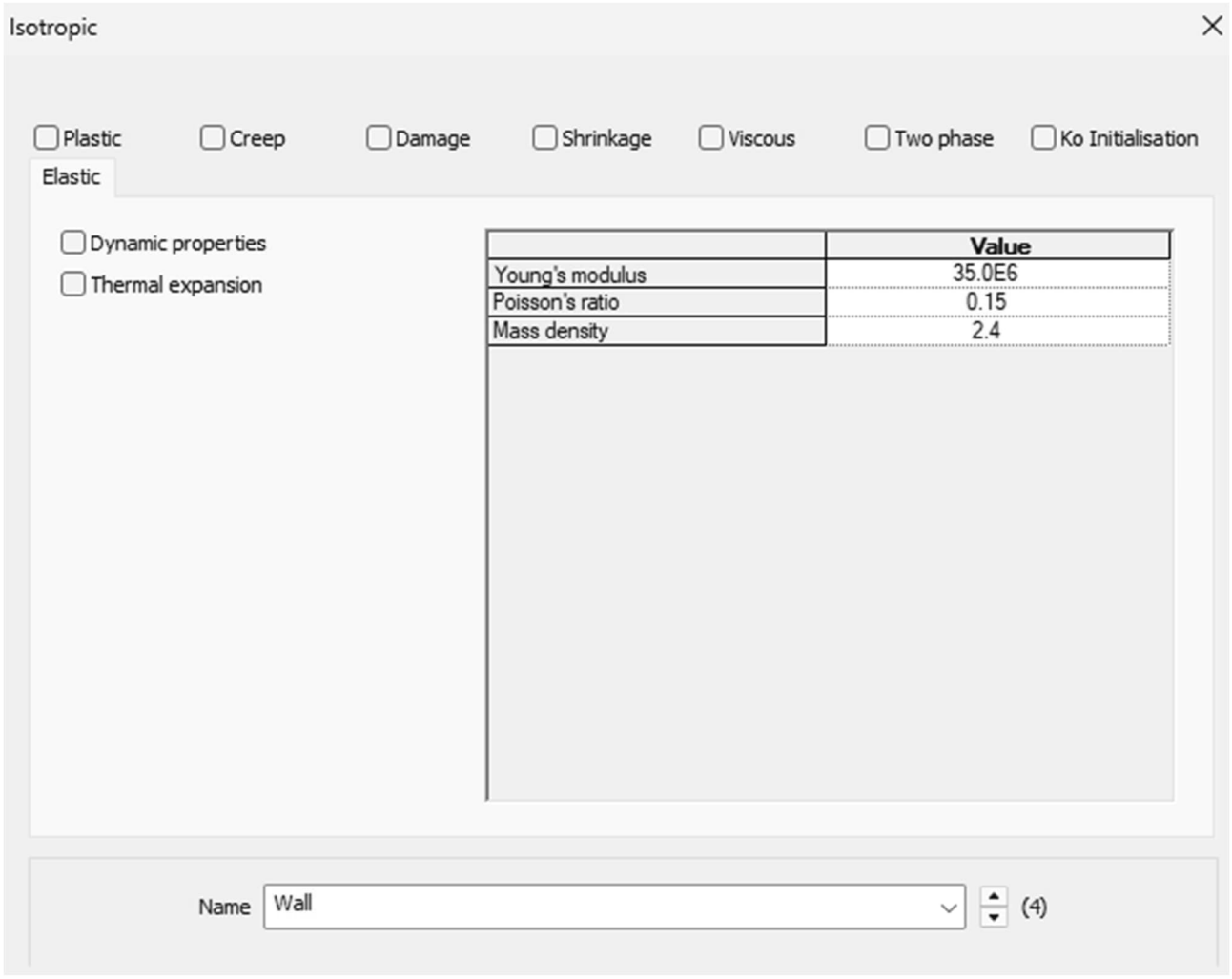


2.6 MATERIAL

2.6.1 Linear elastic material: retaining wall, anchors rods & grouting

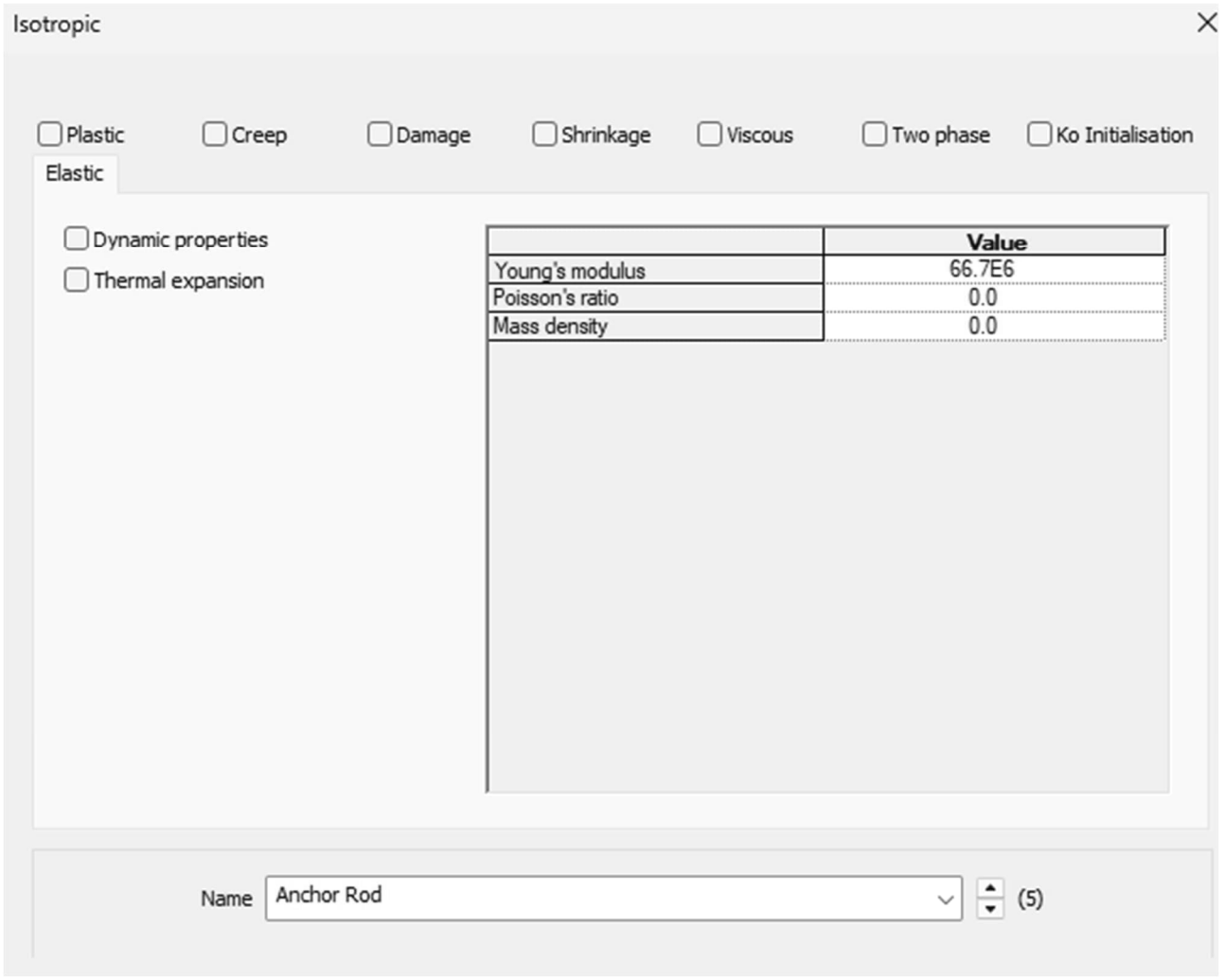
Retaining wall:

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



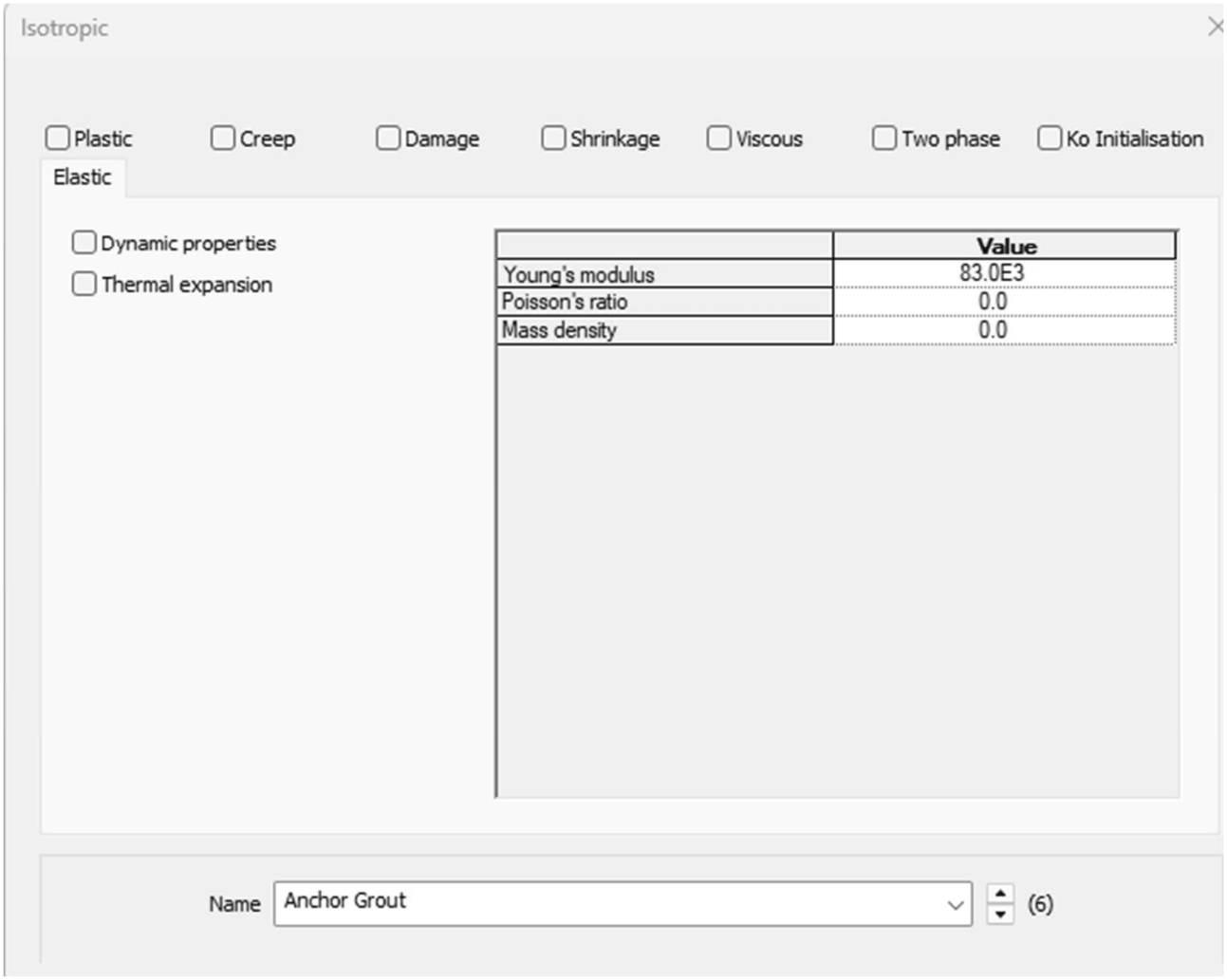
Anchor rods (c/c 3 m) :

The rods are placed c/c 3.0 m out of plain. This can be considered by reducing area of rods or by reducing stiffness corresponding to width 1 m. The later is used thus E-modulus is reduced to 1/3.



Anchor grouts (c/c 3 m) :

The anchor grouts are placed c/c 3.0 m out of plain. This can be considered by reducing area of rods or by reducing stiffness corresponding to width 1 m. The later is used thus E-modulus is reduced to 1/3.



2.6.2 Nonlinear material: soil

Soil is modelled modified Mohr-Coulomb. This model applies a Rankine tensile cut-off to standard Mohr-Coulomb model.

The standard model would predicts tensile stresses beyond the uniaxial tensile limit of the material, while the modified modell uses tension cut-off stress preventing this.

Definition	Parameter	Fill	Sand	Silt
Elastic	Young's Modulus	**8,000** kPa	**30,000** kPa	20,000 kPa
Elastic	Poisson's ratio	**0.3**	**0.3**	0.33
Elastic	Mass density (Fully Saturated)	**2.0**	**2.0**	**1.9**
Plastic	Friction angle	**30.0°**	**34.0°**	**29.0°**
Plastic	Dilation angle	**0 °**	**4.0°**	**0 °**
Plastic	Cohesion	**1.0** kPa	1.0 kPa	8.0°
Plastic (Rankine)	Tensile cut-off stress	**0** kPa	**0** kPa	**0** kPa

Definition	Parameter	Fill	Sand	Silt
Plastic (Rankine)	Compressive cut-off stress	**1E30** kPa	**1E30** kPa	1E30 kPa
Plastic (Rankine)	Damping factor	**0**		
Elastic (once Two-phase tab is selected)	Fully saturated soil density	**2.0** tonnes/m^3	**2.0** tonnes/m^3	**1.9** tonnes/m^3
Two phase (Partially saturated, Saturation)	Bulk modulus of fluid phase	**2.1** MPa	**2.1** MPa	**2.1** MPa
	Porosity of medium	**0.4**	**0.3**	**0.2**
	Hydraulic conductivity in global X, Y, Z	**0.5** m/day	**1.0** m/day	**0.1** m/day
	Density of fluid	**1** tonne/m^3	**1** tonne/m^3	**1** tonne/m^3
	Saturation at residual water content	**0.0**	**0.0**	**0.0**
	Saturation at full water content	**1.0**	**1.0**	**1.0**
(Constant water content)	Permeability factor in partially saturated zone	**1x10^{-3}**	**1x10^{-3}**	**1x10^{-3}**
Ko Initialisation	Coefficient of lateral earth pressure K_0	**0.5**	**0.441**	**0.515**

2.6.3 Nonlinear joint material between retaining wall and soil

The tangential slip surface is defined as seen below. No leakage is assumed through wall.

Defintion	**Parameter**	**Wall/Fill**	**Wall/Sand**
Soil structure interface (tangential slip)	Angle of friction	**20**^{o}	**24**^{o}
Soil structure interface (tangential slip)	Dilatency angle	0	0
Soil structure interface (tangential slip)	Cohesion	**0** kPa	**0.0** m/s
Two Phase	Hydraulic conductivity	**0** kPa	**0.0** m/s

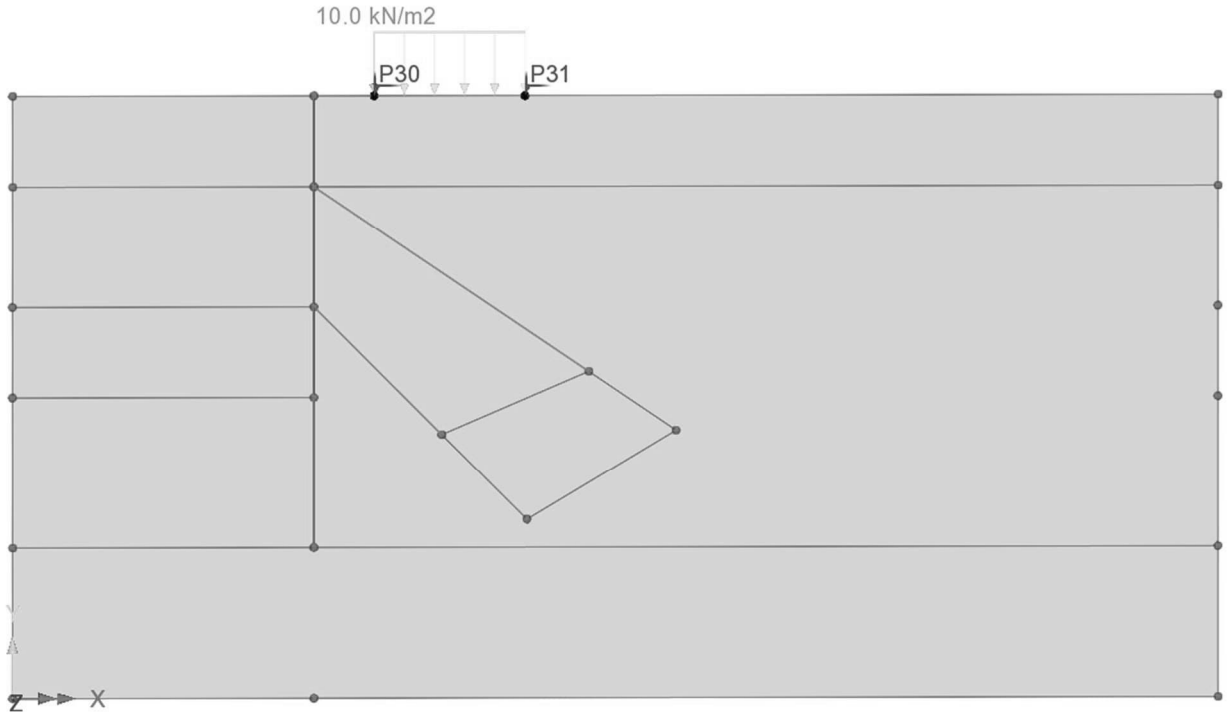
3. LOADS

3.1 Soil weight (Gravity)

Soil weight is determined material density.

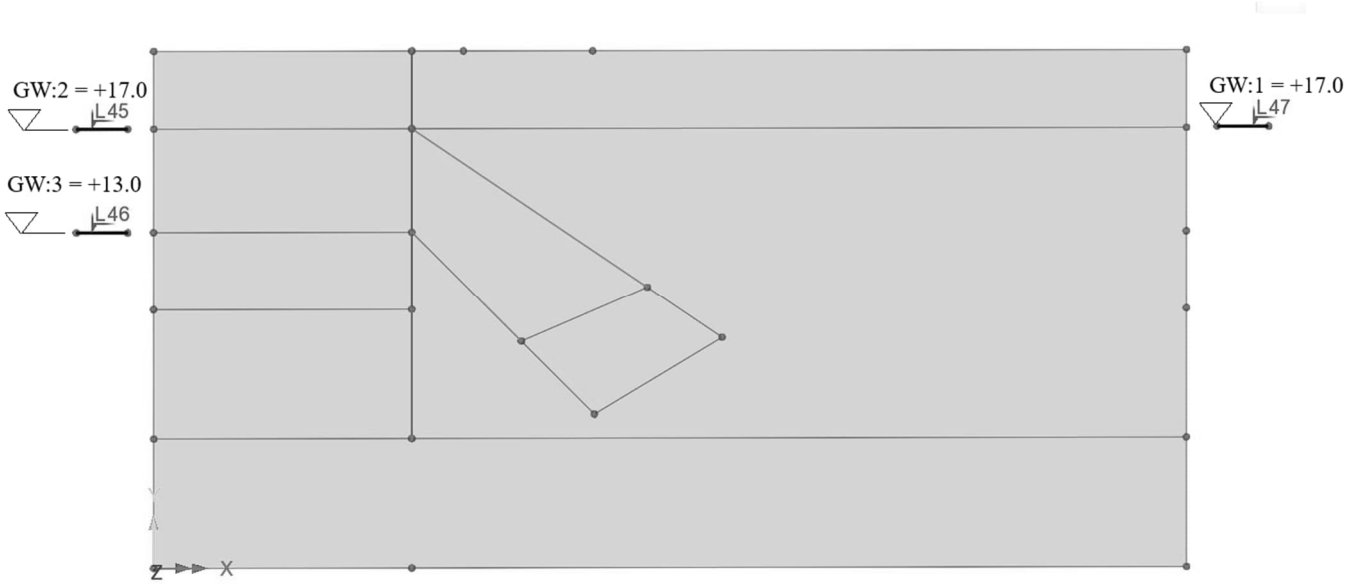
3.2 Surcharge

Surcharge (q = 10 kPa) on top of filling as seen below.



3.3 Ground water levels

Free groundwater surfaces (phreatic surfaces) are used to determine acting water pressures, see used levels.

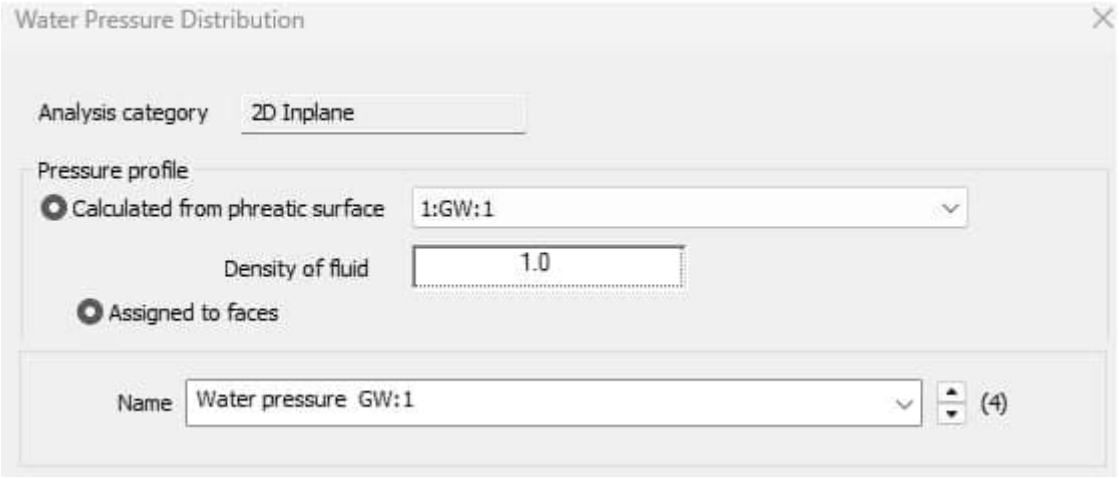


3.4 Water pressure

Water pressure varies according to load cases (construction stages).

3.4.1 Water pressure GW:1

Water pressure is associated to GW:1

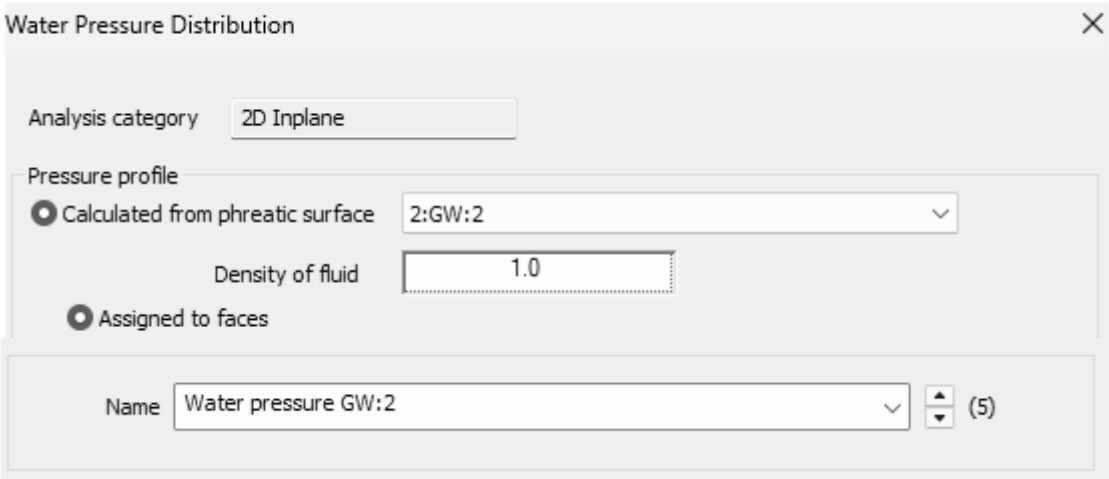


This load acts at load cases (stages) seen below.

Before excavation	☑
Install wall	☑
Surface load 10kPa	☑
Excavation:1	☐
Install anchor:1	☐
Set water level GW:2	☑
Reduction to GW:2	☐
Excavation:2	☐
Install anchor:2	☐
Set water level GW:3	☑
Reduction to GW:3	☐
Excavation:3	☐

3.4.2 Water pressure GW:2

Water pressure is associated to GW:2



This load acts at load cases (stages) seen below.

Before excavation	○
Install wall	○
Surface load 10kP	○
Excavation:1	○
Install anchor:1	○
Set water level G	●
Reduction to GW:	○
Excavation:2	○
Install anchor:2	○
Set water level G	○
Reduction to GW:	○
Excavation:3	○

3.4.3 Water pressure GW:3

Water pressure is associated to GW:3.

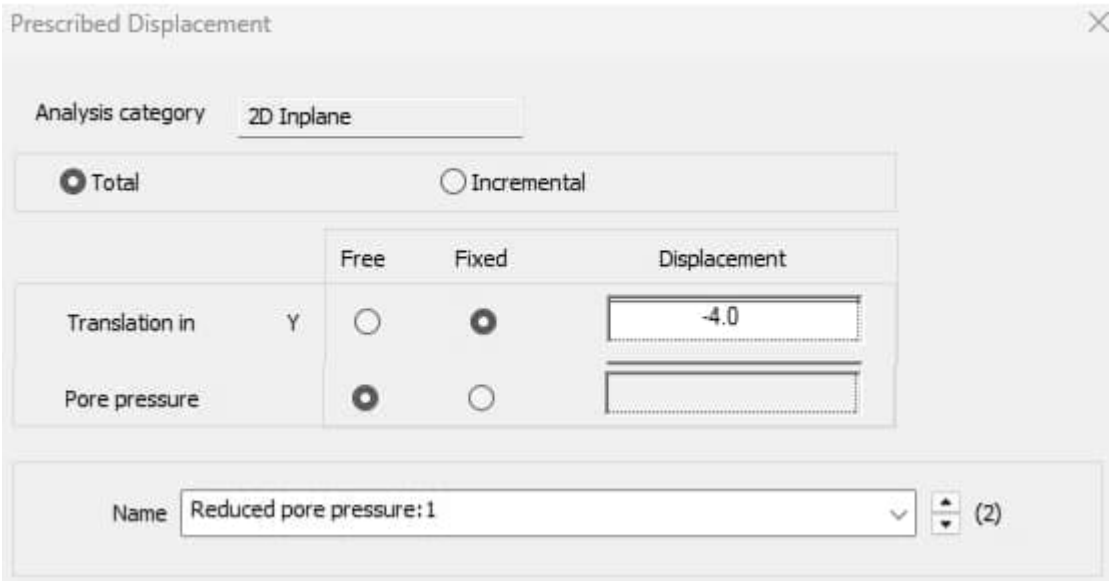
This load acts at load cases (stages) seen below.

Before excavation	○
Install wall	○
Surface load 10kP	○
Excavation:1	○
Install anchor:1	○
Set water level G	○
Reduction to GW:	○
Excavation:2	○
Install anchor:2	○
Set water level G	●
Reduction to GW:	○
Excavation:3	○

3.5 Reduced pore pressure

3.5.1 Reduced pore pressure:1

Reduction from GW:2 (+17.0 m) to GW:3 (+13.0 m) → -4.0 m

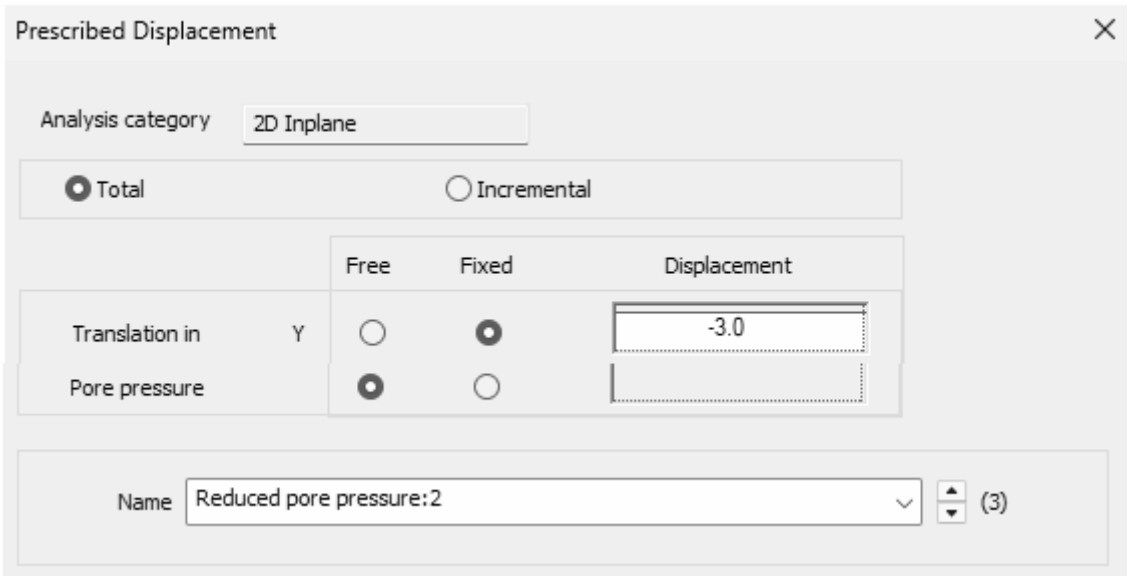


This load acts at load cases (stages) seen below.

Before excavation	○
Install wall	○
Surface load 10kPa	○
Excavation:1	○
Install anchor:1	○
Set water level GW:2	○
Reduction to GW:2	◉
Excavation:2	○
Install anchor:2	○
Set water level GW:3	○
Reduction to GW:3	○

3.5.2 Reduced pore pressure:2

Reduction from GW:3 (+13.0 m) to +10.0 m → -3.0 m



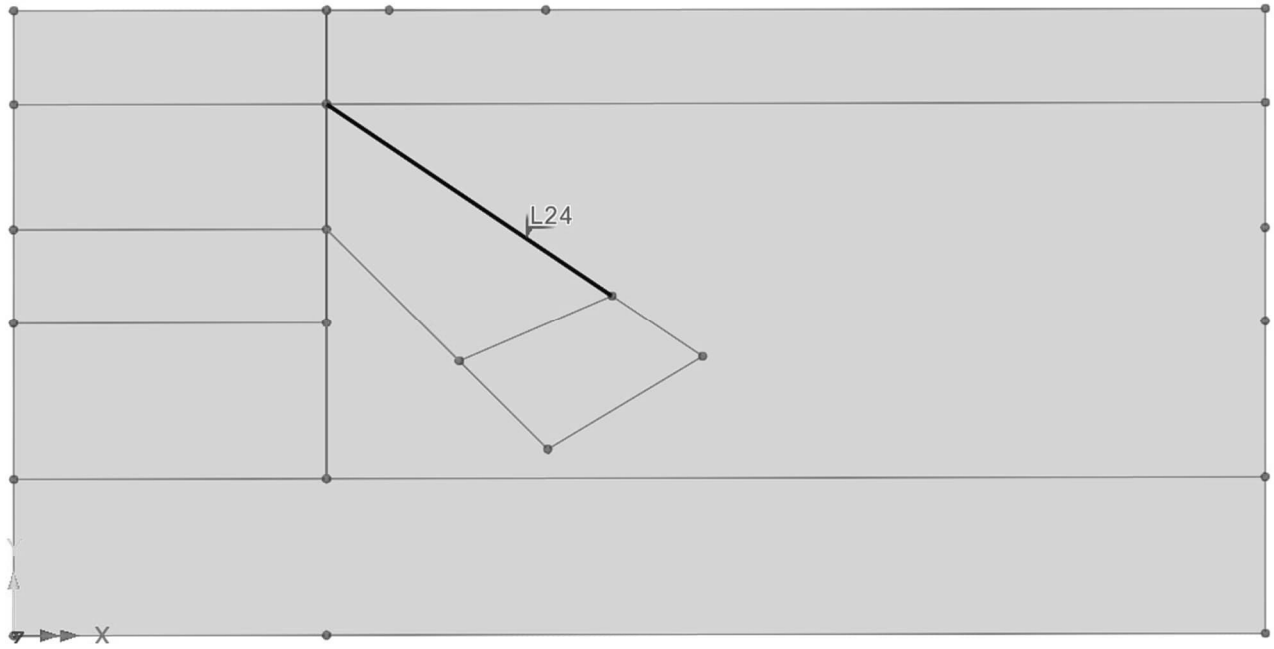
This load acts at load cases (stages) seen below.

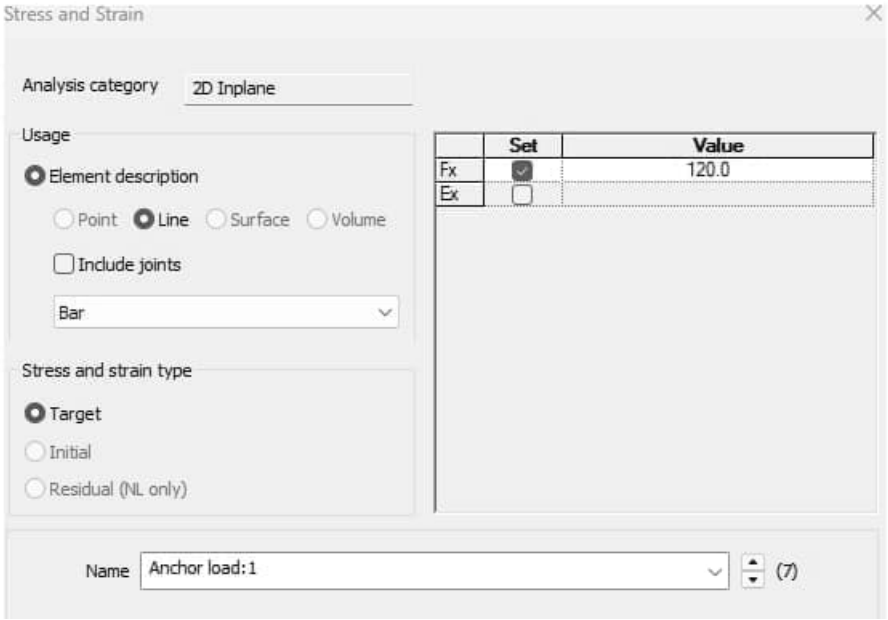
Before excavation	○
Install wall	○
Surface load 10kPa	○
Excavation:1	○
Install anchor:1	○
Set water level GW:2	○
Reduction to GW:2	○
Excavation:2	○
Install anchor:2	○
Set water level GW:3	○
Reduction to GW:3	●

3.6 Anchor loads

3.6.1 Anchor load:1

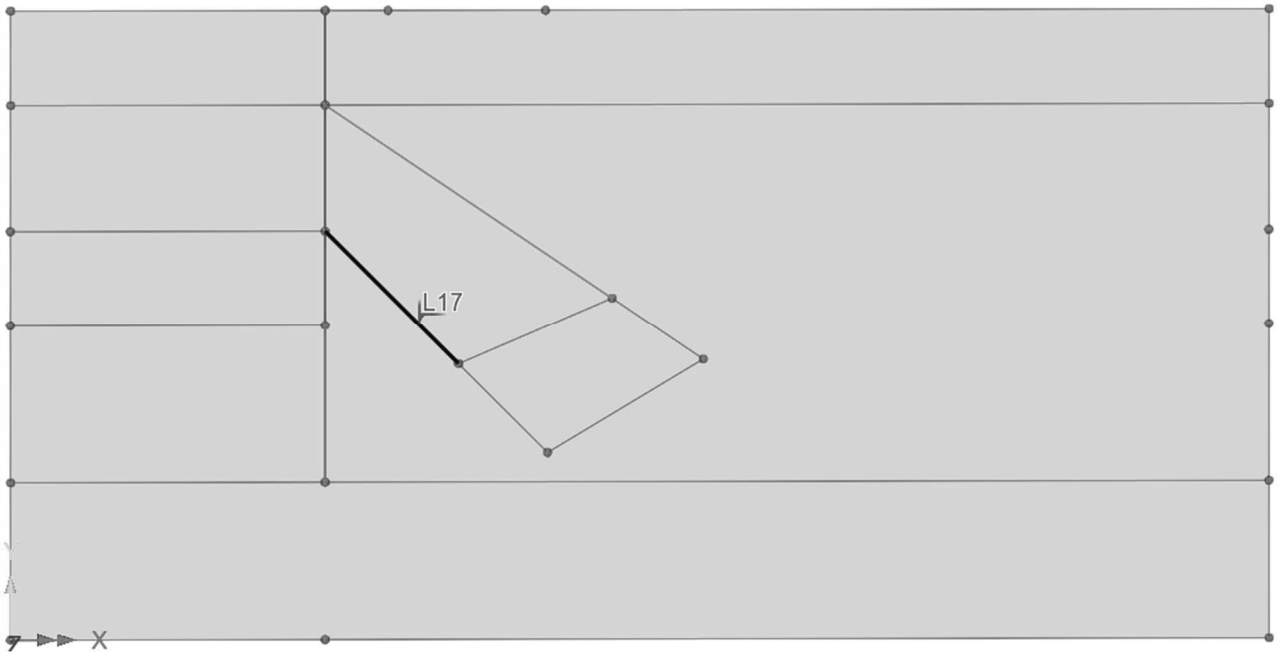
Total anchor load 360 kN (c/c 3 m) → Fx = 120 kN is applied to L24.

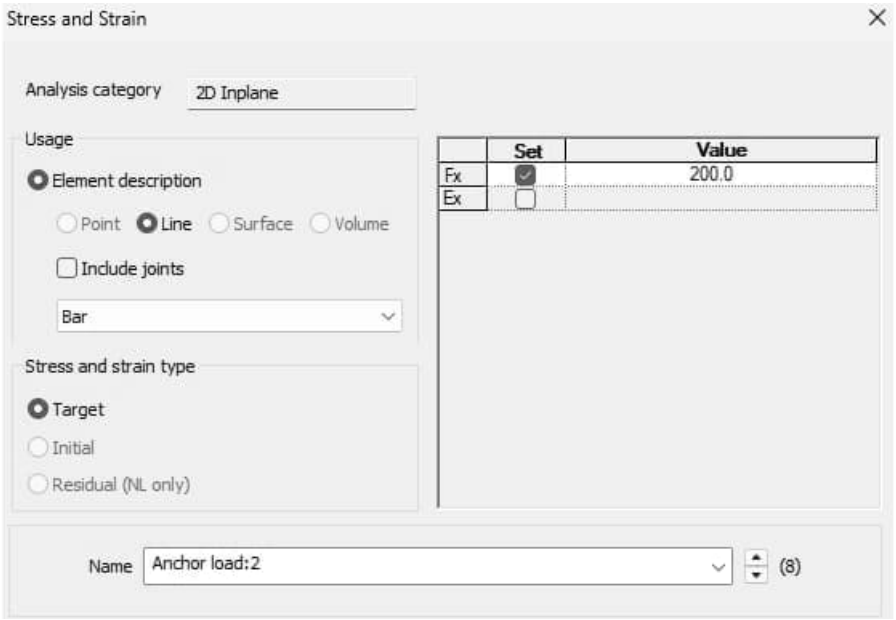




3.6.2 Anchor load:2

Total anchor load 600 kN (c/c 3 m) → Fx = 200 kN is applied to L17.

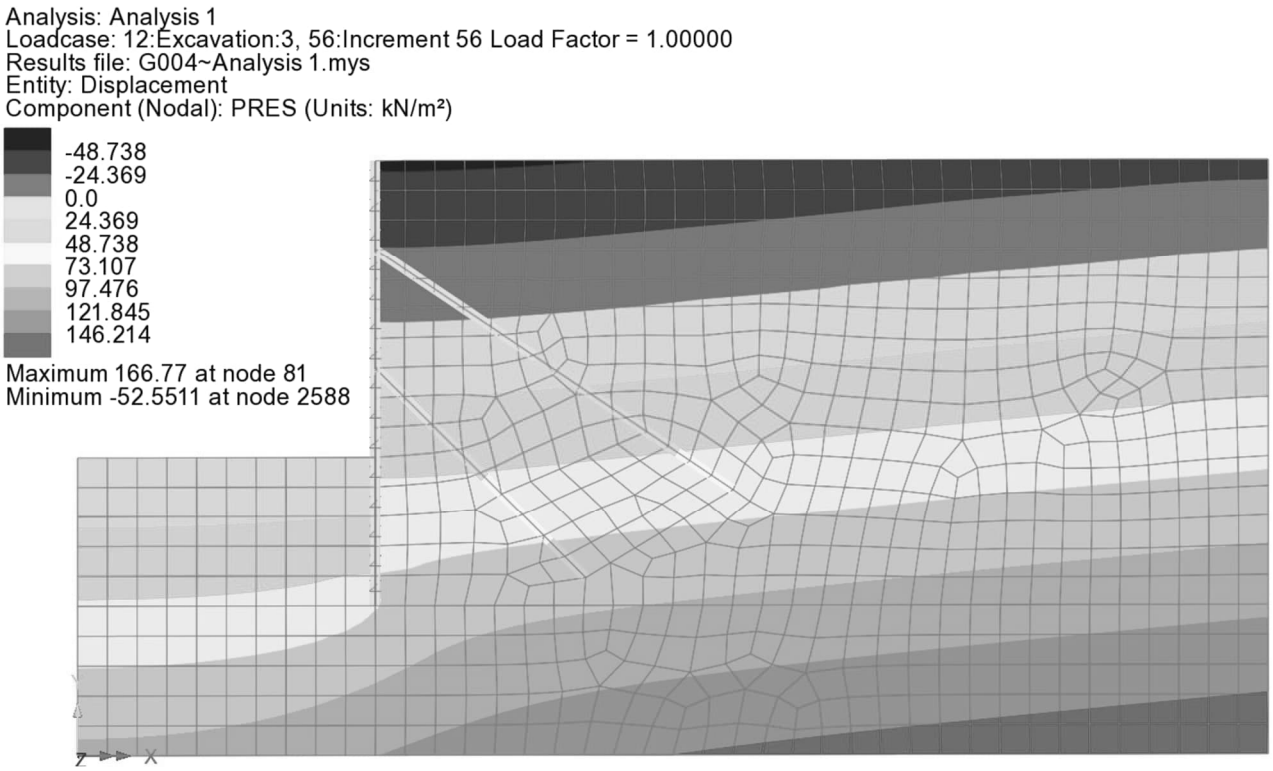




4. RESULTS (FEM-program)

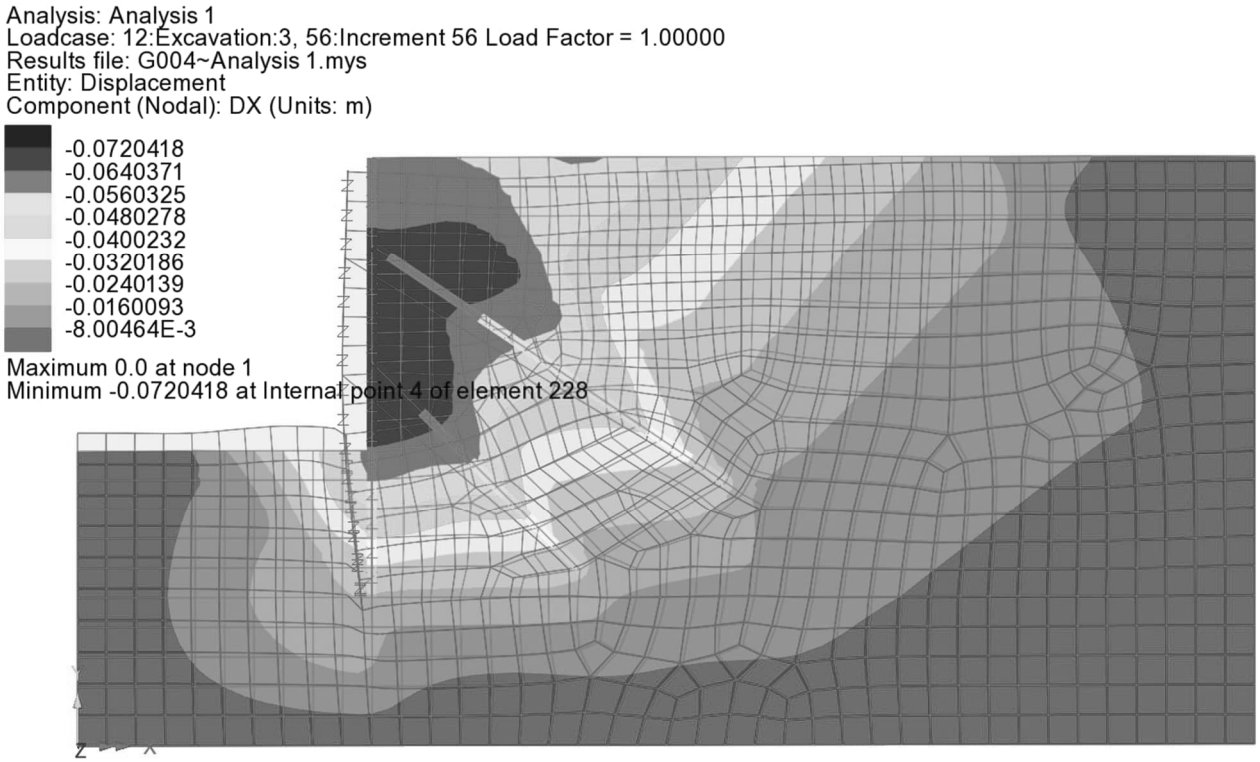
4.1 Water pressure after completed excavation (LC excavation:3)

→ Max Pressure = +167 kPa
Min Pressure = -52 kPa



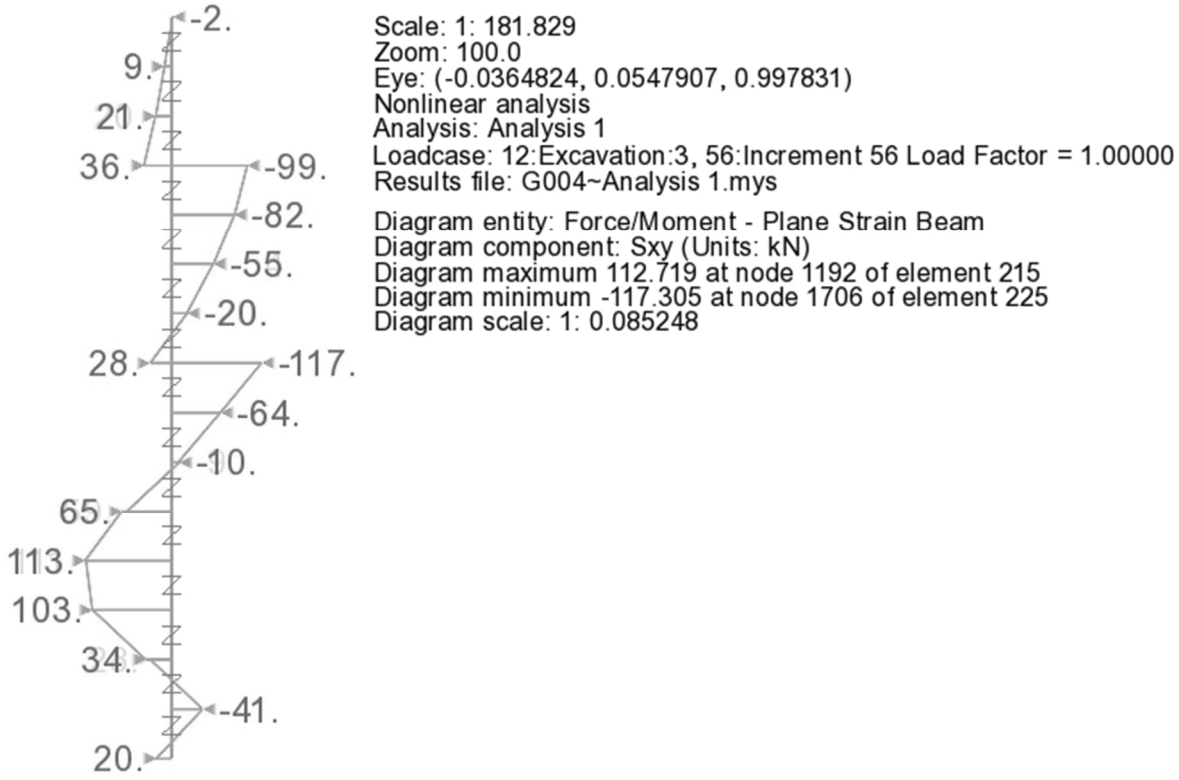
4.2 Horizontal displacement after completed excavation (LC excavation:3)

→ Min Dx = -0.082 m



4.3 Shear force retaining wall after completed excavation (LC excavation:3)

→ Max Sxy = +113 kN
Min Sxy = -117 kN



4.3 Bending moment retaining wall after completed excavation (LC excavation:3)

→ Max Mz = +272kNm
Min Mz = -47 kNm

Scale: 1: 181.829
Zoom: 100.0
Eye: (-0.0364824, 0.0547907, 0.997831)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 12:Excavation:3, 56:Increment 56 Load Factor = 1.00000
Results file: G004~Analysis 1.mys

Diagram entity: Force/Moment - Plane Strain Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 272.507 at Internal point 9 of element 220
Diagram minimum -47.0517 at node 2203 of element 238
Diagram scale: 1: 0.0366963