Braced sheet pile box

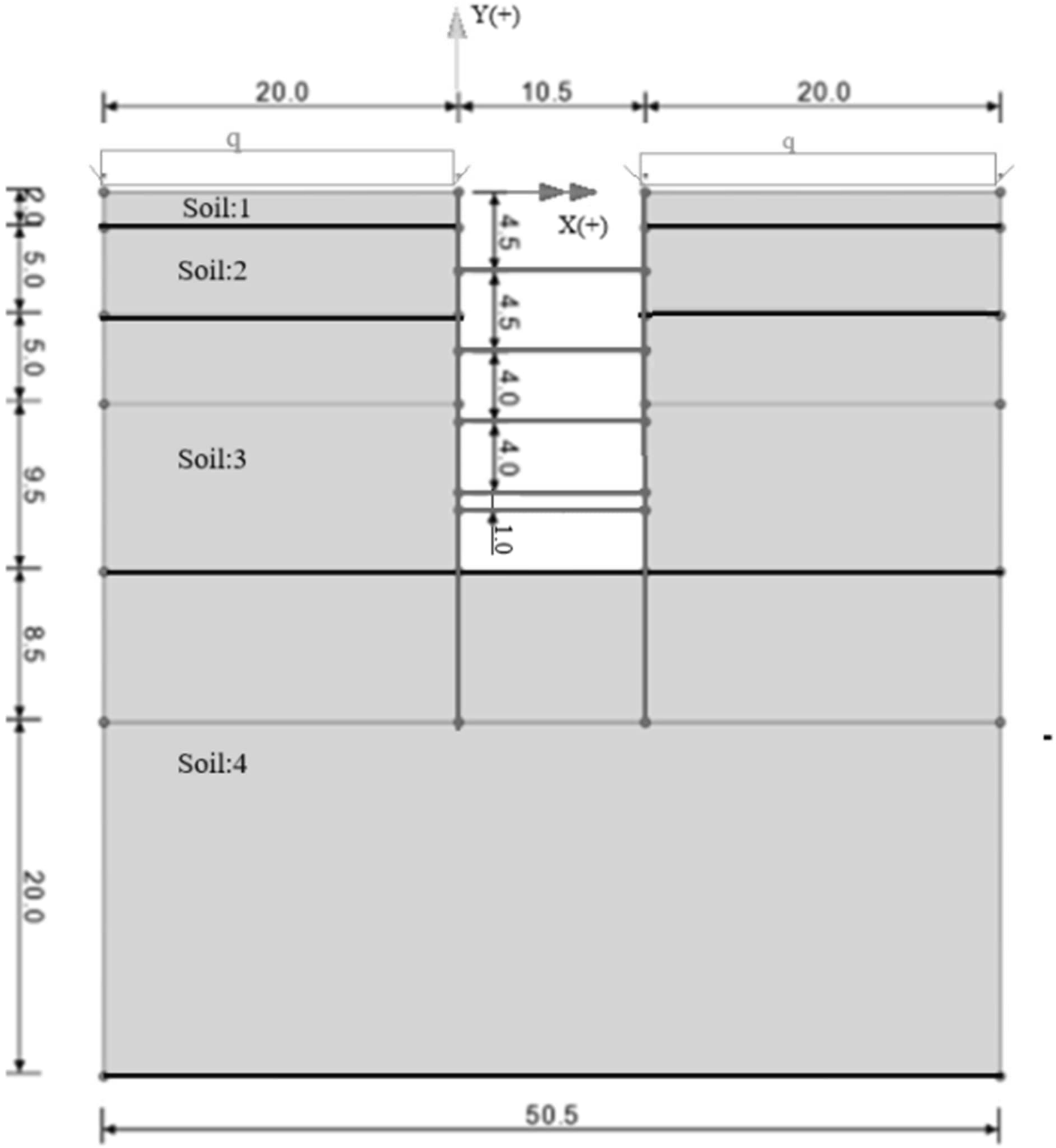
Table of content

Appendix
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

1.2 SOIL PROPROPETIES

Layer	Mass Density (t/m^3)	Young's modulus, E (kPa)	Poisson's ratio, ν	Angle of friction, φ	Cohesion, c	Earth pressure coefficient, K_0
Soil:1	1.8	10.0E3	0.3	30	1	0.5
Soil:2	1.8	12.3E3	0.3	30	1	0.5
Soil:3	1.9	34.5E3	0.3	34	1	0.44
Soil:4	1.9	38.3E3	0.3	36	1	0.41

2. SYSTEM ANALYSIS

2.1 GENERAL

Below is short description of assumptions used in the analysis.

There are in total 4 different layer of soil.

Analysis is nonlinear analysis since soil material is nonlinear.

Surface elements are modelled as plain strain element that quadratic (QPN8).
.
Beam elements are modelled as 2D plain strain beams (BAR2).

In order to handle excavation a total of 6 loadcases (LC) are needed.

Depending on stage soil, soil and struts are activated & deactivated.

Interface elements are needed to modell interaction between soil and retaing wall.
A reset of deformations is assigned to all nodes after installation of sheet piles (LC 2) in order to reset deformations without modifying the state of stress.

LC nr	Name	Activate	Deactivate
1	Initial conditions	-	Wall & Strut 1-4
2	Installation sheet piles	Wall	-
3	Excavation:1	Strut 1	Soil excavation:1
4	Excavation:2	Strut 2	Soil excavation:2
5	Excavation:3	Strut 3	Soil excavation:3
6	Excavation:4	Strut 4	Soil excavation:4

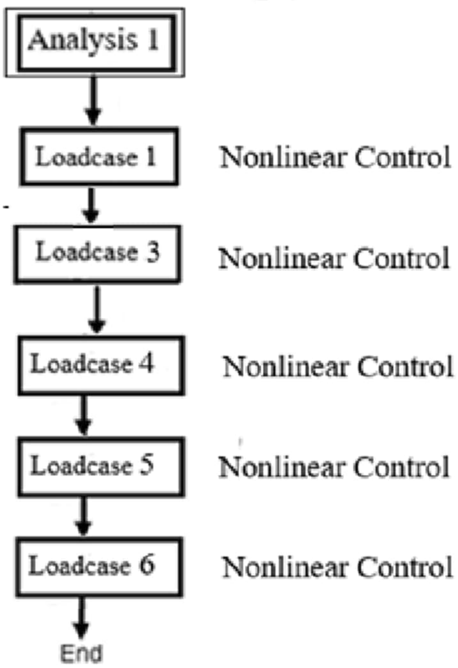
2.2 NONLINEAR ANALYSIS

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.

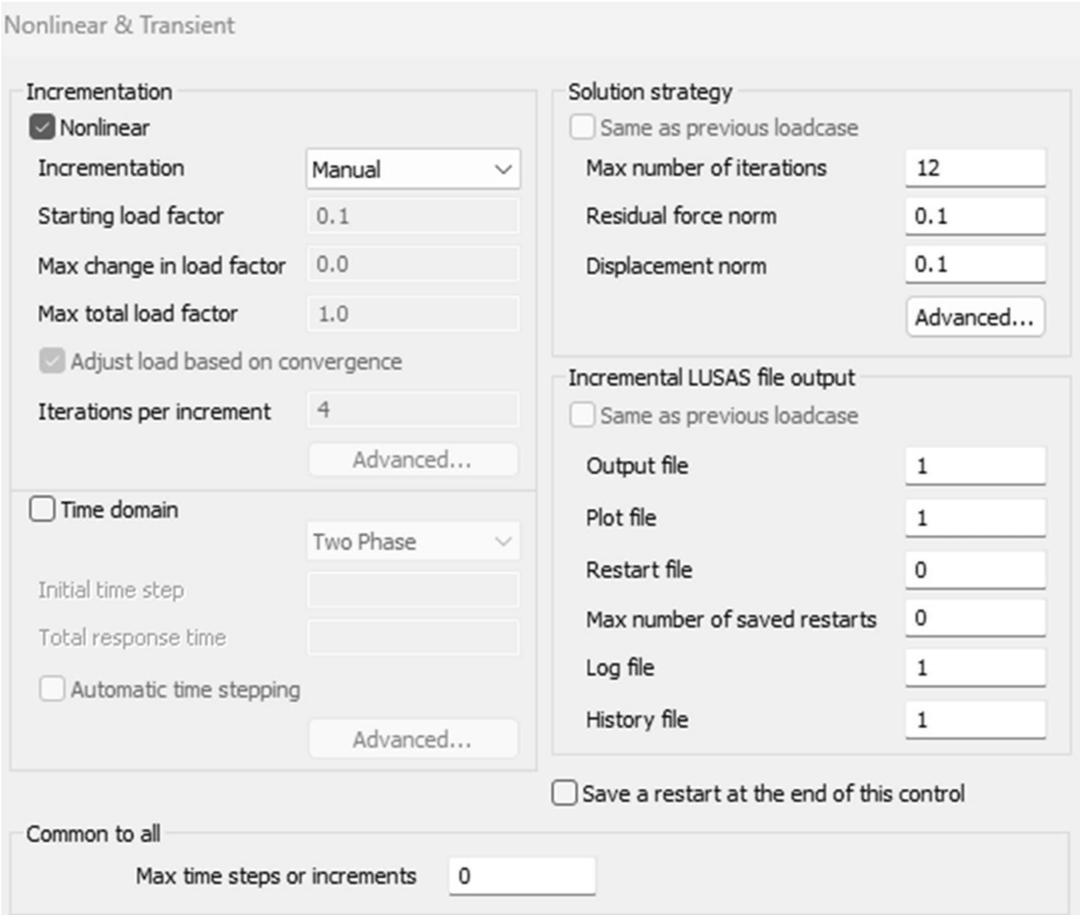
Displacement norm:
The limit for the sum of the squares of the iterative displacements as a percentage of the sum of the squares of the incremental displacements (DTNRM). Only translation degrees of freedom are considered.



LC nr	Name	Type analysis	Incrementation
1	Initial conditions	Nonlinear	Manual
2	Installation sheet piles	Nonlinear	Manual
3	Excavation:1	Nonlinear	Manual
4	Excavation:2	Nonlinear	Automatic
5	Excavation:3	Nonlinear	Automatic
6	Excavation:4	Nonlinear	Automatic

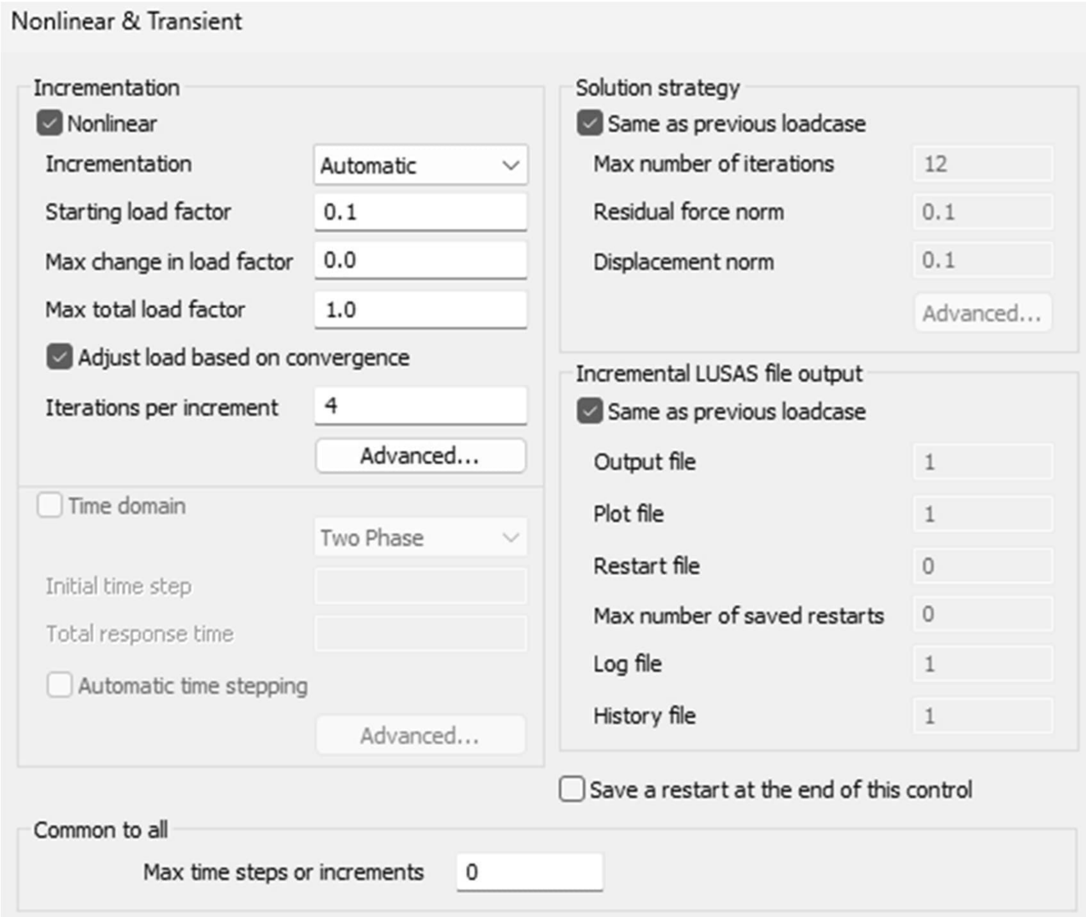
<u>Manual</u>

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



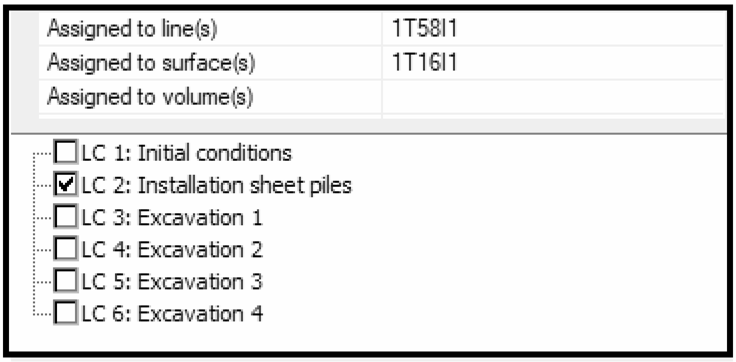
<u>Automatic</u>

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

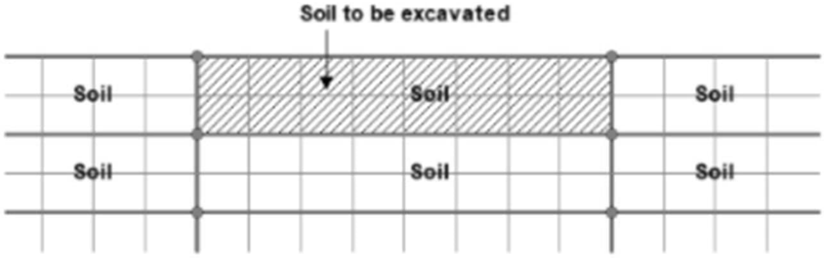


2.3 RESET DEFORMATIONS

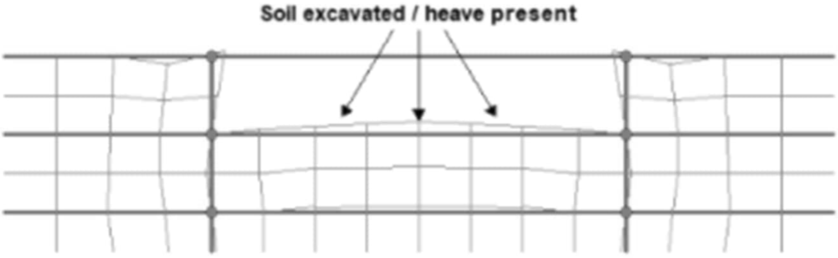
After installation sheet piles (LC 2) all node deformations associated all lines and surfaces.



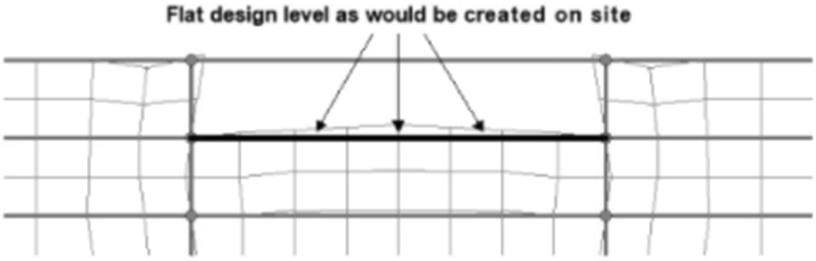
Principle of reset of deformations of lines (also applies to surfaces):



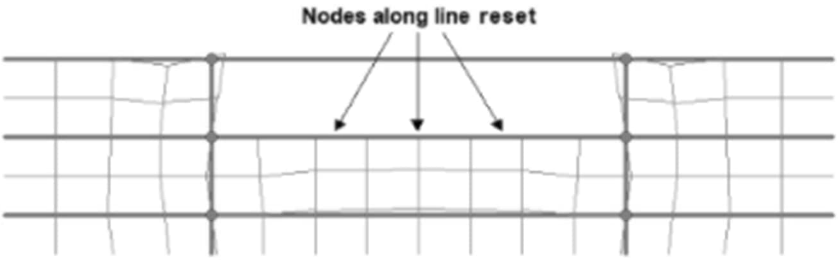
Excavation between sheet pile retaining walls



Soil excavation deforms walls and causes soil heave as weight removed



Assign a 'Reset Deformation - Nodes' attribute to the line at the bottom of the excavation. This resets the nodes along the line to their undeformed locations to model the flat design level that would be created on site.



Mesh configuration after all active nodes along line at bottom of excavation have been reset.

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.

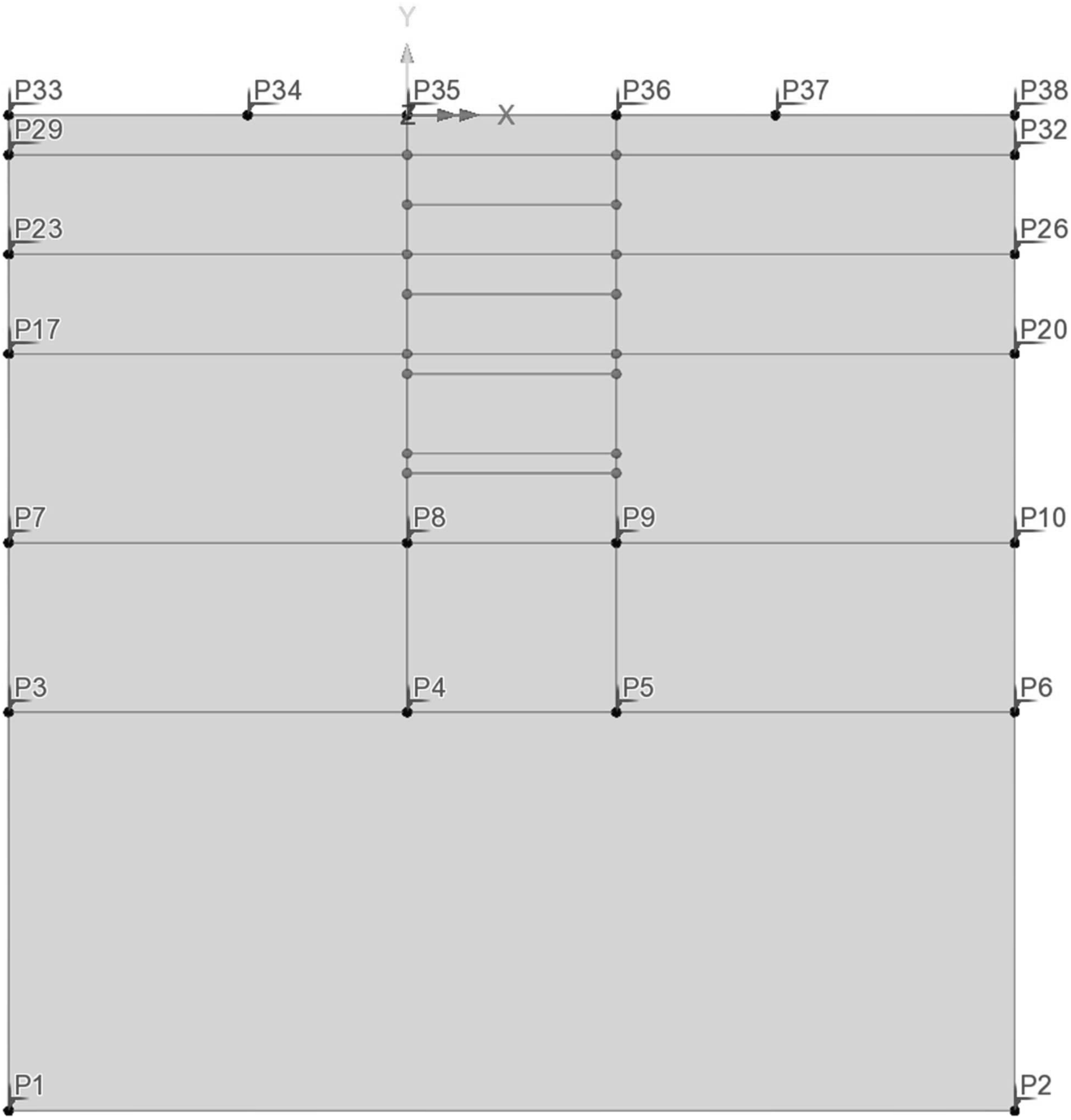
Sketches are generated by using POINTS, LINES and SURFACES.

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

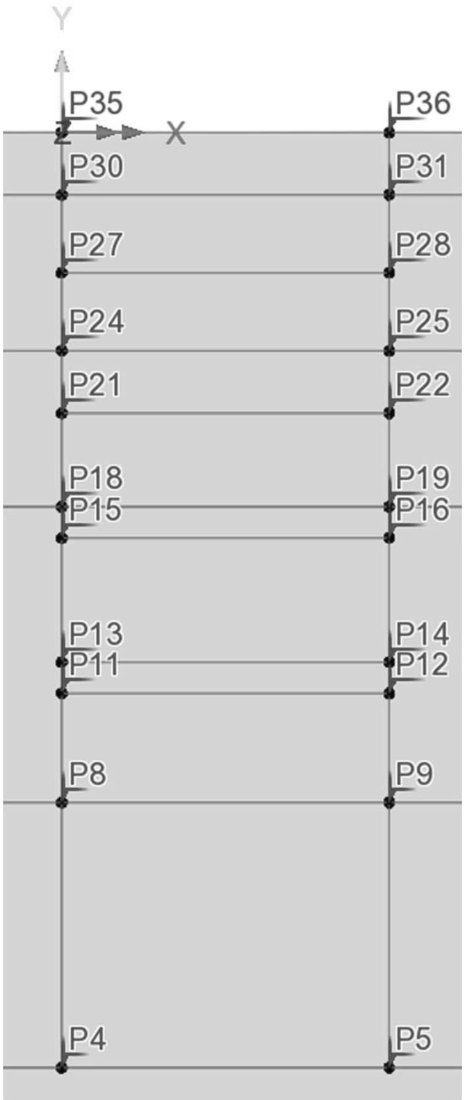
All POINTS needed to describe LINES are found in attachment 1.

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

2.4.1 Geometry: Points

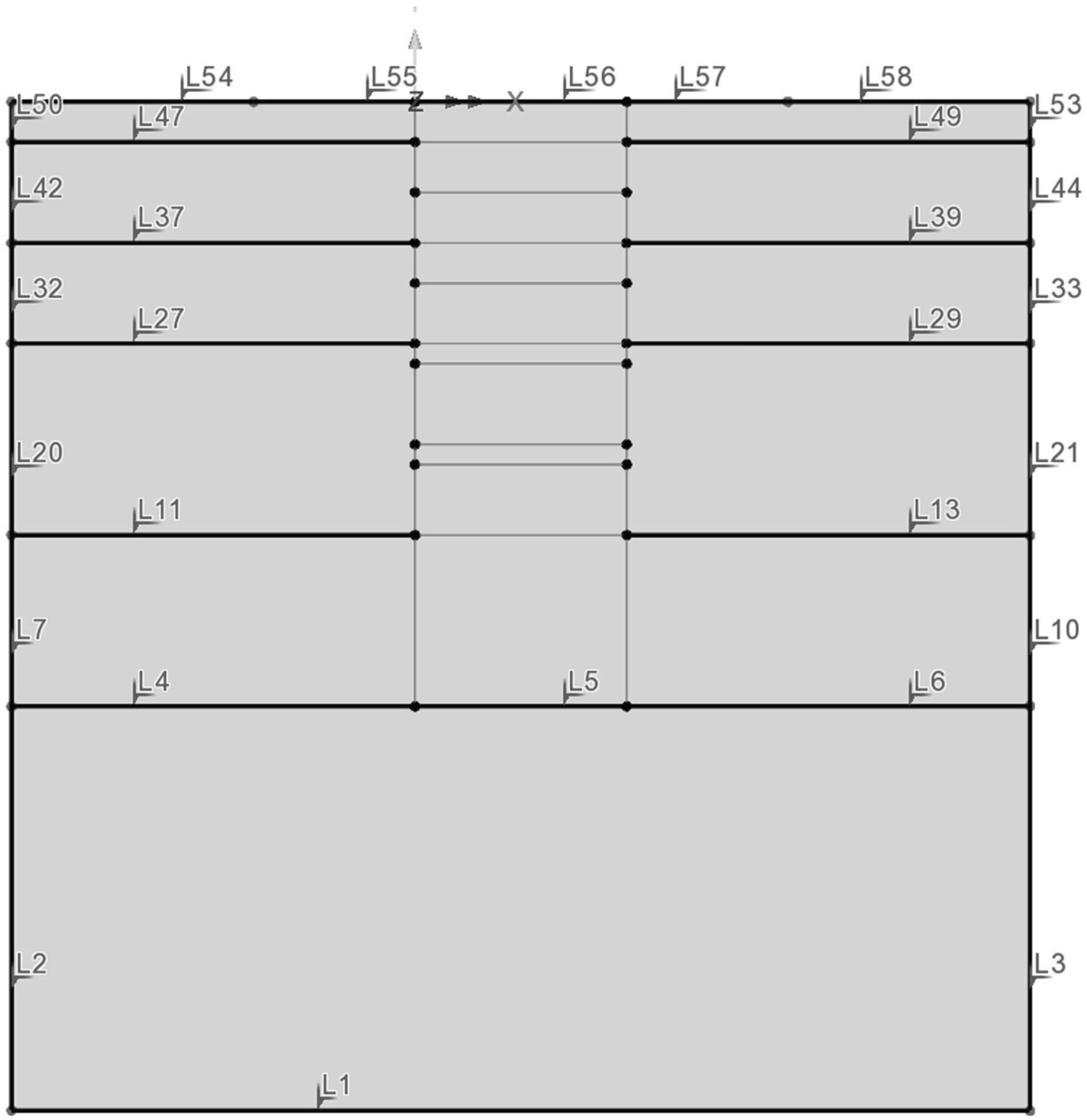


ELEVATION
Overall

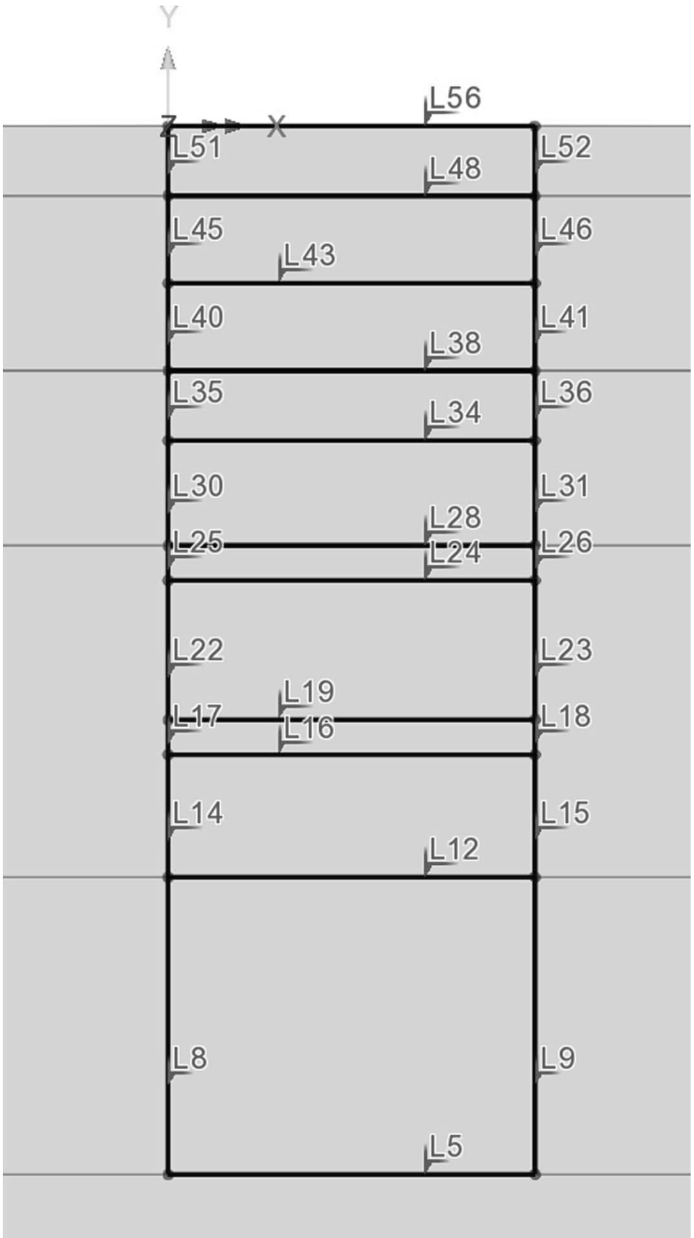


ELEVATION
Detail

2.4.2 Geometry: Lines

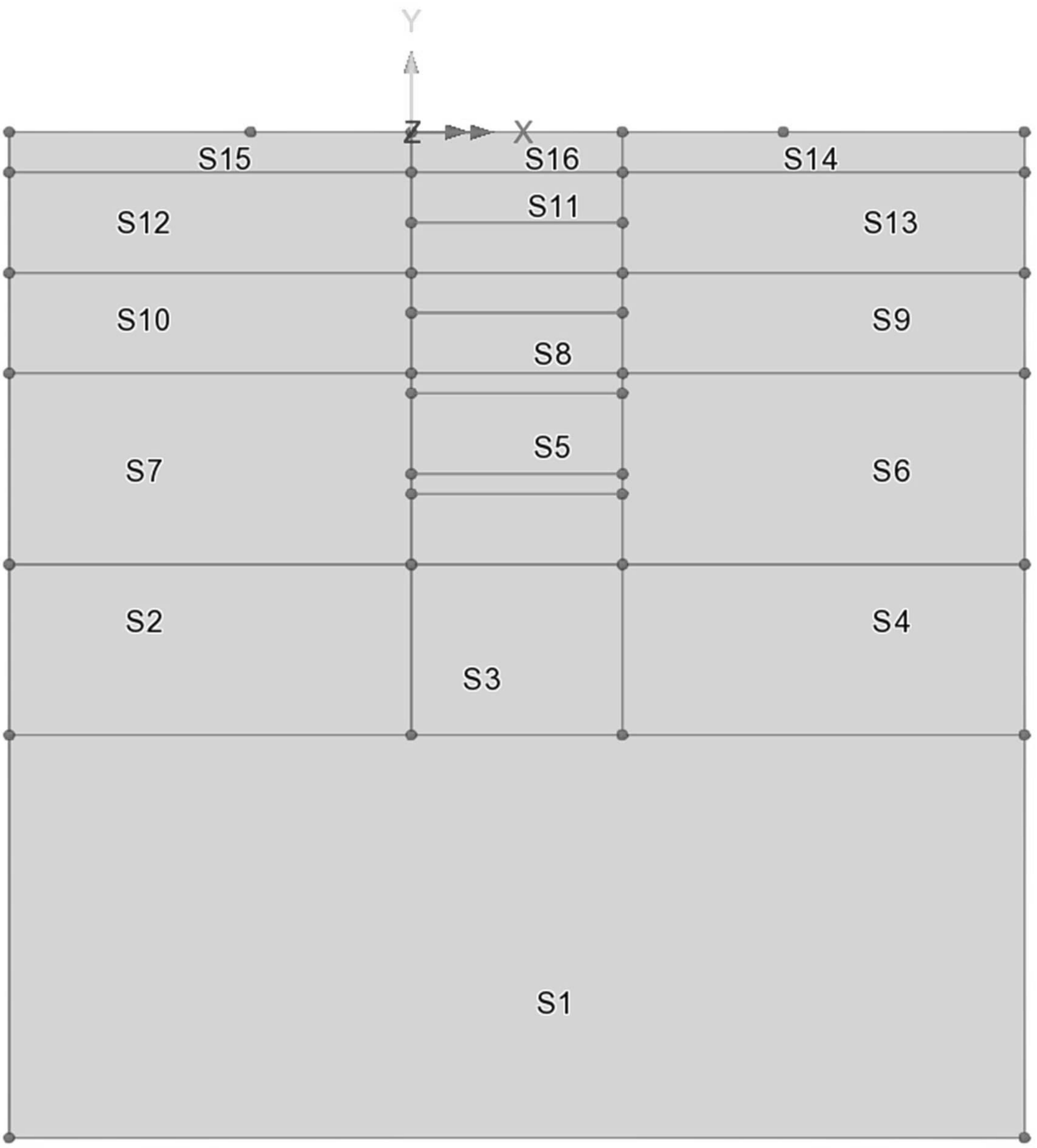


ELEVATION
Overall



<u>ELEVATION</u>
Detail

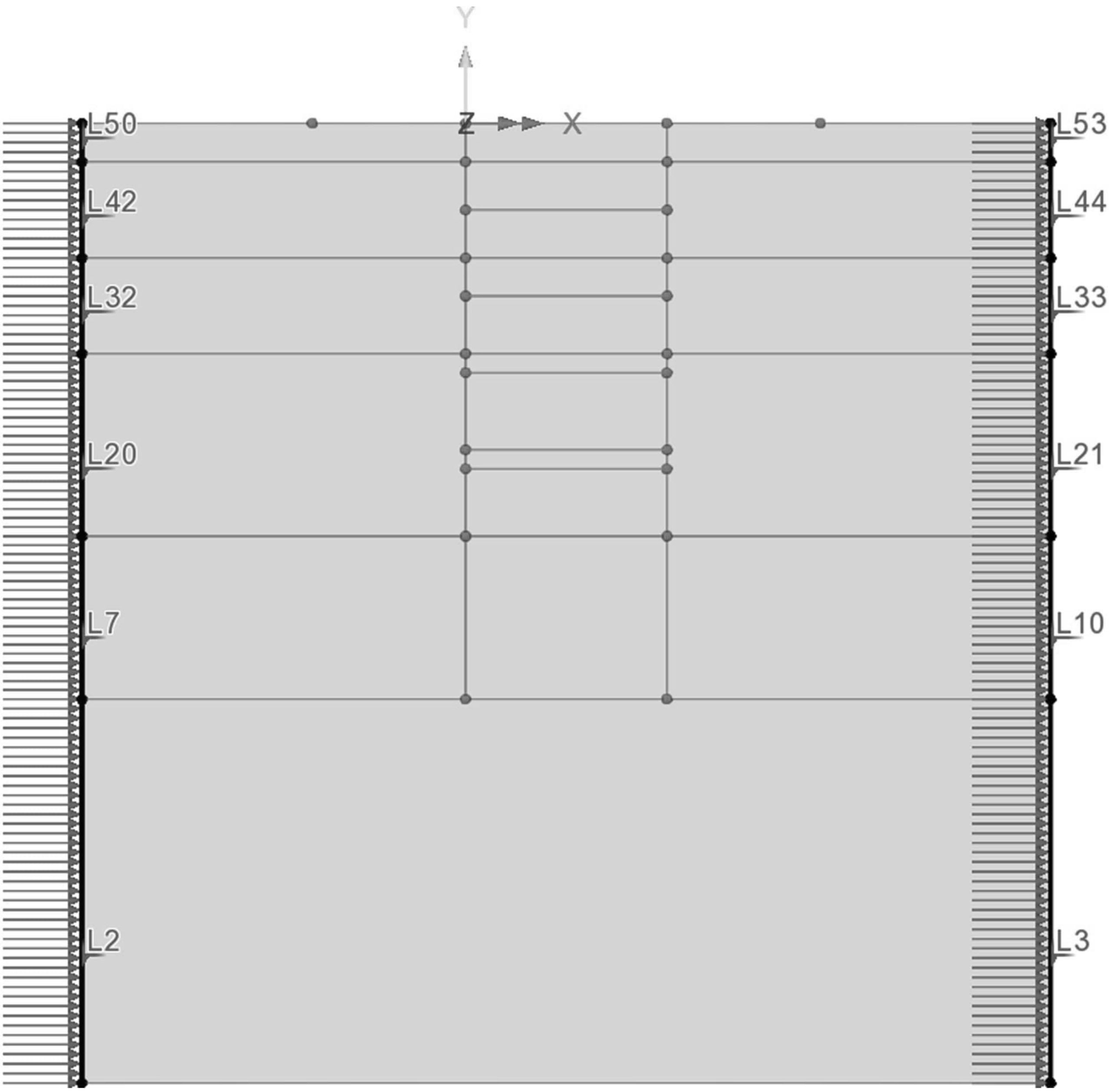
2.4.3 Geometry: Surfaces



ELEVATION
Overall

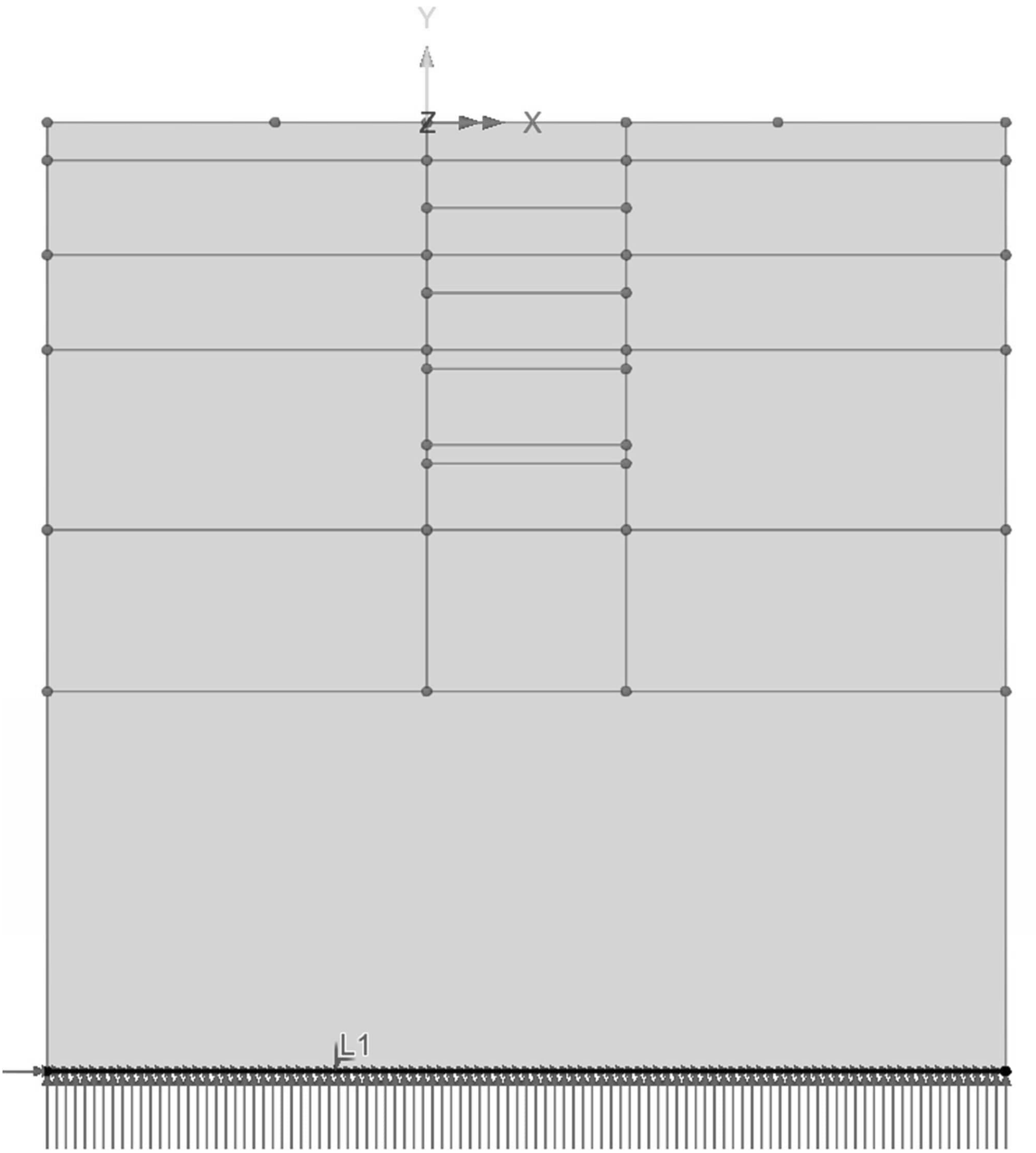
2.5 BOUNDARY CONDITIONS

2.5.1 Horizontal boundary soil: Fixed X



ELEVATION
Overall

2.5.2 Vertical boundary soil: Fixed XY



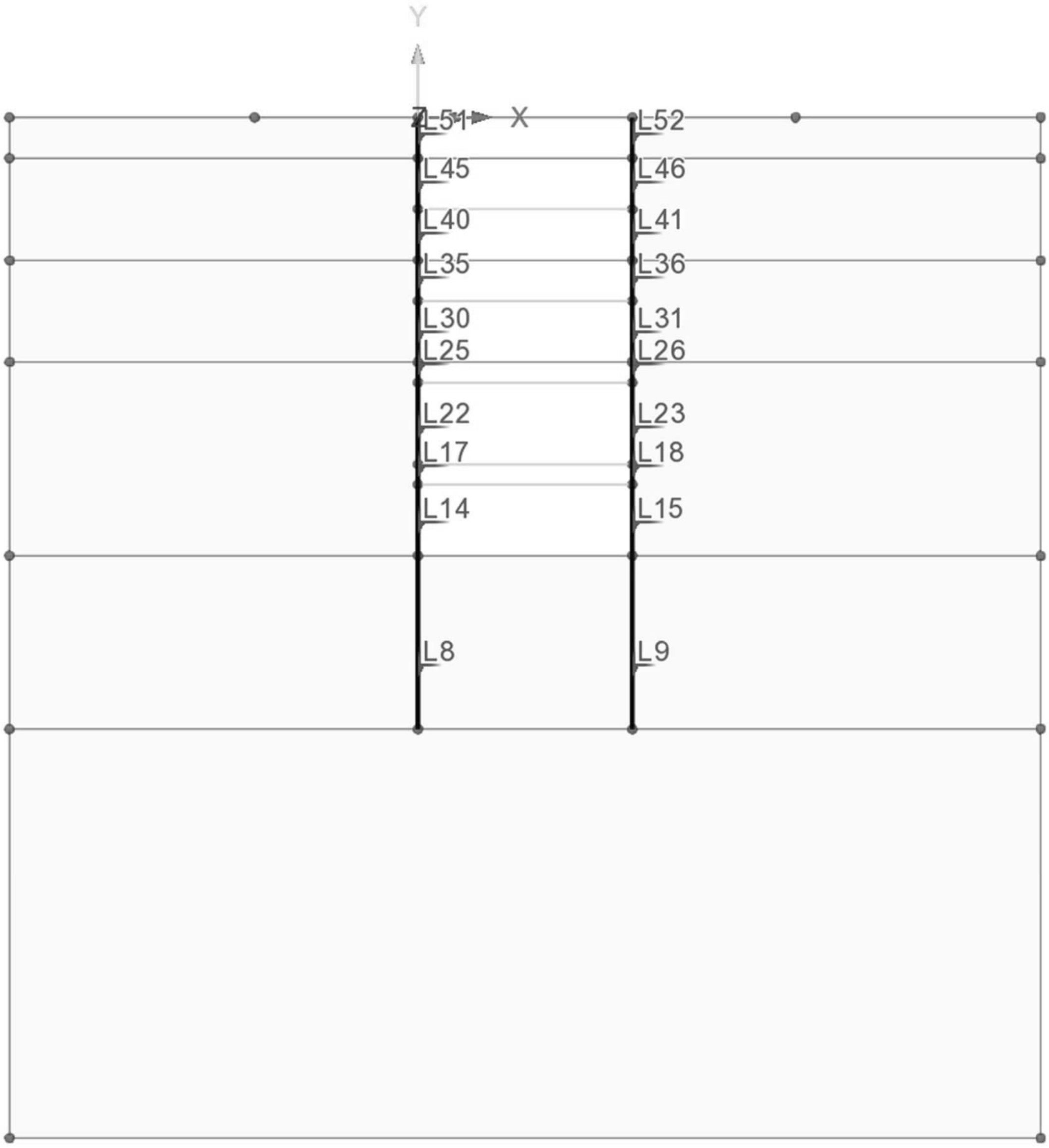
ELEVATION
Overall

2.6 MESH

2.6.1 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	Order element	Lines
Wall	BMI3N	1	Quadratic	See sketch below.

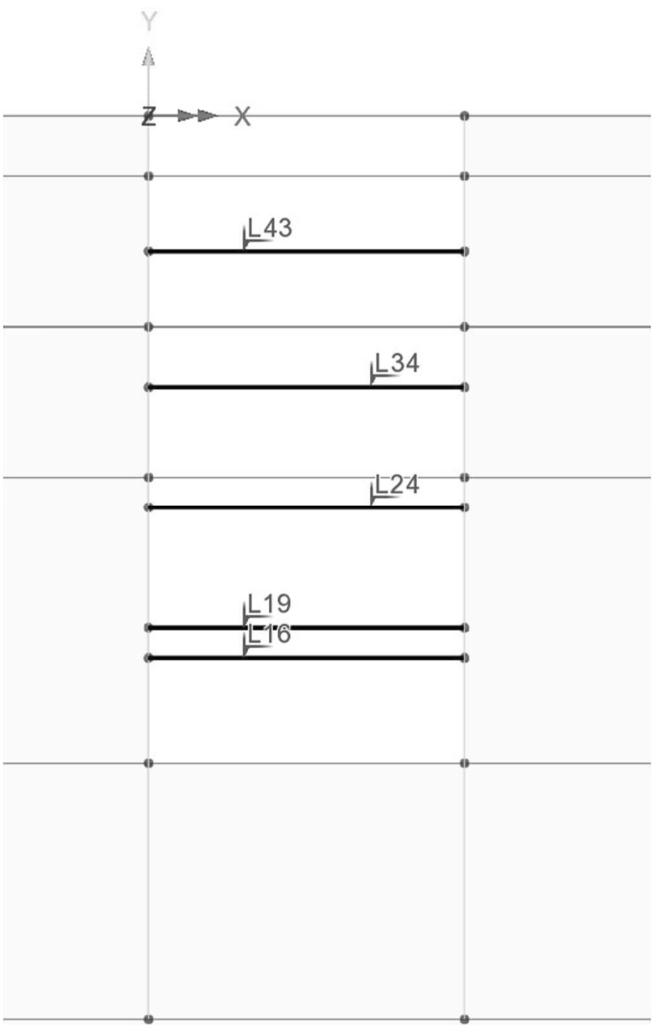


ELEVATION
Overall

2.6.2 Strut: Bar element

Horizontal struts is modelled as seen below.

Name	Element type	Number of divisions	Order element	Lines
BAR2	Bar	1	Linear	See sketch below.



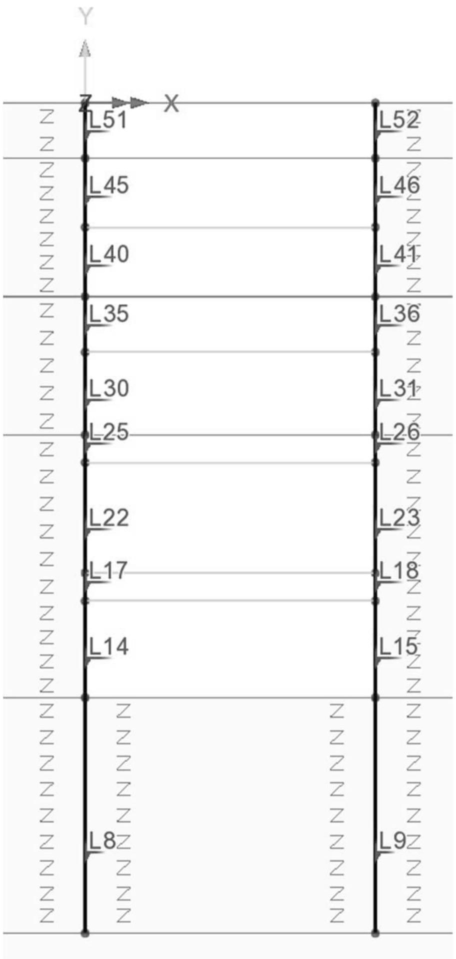
ELEVATION
Detail.

2.6.3 Interface element between wall and soil: Interface element (IPN6P)

The interface between soil and wall is modelled as seen below.
The element is not phase since undrained and drained analyis is not reqired. The element is used for modeling standard Mohr-Coulomb friction contact in soil/structure interactions.

Name	Element type	Element length	Order element	Lines
IPN6	Interface	Automatic	Quadratic	See sketch below.

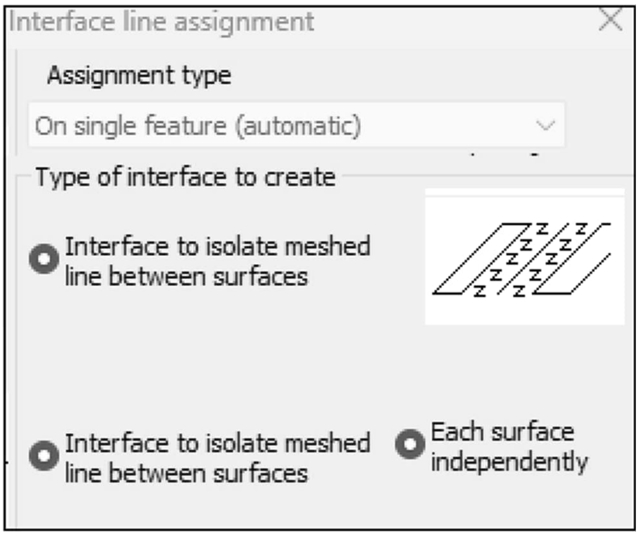
‘



ELEVATION
Detail.

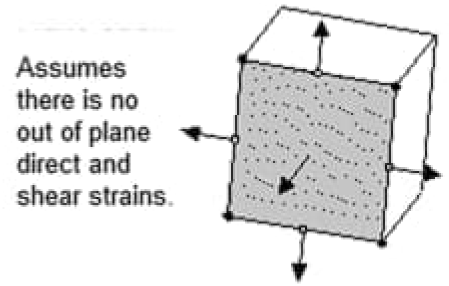
<u>Remark</u>

When applying the interface element, a single method is considered that automatically creates joint on either side of line defining wall, thus no need to use unmerged points & lines.

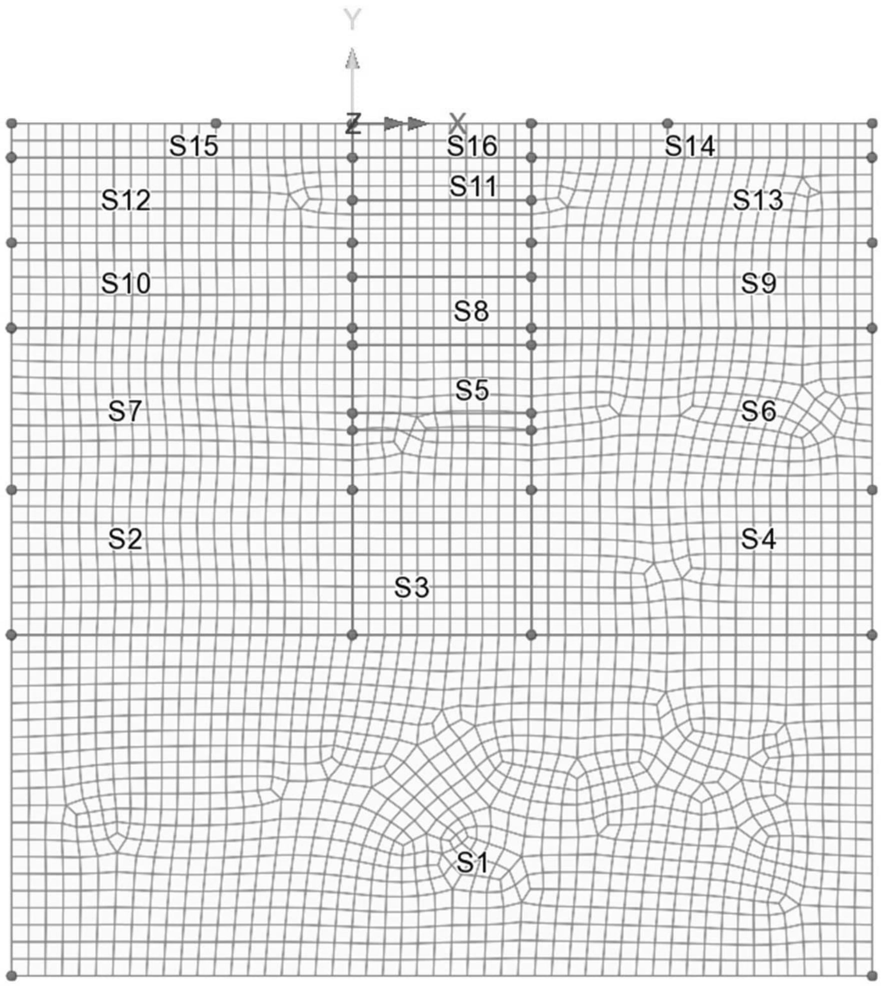


2.6.4 Soil: plain strain surface elements (QPN8)

Soil is modelled using surface elements as seen below.



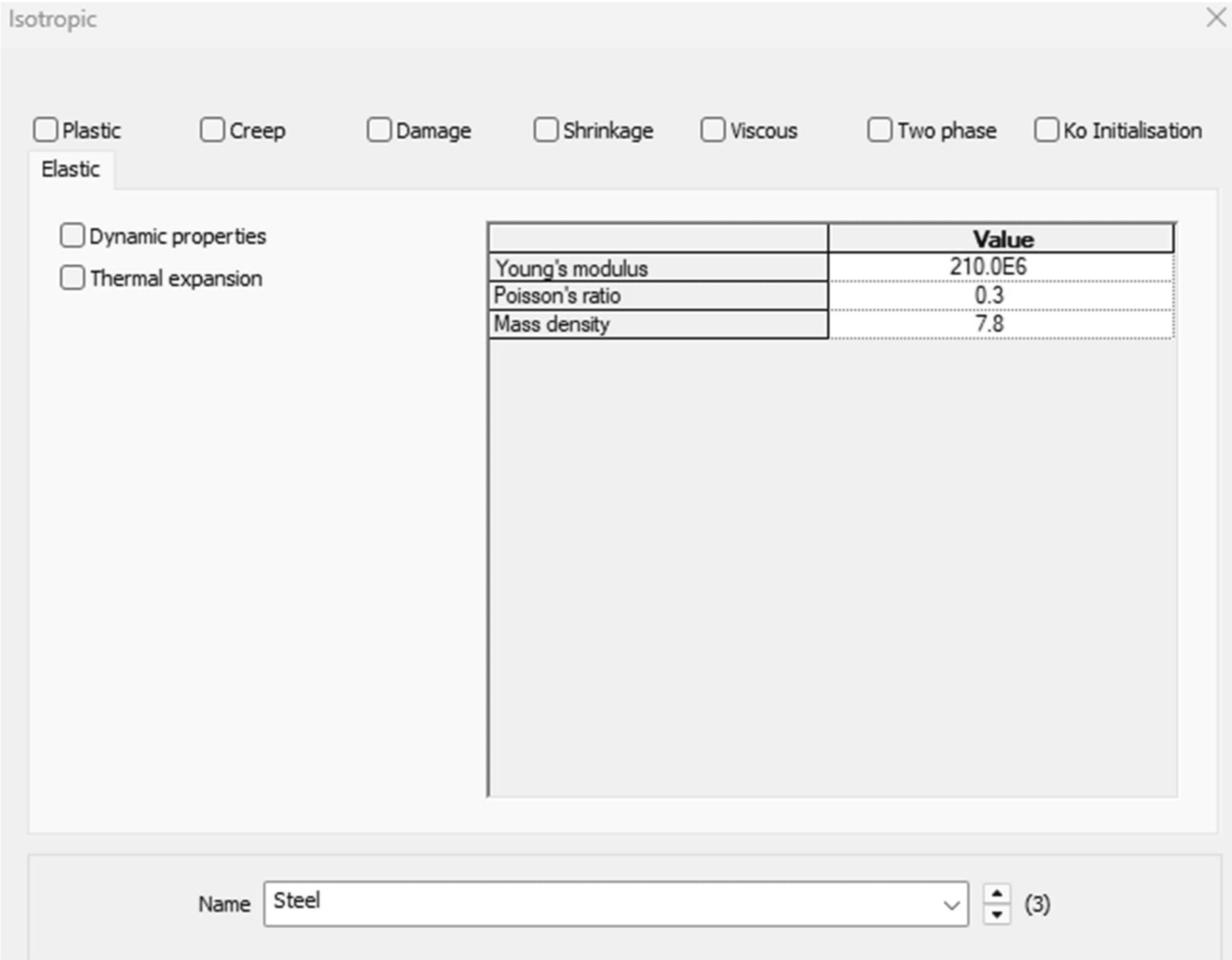
Name	Element type	Element size	Order element	Mesh	Surfaces
QPN8	Plain strain	1 m	Quadratic	Irregular	See below



ELEVATION
Overall

2.7 MATERIAL

2.7.1 Linear elastic material: wall & strut

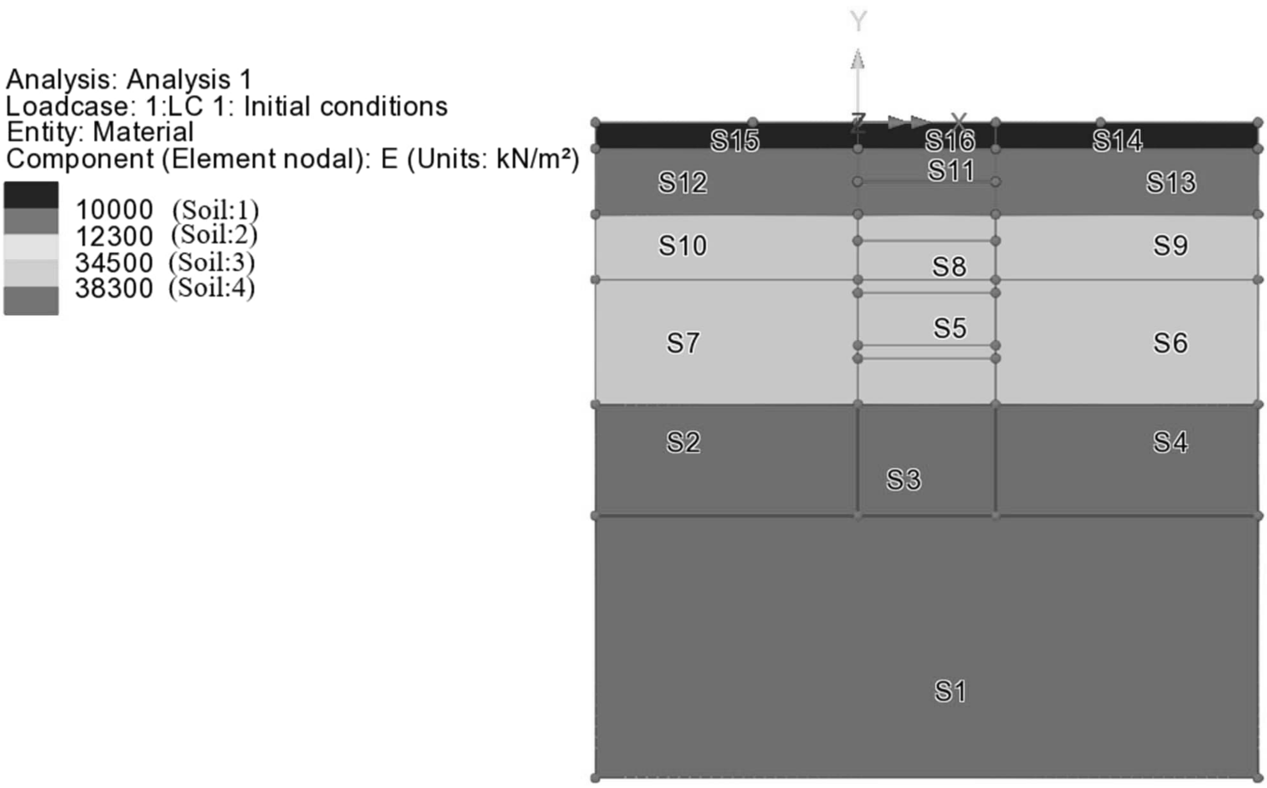


2.7.2 Nonlinear material: soil

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.

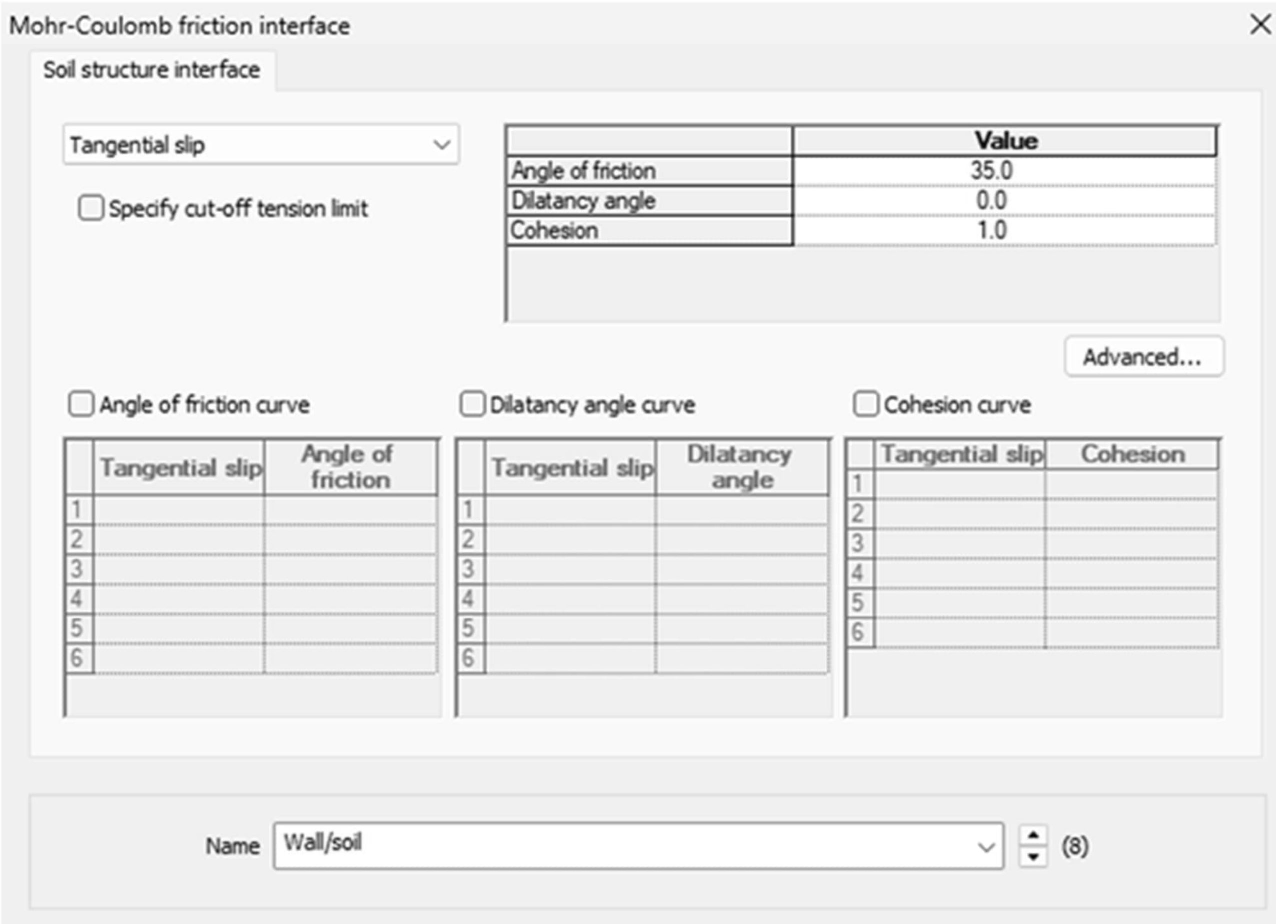
Layer	Mass Density (t/m^3)	Young's modulus, E (kPa)	Poisson's ratio, ν	Angle of friction, φ	Cohesion, c	Earth pressure coefficient, K_0
Soil:1	1.8	10.0E3	0.3	30	1	0.5
Soil:2	1.8	12.3E3	0.3	30	1	0.5
Soil:3	1.9	34.5E3	0.3	34	1	0.44
Soil:4	1.9	38.3E3	0.3	36	1	0.41



ELEVATION
Overall

2.7.3 Nonlinear joint material between retaining wall and soil

The joints between wall and soil are assumed to be same along all surfaces, see choice below.

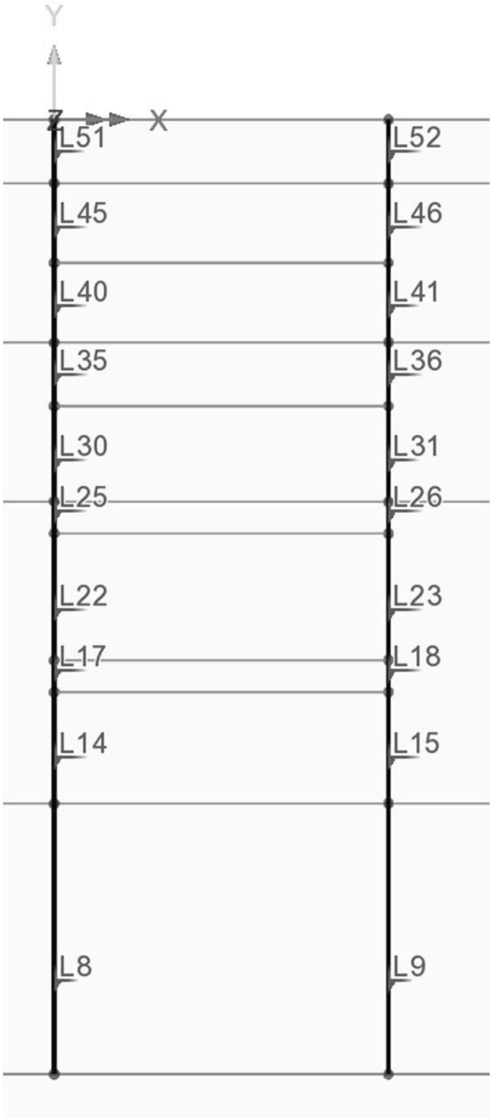


2.8 CROSS SECTIONS

Beams are defined cross section properties.

2.8.1 Sheet piles

Sheet piles is replaced by fictive massive beam with t = 0.1 m.

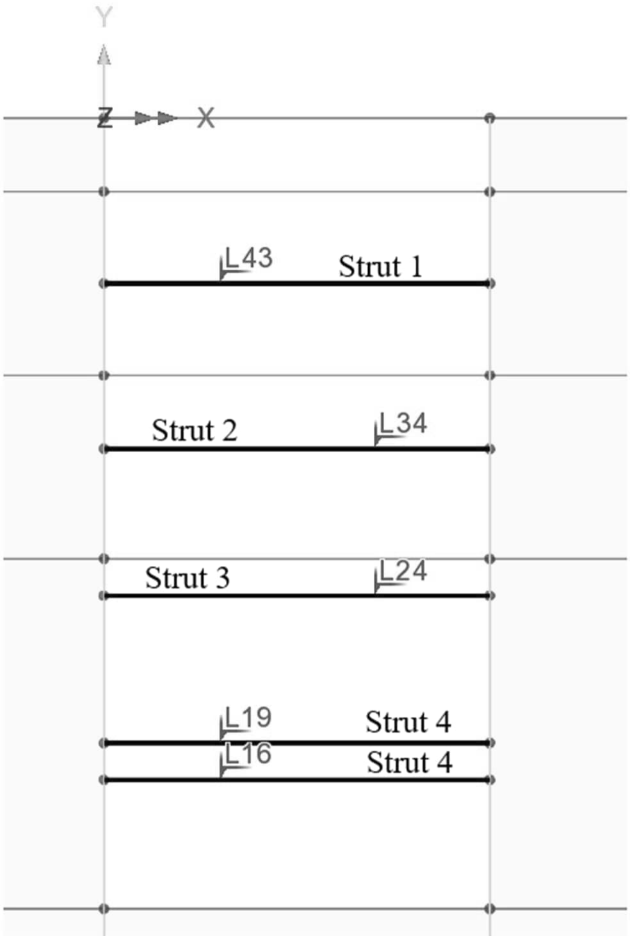


ELEVATION
Detail

2.8.2 Struts

There are 4 level of struts (∴ Strut 1-4).

Strut	Strut spacing (m)	Section area (m^2)
1	6	0.02696
2	6	0.02696
3	6	0.053992
4	6	0.08000
5	6	0.08000



ELEVATION
Detail

3. LOADS

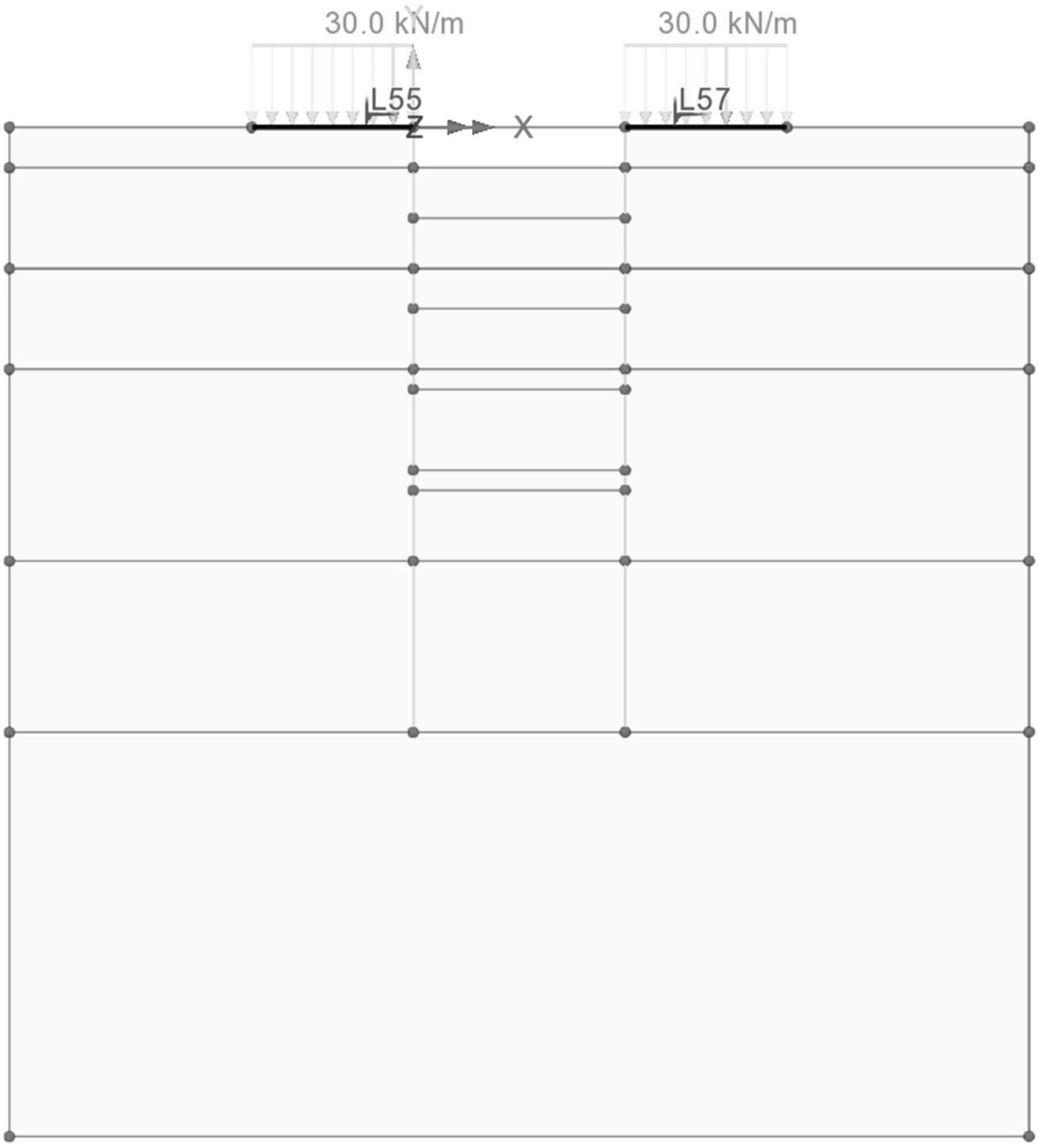
Only gravity loads and surcharge are considered in this example.

3.1 Soil weight (Gravity)

Soil weight is determined material density.

3.2 Surcharge

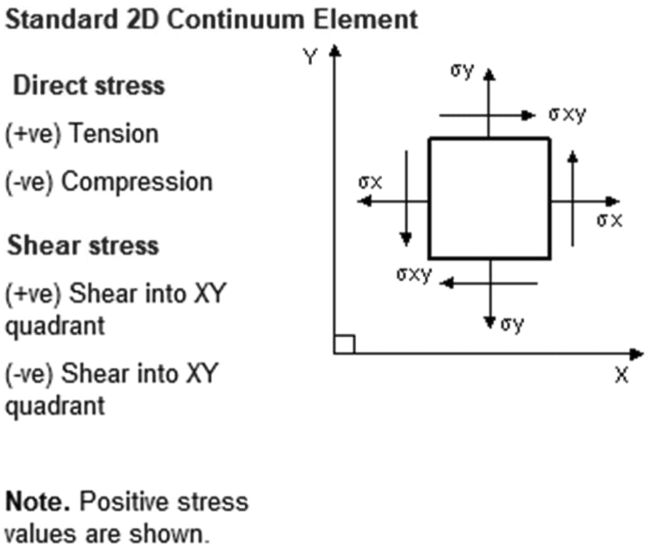
Surcharge (q = 35 kPa) is applied during excavation:1 (LC 3) and brought forward to excavation:4 (LC 6).



ELEVATION
Overall

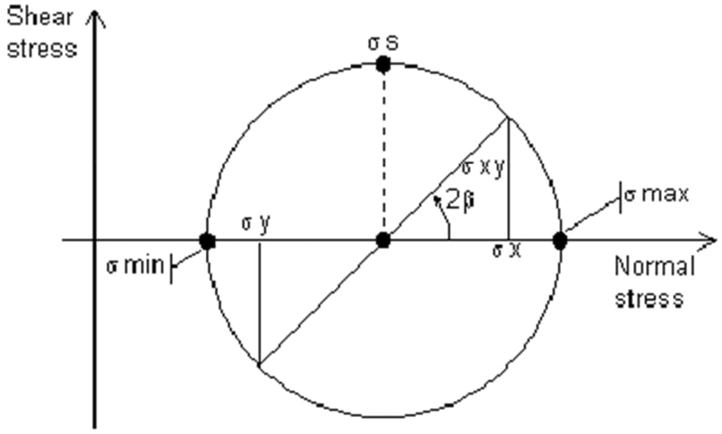
4. RESULTS (FEM-program)

4.1 Earth pressure



Output Notation for Principal Stresses

For a bi-axial stress state, the Mohr's circle representation of a stress field is:



where:

σmax is the maximum principal stress.

σmin is the minimum principal stress

σs is the maximum shear stress

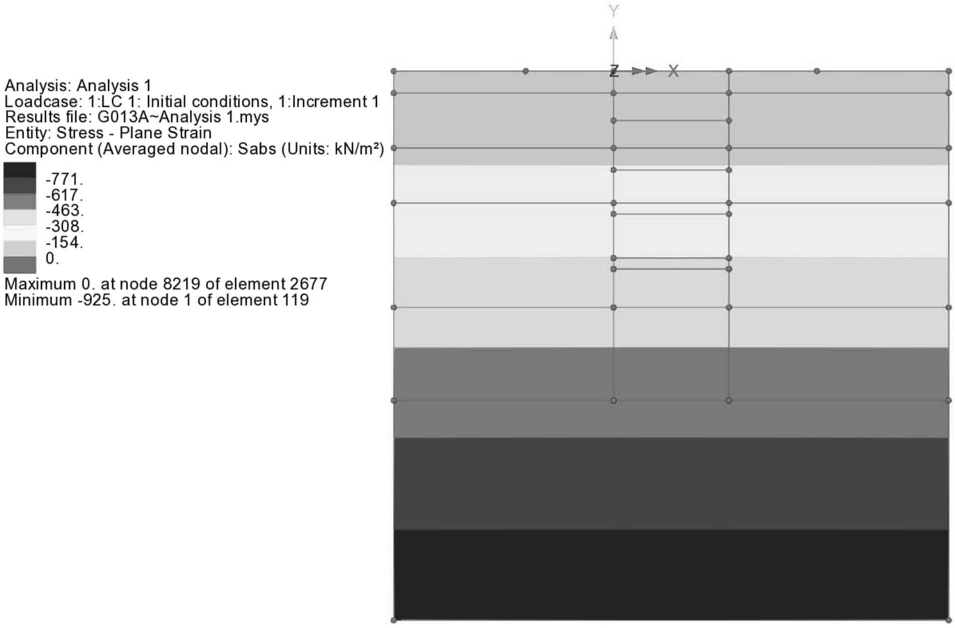
β defines the orientation of the principal axis (the plane on which the principal stresses act).

σx, σy, σxy represent an arbitrary two dimensional stress state.

SX	Direct stress in global X direction
SY	Direct stress in global Y direction
SZ	Direct stress in global Z direction
SXY	Shear stress in Y-direction on a plane normal to X
SYZ	Shear stress in YZ plane
SZX	Shear stress in ZX plane
SMax	Maximum principal stress
SMin	Minimum principal stress
S1	Major principal stress
S2	Intermediate principal stress
S3	Minor principal stress
Sabs	Signed largest value of principal
β	Angle between E1 and x axis
SI	Maximum shear stress
SE	Equivalent stress (von Mises)

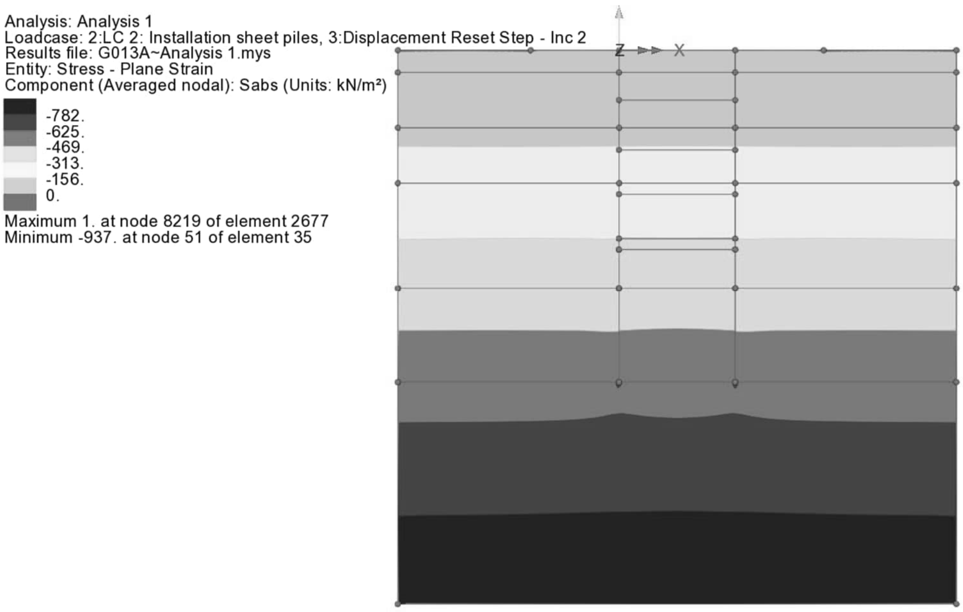
4.1.1 LC 1

→ Min Sabs = -925 kPa



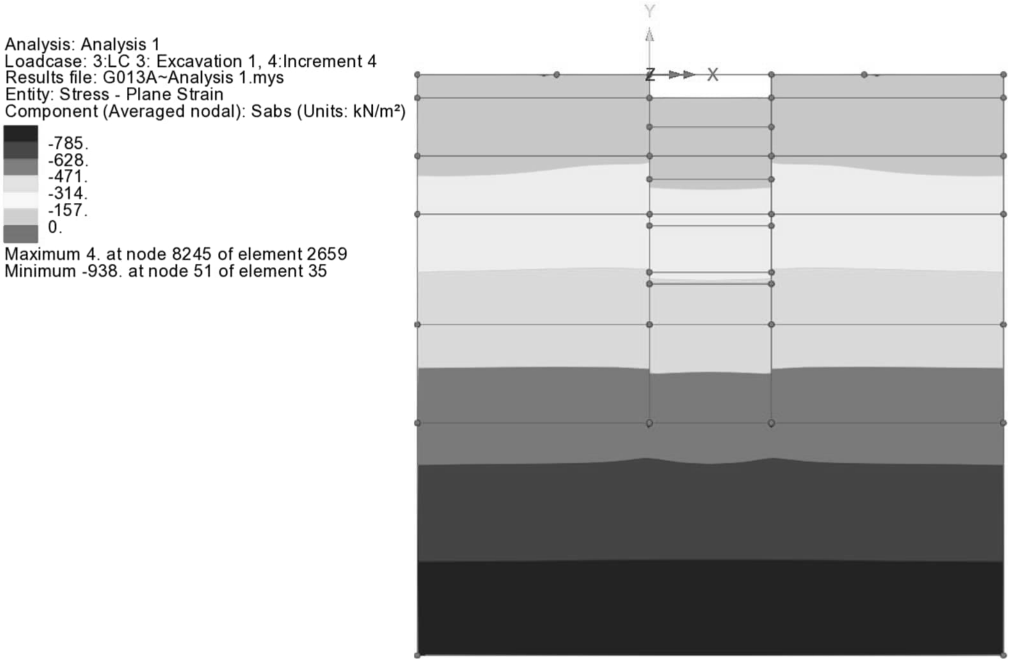
4.1.2 LC 2

→ Min Sabs = -1089 kPa



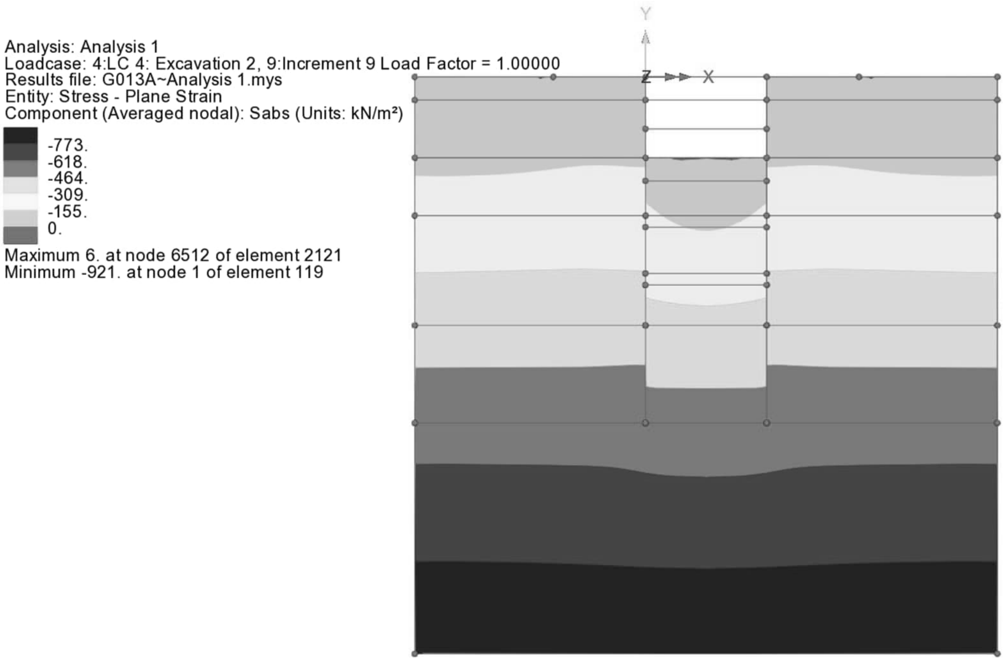
4.1.3 LC 3

→ Min Sabs = -938 kPa



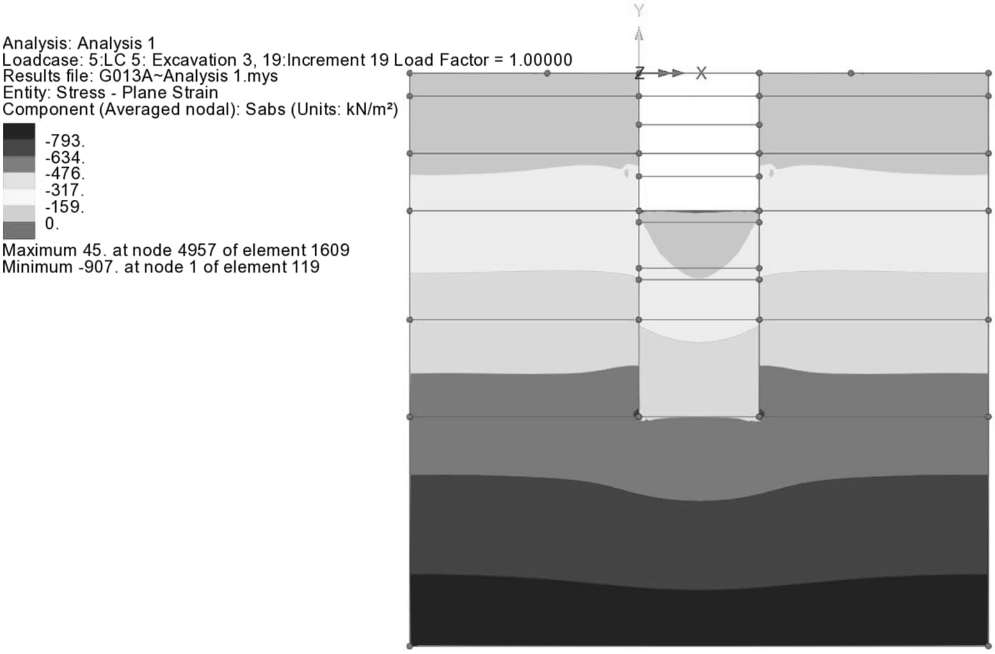
4.1.4 LC 4

→ Min Sabs = -921 kPa



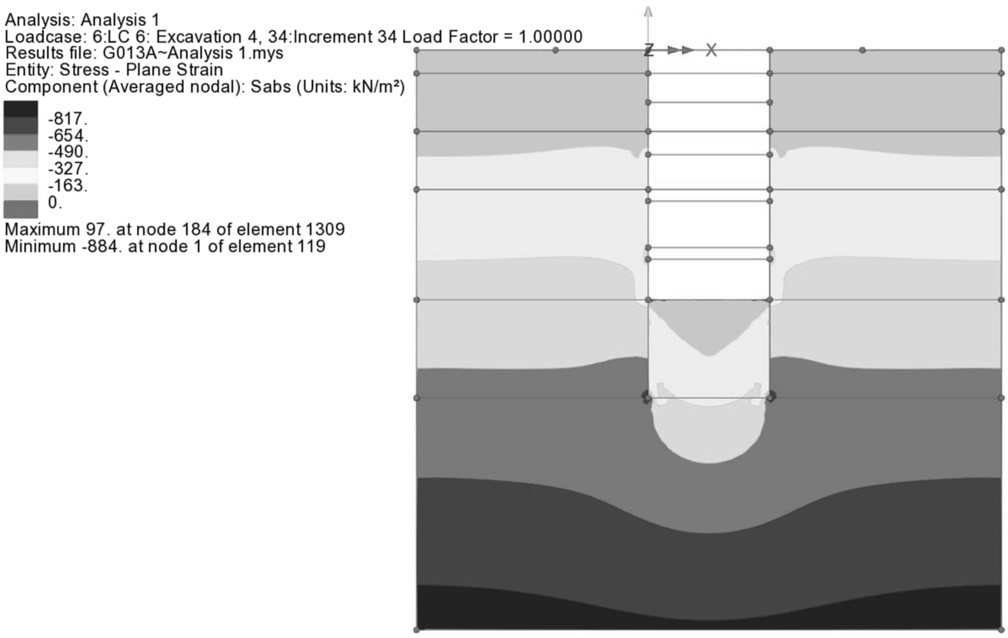
4.1.5 LC 5

→ Min Sabs = -907 kPa



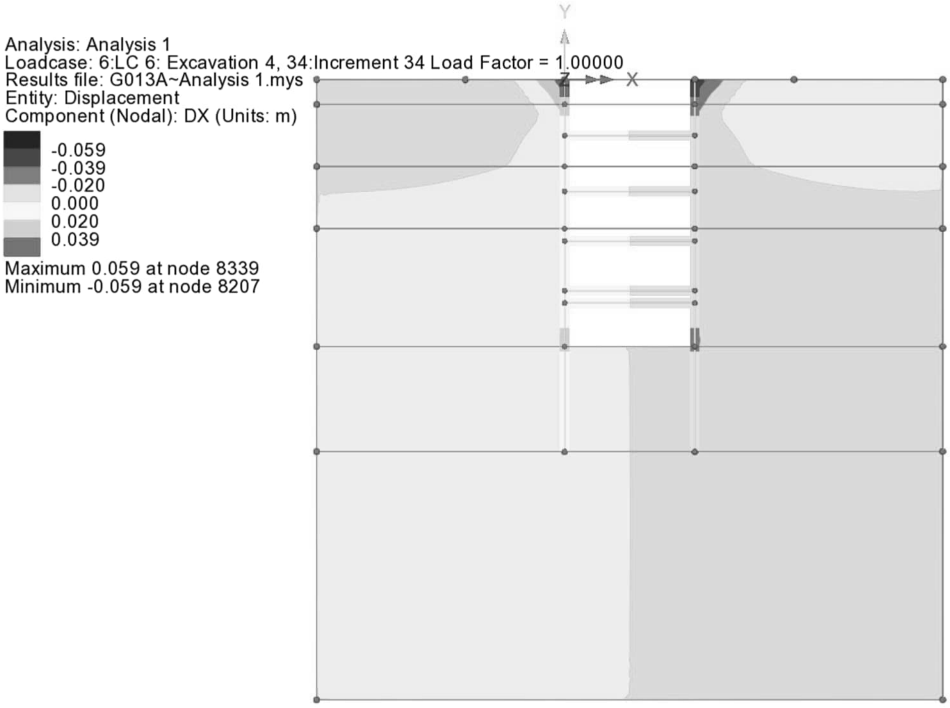
4.1.6 LC 6

→ Min Sabs = -884 kPa



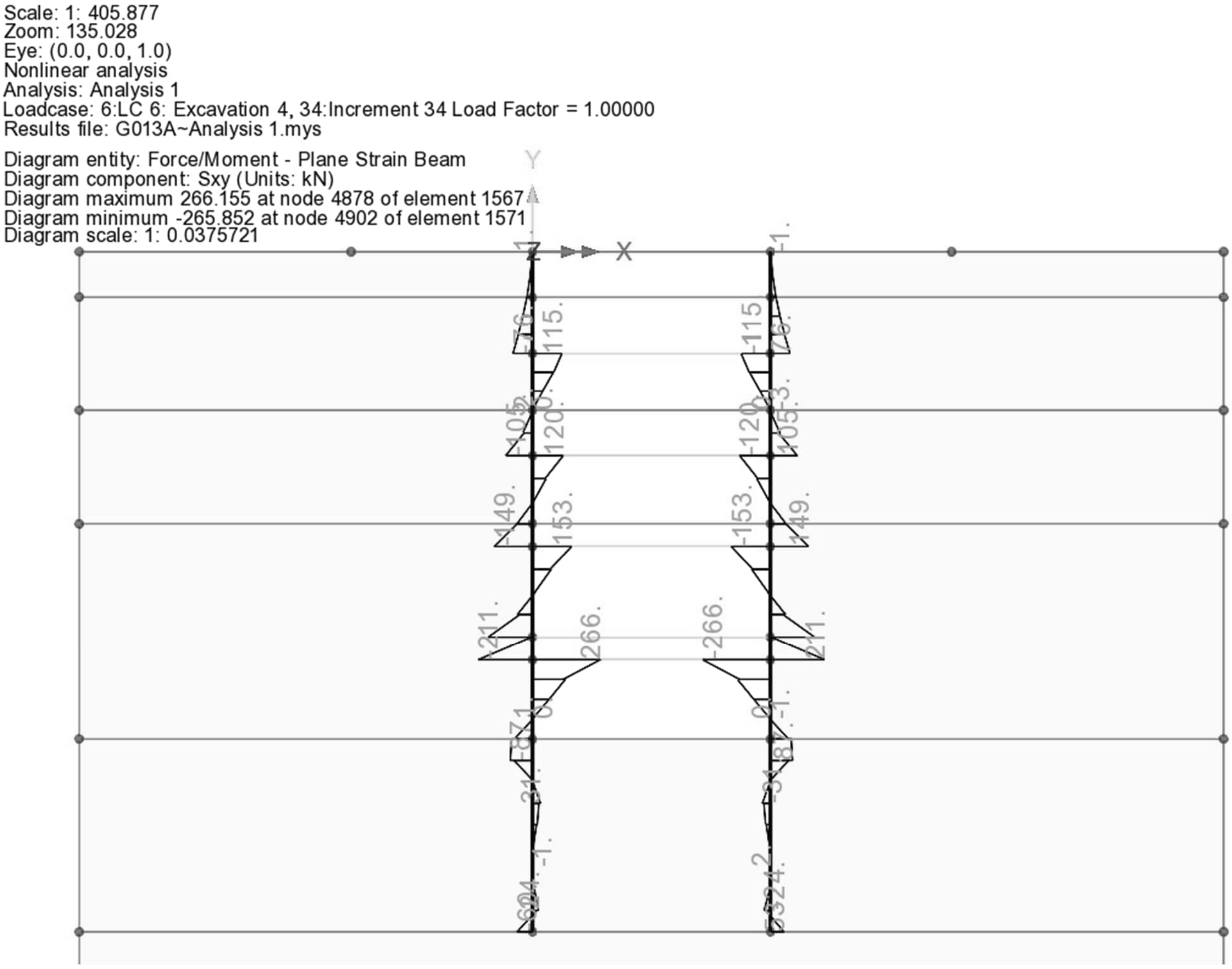
4.2 Horizontal displacement after completed excavation (LC 6)

→ Max Dx = +0.059 m
Min Dx = -0.059 m



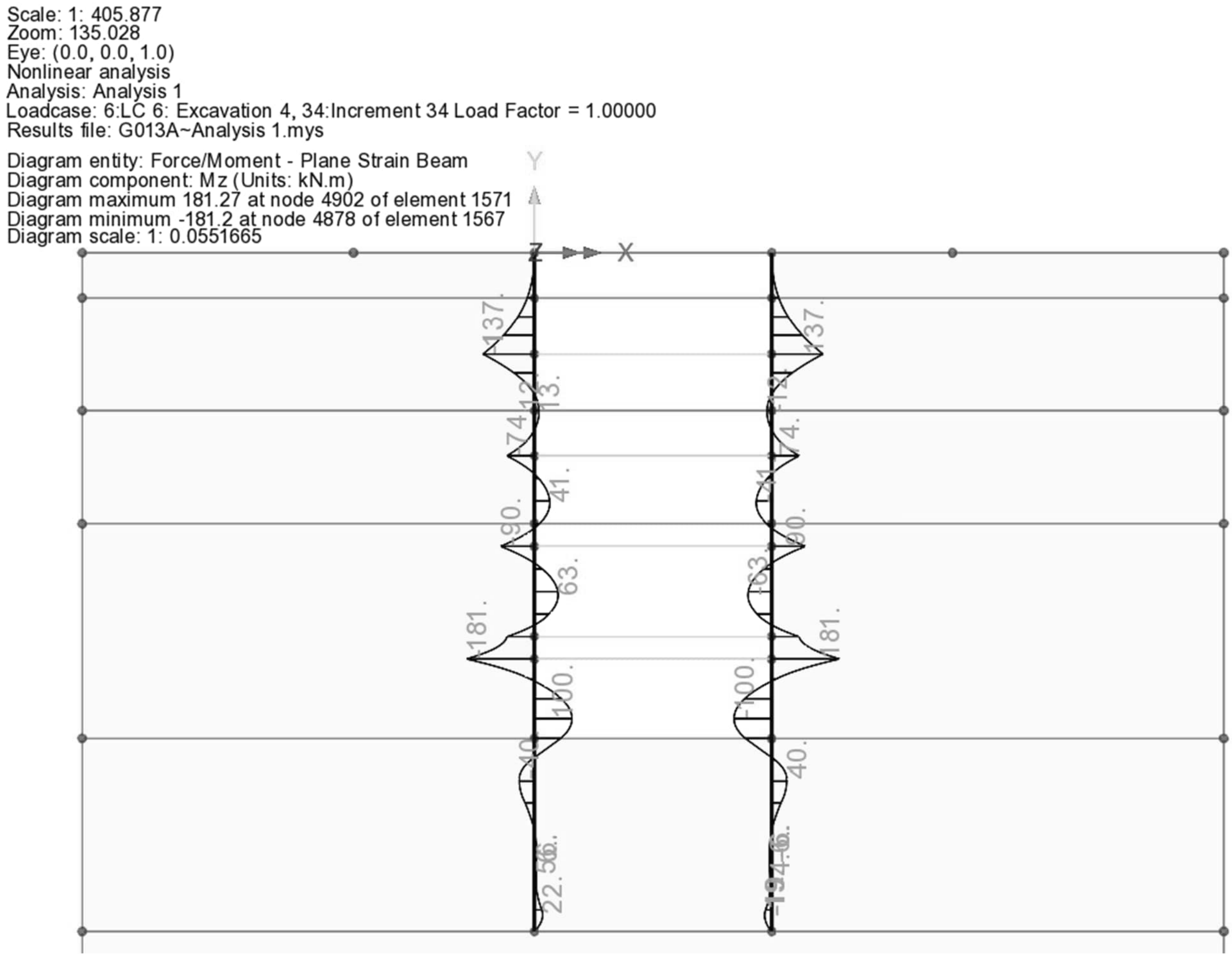
4.3 Shear force sheet pile after completed excavation (LC 6)

→ Max Sxy = +266kN
Min Sxy = -266kN



4.4 Bending moment sheet pile after completed excavation (LC 4)

→ Max Mz = +181 kNm
Min Mz = -181 kNm



4.5 Normal axial struts (LC 4)

→ Max Fx = -174 kN
Min Fx = -492 kN