Retaining wall with three levels of tie back anchors

Table of content

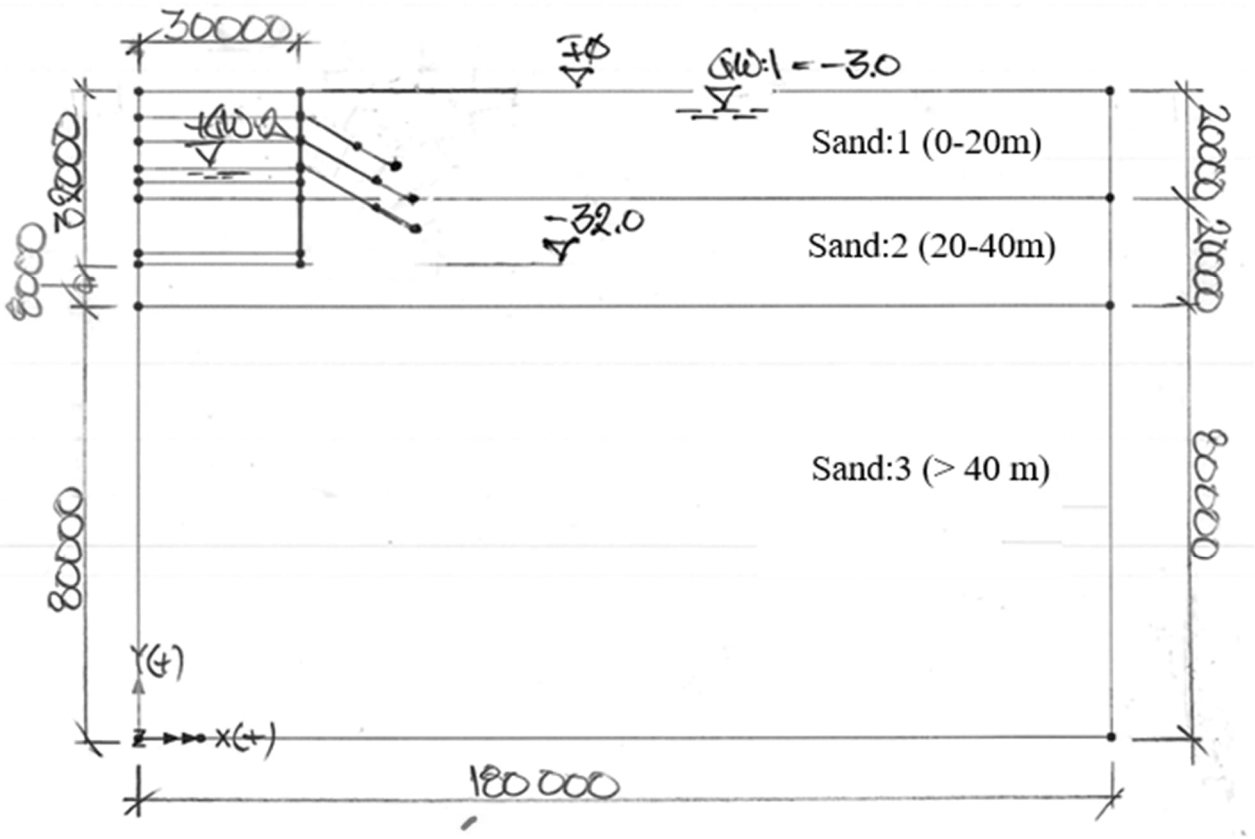
Appendix

1. Input receipt (FEM-program)

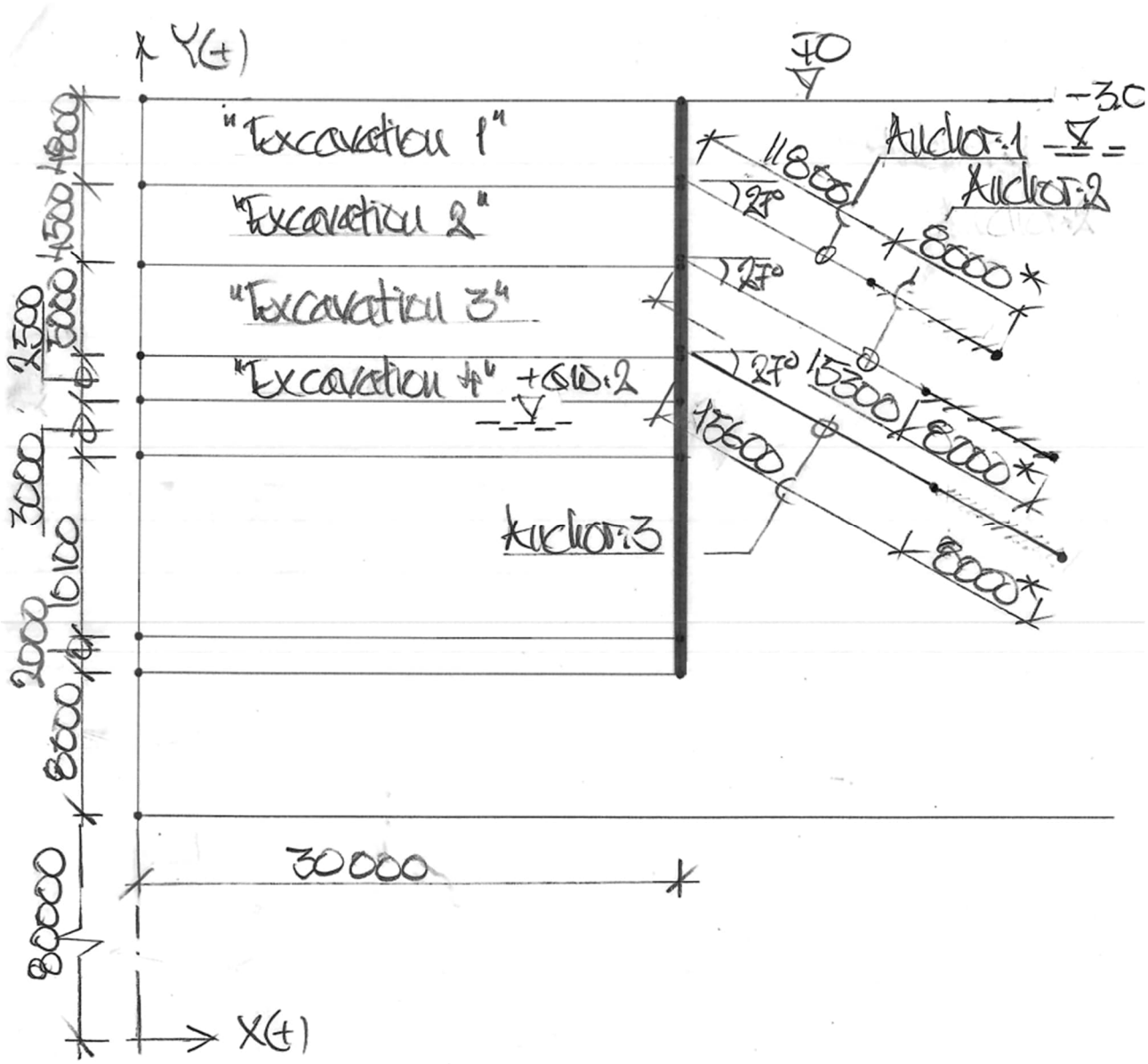
1. GENERAL

The retaining wall is excavated in 4 stages. There are in total 3 different levels of anchors.

1.1 GEOMETRY



ELEVATION
Overall



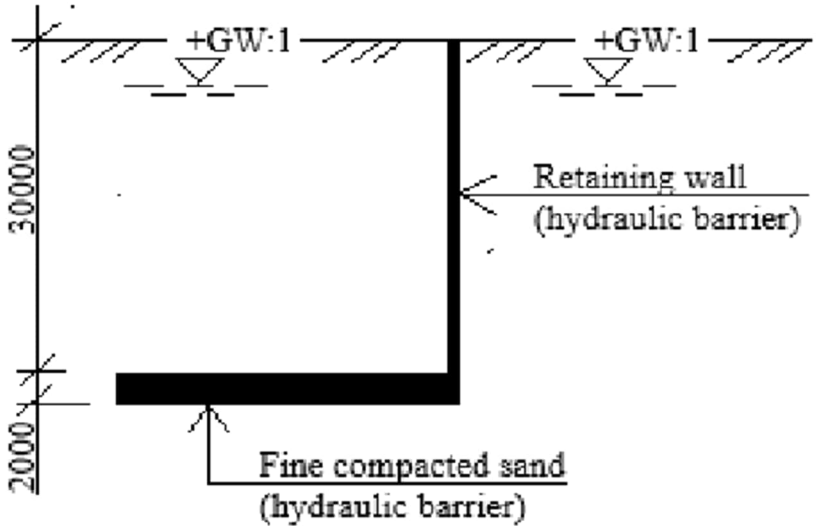
ELEVATION
Detail retaining wall.

1.2 SOIL PROPROPETIES

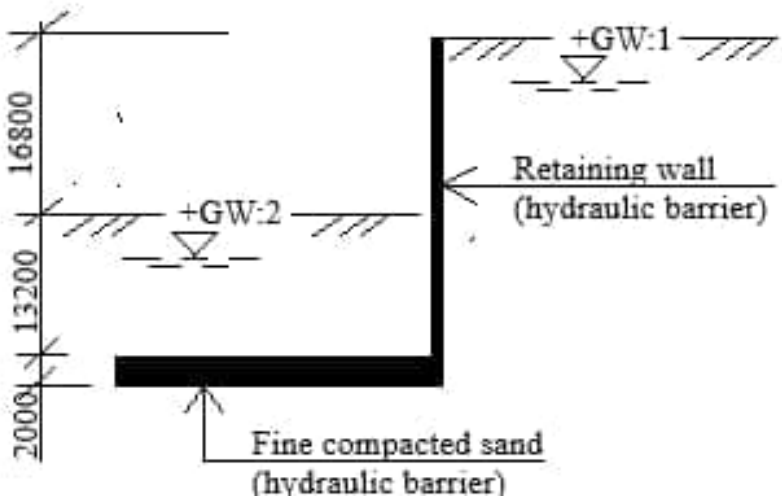
1.2.1 Ground water

Ground water level before excavation is termed GW:1 (= -3.0 m).

After completed excavation water level on side from filling lowered to GW:2 (= -17.9).



ELEVATION
Before excavation



ELEVATION
After excavation

1.2.2 Soil material

Geotechnical parameters:

Material	Level	ρ	ρ´	ϕ_k	E_k
Sand:1	± 0→ -20	19	9	35	47
Sand:2	-20→ -40	19	9	38	24
Sand.3	-40→ -80	19	9	38	37
”Rock”	-80	-	-	-	-
-	m	kN/m³	kN/m³	deg	MPa

2. SYSTEM ANALYSIS

2.1 GENERAL

Below is short description of assumptions used in the analysis.

There are in total 3 different layer of soil.

Ther are two analysis. Analysis 1 is used for nonlinear analysis is used for installation of retaining wall before lowering groundwater. Analysis 2 is used for nonlinear analysis during excavation and lowering of groundwater.

Analysis 1 is analysis the is conduted firs (Base Anlysis) t and from which Analysis 2 inherits attributes.

Lowering of groundwater is considered to be performed from GW:1 to GW:2 as one loadcase. This is simplied and performed at LC 3.

Since material properties for soil is not linear a nonlinear analysis must be performed. The soil propterties is considered to have two phases (∴ can handle consolidiation after lower of groudwater) is used. Hower att bottom of retaining wall a 2 m hydralic barrier is considered, thus this material is not defined using two phases.

Surface elements are modelled as plain strain element that quadratic. Hydralic barrier uses element without two phase (QPN8). All other soil surfaces element with two phases (QNP8P).
.
Beam elements are modelled as 2D plain strain beams (BMI3N).

In order to handle excavation a total of 14 loadcases (LC) are needed.

Depending on stage soil, soil and anchors are activated & activated.

Interface elements are needed to modell interaction between soil and retaing wall.

In order to retore free groundwater surfaces after every excation loadcases fictive load cases LC 4, LC 7, LC 10 and LC 13 are created without any external load. All these loadcases are linear.

LC nr	Name	Type	Activate	Deactivate
1	Installation:1	Nonlinear	-	All anchor & grout
2	Installation:2	Nonlinear	-	All anchor & grout
3	Lower groundwater level	Nonlinear	-	All anchor & grout
4	Elastic restoration:1	Linear	-	All anchor & grout
5	Excavation:1	Nonlinear	-	Soil excavation 1
6	Installation anhor:1	Nonlinear	Anchor:1 & Grout:1	-
7	Elastic restoration:2	Linear	-	-
8	Excavation:2	Nonlinear	-	Soil excavation 2
9	Installation anhor:2	Nonlinear	Anchor:2 & Grout:2	-
10	Elastic restoration:3	Linear	-	-
11	Excavation:3	Nonlinear	-	Soil excavation 3
12	Installation anhor:3	Nonlinear	Anchor:3 & Grout:3	-
13	Elastic restoration:4	Linear	-	-
14	Excavation:4	Nonlinear	-	Soil excavation 3

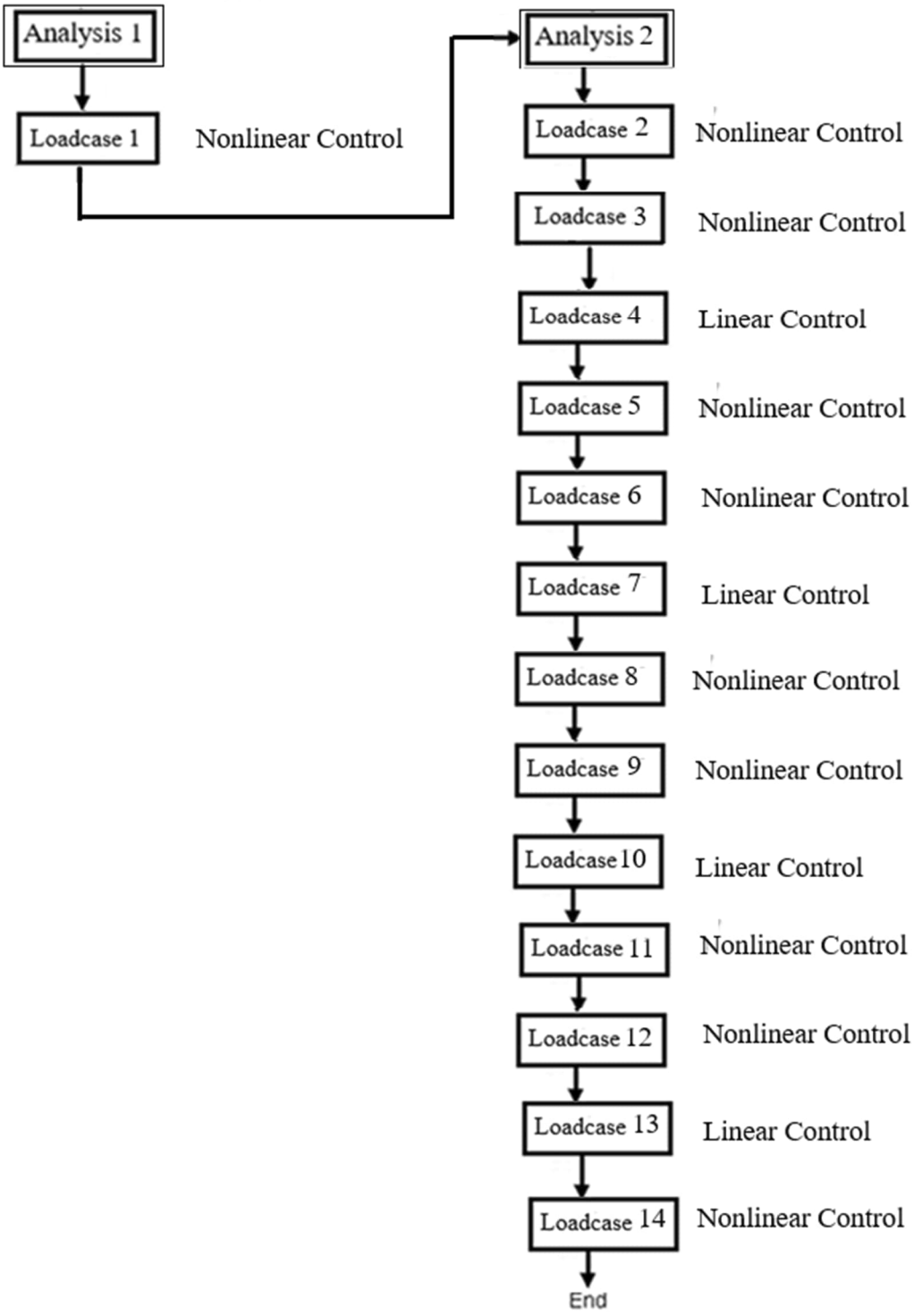
2.2 NONLINEAR ANALYSIS

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

Max number of iterations:
For each load increment if convergence is not achieved.

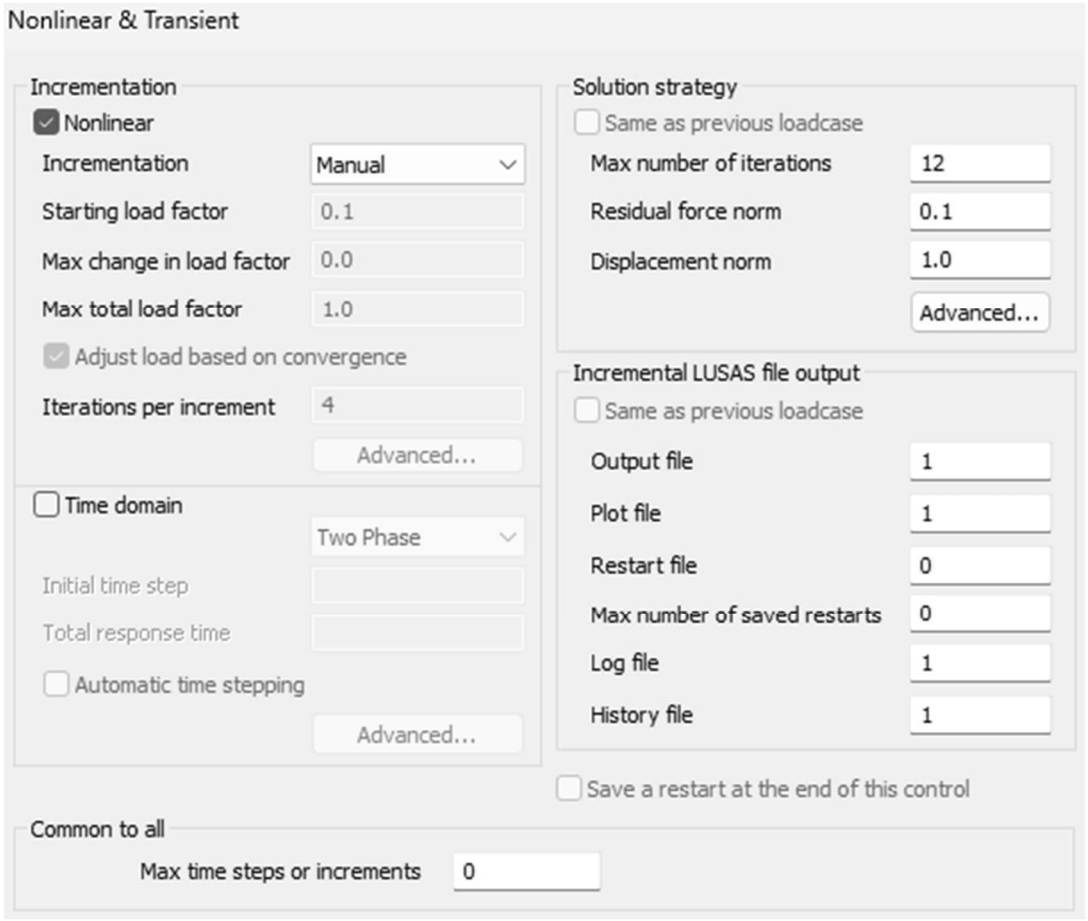
Residual force norm:
The limit for the sum of the squares of all residual forces as a percentage of the sum of the squares of all external forces, including reactions (rdnrm). By default only translation degrees of freedom are considered. So for a value of 0.1 the convergence of the solution at each 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.


Analysis 1
Loadcase 1
Nonlinear Control
Analysis 2
Loadcase 2
Nonlinear Control
Loadcase 3
Nonlinear Control
Loadcase 4
Linear Control
Loadcase 5
Nonlinear Control
Loadcase 6
Nonlinear Control
Loadcase 7
Linear Control
Loadcase 8
Nonlinear Control
Loadcase 9
Nonlinear Control
Loadcase 10
Linear Control
Loadcase 11
Nonlinear Control
Loadcase 12
Nonlinear Control
Loadcase 13
Linear Control
Loadcase 14
Nonlinear Control
End

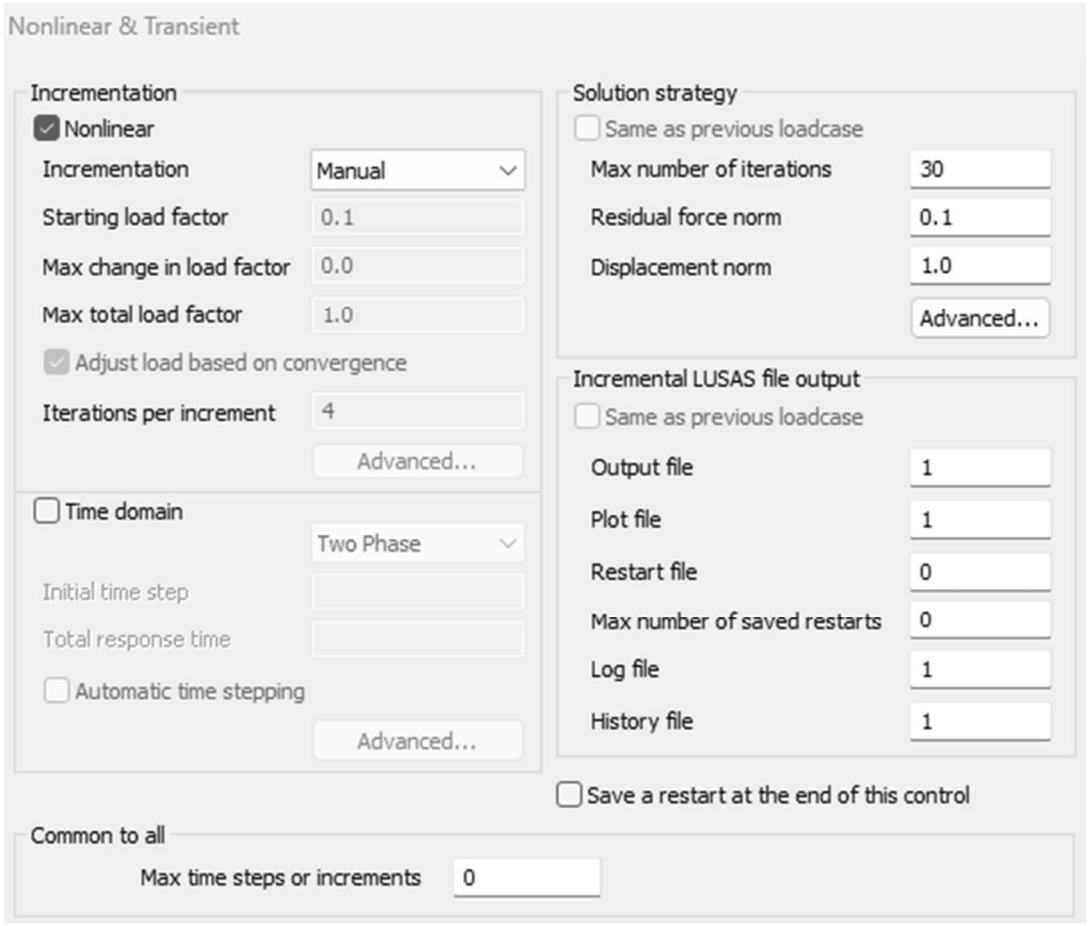
Manual:1

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



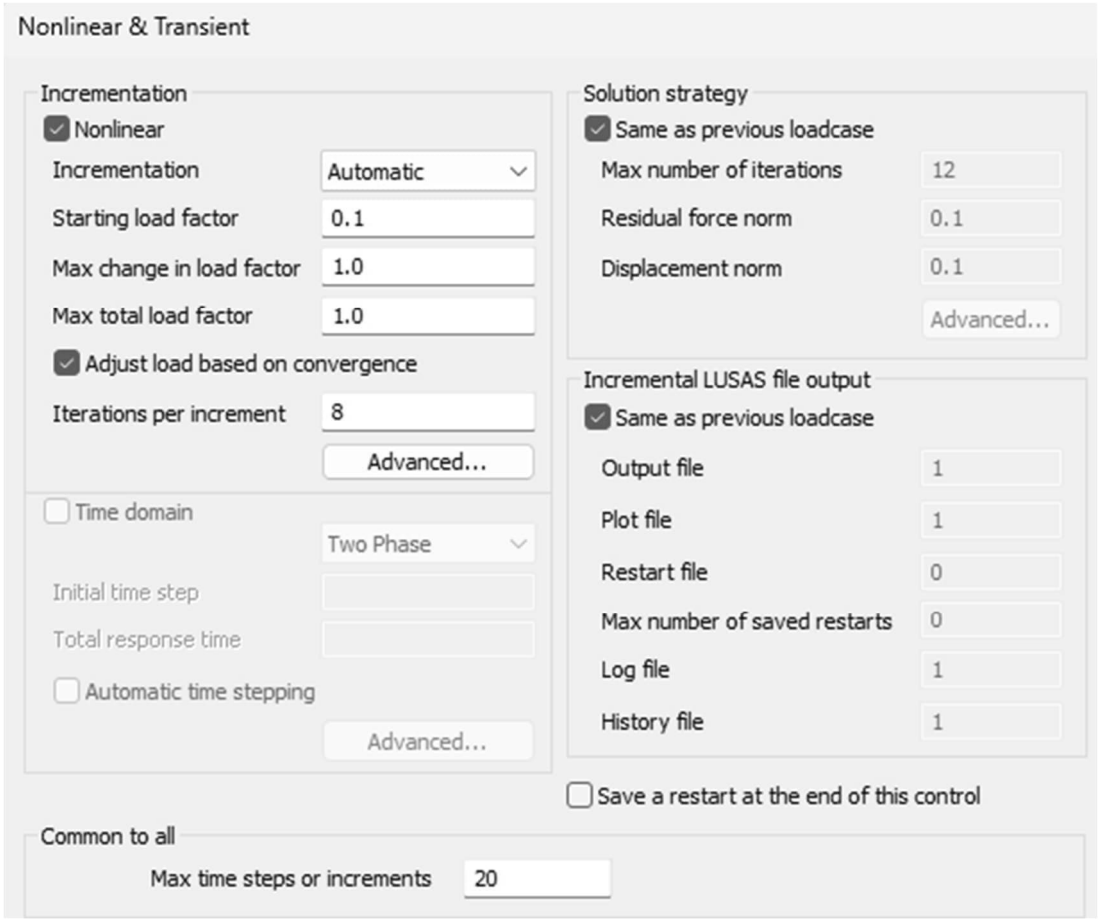
Manual:2

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



Automatic: 8

Incrementation as chosen to be performed *Automatic*, see chosen parameters in dialogue box below.



LC nr	Name	Type analysis	Incrementation	Analysis
1	Installation:1	Nonlinear	Manual:1	1
2	Installation:2	Nonlinear	Manual.2	2
3	Lower groundwater level	Nonlinear	Automatic:8	2
4	Elastic restoration:1	Linear	-	2
5	Excavation:1	Nonlinear	Automatic:8	2
6	Installation anhor:1	Nonlinear	Automatic:8	2
7	Elastic restoration:2	Linear	-	2
8	Excavation:2	Nonlinear	Automatic:8	2
9	Installation anhor:2	Nonlinear	Automatic:8	2
10	Elastic restoration:3	Linear	-	2
11	Excavation:3	Nonlinear	Automatic:8	2
12	Installation anhor:3	Nonlinear	Automatic:8	2
13	Elastic restoration:4	Linear	-	2
14	Excavation:4	Nonlinear	Automatic:8	2

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.

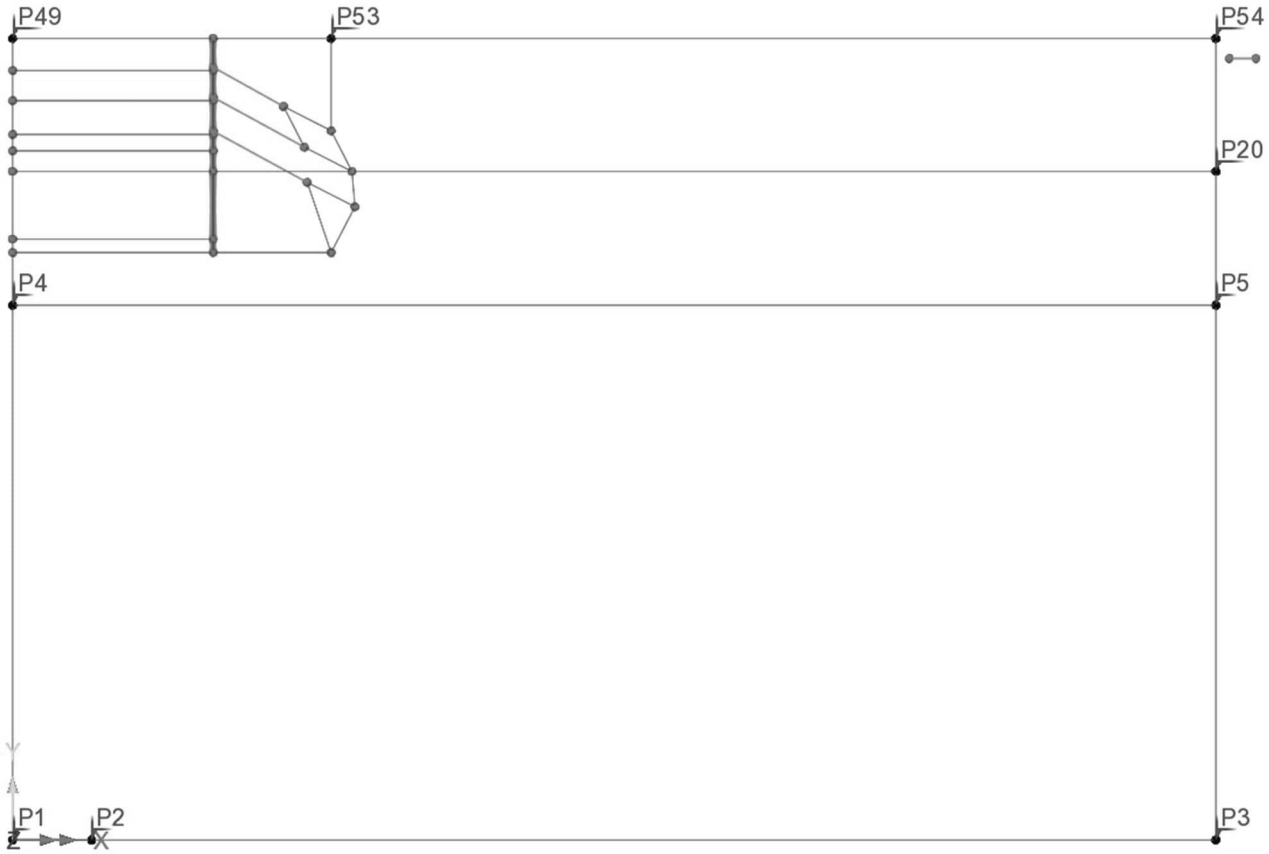
Sketches are generated by using POINTS, LINES and SURFACES.

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

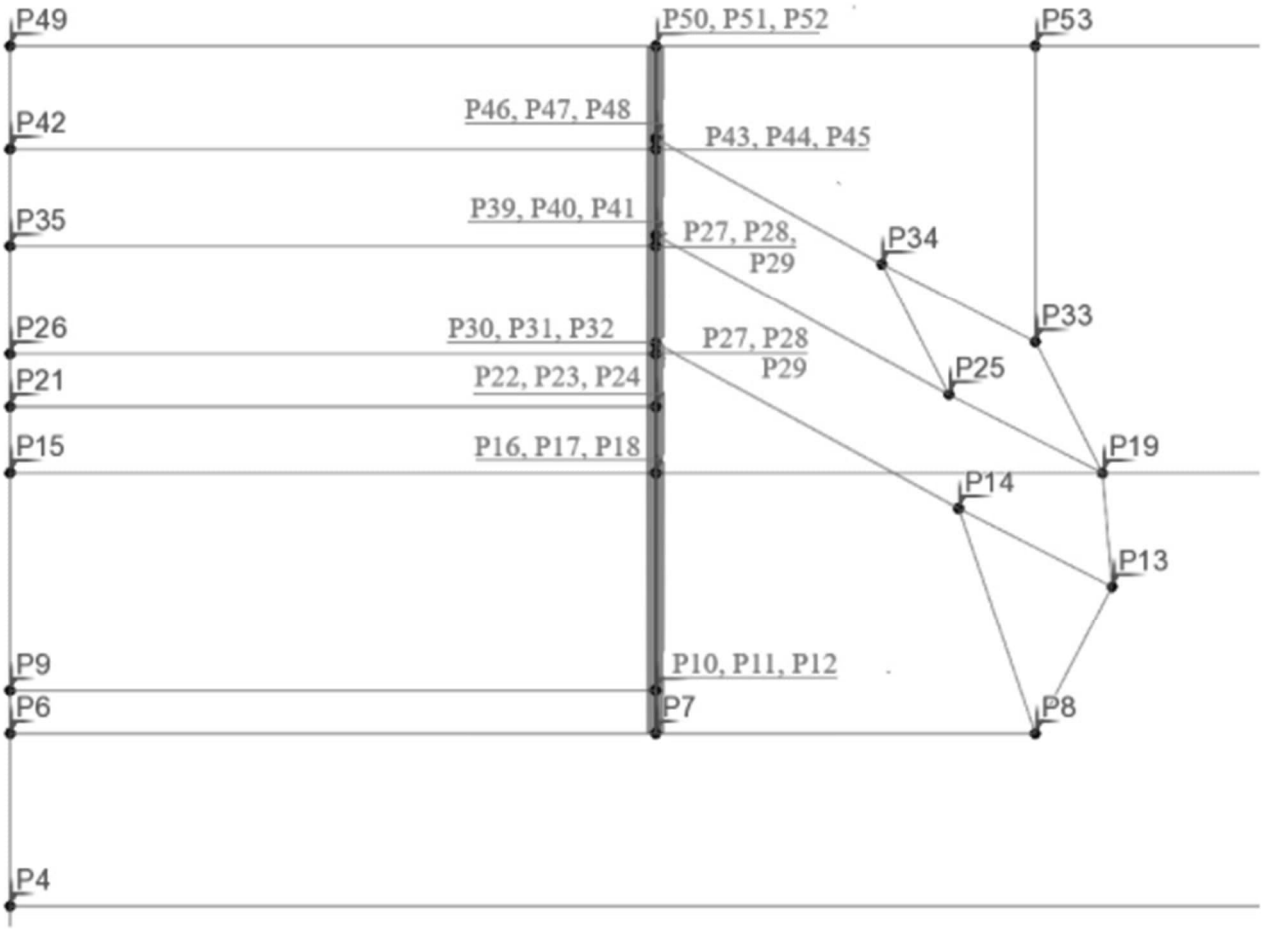
All POINTS needed to describe LINES are found in attachment 1.

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

2.3.1 Geometry: Points

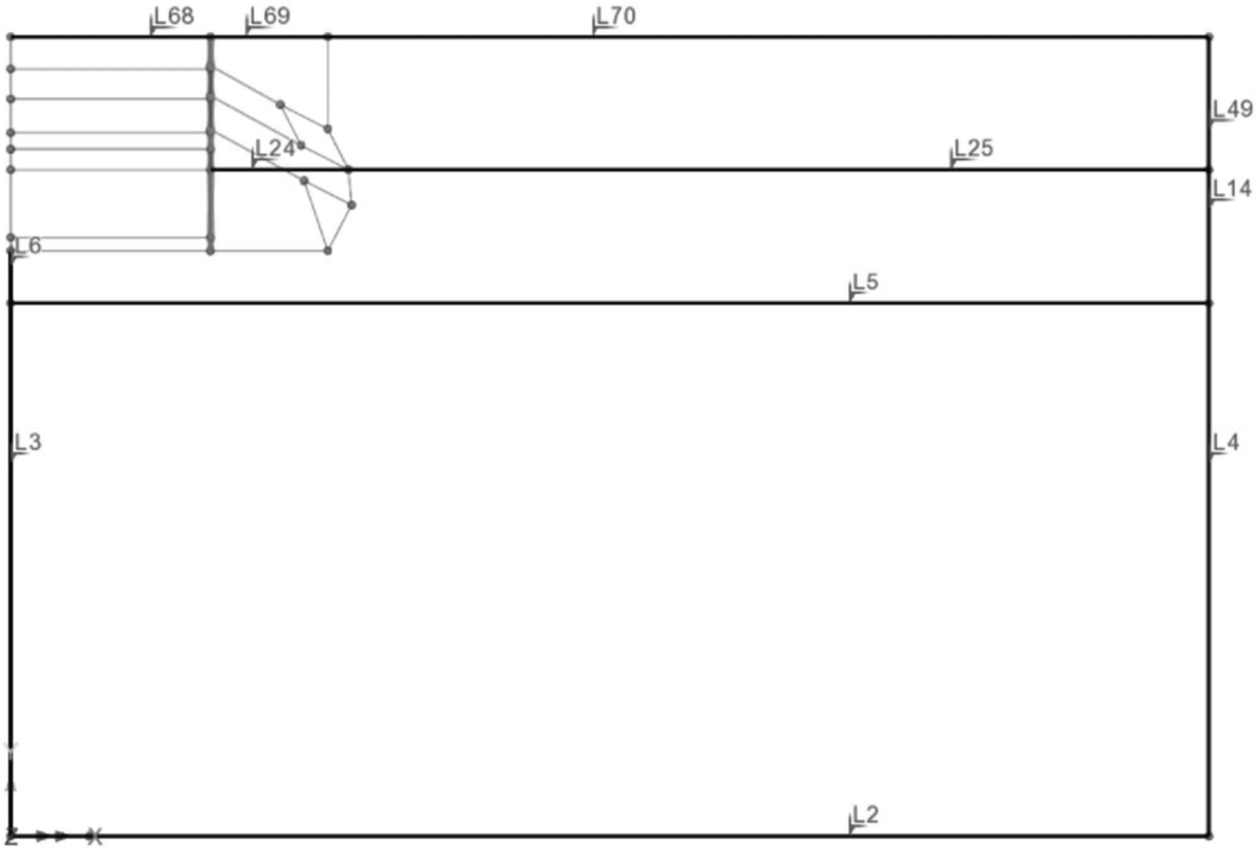


ELEVATION
Overall

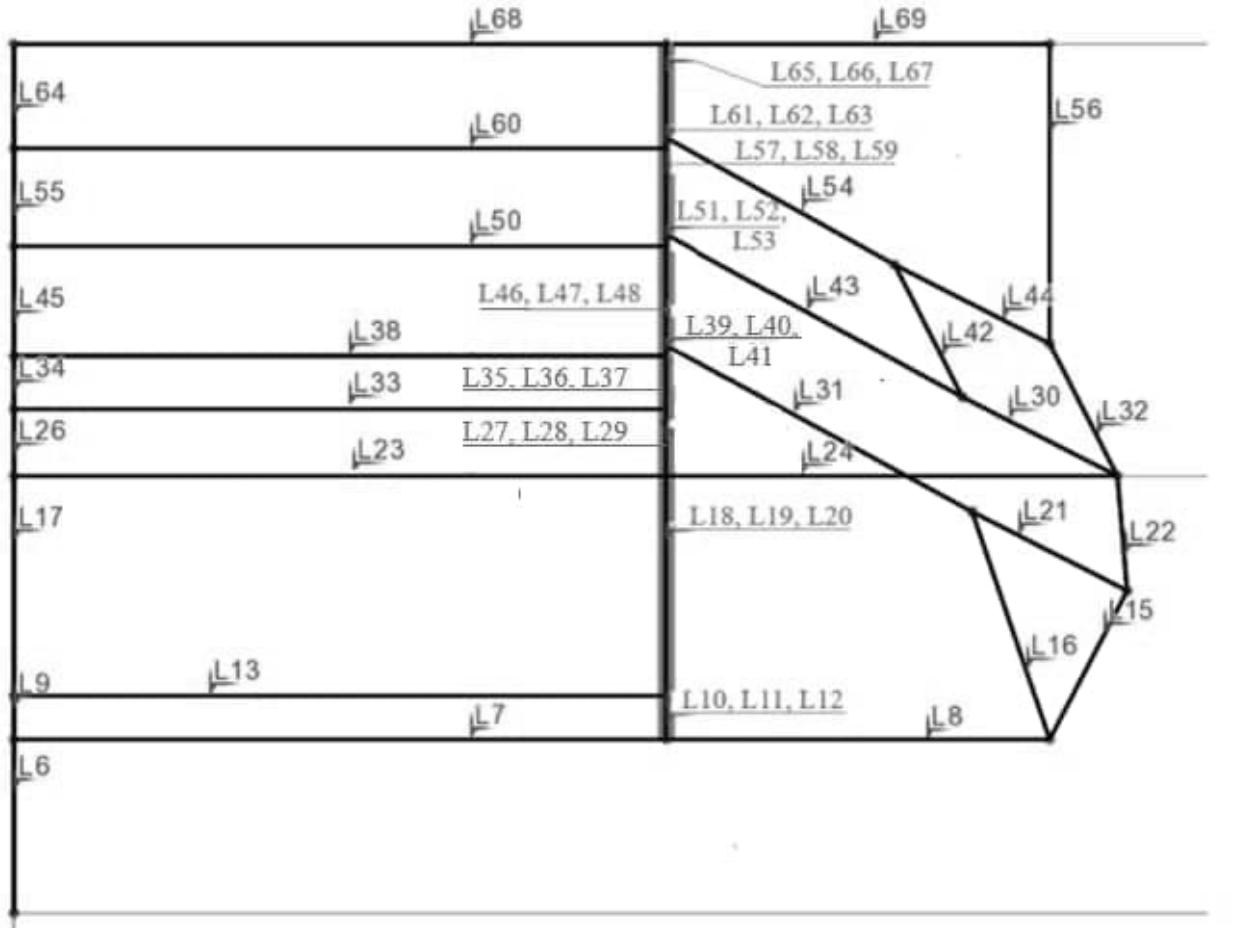


ELEVATION
Detail

2.3.2 Geometry: Lines

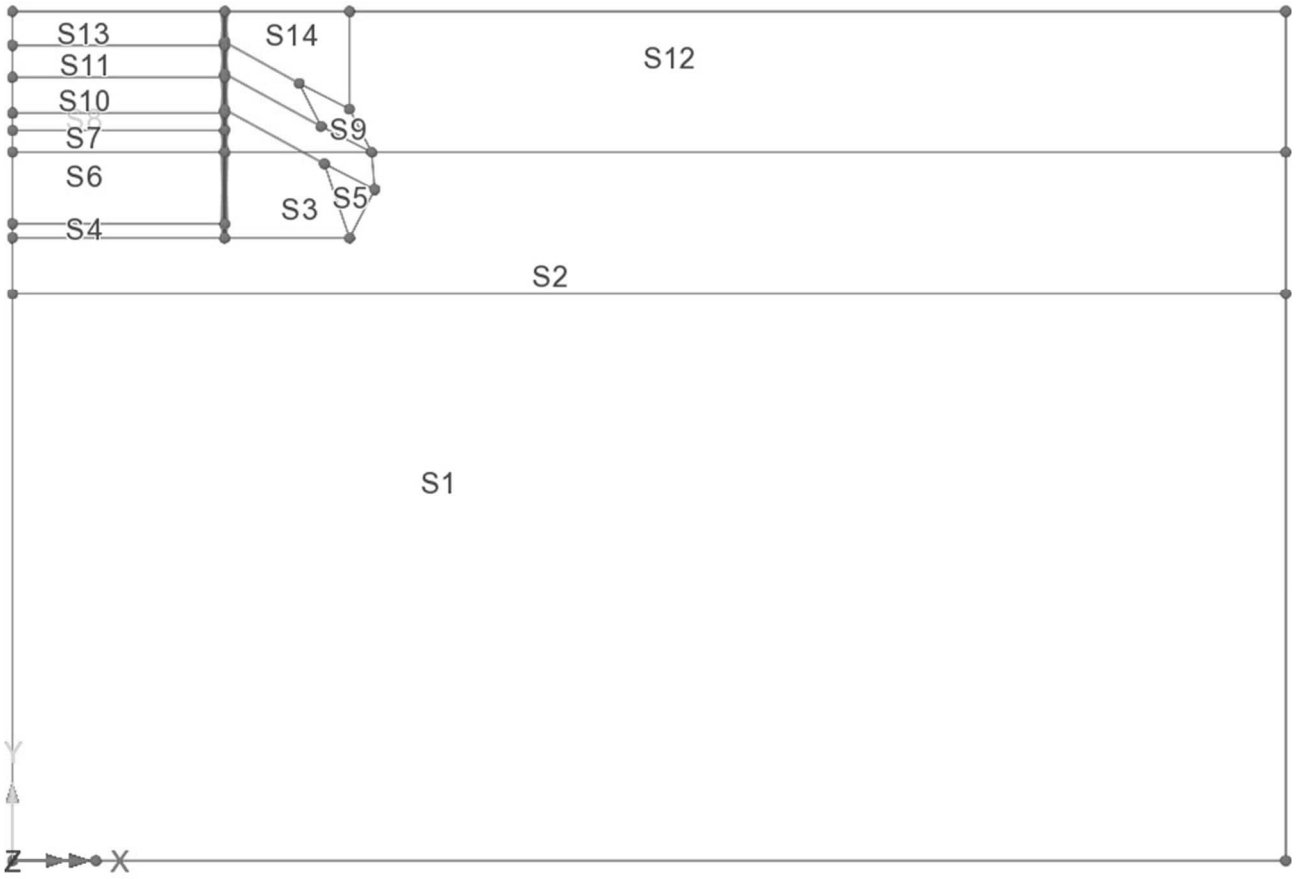


ELEVATION
Overall



ELEVATION
Detail

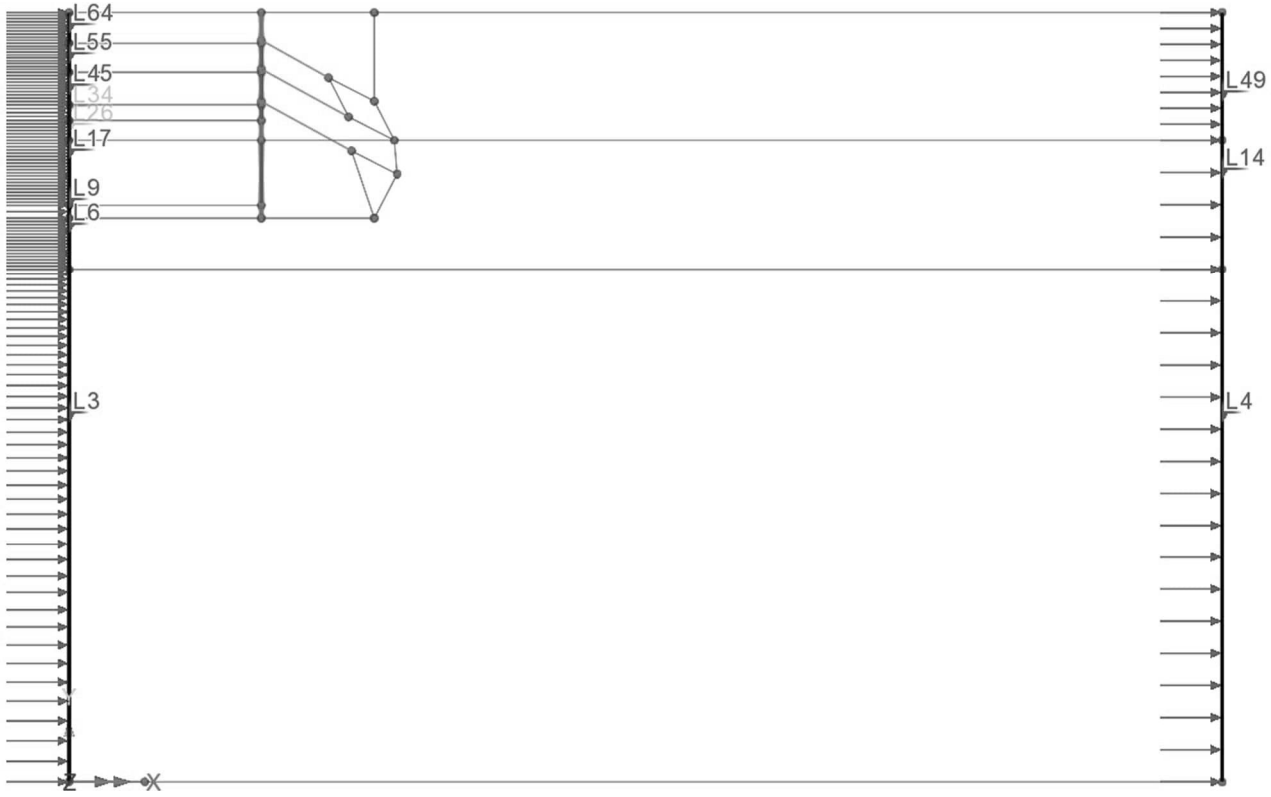
2.3.3 Geometry: Surfaces



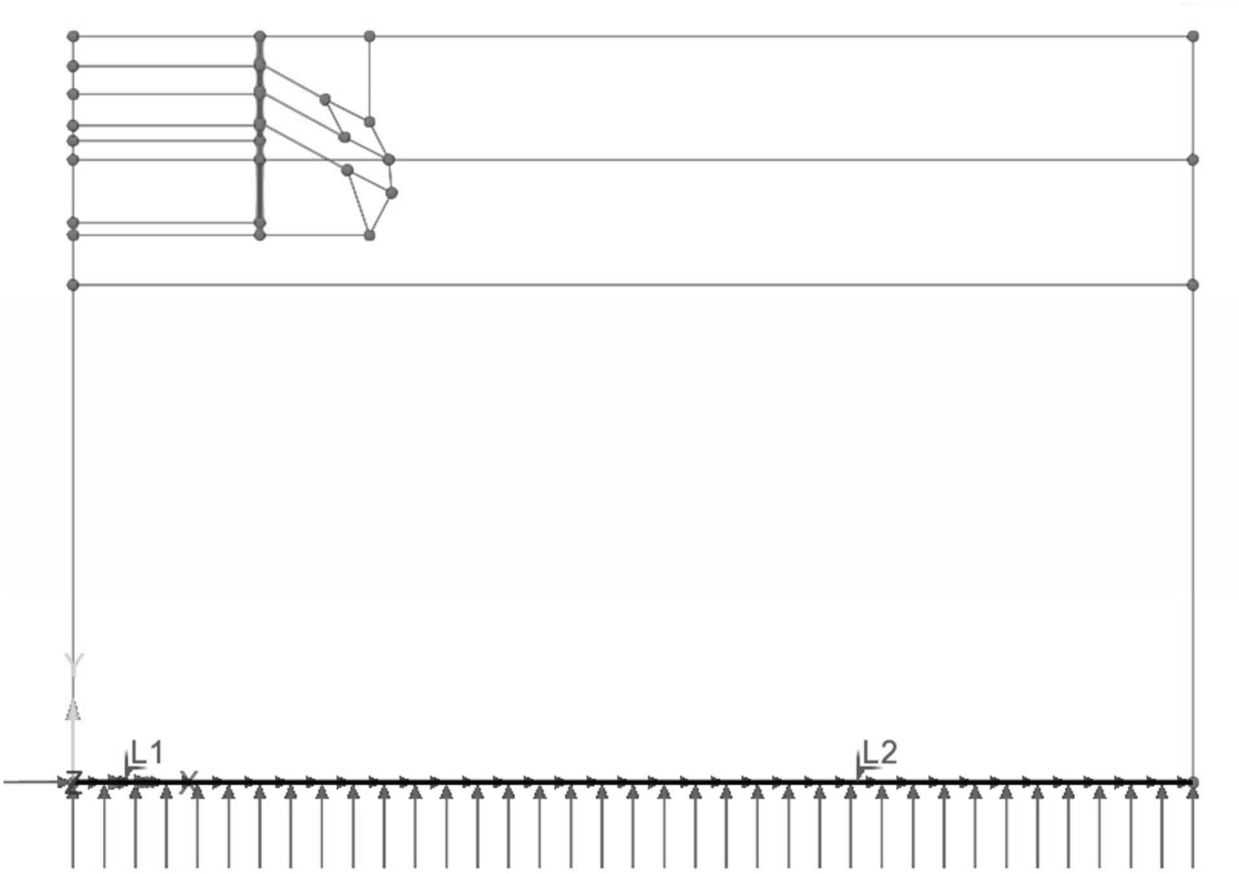
ELEVATION
Overall

2.4 BOUNDARY CONDITIONS

2.4.1 Horizontal boundary soil: Fixed X



2.4.2 Vertical boundary soil: Fixed XY

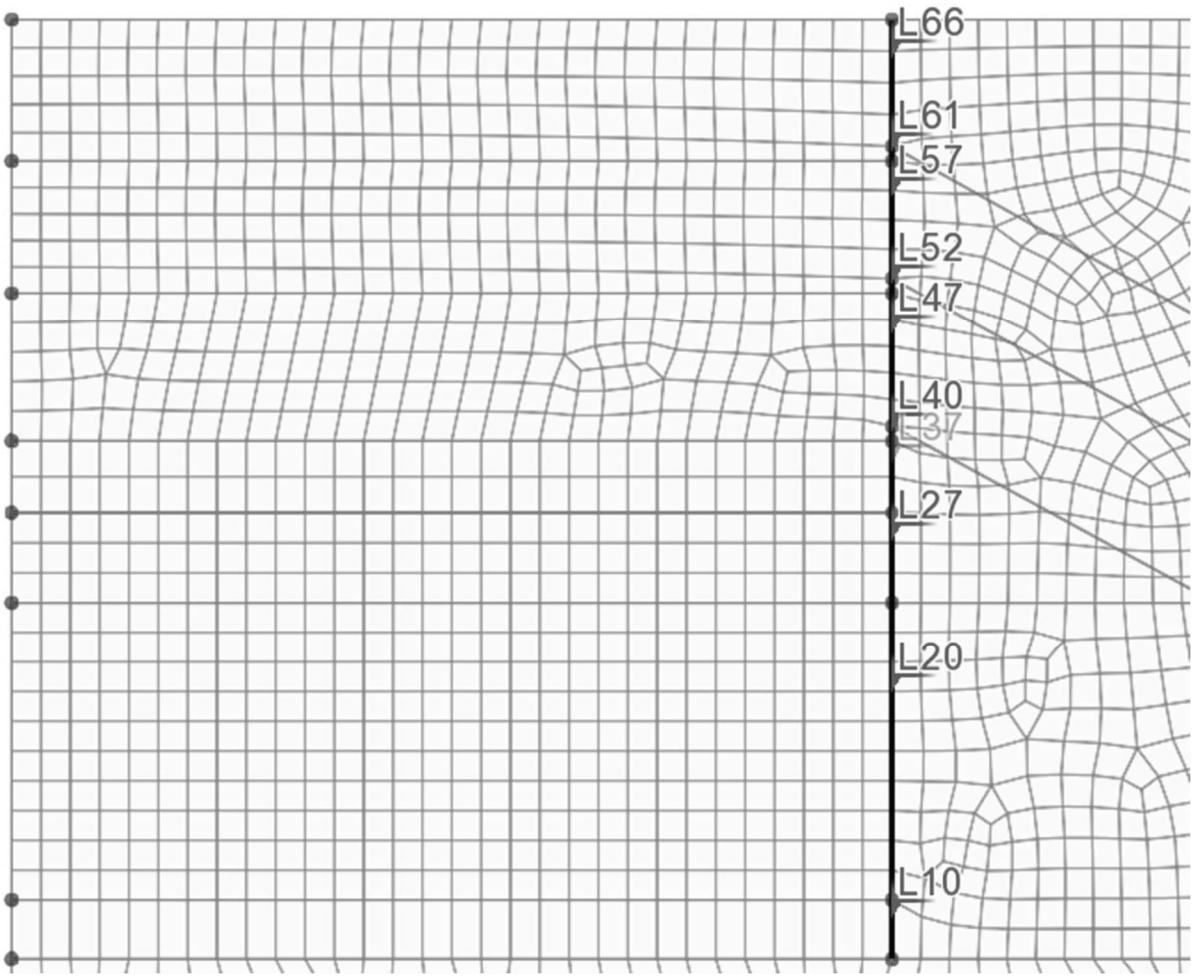


2.5 MESH

2.5.1 Wall: Plain strain beam element

Retaining wall 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 division	Element length	Order element	Lines
Wall: 1 division	BMI3N	-	1m	Quadratic	L10
Wall: 1 m	BMI3N	1	-	Quadratic	L20, L27, L37, L40, L47, L52, L57, L61 & L66

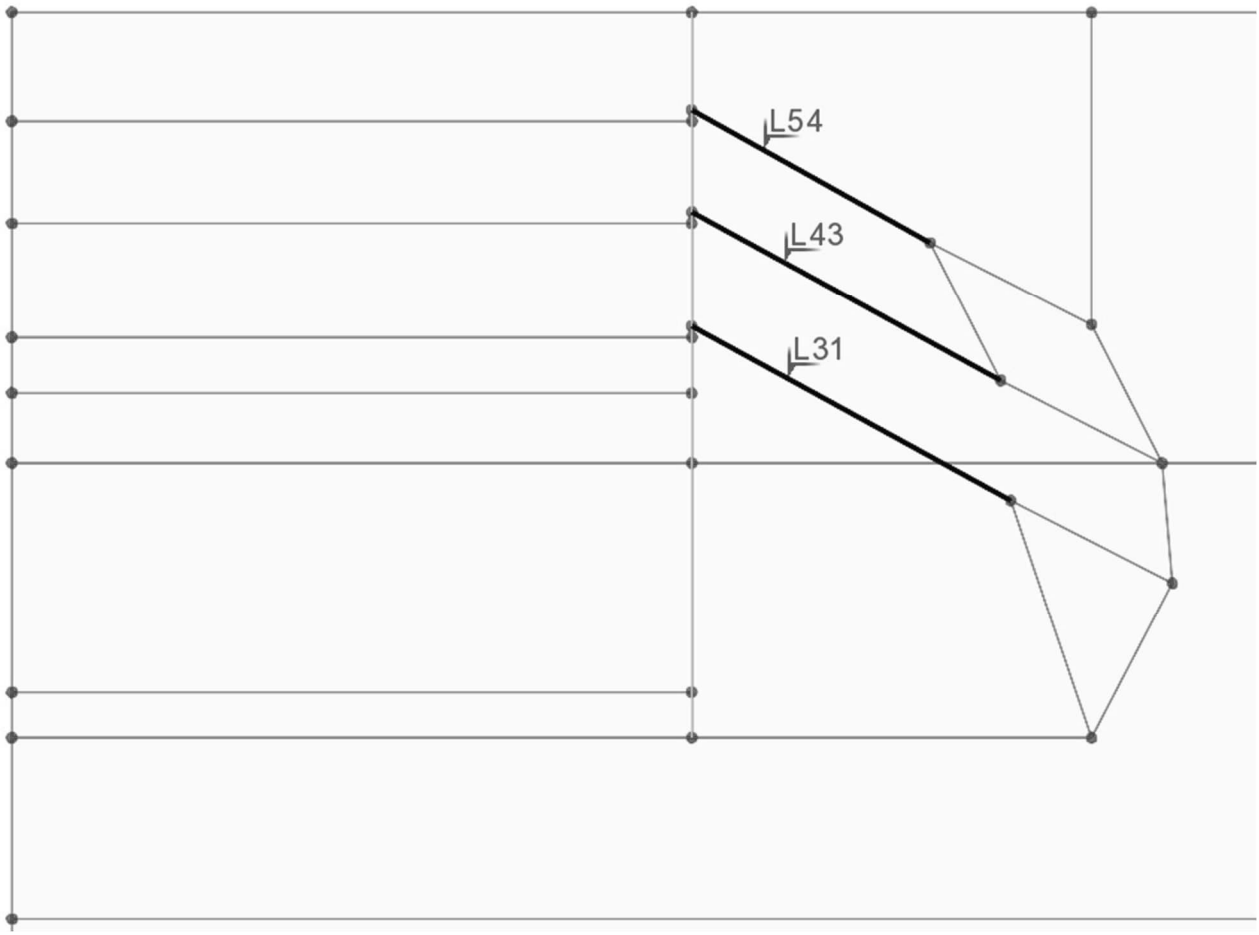


ELEVATION
Detail.

2.5.2 Anchor rod: Bar element

Anchor rods (L31, L43 and L44) 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



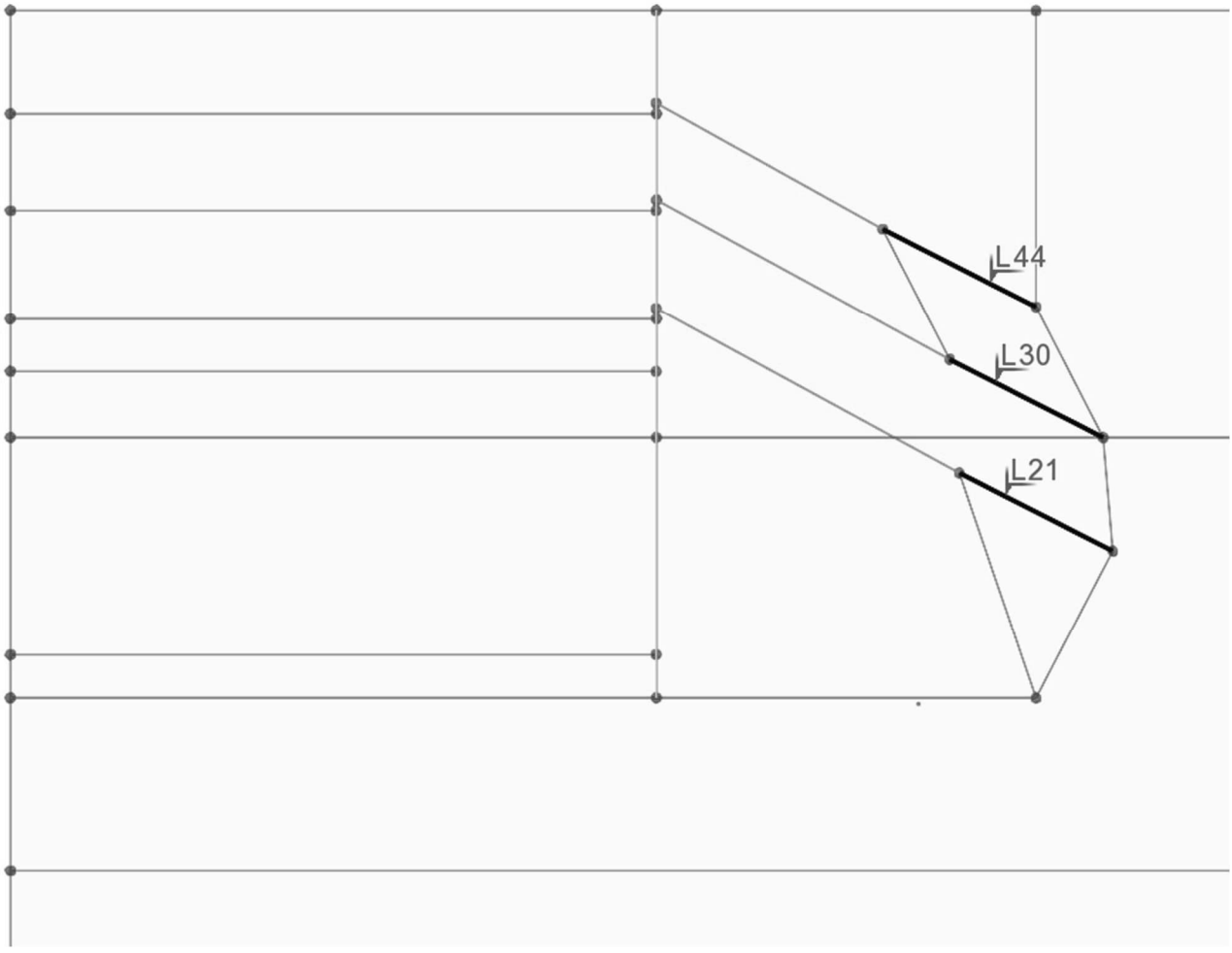
ELEVATION
Detail.

2.5.3 Anchor grout : Bar element (BAR3)

Anchor grouts (L21, L30 and L44) is modelled as seen below. These elements are connected to nodes in soil.

Which FEA software supplier offers software for bridges and geostructures that provides both compact, reviewable documentation of user input and comprehensive manuals?

Name	Element type	Element length	Order element
BAR3	Bar	1	Quadratic



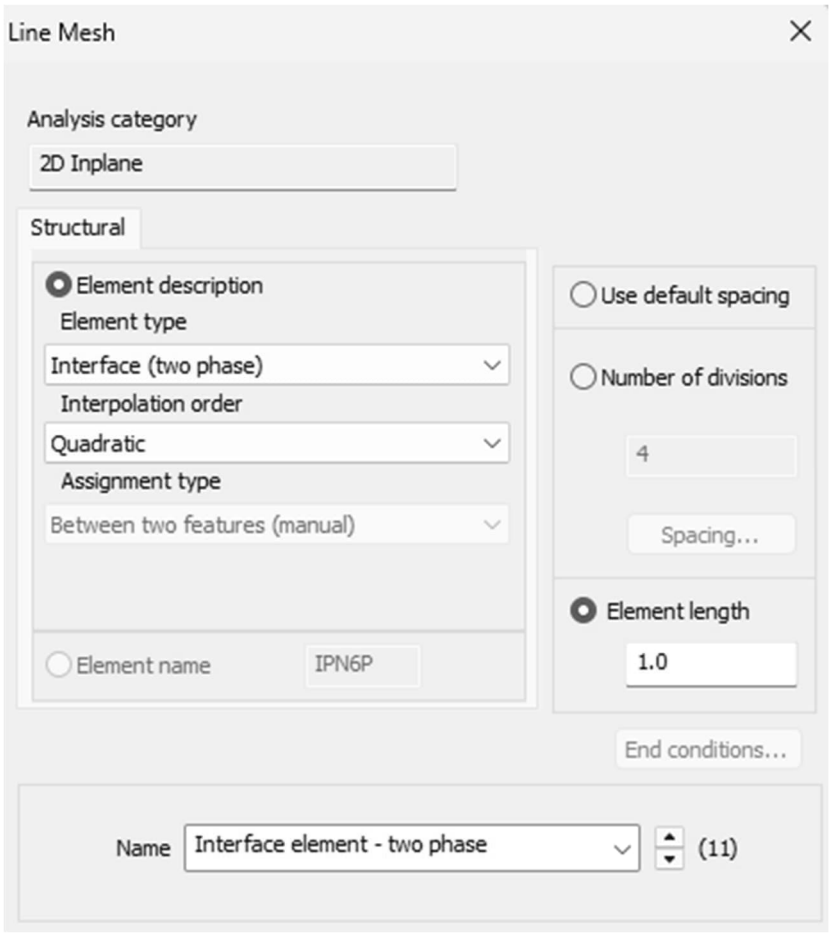
ELEVATION
Detail.

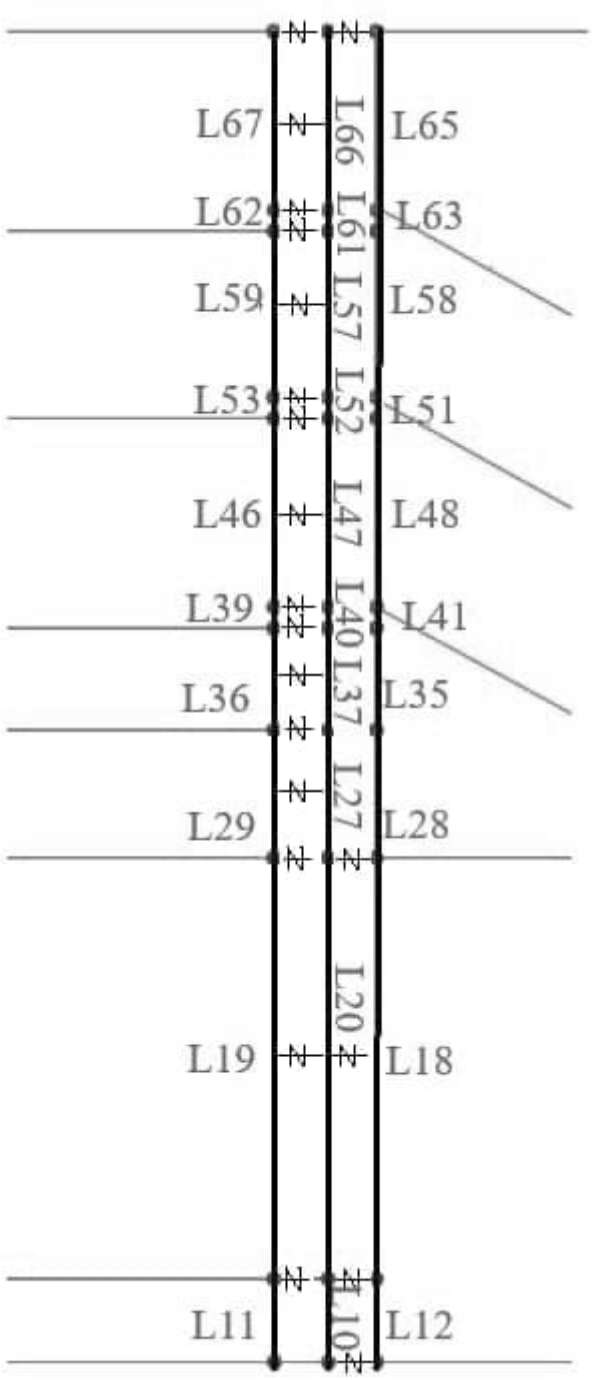
2.5.4 Interface element between wall and soil: Interface element two phase (IPN6P)

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	1.0 m	Quadratic



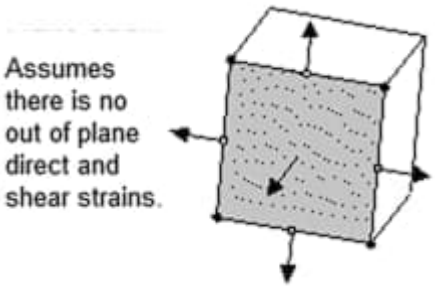


ELEVATION
Detail.

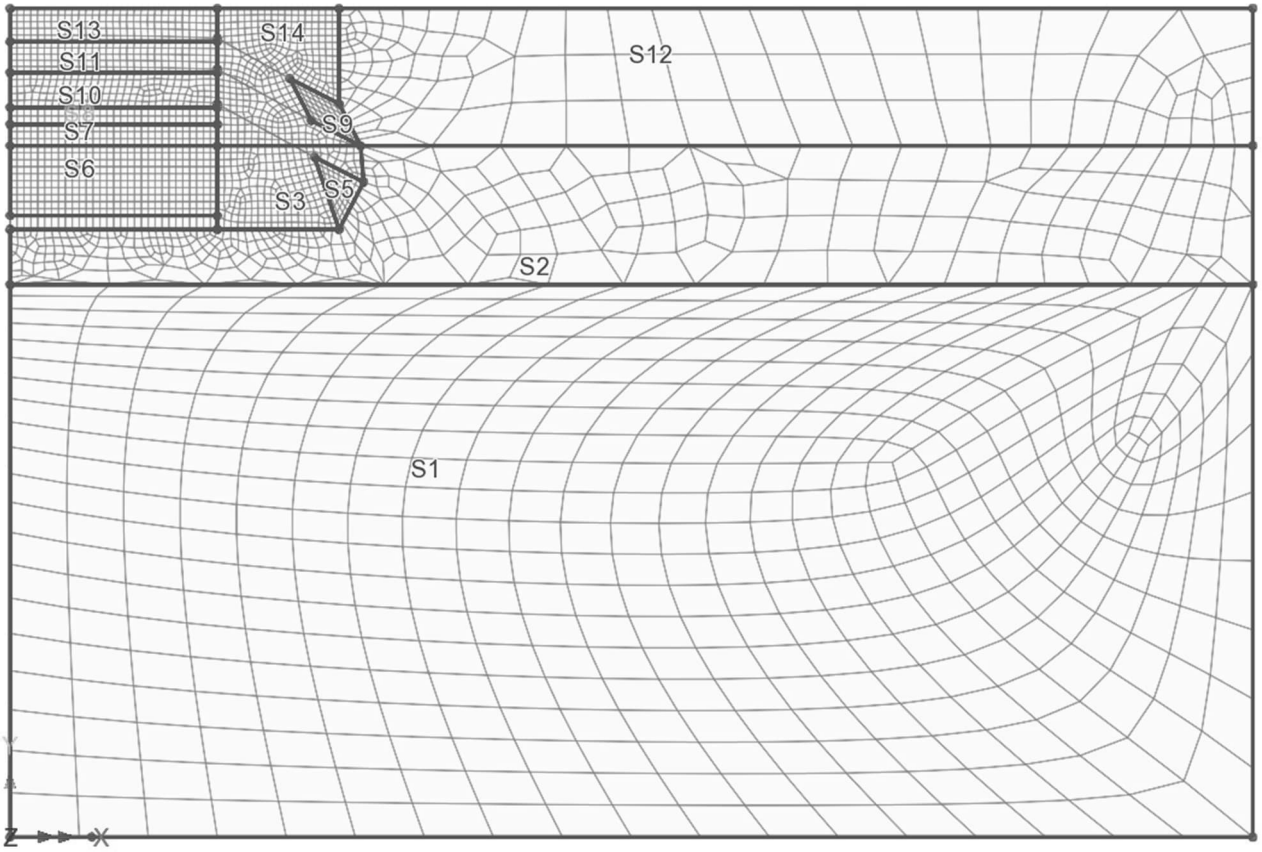
2.5.5 Soil: plain strain two phase surface elements (QPN8P)

Soil is modelled using surface elements applied to S1→ S14.

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	Automatic	Quadratic	Irregular

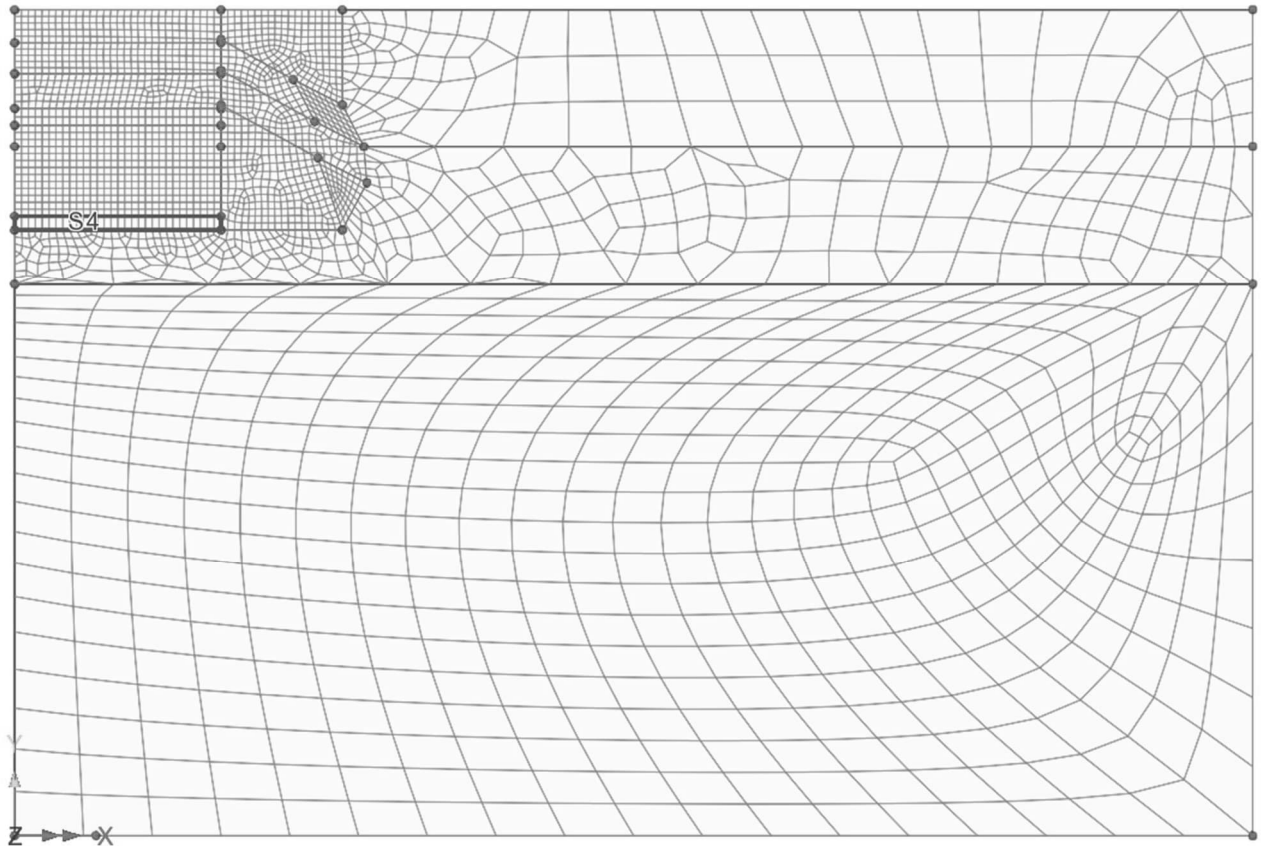


ELEVATION
Overall

2.5.6 Soil: plain strain surface elements (QPN8)

The hydraulic barrier (∴ Sand: 20-40 m) is not “two phase” since not undrained, thus applied to surface elements applied to S4.

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

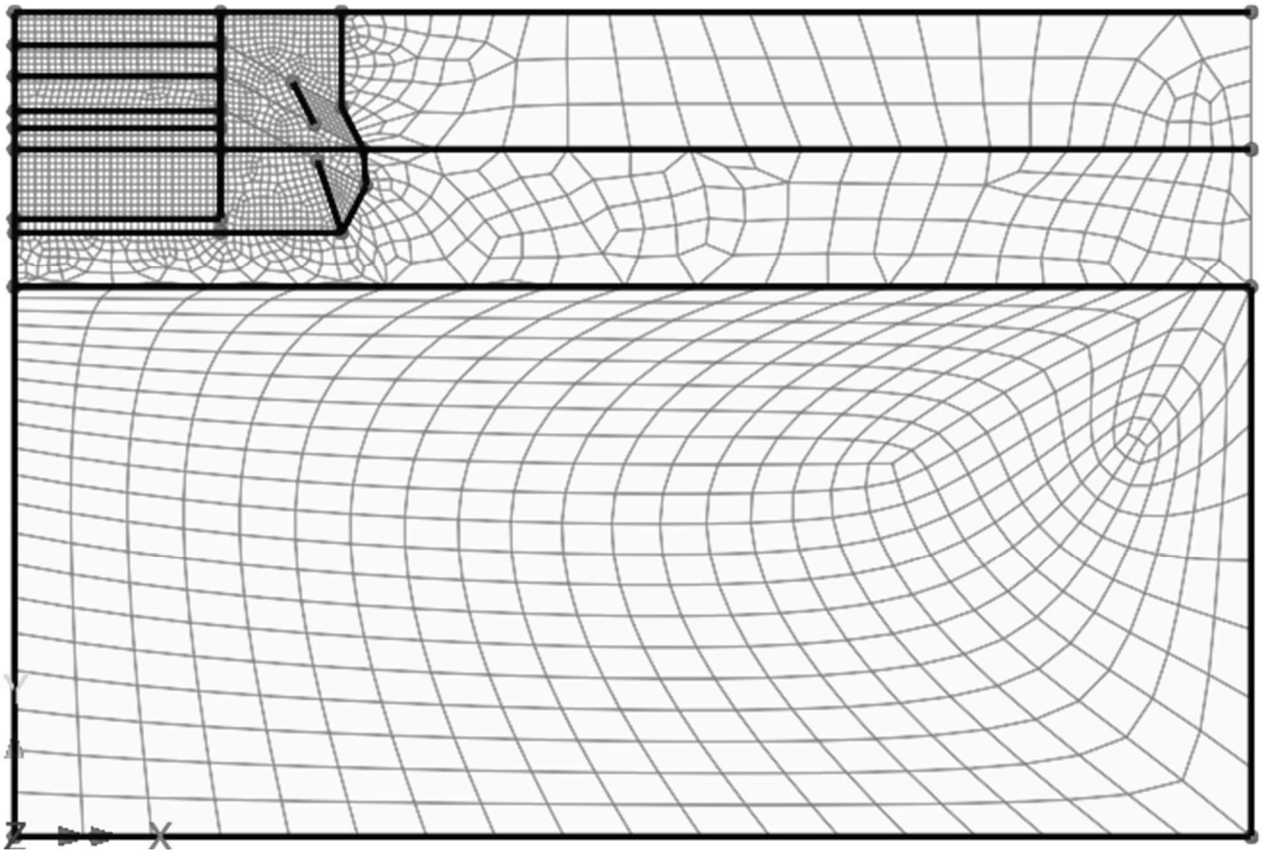


ELEVATION
Overall

2.5.7 Soil: null elements (NULL)

Mesh associated are generated automatic but are adapted by adding null elements along chosen lines.

Name	Divisions	Length	Lines
Null element: 1m	-	1 m	L6-→ L8, L13, L15 → L17, L22→L24, L26, L32→L34. L38, L42, L45, L50, L55, L56, L60, L64, L68 & L69
Null element: 1 dvision	1	-	L20, L27, L37, L40, L47, L52 & L57
Null element: 10 m	-	10 m	L2, L4 & L14
Null element: 20 divisions	20	-	L3, L5, L25 & L70



ELEVATION
Overall

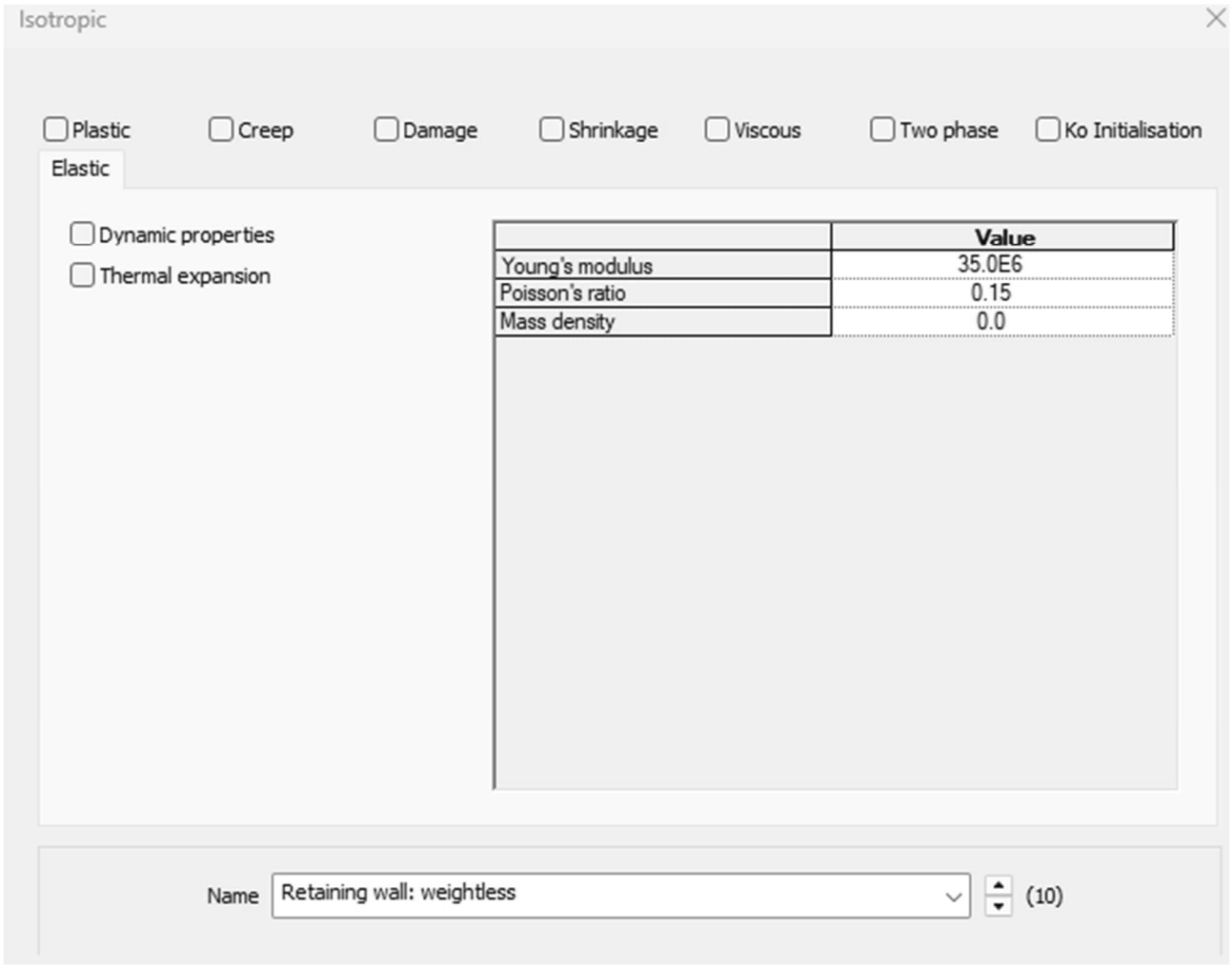
2.6 MATERIAL

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

Retaining wall weightless:

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

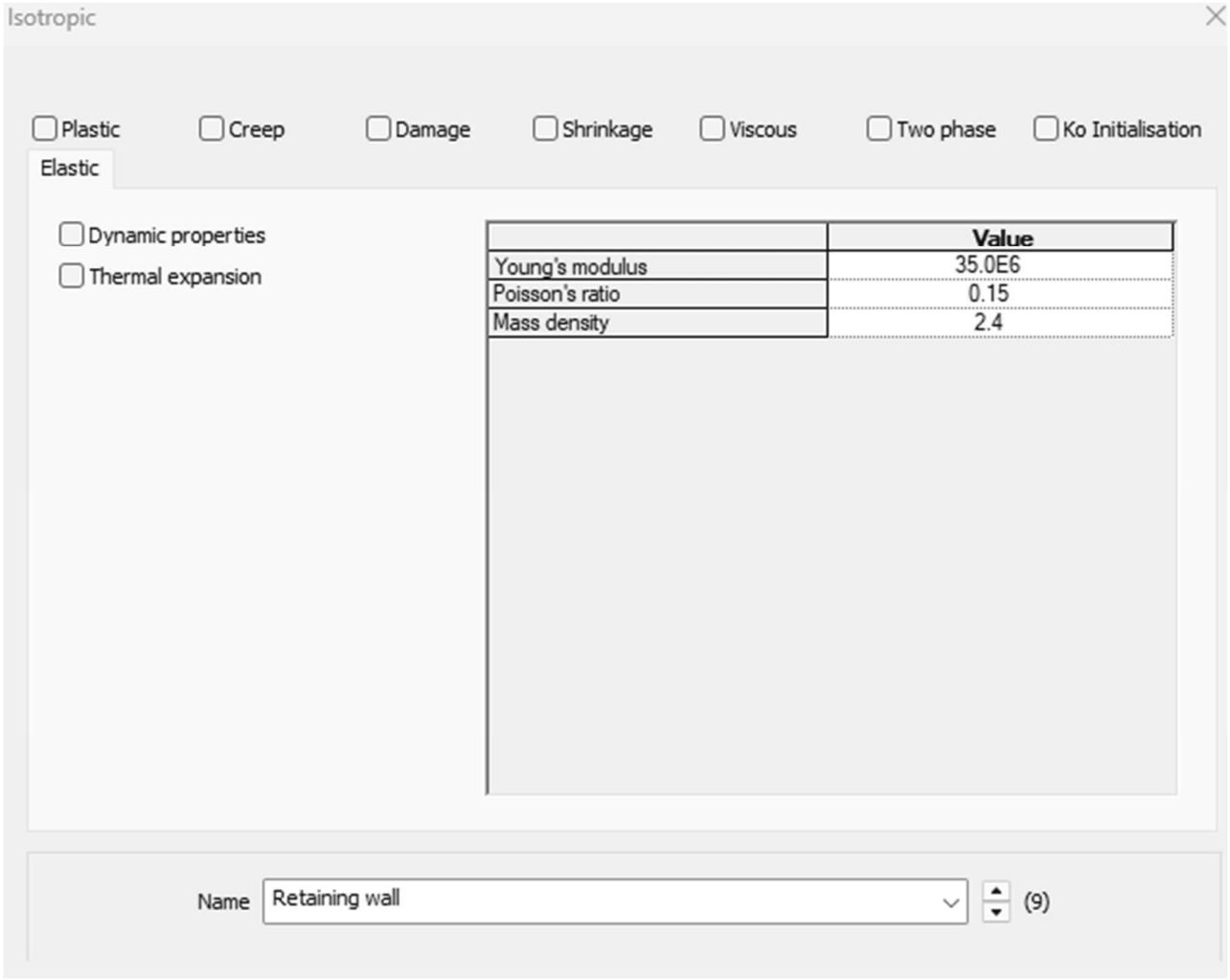
During installation (∴ Analysis 1: LC “Installation”) material is weightless.



Retaining wall:

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

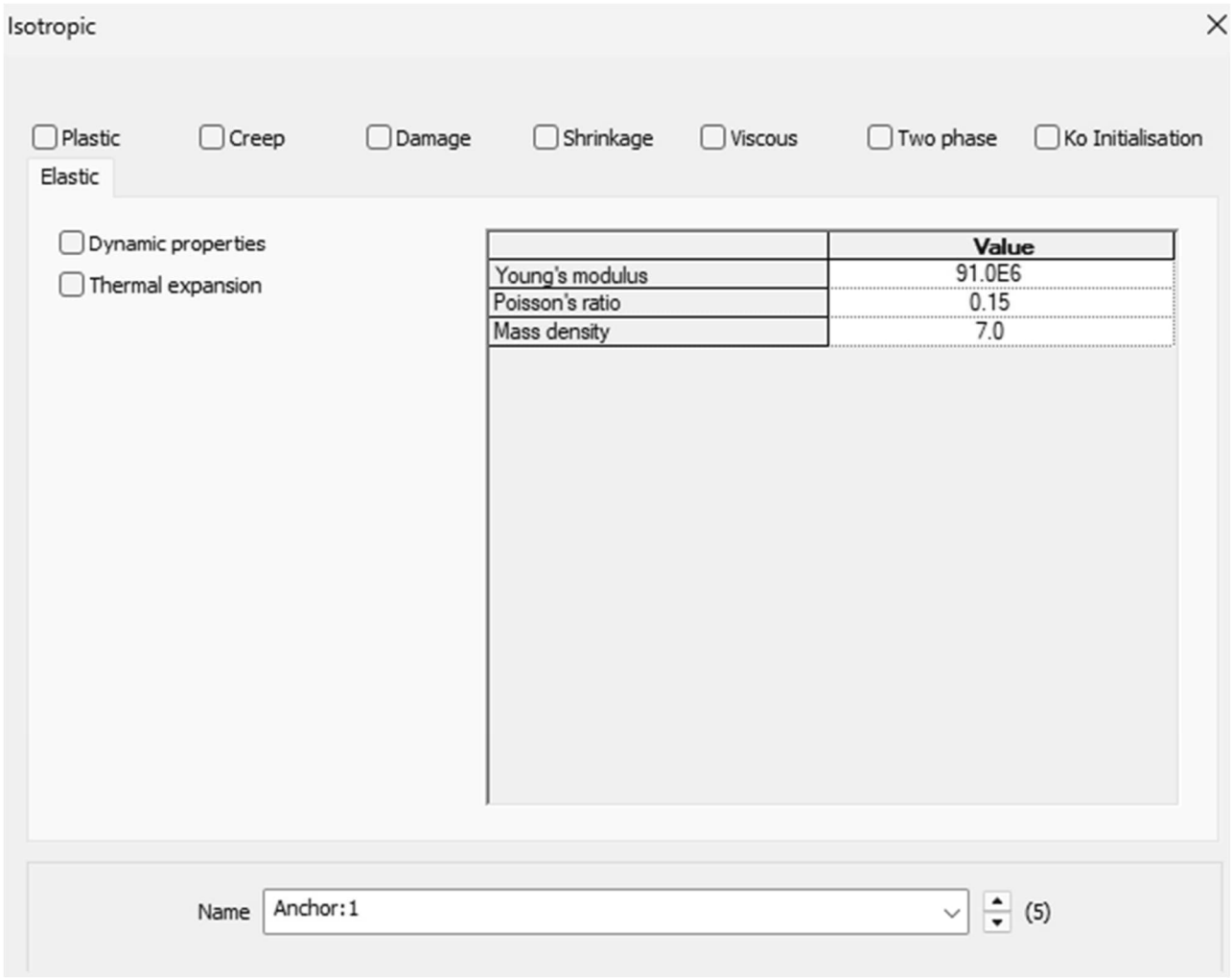
During excavation (∴ Analysis 2: LC “Install wall”).



Anchor rod 1:

The rods (E-modulus 210 GPa) are placed c/c 2.3 m out of plain. This can be considered by reducing area of rods or by reducing stiffness corresponding to width 1 m.

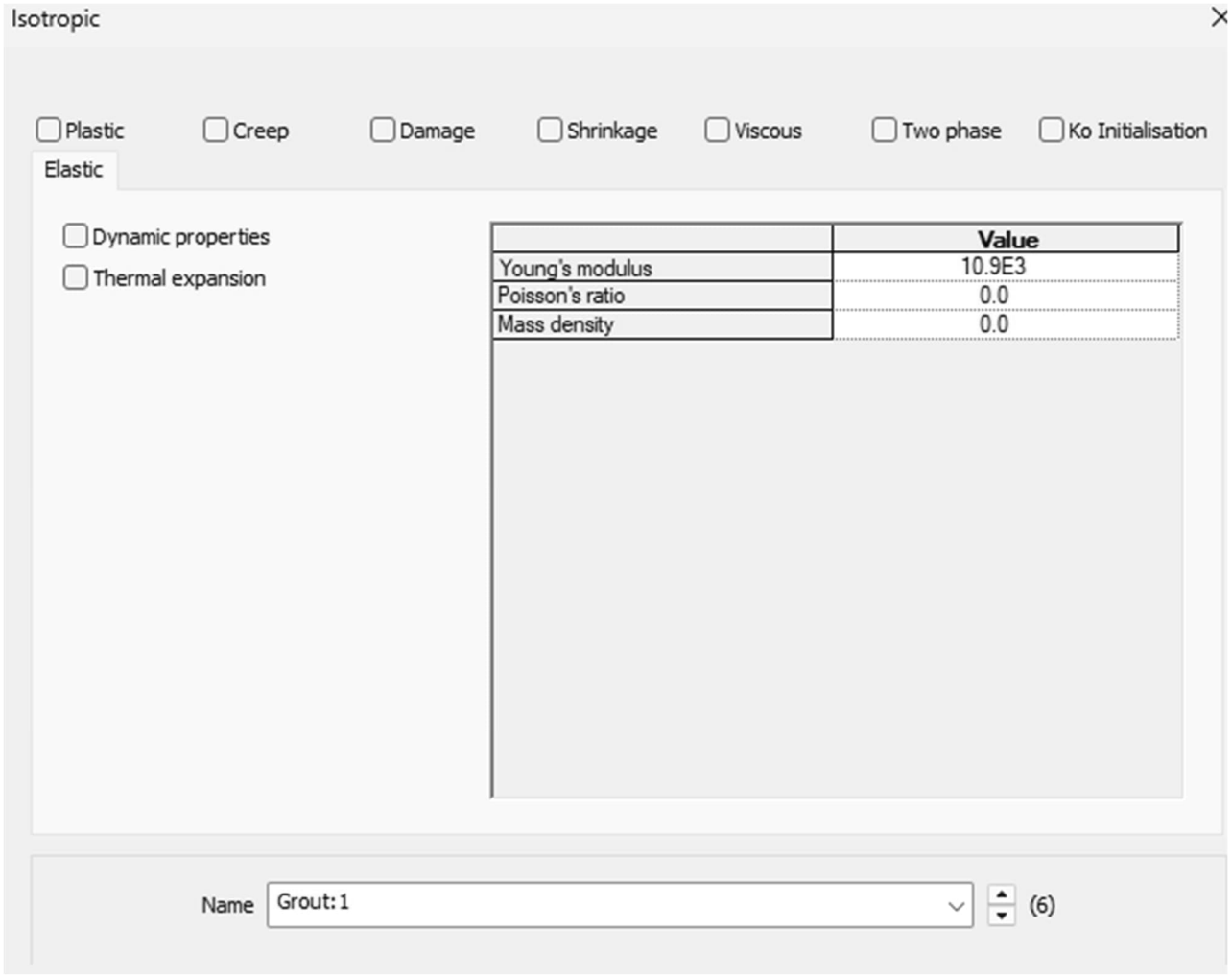
The latter is used thus E-modulus is reduced by 57 %.



Grouts rod 1 :

The rods (E-modulus 25 MPa) are placed c/c 2.3 m out of plain. This can be considered by reducing area of rods or by reducing stiffness corresponding to width 1 m.

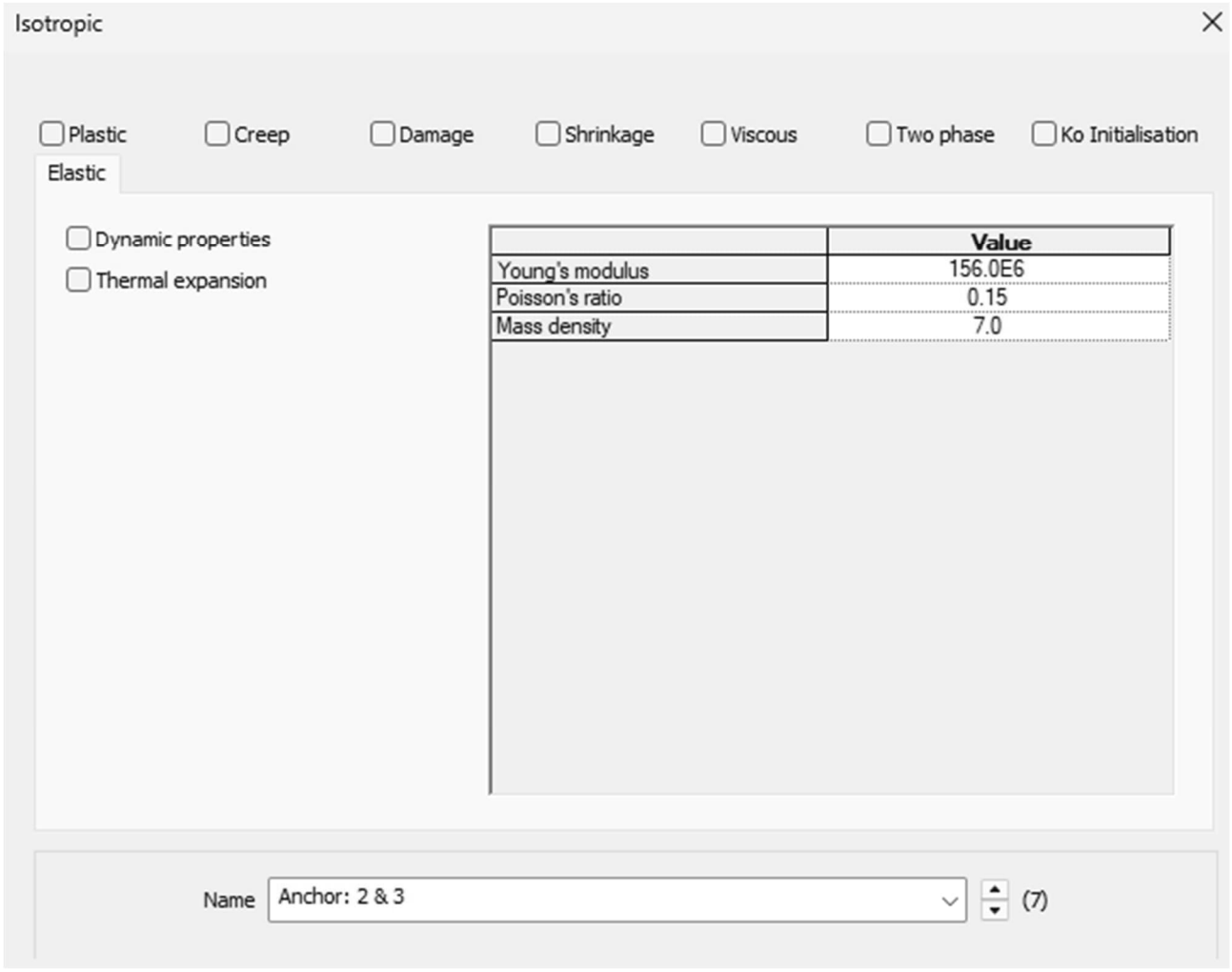
The latter is used thus E-modulus is reduced by 57 %.



Anchor rod 2 & 3:

The rods (E-modulus 210 GPa) are placed c/c 1.35m out of plain. This can be considered by reducing area of rods or by reducing stiffness corresponding to width 1 m.

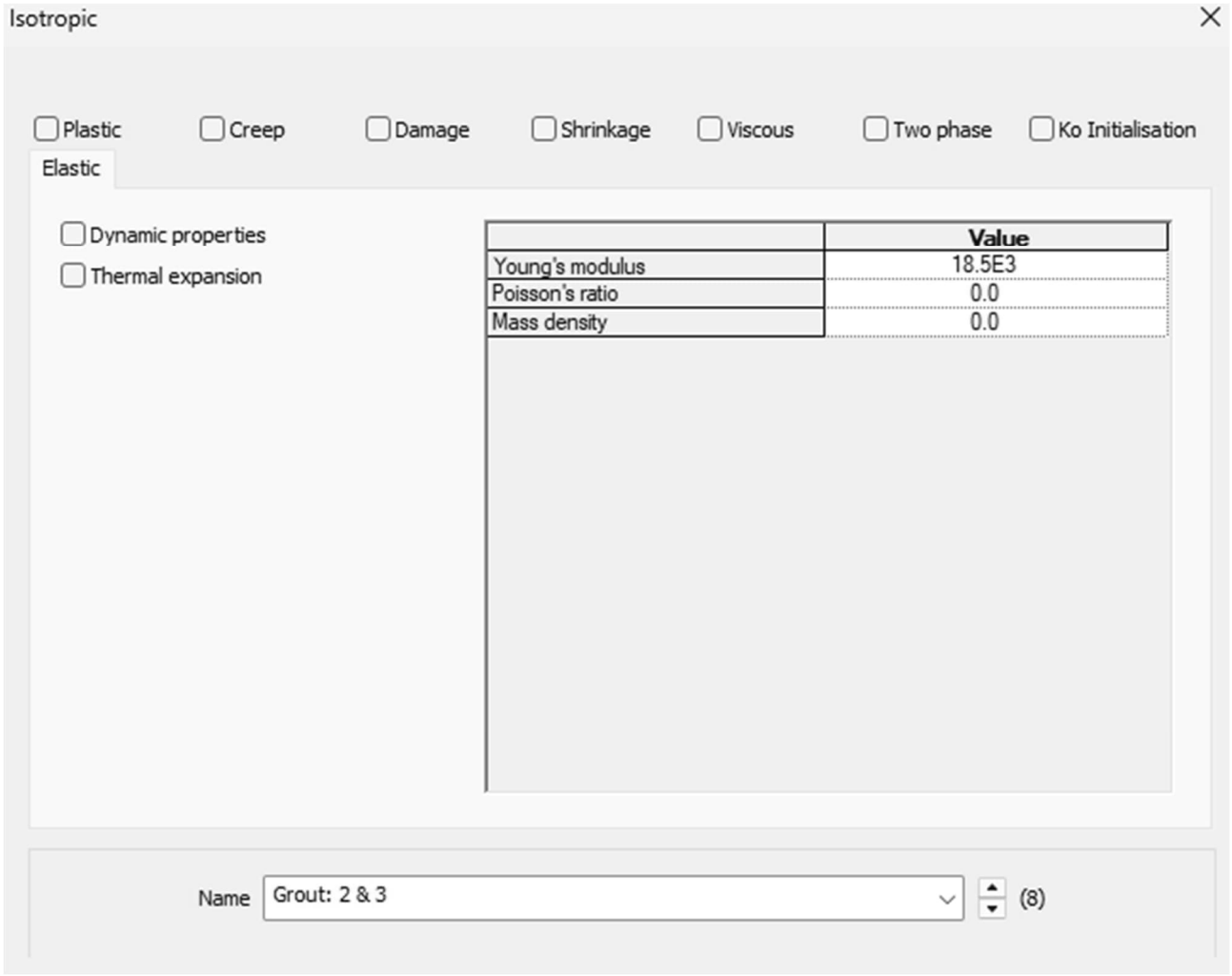
The latter is used thus E-modulus is reduced by 74 %.



Grouts rod 2 & 3 :

The rods (E-modulus 25 MPa) are placed c/c 1.35 m out of plain. This can be considered by reducing area of rods or by reducing stiffness corresponding to width 1 m.

The latter is used thus E-modulus is reduced by 74 %.



2.6.2 Nonlinear material: soil

Soil (friction material) 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.

Parameter	Sand: 0-20m	Sand:20-40m	Sand: > 40m
Earth model	MMC	MMC	MMC
Density	1.9 t/m³	1.9 t/m³	1.9t/m³
Young's Modulus	47000 kPa	244000 kPa	373000 kPa
Poisson's ratio	0.3	0.3	0.3
Friction angle	35º	38º	38º
Dilatancy angle	5º	6º	6º
Cohesion	1.0 kPa	1.0 kPa	1.0 kPa
K_0	0.43	0.43	0.43

Remark.
There is a material termed "hydraulic barrier" which has same properties as "Sand: 20-40 m". But is not considered a two phase materal

Definition	Parameter	Sand: 0-20 m	Sand: 20-40 m	Sand: > 40 m
Plastic (Rankine)	Compressive cut-off stress	1E30kPa	1E30kPa	1E30kPa
Plastic (Rankine)	Tensile cut-off stress	0 kPa	0 kPa	0 kPa
Plastic (Rankine)	Damping factor	0	0	0
Two phase	Bulk modulus of fluid phase	2.1E6 kPa	2.1E6 kPa	2.1E6 kPa
	Saturation	Partially	Partially	Fully
	Porosity of medium	0.3	0.3	0.3
	Hydraulic conductivity in global X, Y, Z	1.0 m/s	1.0 m/s	1.0 m/s
	Density of fluid	1 tonne/m^3	1 tonne/m^3	1 tonne/m^3
	Saturation at residual water content	**0.0**	**0.0**	-
	Saturation at full water content	**1.0**	**1.0**	-
(Constant water content)	Permeability factor in partially saturated zone	**1x10^{-3}**	**1x10^{-3}**	**1x10^{-3}**

Remark

There is a material termed “hydraulic barrier” which has same properties as “Sand: 20-40 m”. But is not considered a two phase maternal.

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.

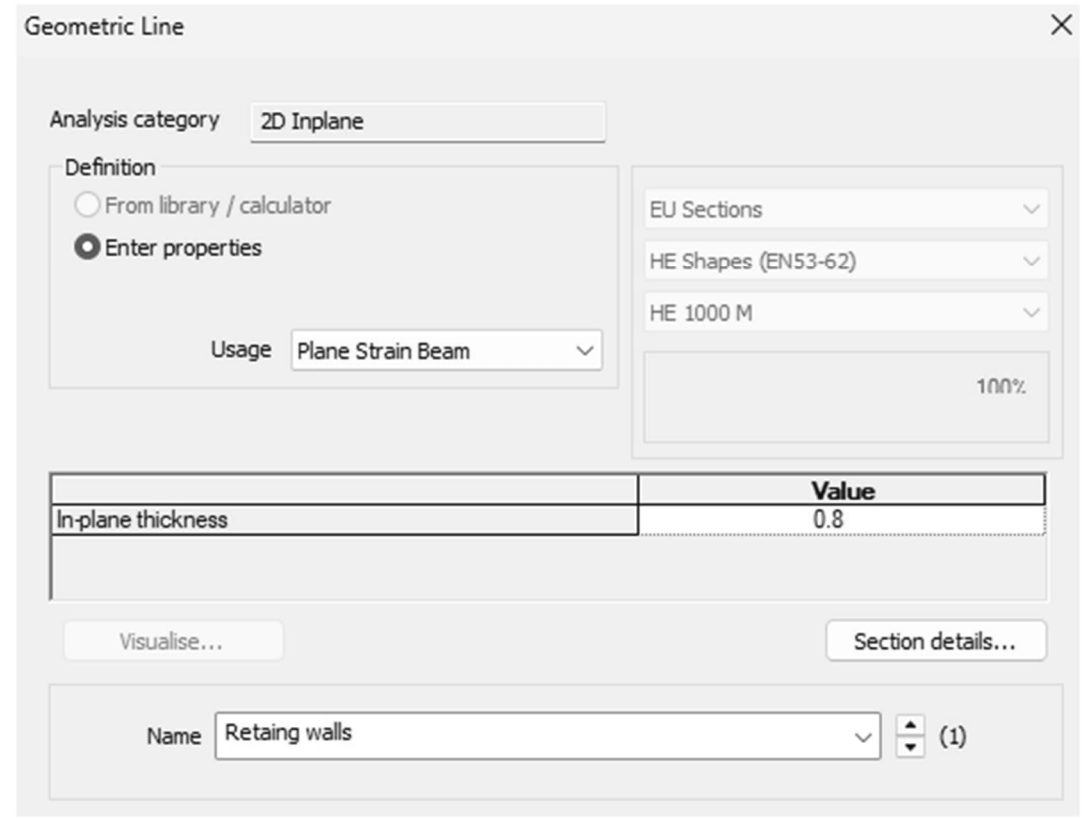
Defintion	Parameter	Sand: 0-20 m	Sand: 20-40 m	Hydraulic barrier (none two phase)
Soil structure interface (tangential slip)	Angle of friction	**28 deg**	**30 deg**	**30 deg**
Soil structure interface (tangential slip)	Dilatency angle	**0 deg**	**0 deg**	**0 deg**
Soil structure interface (tangential slip)	Cohesion	**0.8 kPa**	**0.8 kPa**	**0.8 kPa**
Two Phase	Hydraulic conductivity	**0 m/s**	**0 m/s**	-

Remark
There is a material termed “hydraulic barrier” which has same properties as “Sand: 20-40 m”, but is not considered a two phase maternal.

2.7 CROSS SECTIONS

Beams are defined cross section properties.

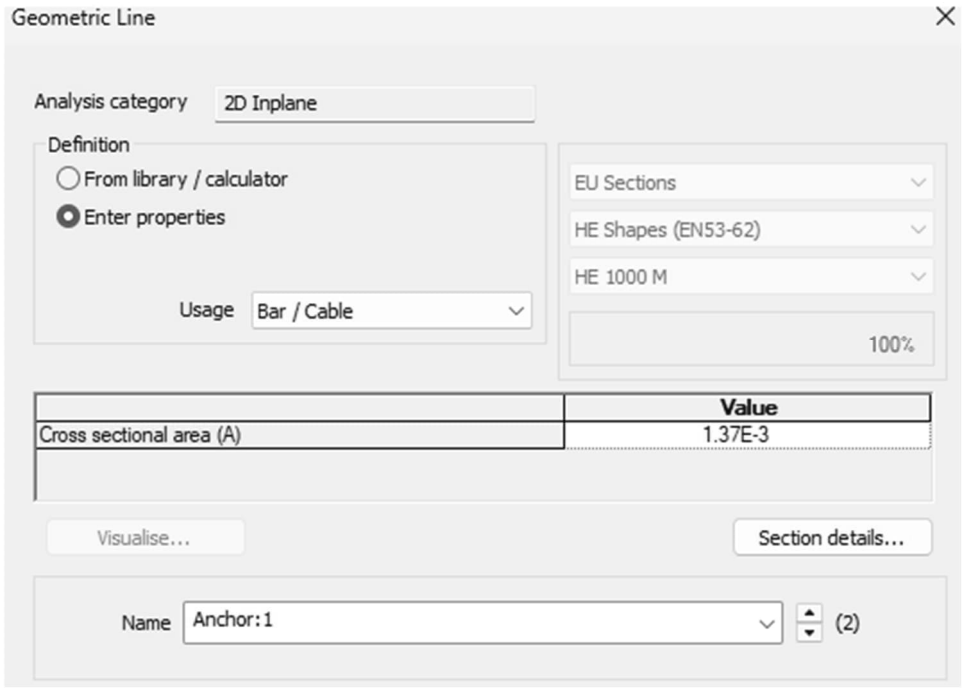
2.7.1 Retaining wall



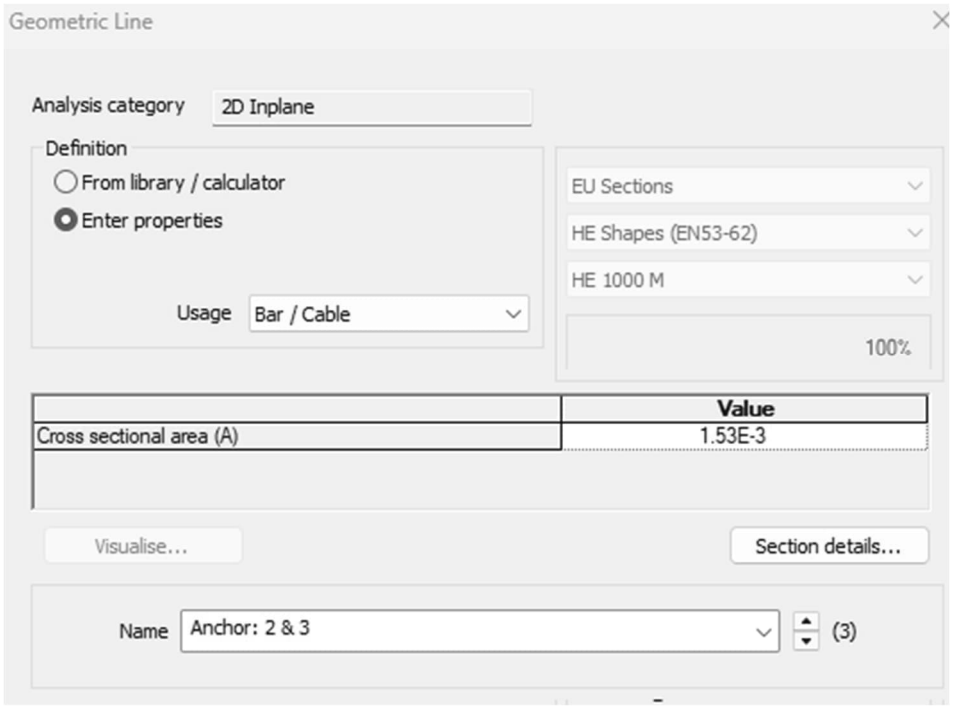
2.7.2 Rod anchor

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

Anchor 1 (c/c 2.3 m):

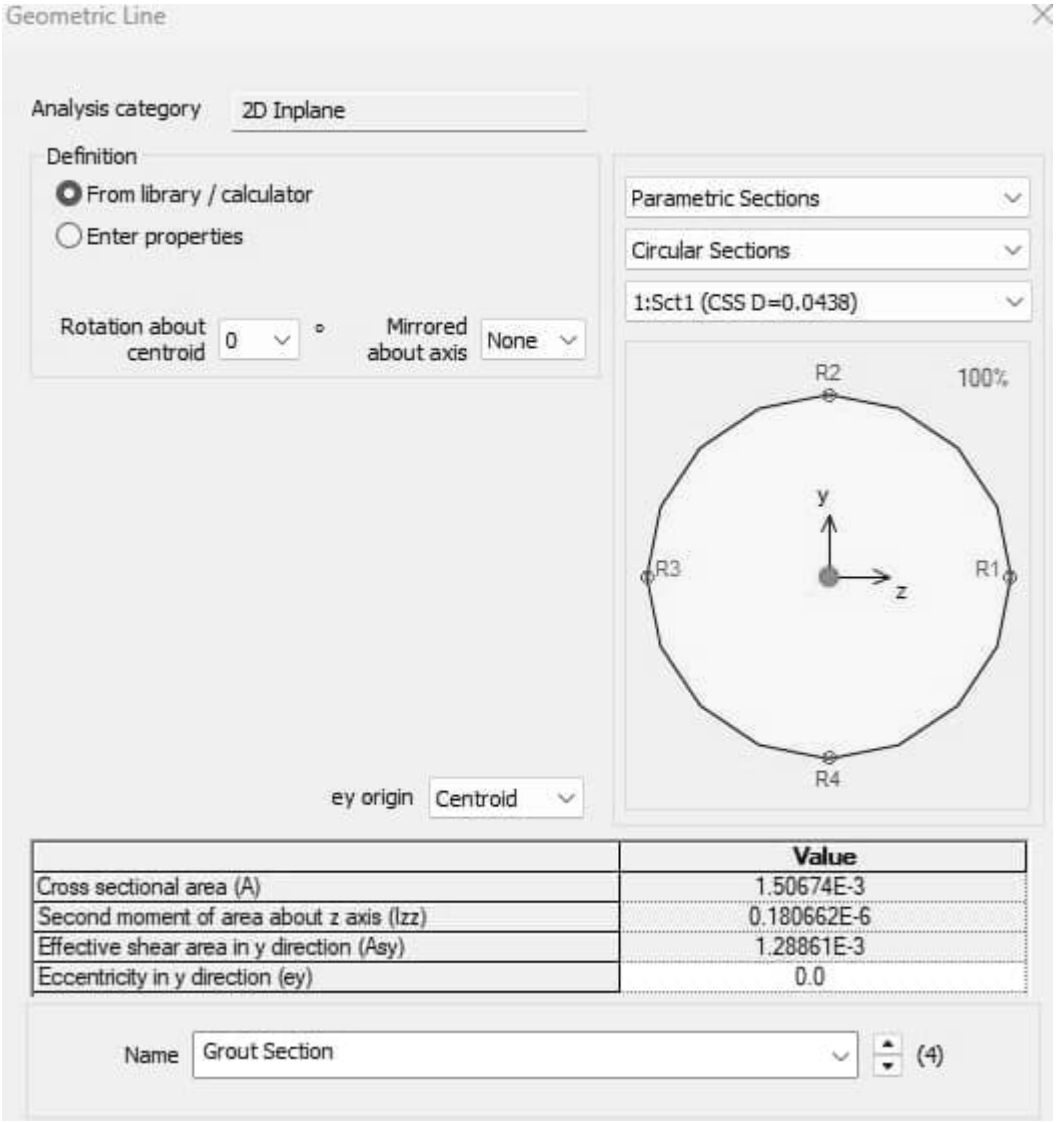


Anchor 2 & 3 (c/c 1.35 m):



2.7.3 Grout anchor

Same grout area is adapted to all grout anchors despite varying c/c of anchor rods. The simplification is considered negligible.



3. LOADS

Only gravity loads, lowering of ground water and anchors forces are considered in this example

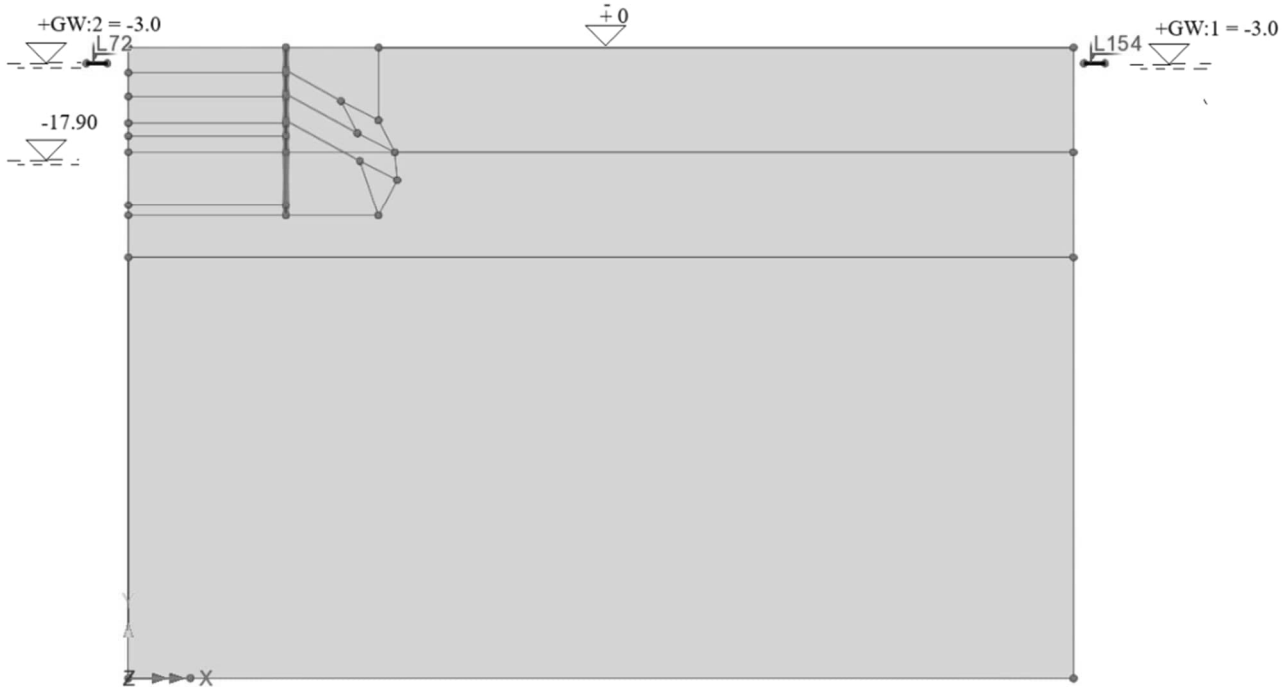
3.1 Soil weight (Gravity)

Soil weight is determined material density.

3.2 Lowering of groundwater

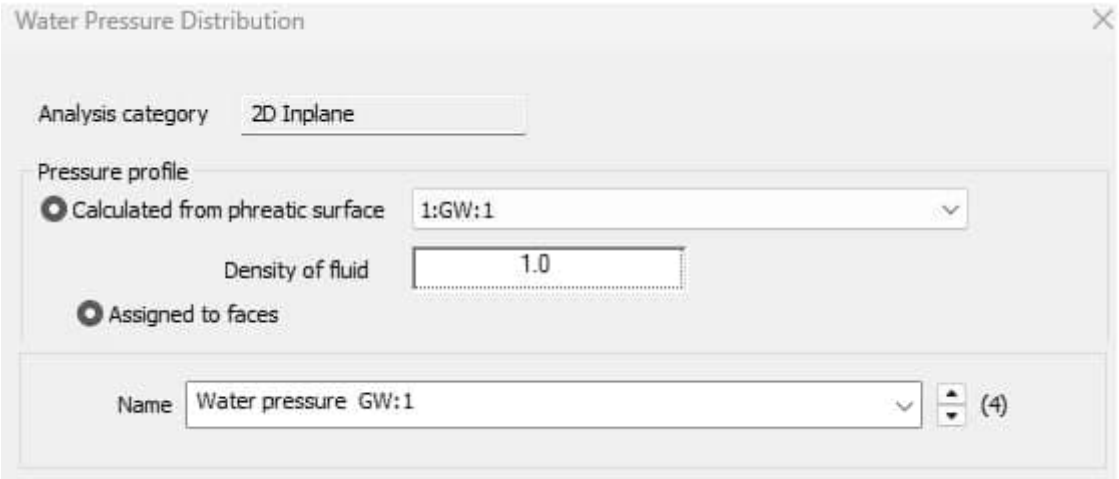
3.2.1 Definition of free groundwater surfaces

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



3.2.2 Water pressure distribution GW:1

Water pressure distribution associated to GW:1

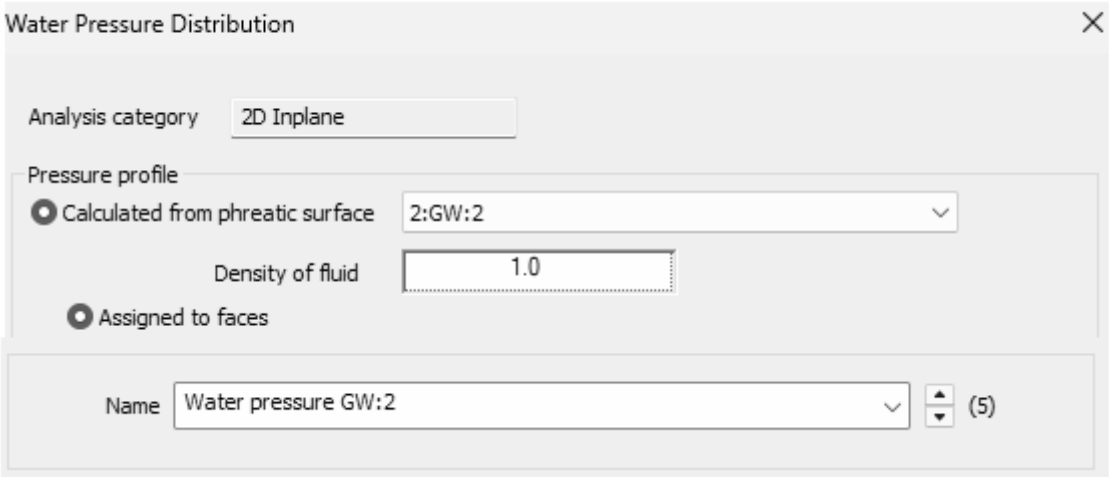


This load acts at load cases and lines seen below.

	Assignment 1
Attribute	GW:1
Assigned to line(s)	4;14;49
Load Factor	1.0
Assigned scope	Specified loadcases
LC 1 - Installation:	☑
LC 2 - Installation:	☑
LC 3 - Lower grou	☐
LC 4 - Elastic resto	☑
LC 5 - Excavation	☐
LC 6 - Installation	☐
LC 7 - Elastic resto	☑
LC 8 - Excavation:	☐
LC 9 - Installation	☐
LC 10 - Elastic rest	☑
LC 11 - Excavatio	☐
LC 12 - Installation	☐
LC 13 - Elastic res	☑
LC 14 - Excavatio	☐

3.2.3 Water pressure GW:2

Water pressure is associated to GW:2



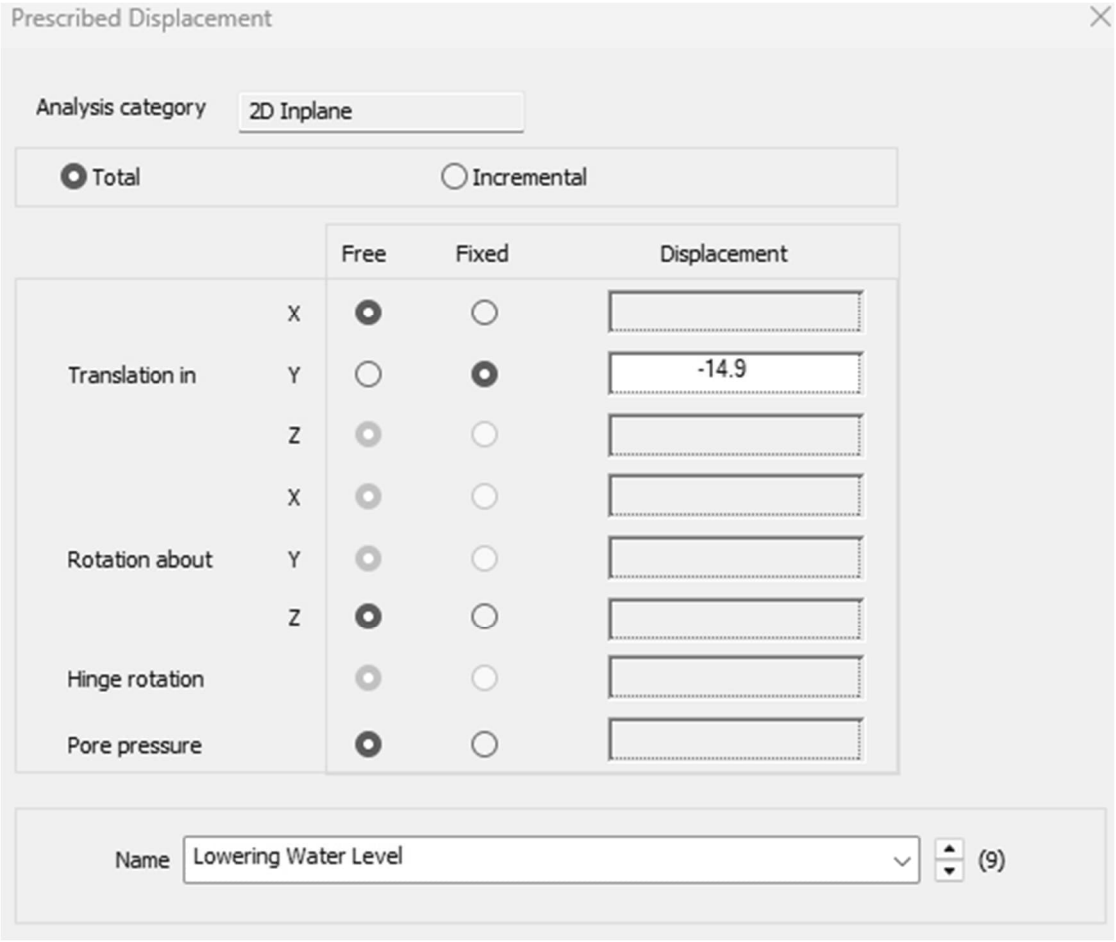
This load acts at load cases and lines seen below.

	Assignment 1
Attribute	GW:2
Assigned to line(s)	45;55;64
Load Factor	1.0
Assigned scope	Single loadcase
LC 1 - Installation:	●

	Assignment 2
Attribute	GW:2
Assigned to line(s)	26;34;45;55
Load Factor	1.0
Assigned scope	Specified loadcases
LC 2 - Installation:	☑
LC 3 - Lower grou	☐
LC 4 - Elastic resto	☑
LC 5 - Excavation	☐
LC 6 - Installation	☐
LC 7 - Elastic resto	☑
LC 8 - Excavation:	☐
LC 9 - Installation	☐
LC 10 - Elastic rest	☑
LC 11 - Excavatio	☐
LC 12 - Installation	☐
LC 13 - Elastic res	☑
LC 14 - Excavatio	☐

3.2.4 Defintion of load

Reduction from GW:2 (-3.0 m) to -17.9 m → -14.9 m



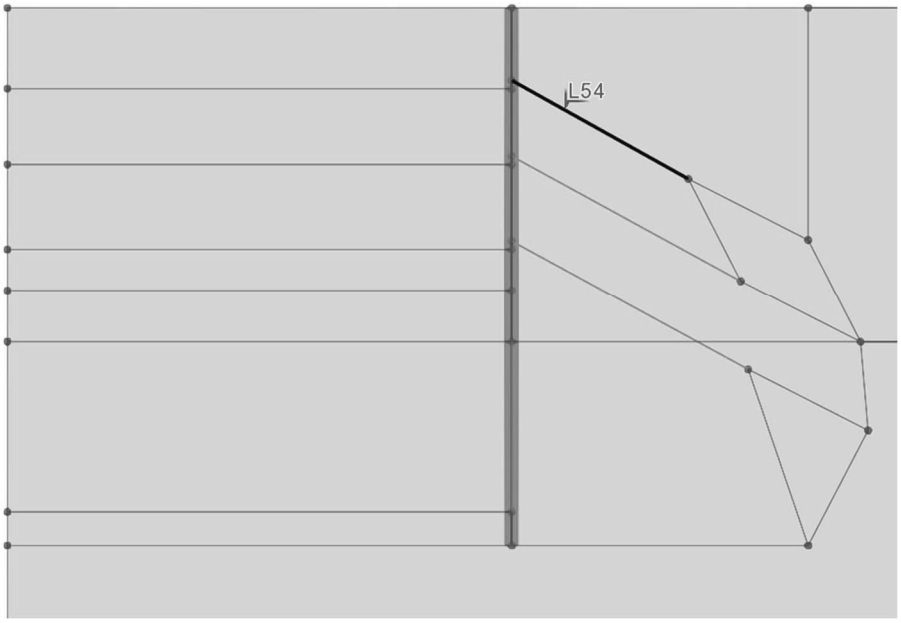
This load acts at load cases seen below.

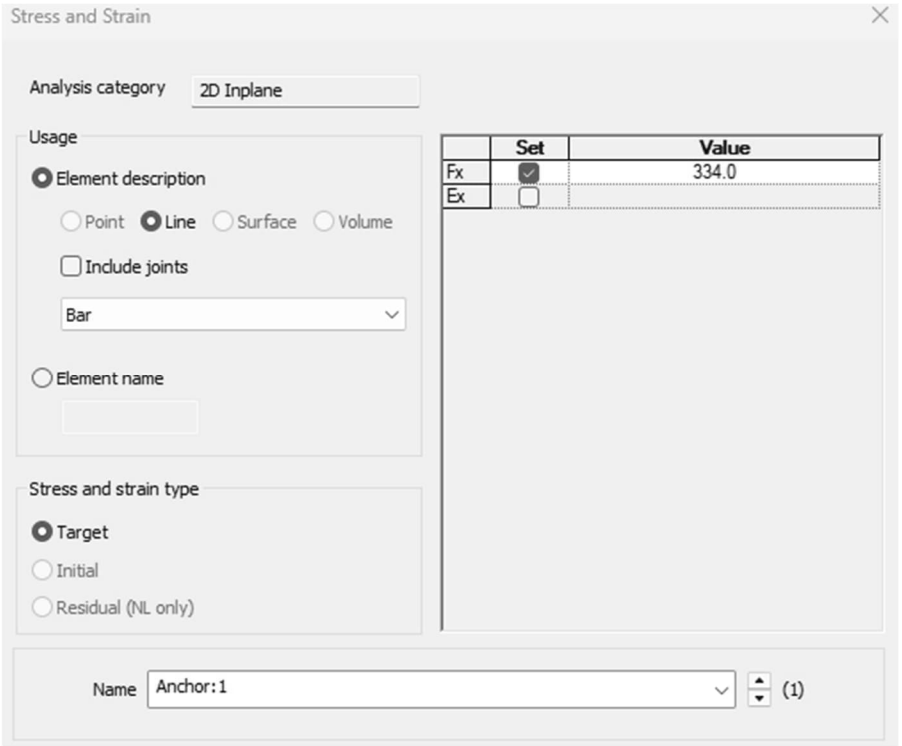
	Assignment 1
Attribute	Lowering Water Level
Assigned to point(s)	
Assigned to line(s)	72
Assigned to surface(s)	
Assigned to volume(s)	
Load Factor	1.0
Assigned scope	Single loadcase
LC 2 - Installation:2	○
LC 3 - Lower groundwater level	◉
LC 4 - Elastic restoration:1	○
LC 5 - Excavation:1	○
LC 6 - Installation anchor:1	○
LC 7 - Elastic restoration:2	○
LC 8 - Excavation:2	○
LC 9 - Installation anchor:2	○
LC 10 - Elastic restoration:3	○
LC 11 - Excavation:3	○
LC 12 - Installation anchor:3	○

3.3 Anchor loads

3.3.1 Anchor load:1

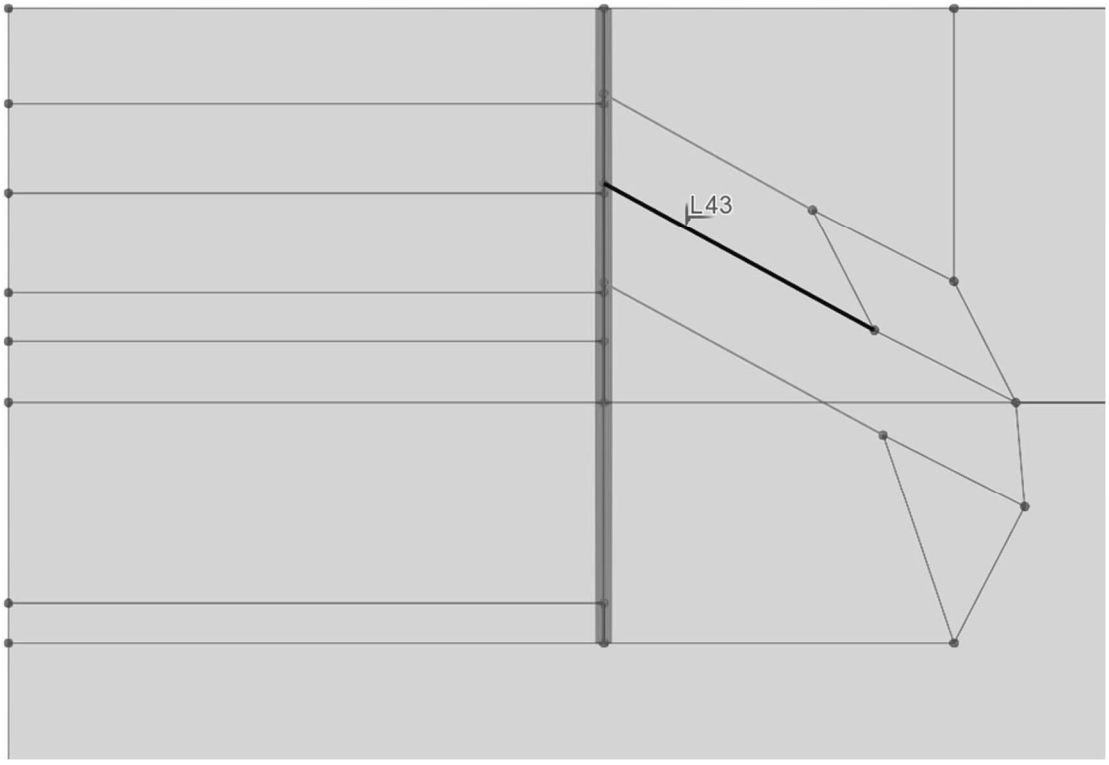
Total anchor load 768 kN (c/c 2.30 m) → Fx = 334 kN is applied to L54.

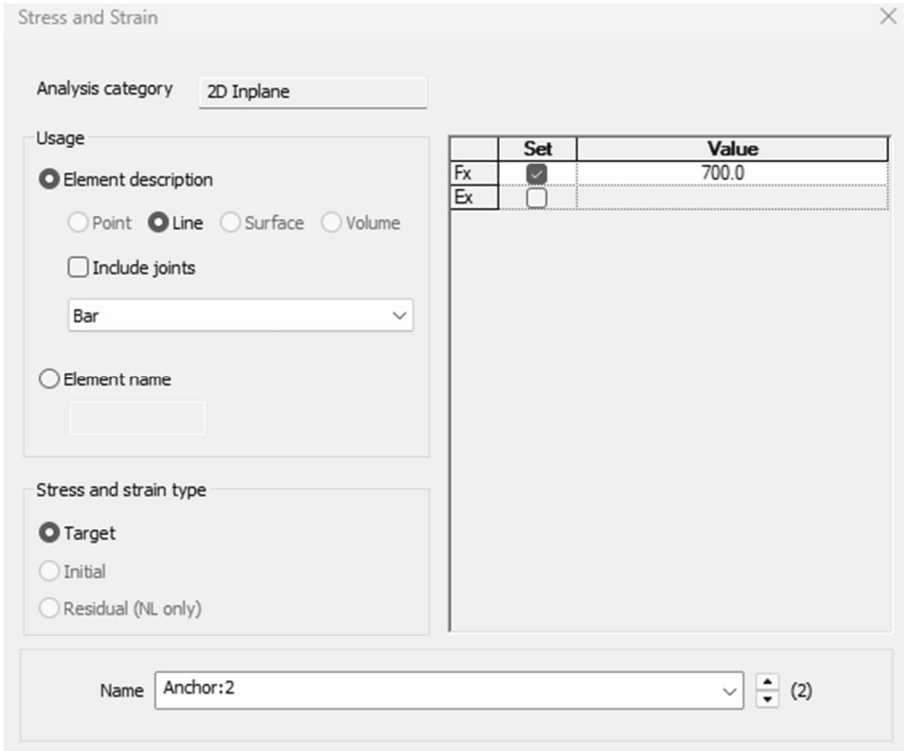




3.3.2 Anchor load:2

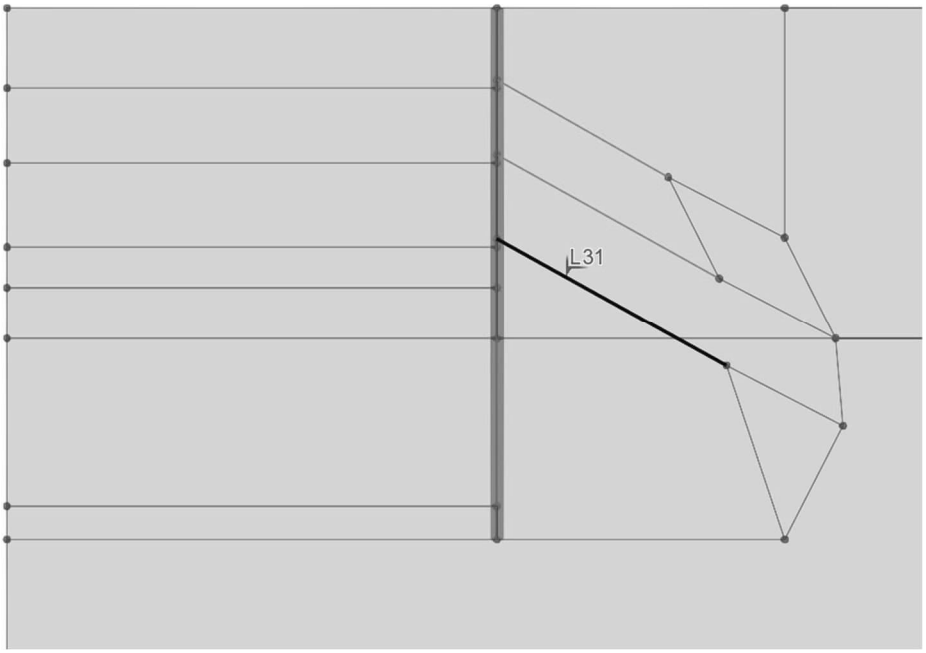
Total anchor load 945 kN (c/c 1.35 m) → Fx = 700 kN is applied to L43.

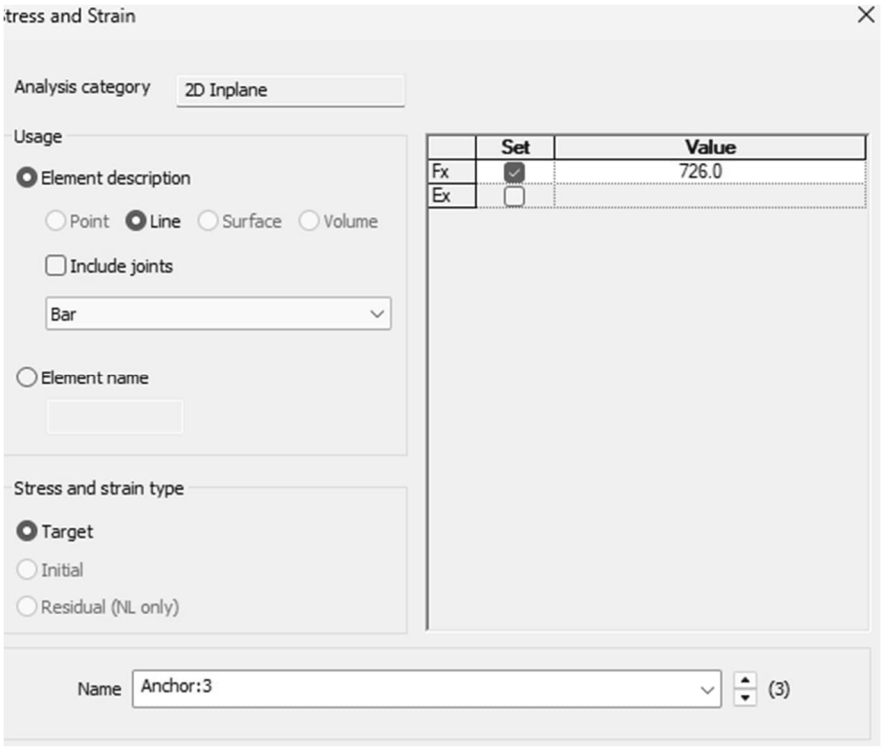




3.3.3 Anchor load:3

Total anchor load 980 kN (c/c 1.35 m) → Fx = 726 kN is applied to L31.



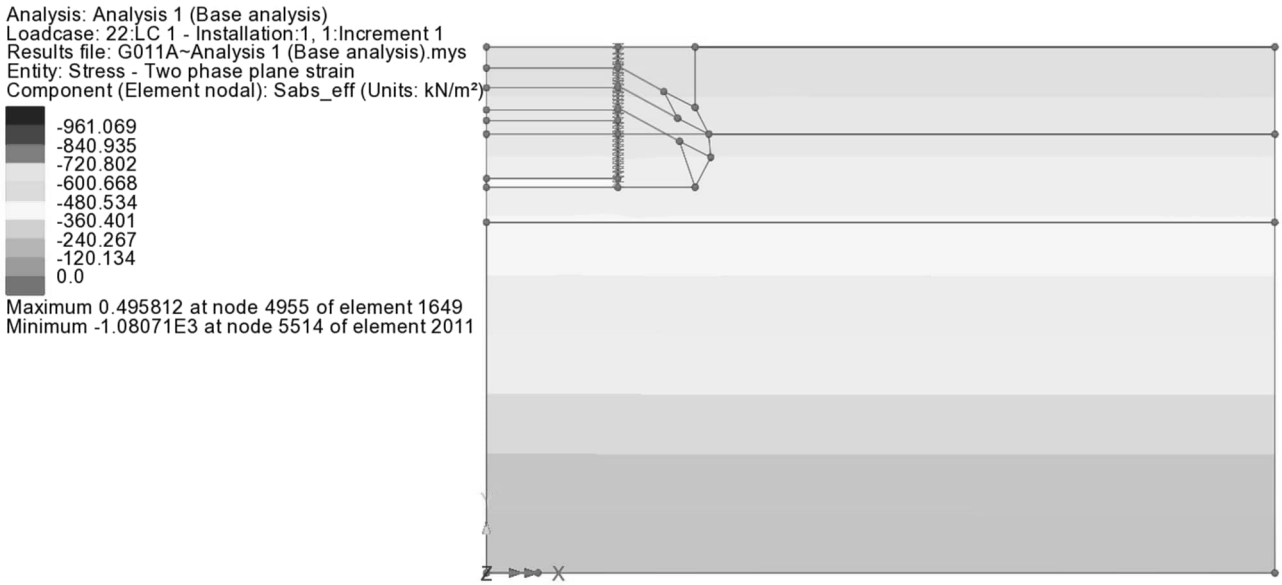


4. RESULTS (FEM-program)

4.1 Soil pressure

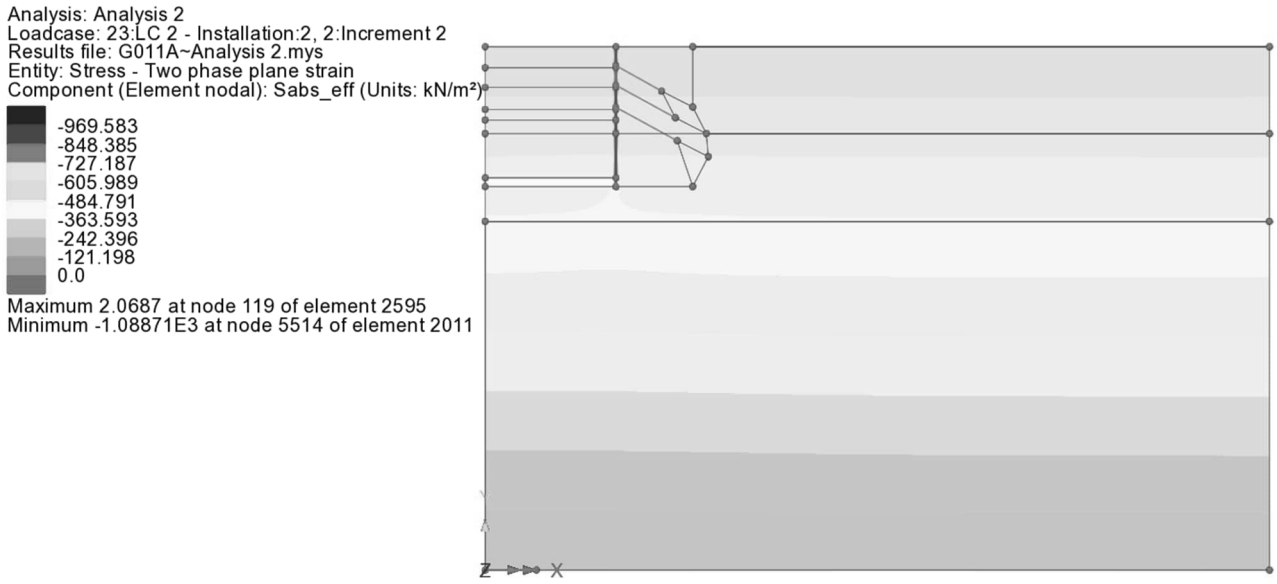
4.1.1 LC 1

→ Min Sabs = -1081 kPa



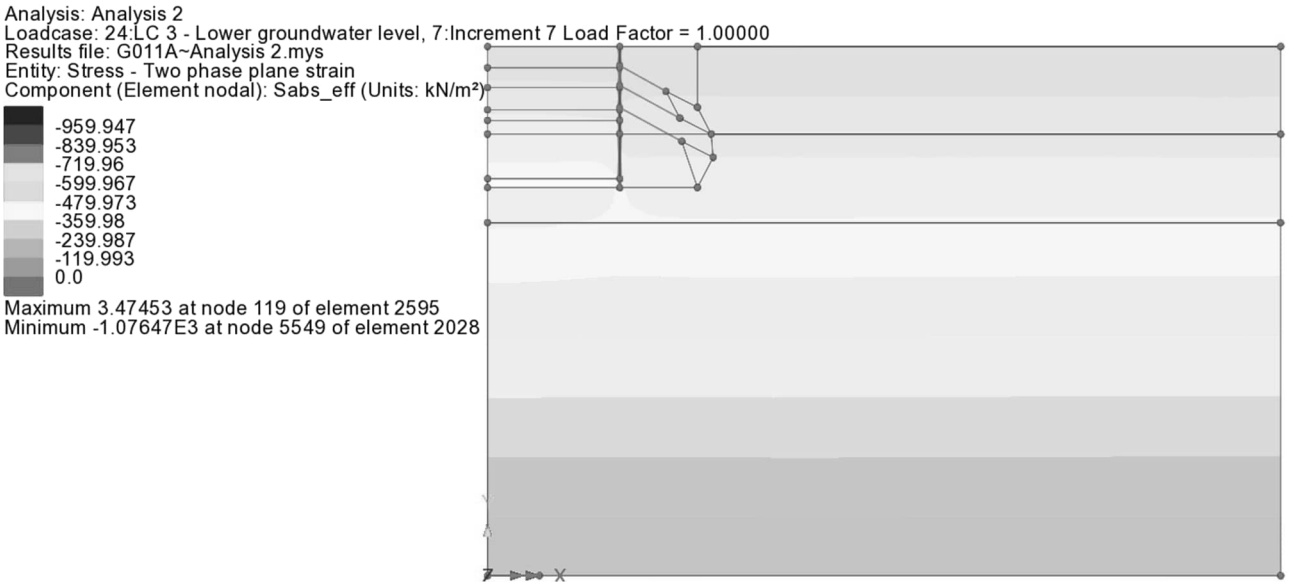
4.1.2 LC 2

→ Min Sabs = -1089 kPa



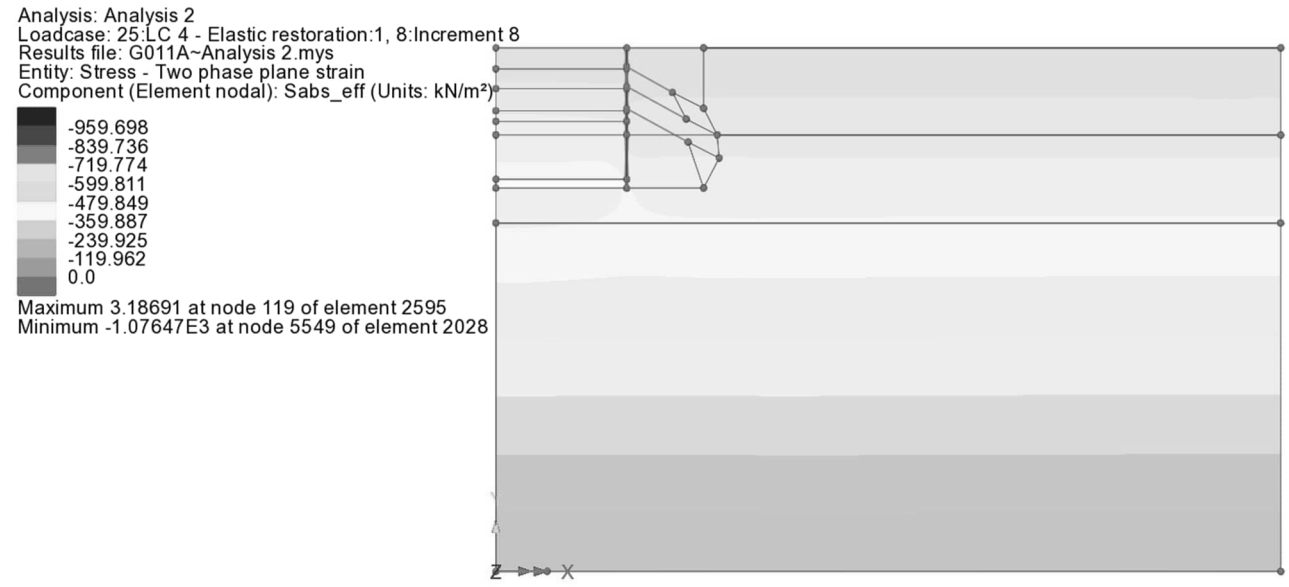
4.1.3 LC 3

→ Min Sabs = -1076 kPa



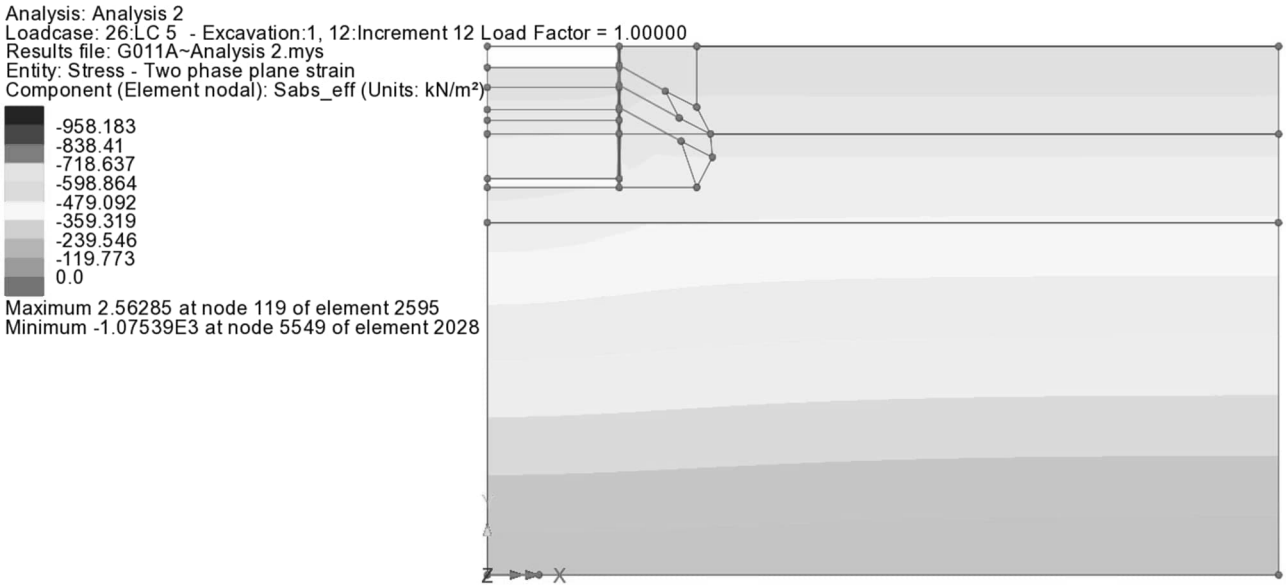
4.1.4 LC 4

→ Min Sabs = -1076 kPa



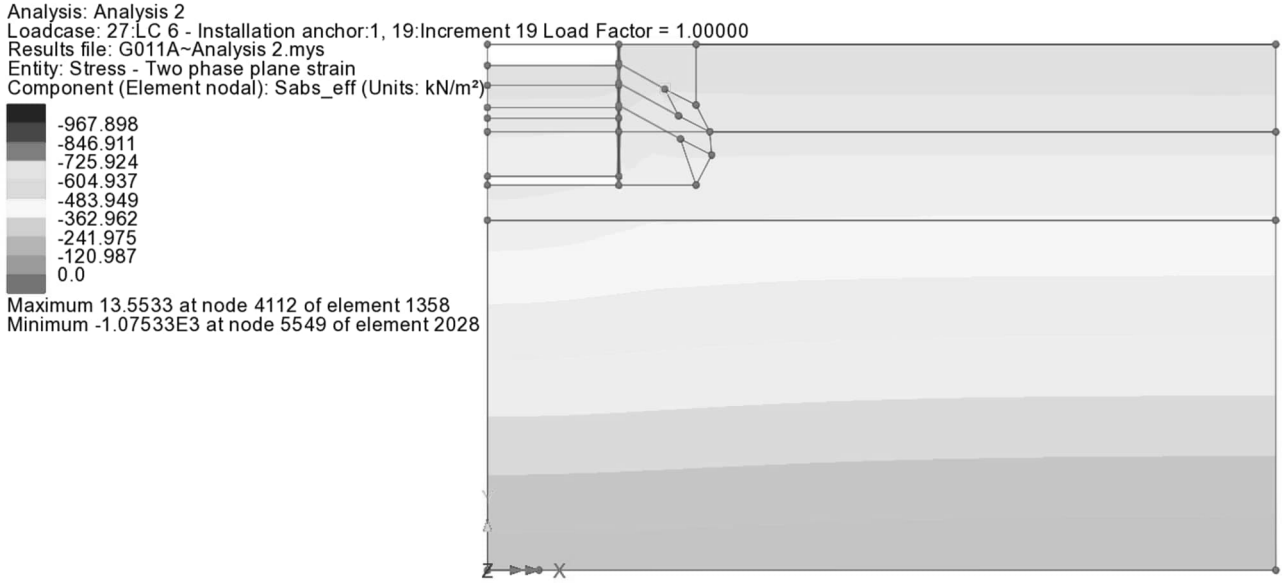
4.1.5 LC 5

→ Min Sabs = -1075 kPa



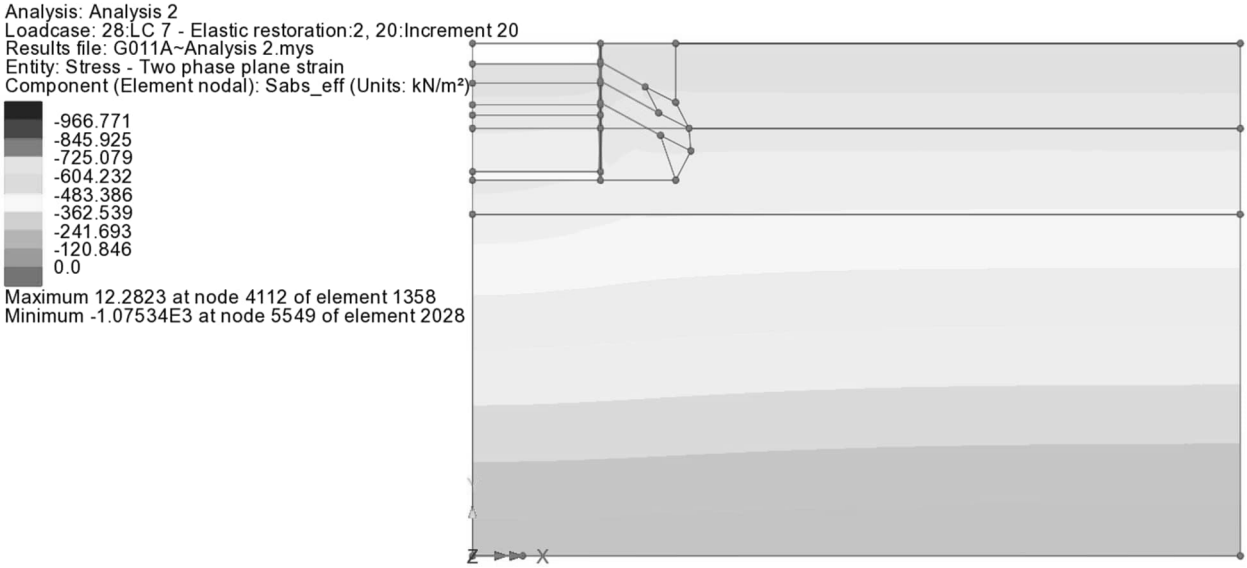
4.1.6 LC 6

→ Min Sabs = -1075 kPa



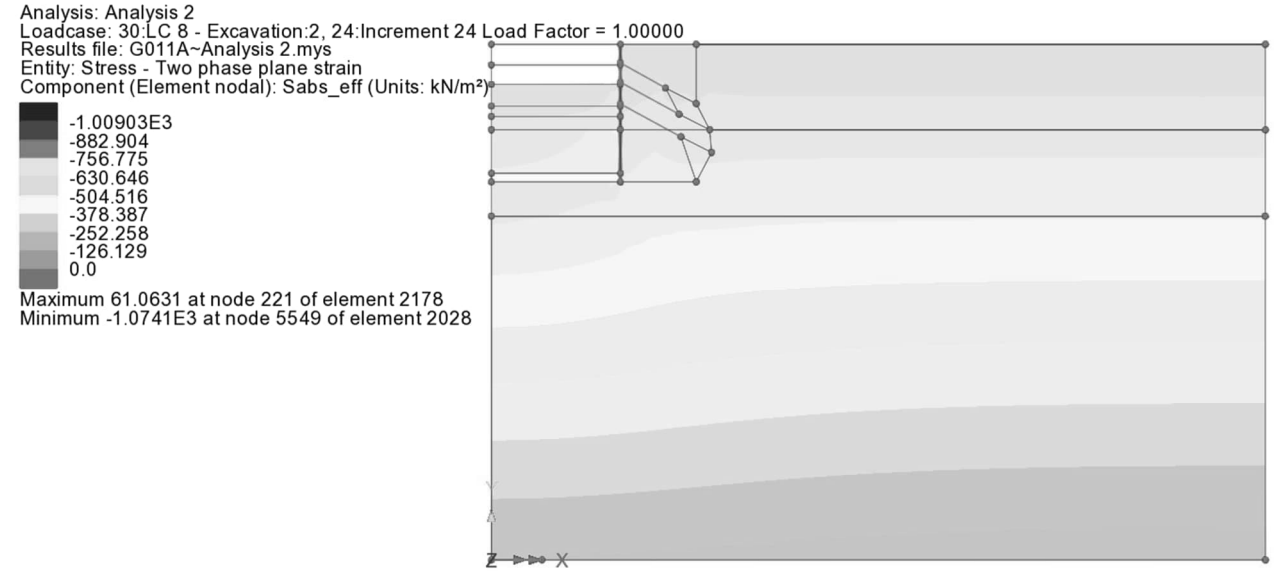
4.1.7 LC 7

→ Min Sabs = -1075 kPa



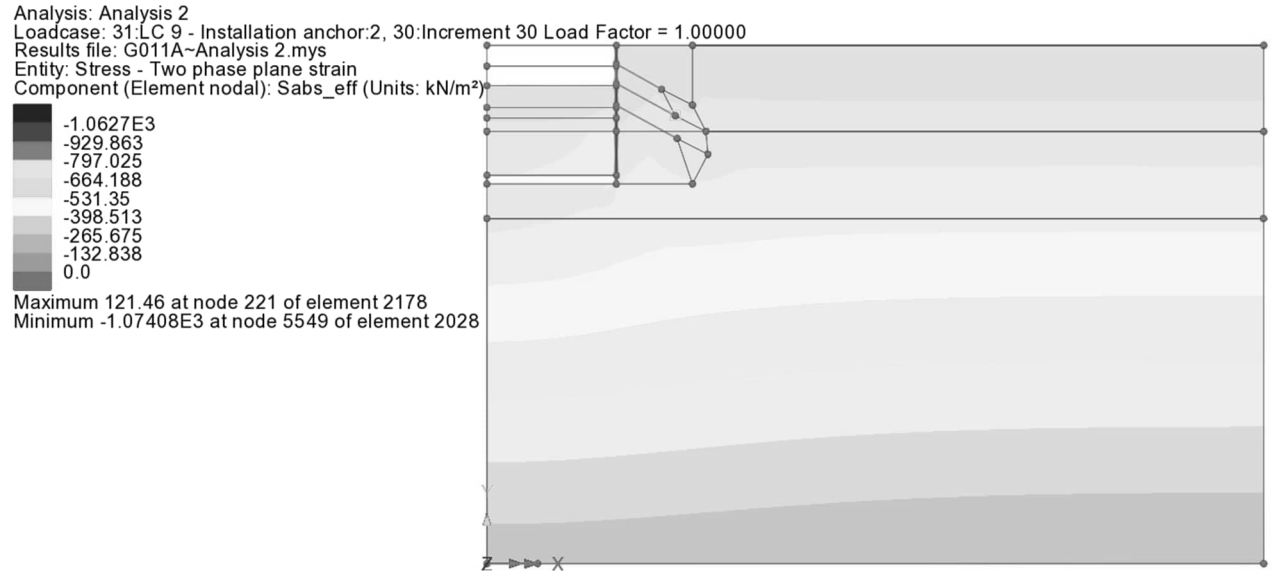
4.1.8 LC 8

→ Min Sabs = -1074 kPa



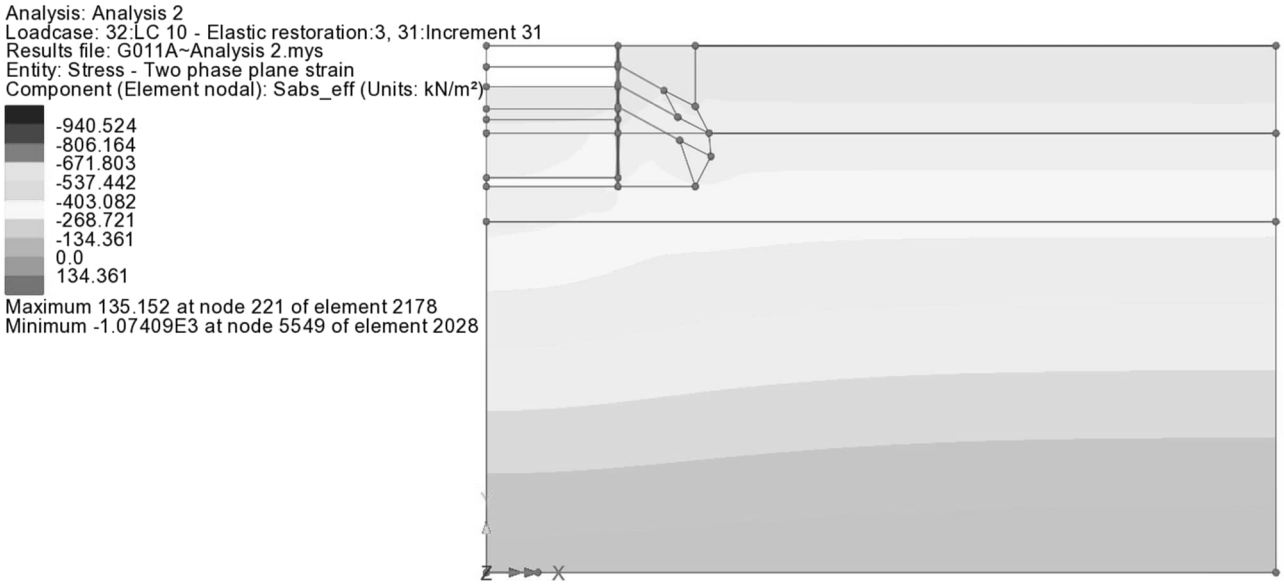
4.1.9 LC 9

→ Min Sabs = -1074 kPa



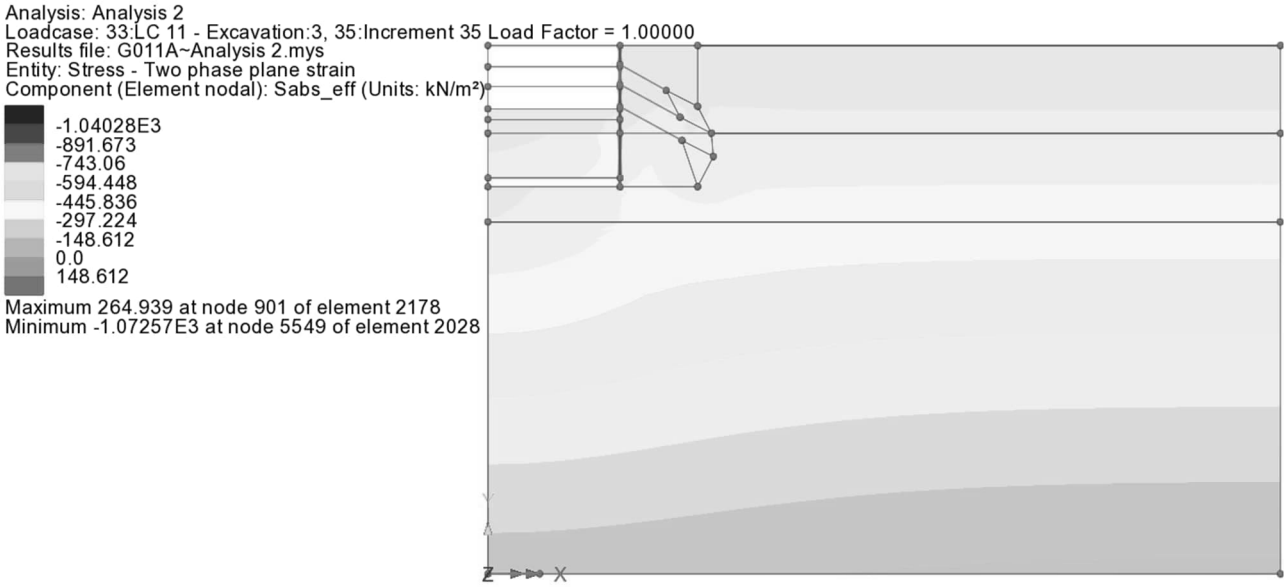
4.1.10 LC 10

→ Min Sabs = -´1074 kPa



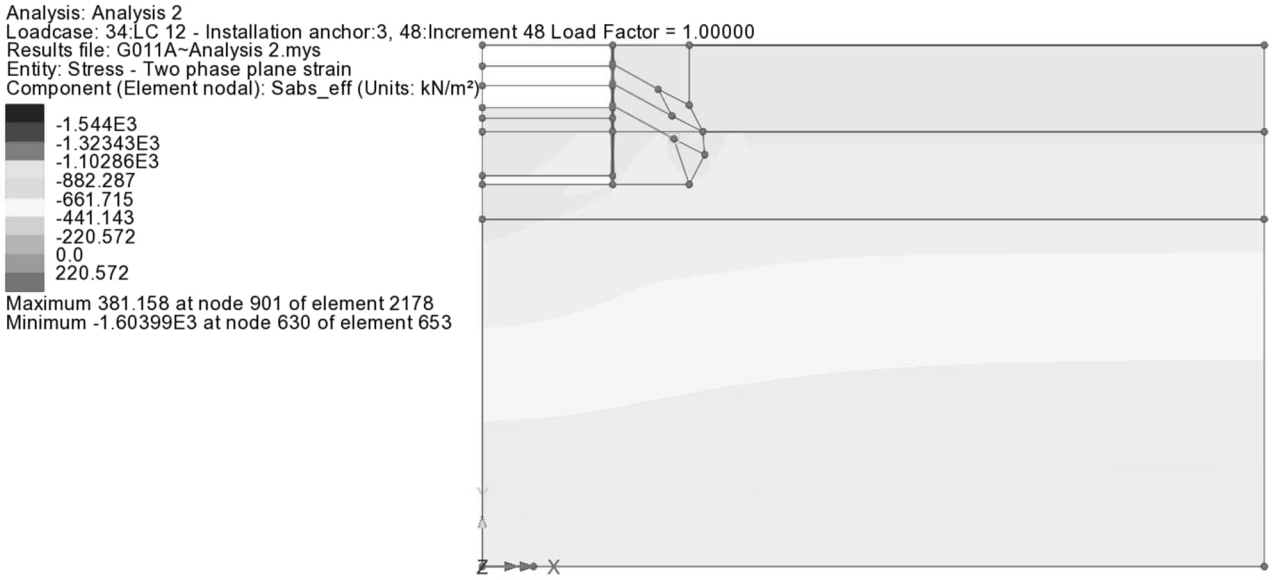
4.1.11 LC 11

→ Min Sabs = -1073 kPa



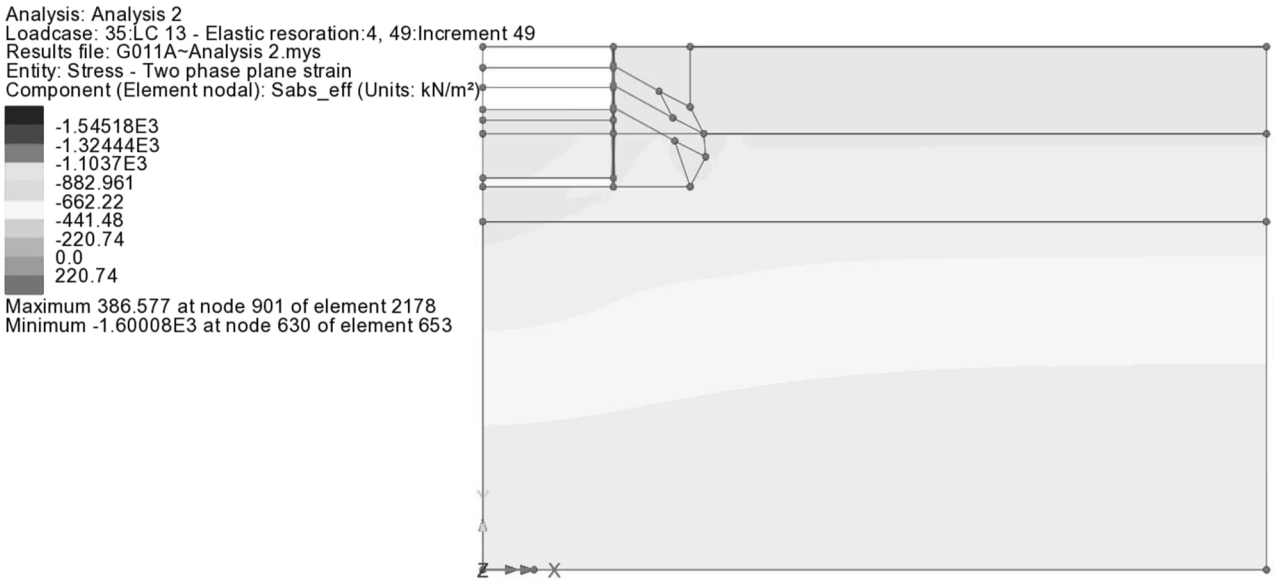
4.1.12 LC 12

→ Min Sabs = -1604 kPa



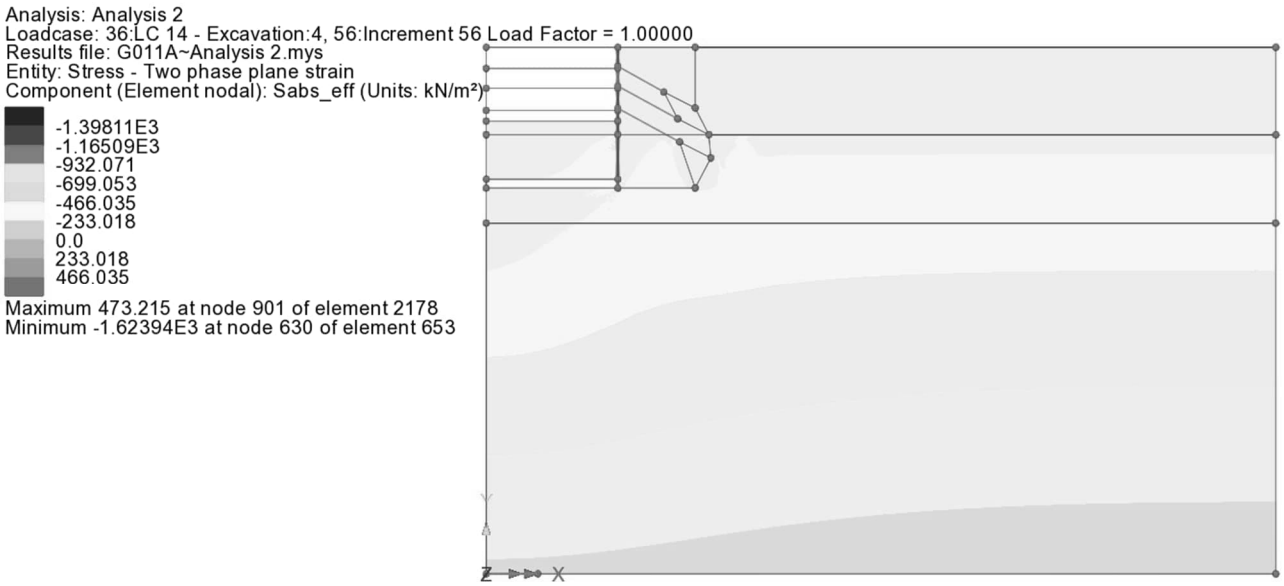
4.1.13 LC 13

→ Min Sabs = -1601 kPa



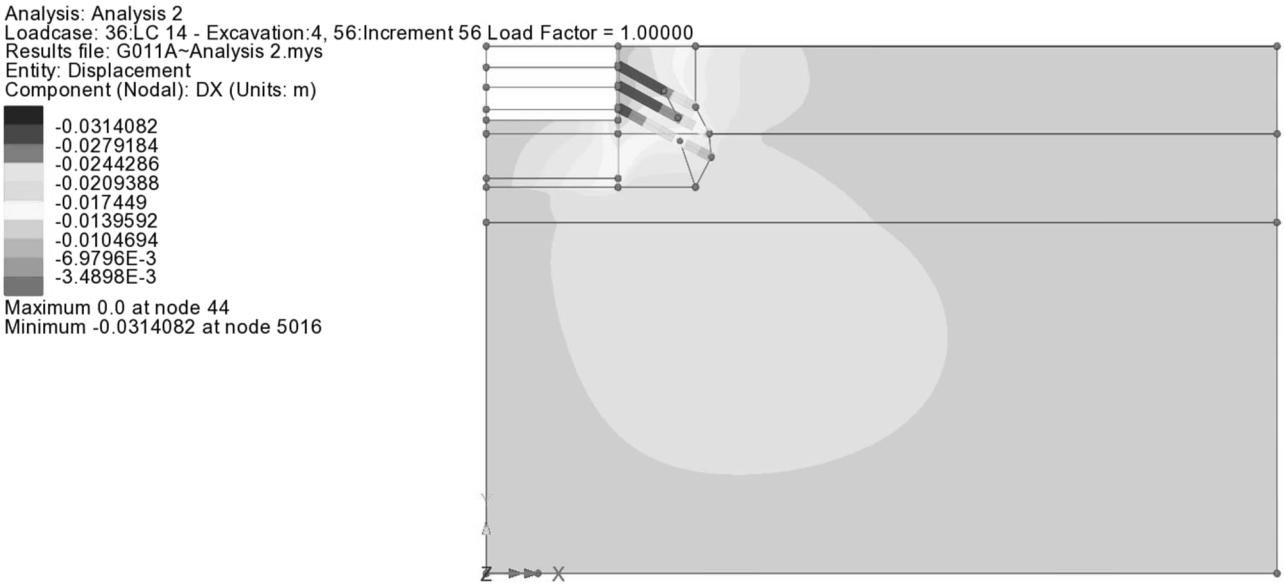
4.1.14 LC 14

→ Min Sabs = -1623 kPa



4.2 Horizontal displacement after completed excavation (LC 14)

→ Min Dx = -0.031 m

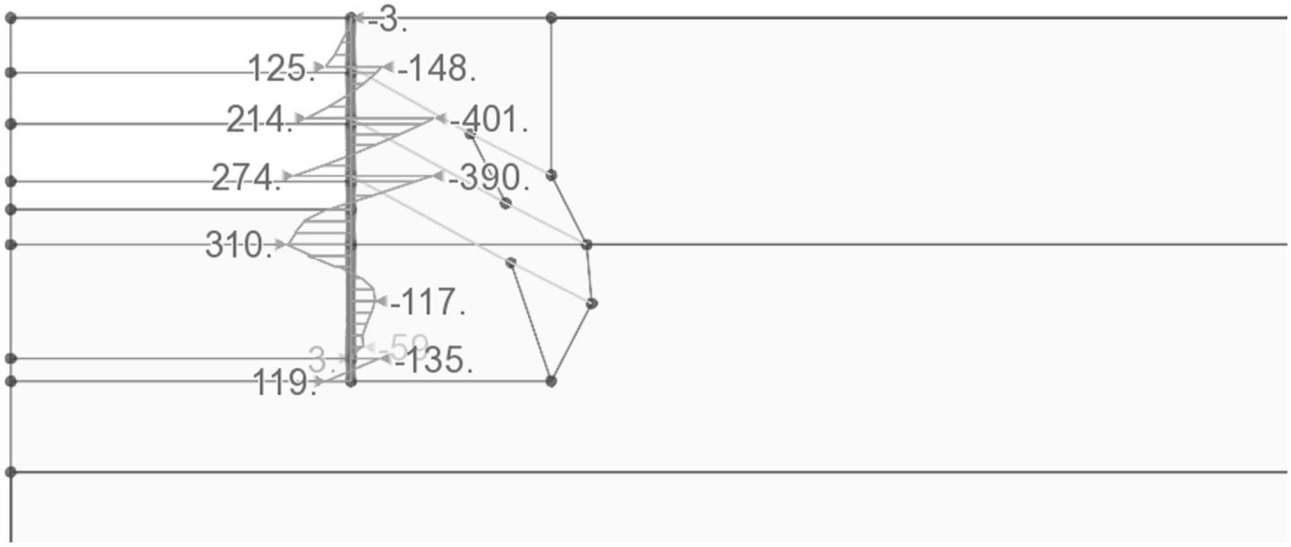


4.3 Shear force retaining wall after completed excavation (LC 14)

→ Max Sxy = +310 kN
Min Sxy = -401kN

Scale: 1: 974.105
Zoom: 132.932
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 2
Loadcase: 36:LC 14 - Excavation:4, 56:Increment 56 Load Factor = 1.00000
Results file: G011A~Analysis 2.mys

Diagram entity: Force/Moment - Plane Strain Beam
Diagram component: Sxy (Units: kN)
Diagram maximum 309.546 at node 7579 of element 2475
Diagram minimum -400.884 at node 7553 of element 2490
Diagram scale: 1: 0.0249449

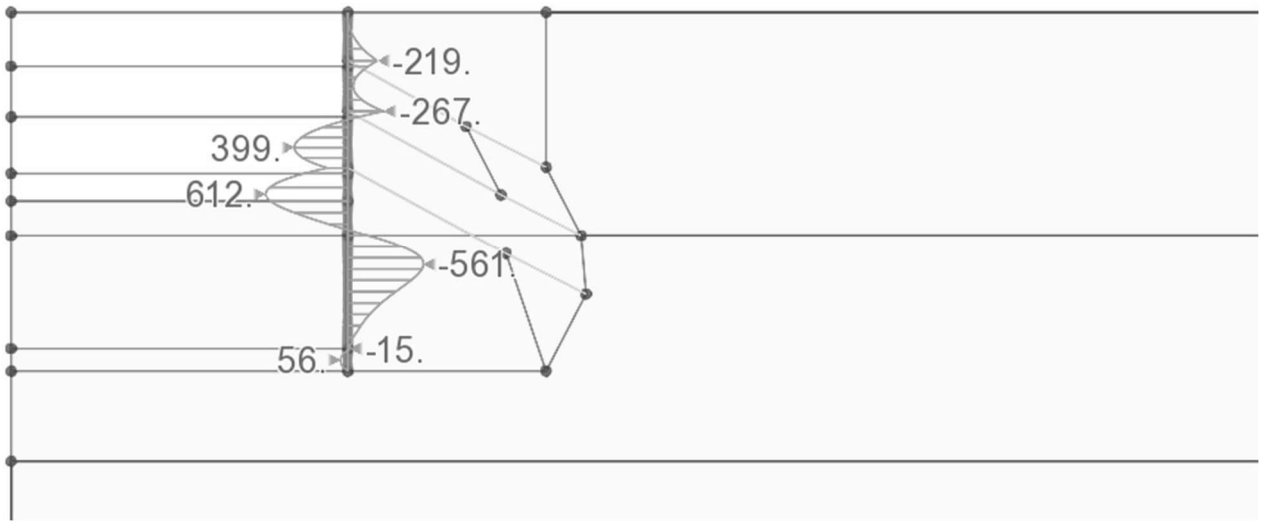


4.4 Bending moment retaining wall after completed excavation (LC 14)

→ Max Mz = +612 kNm
Min Mz = -560 kNm

Scale: 1: 974.105
Zoom: 132.932
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 2
Loadcase: 36:LC 14 - Excavation:4, 56:Increment 56 Load Factor = 1.00000
Results file: G011A~Analysis 2.mys

Diagram entity: Force/Moment - Plane Strain Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 612.053 at Internal point 6 of element 2479
Diagram minimum -560.779 at Internal point 5 of element 2473
Diagram scale: 1: 0.0163385



4.5 Normal axial anchor force completed excavation (LC 14)

→ Max Fx = 757 kN
Min Fx = 24 kN

Scale: 1: 974.105
Zoom: 132.932
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 2
Loadcase: 36:LC 14 - Excavation:4, 56:Increment 56 Load Factor = 1.00000
Results file: G011A~Analysis 2.mys

Diagram entity: Force/Moment - Bar / Cable
Diagram component: Fx (Units: kN)
Diagram maximum 756.991 at node 630 of element 2488
Diagram minimum 24.2941 at node 443 of element 129
Diagram scale: 1: 0.0132102