

Braced sheet pile box

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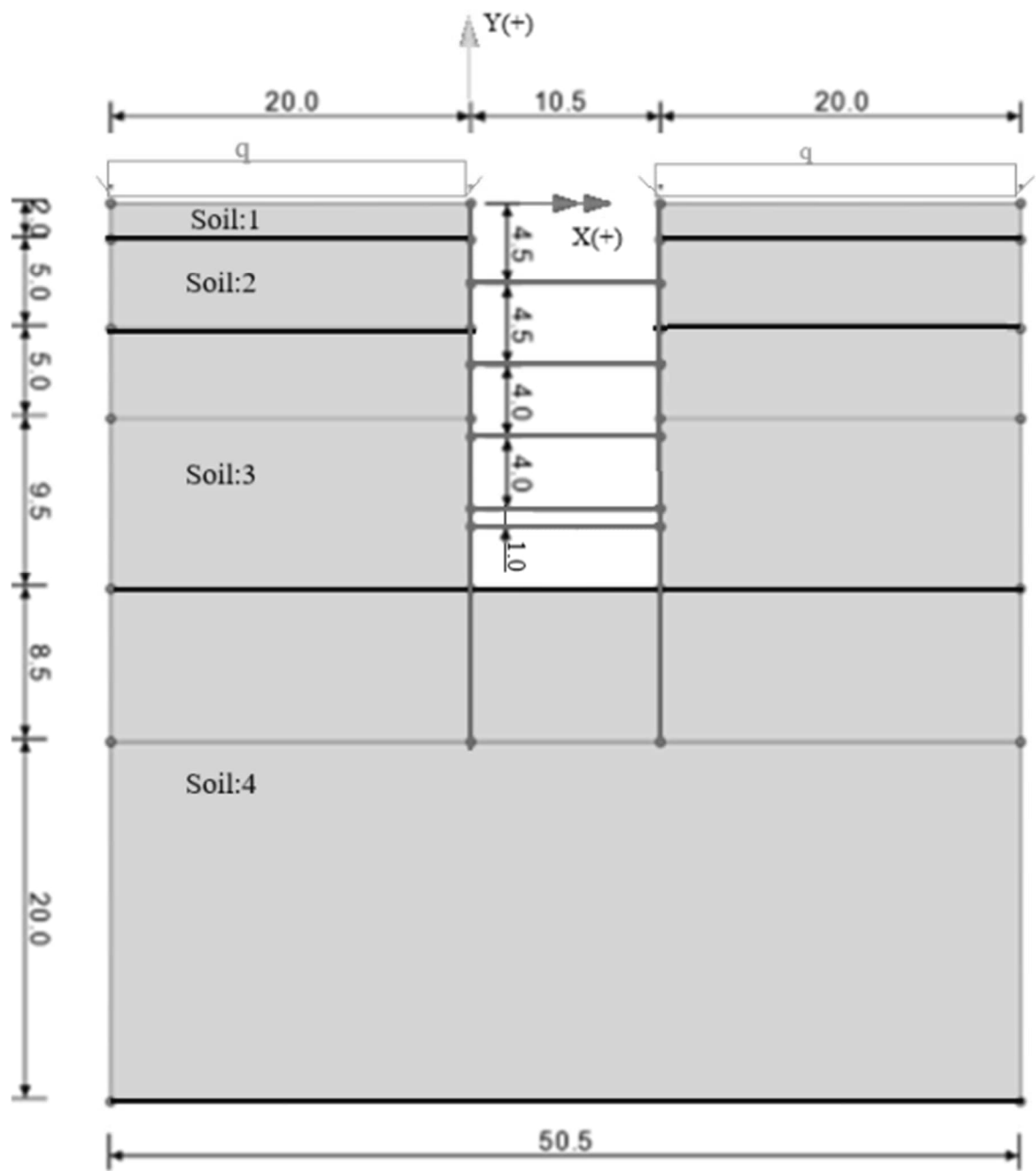
Input receipt (FEM-program)

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1. GENERAL

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

1.1 GEOMETRY



ELEVATION
Overall

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1.2 SOIL PROPERTIES

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

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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 retaining 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

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2.2 NONLINEAR ANALYSIS

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

Max number of iterations:

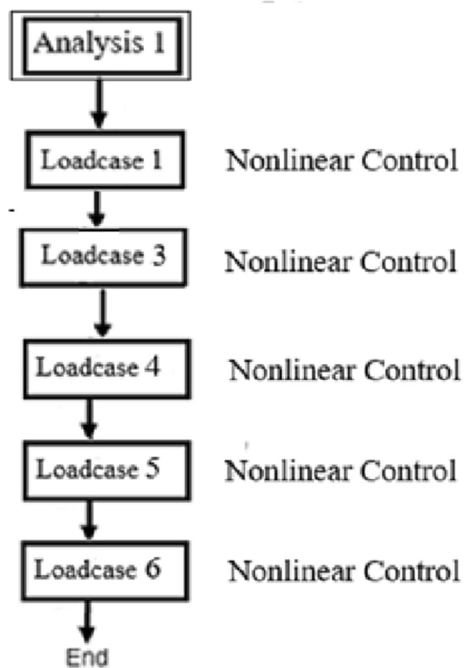
For each load increment if convergence is not achieved.

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.



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

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Manual

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

Nonlinear & Transient

Incrementation

☒ Nonlinear

Incrementation
Manual

Starting load factor
0.1

Max change in load factor
0.0

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
0

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Automatic

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

Nonlinear & Transient

Incrementation

☒ Nonlinear

Incrementation

Automatic

Starting load factor

0.1

Max change in load factor

0.0

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

0

File : Braced sheet pile box
Datum : 2026-07-23
Tid : 13:11

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2.3 RESET DEFORMATIONS

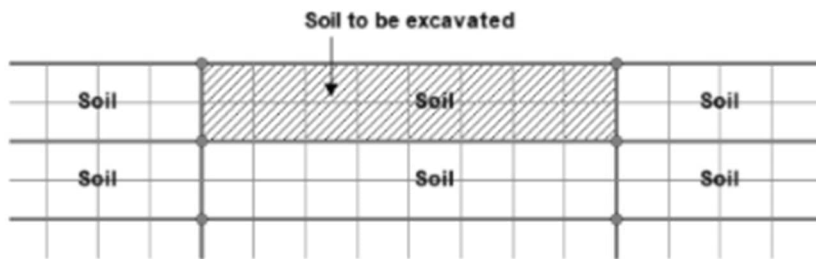
After installation sheet piles (LC 2) all node deformations associated all lines and surfaces.

Assigned to line(s)	1T5811
Assigned to surface(s)	1T1611
Assigned to volume(s)	

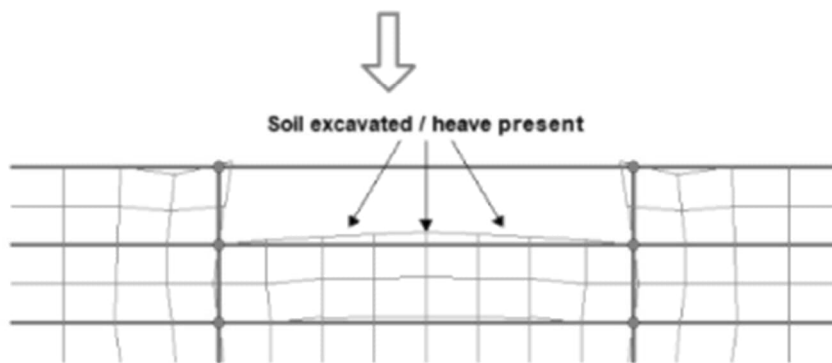
☐ LC 1: Initial conditions
☒ LC 2: Installation sheet piles
☐ LC 3: Excavation 1
☐ LC 4: Excavation 2
☐ LC 5: Excavation 3
☐ LC 6: Excavation 4

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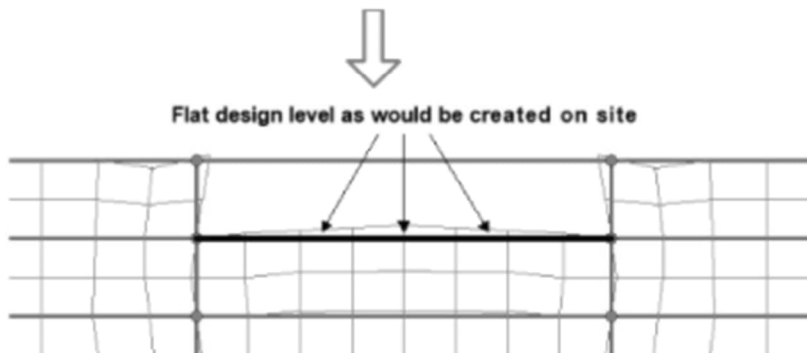
Principle of reset of deformations of lines (also applies to surfaces):



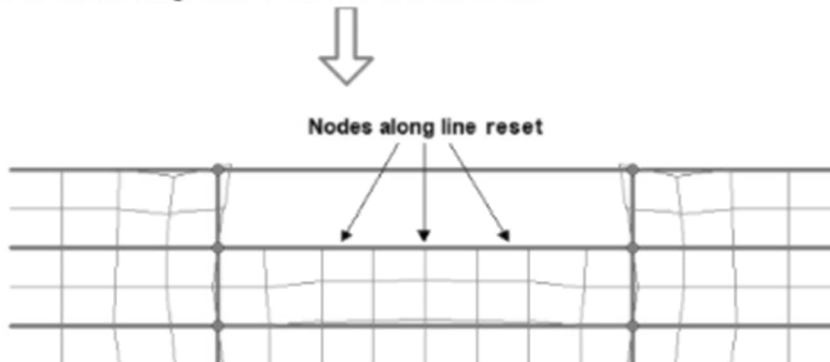
Excavation between sheet pile retaining walls



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.

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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.

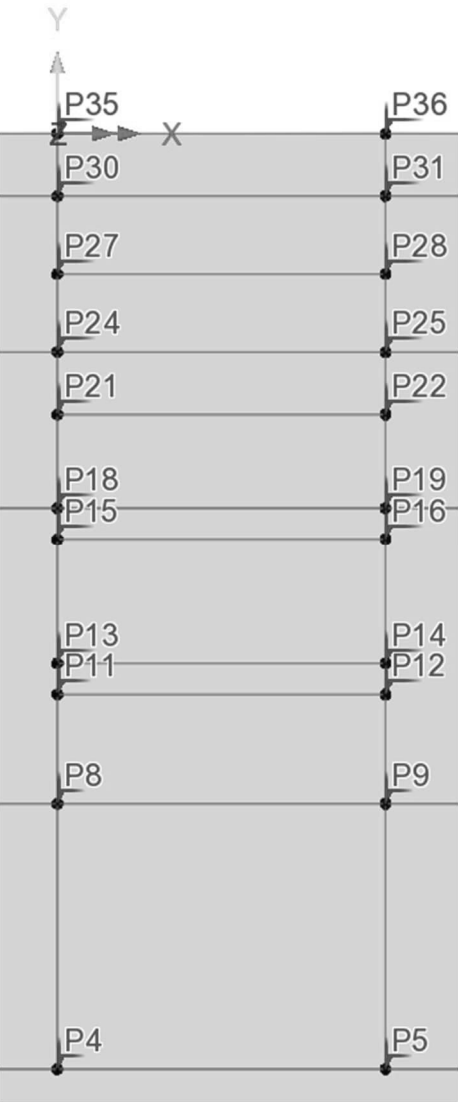
Sketches are generated by using POINTS, LINES and SURFACES.

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.

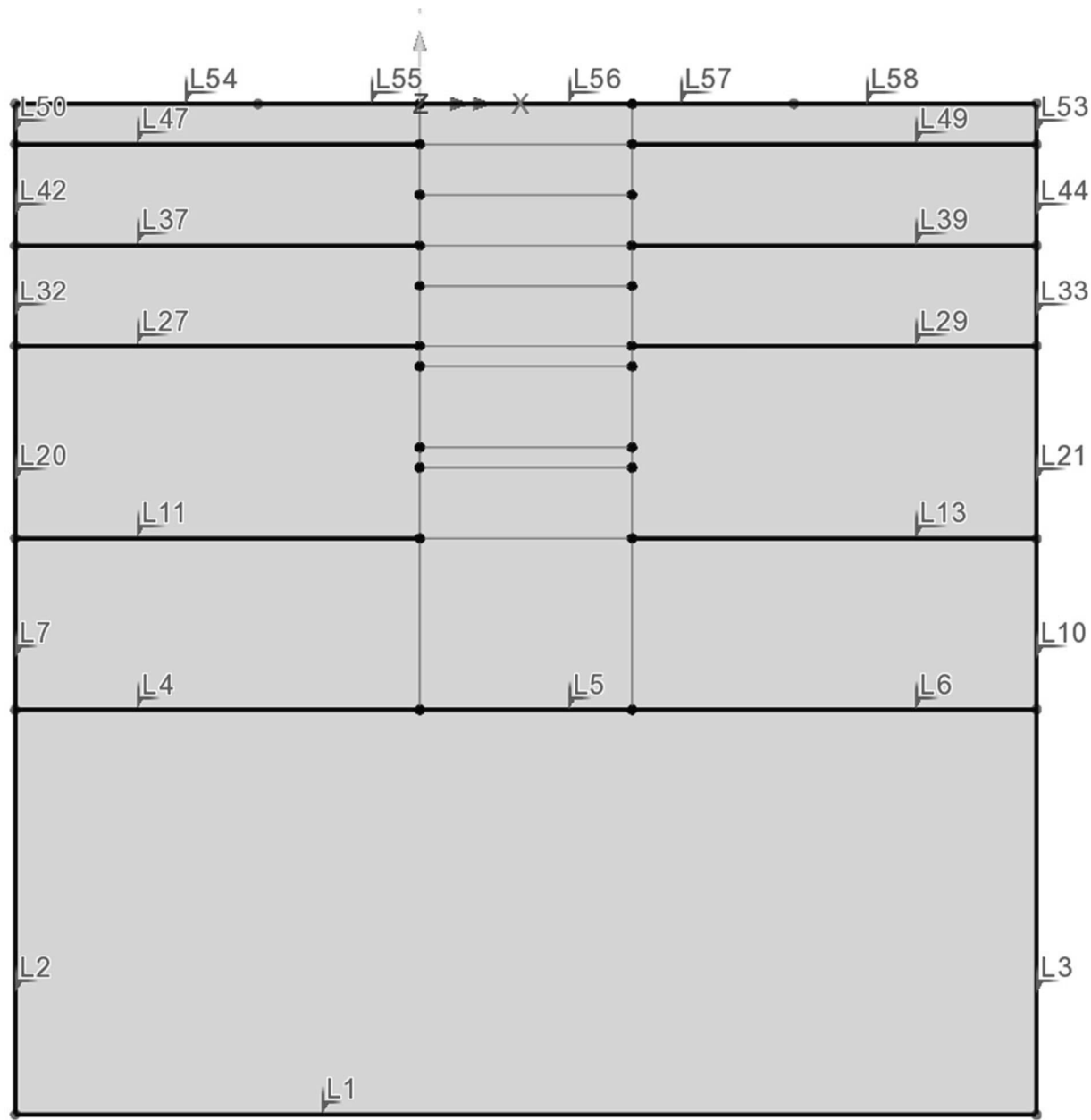
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ELEVATION
Detail

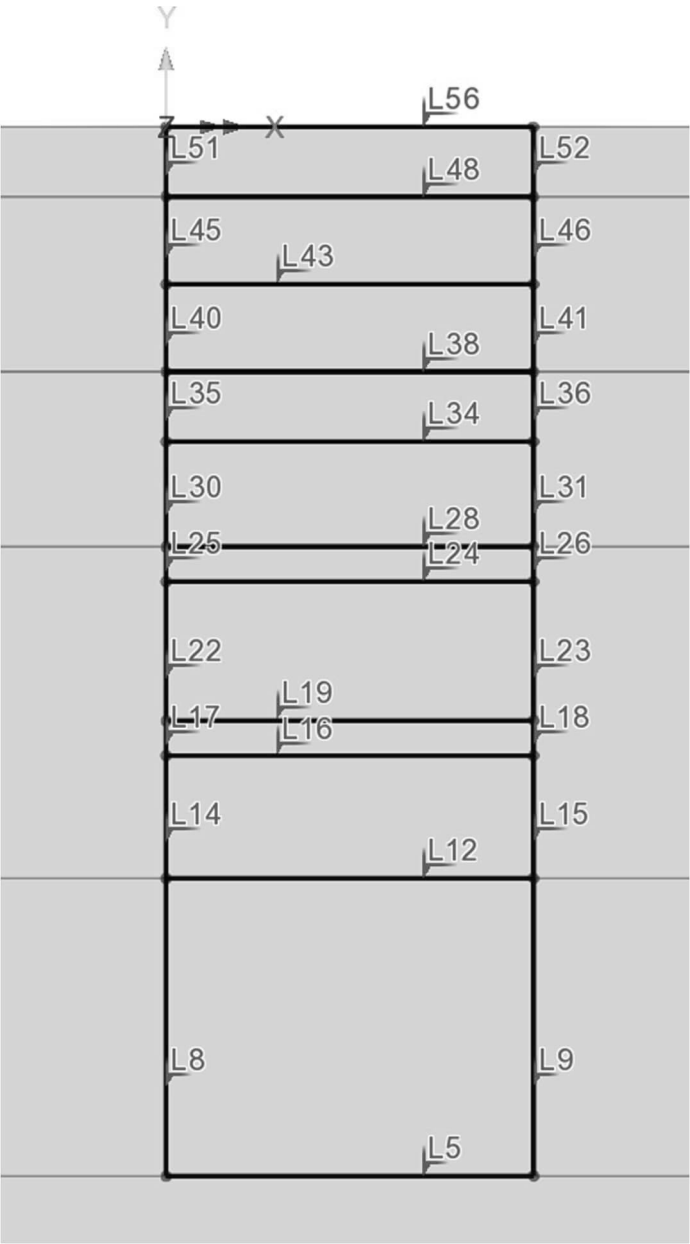
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2.4.2 Geometry: Lines



ELEVATION
Overall

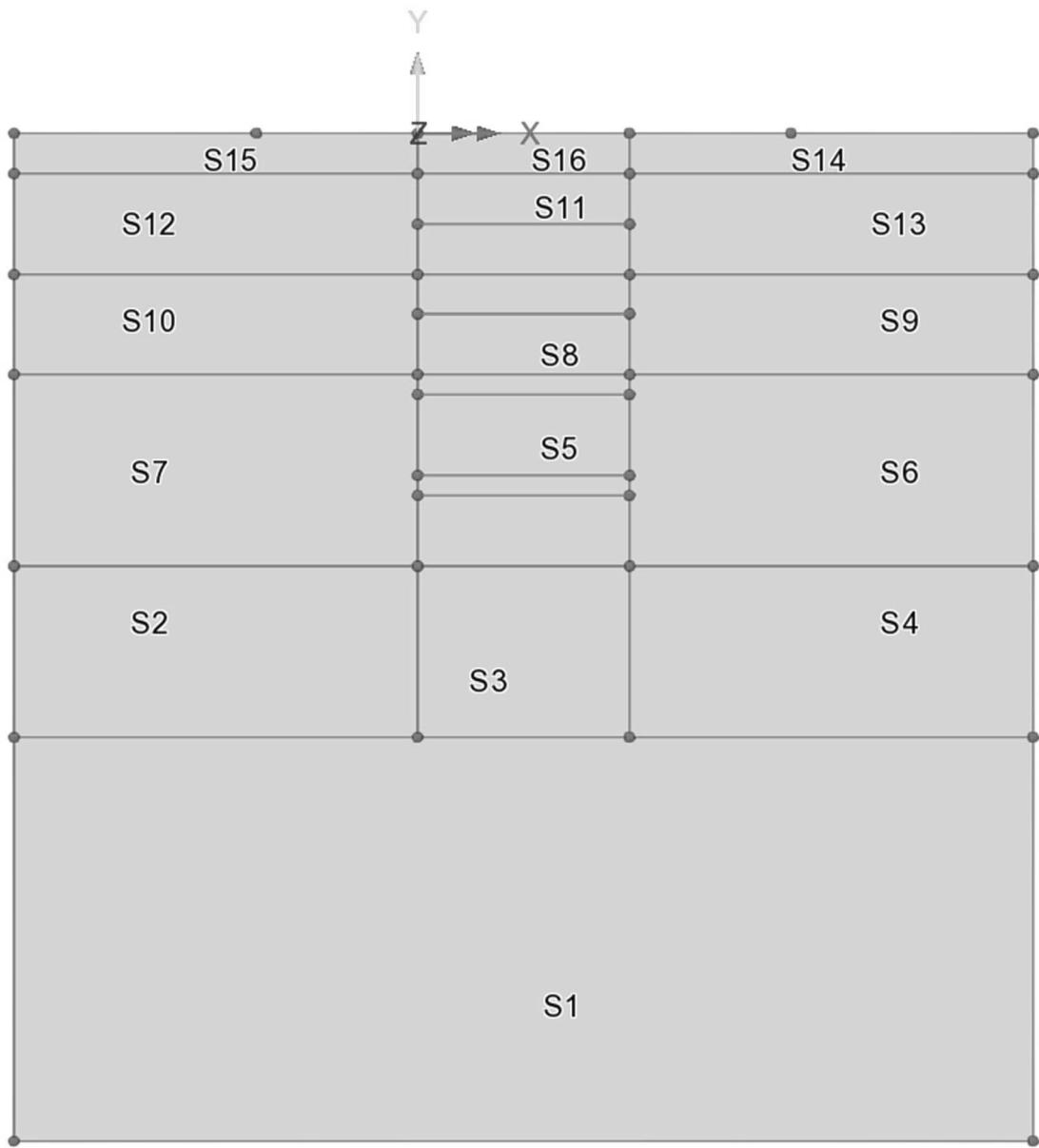
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Detail

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2.4.3
Geometry: Surfaces

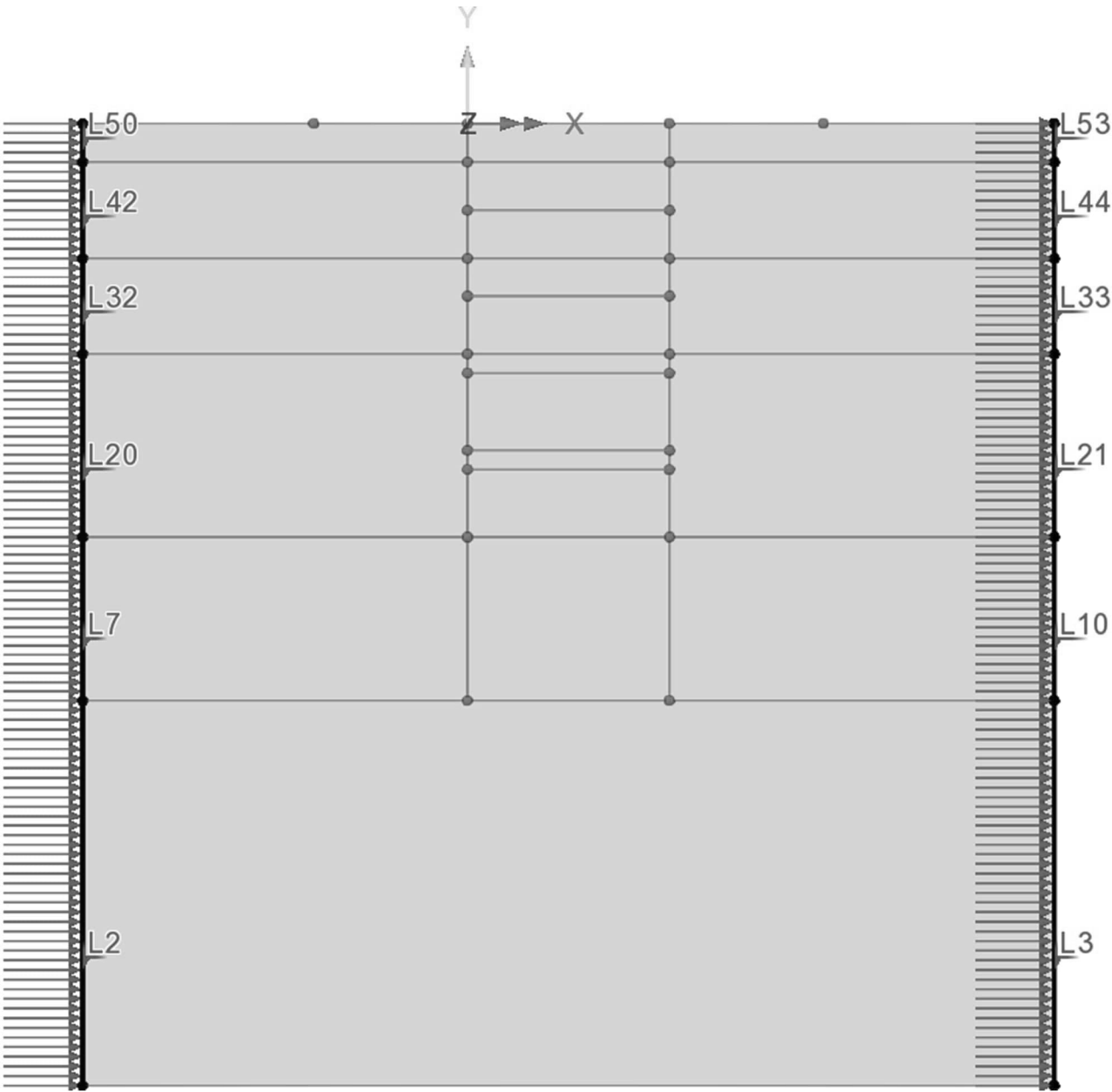


ELEVATION
Overall

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2.5 BOUNDARY CONDITIONS

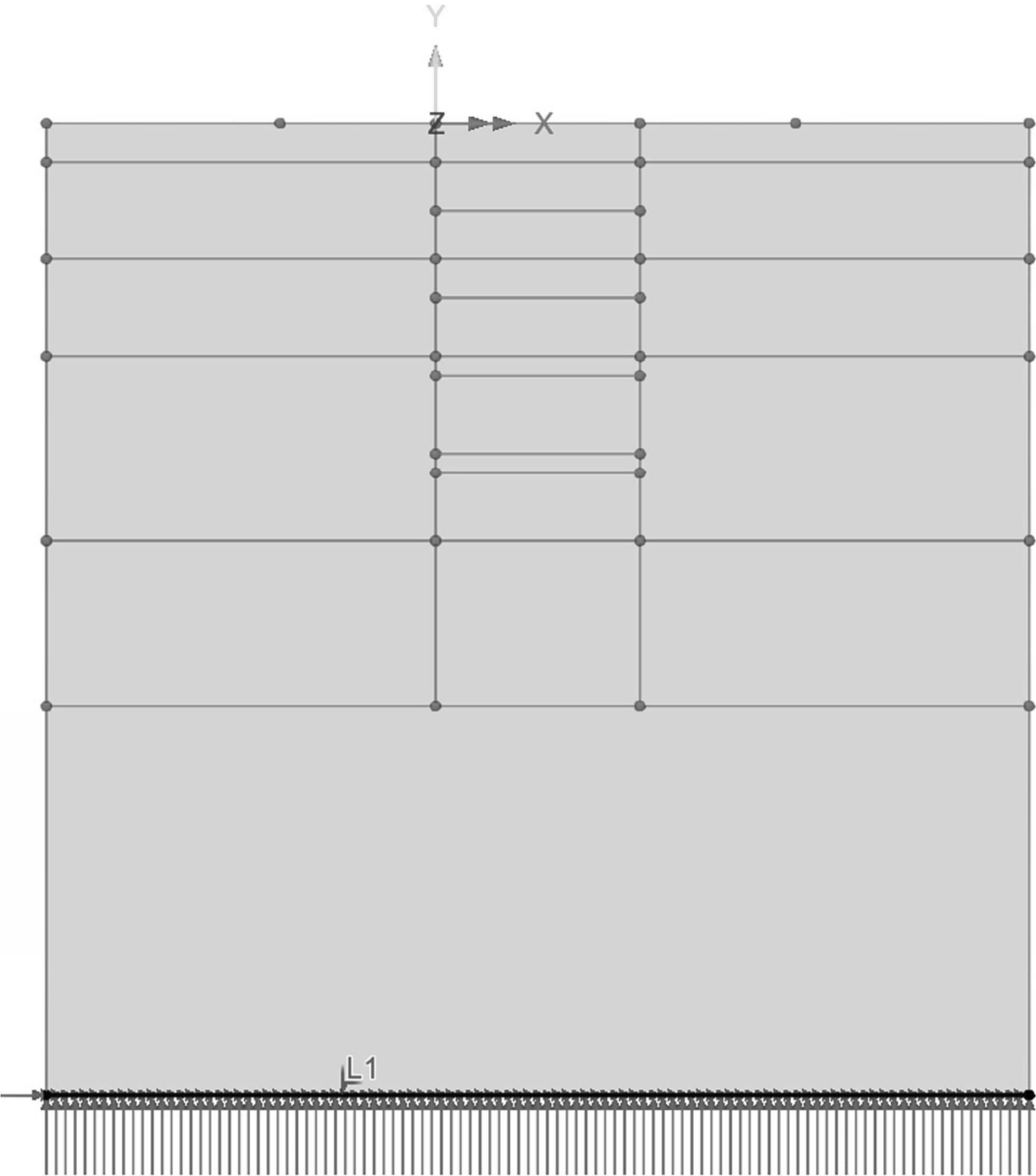
2.5.1 Horizontal boundary soil: Fixed X



ELEVATION
Overall

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2.5.2
Vertical boundary soil: Fixed XY



ELEVATION
Overall

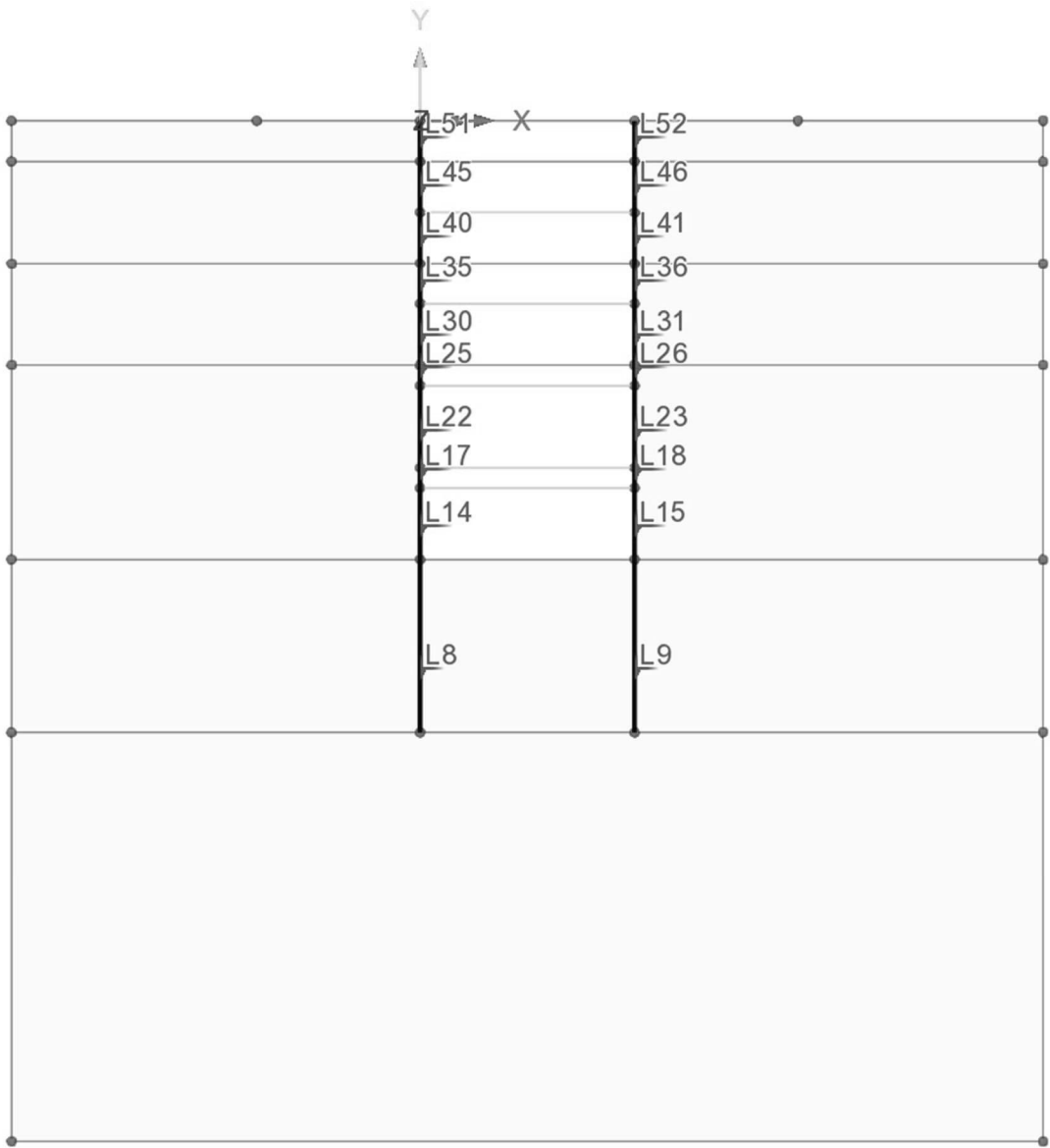
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2.6 MESH

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.



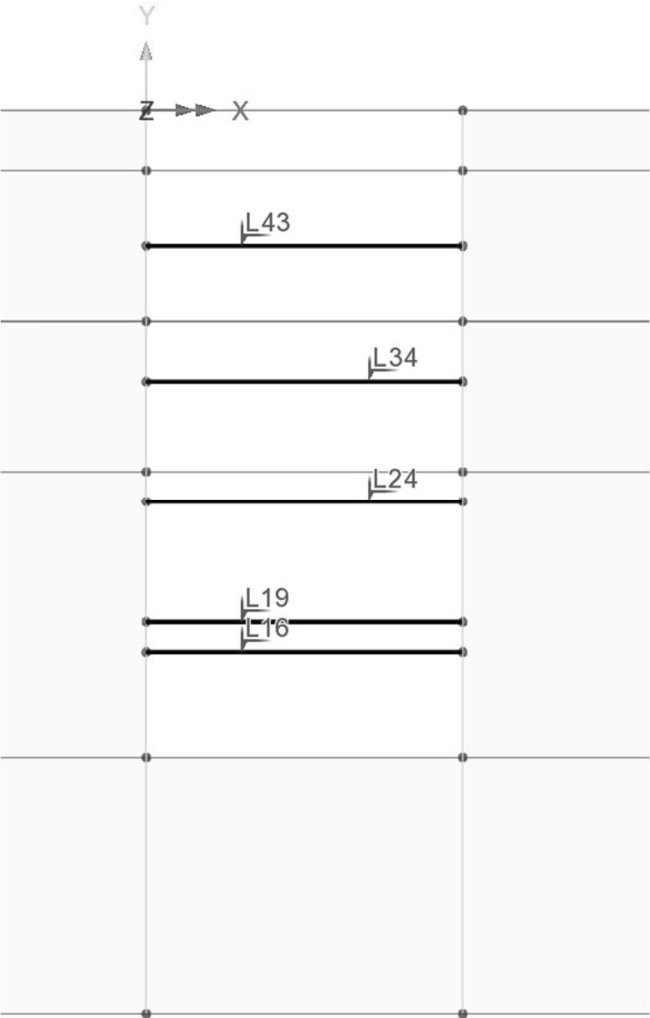
ELEVATION
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2.6.2 Strut: Bar element

Horizontal struts is modelled as seen below.

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



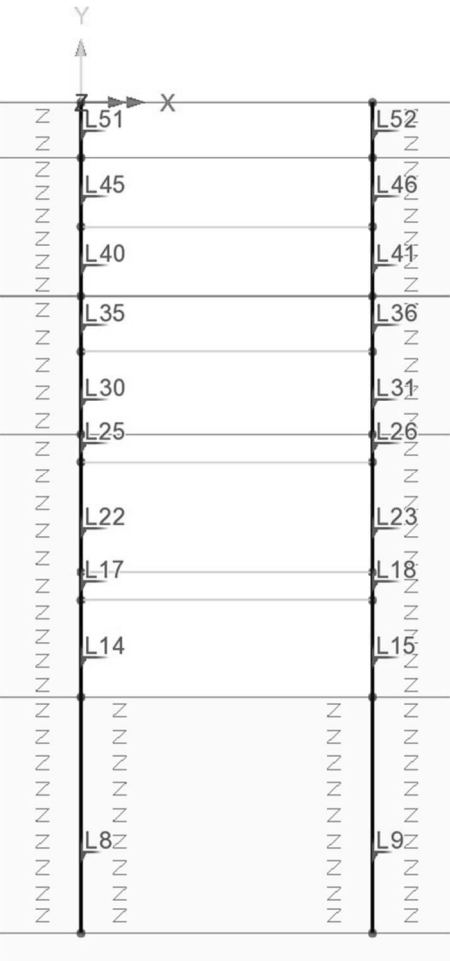
ELEVATION
Detail.

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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 analysis is not required. 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.

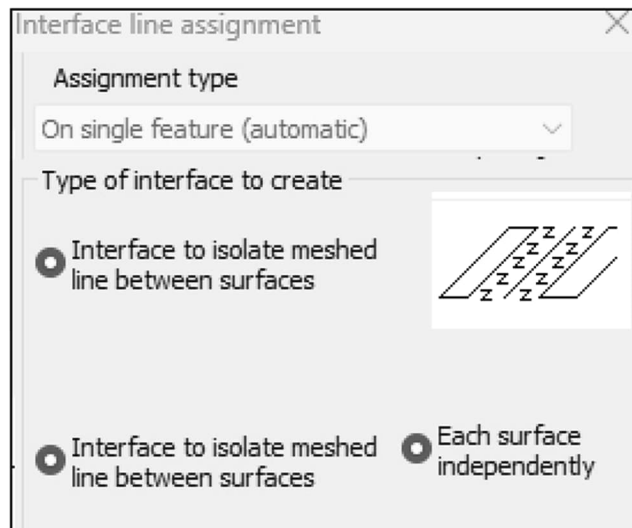


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Remark

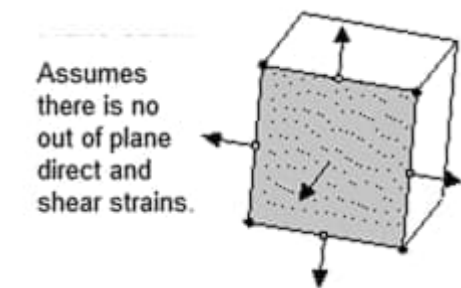
When applying the interface element, a single method is considered that automatically creates joint on either side of line defining wall, thus no need to use unmerged points & lines.



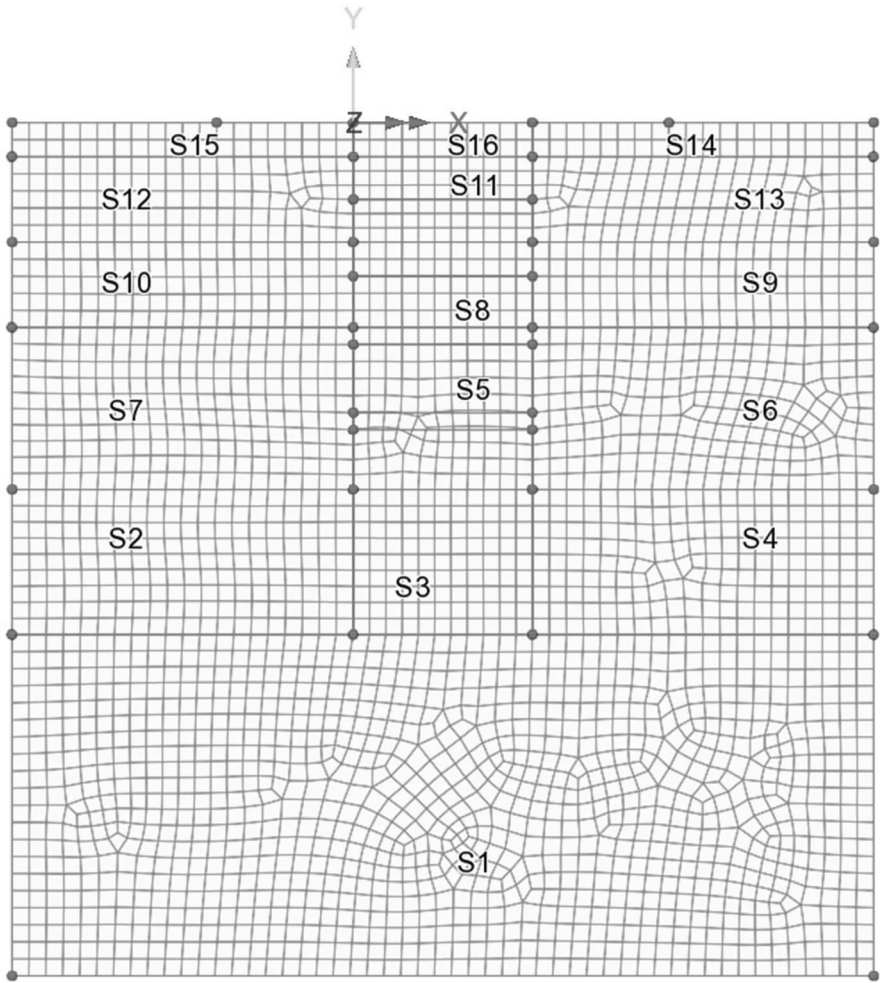
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2.6.4 Soil: plain strain surface elements (QPN8)

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



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2.7 MATERIAL

2.7.1 Linear elastic material: wall & strut

Isotropic

☐ Plastic☐ Creep☐ Damage☐ Shrinkage☐ Viscous☐ Two phase☐ Ko Initialisation

Elastic

☐ Dynamic properties☐ Thermal expansion

	Value
Young's modulus	210.0E6
Poisson's ratio	0.3
Mass density	7.8

Name

Steel

(3)

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2.7.2 Nonlinear material: soil

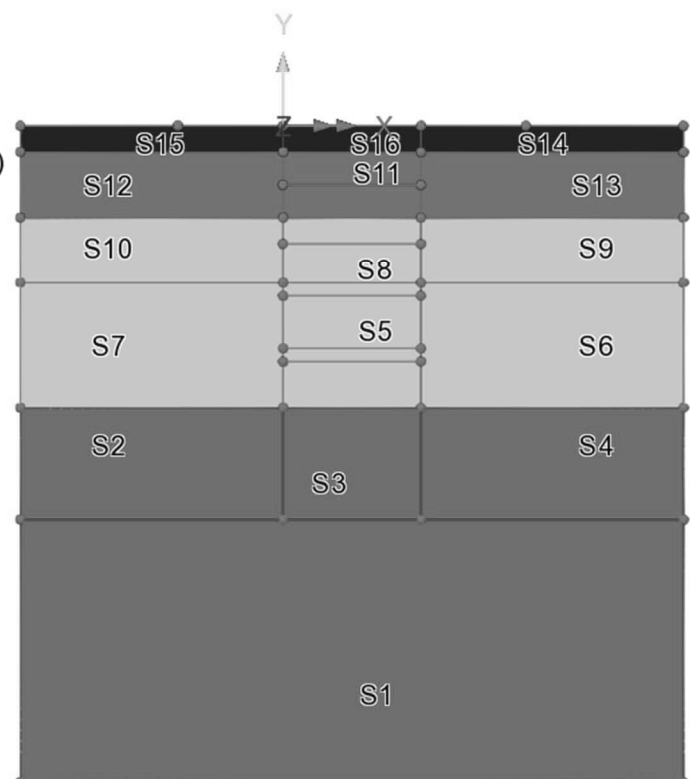
Soil (friction material) is modelled modified Mohr-Coulomb. This model applies a Rankine tensile cut-off to standard Mohr-Coulomb model.

The standard model would predicts tensile stresses beyond the uniaxial tensile limit of the material, while the modified model 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

Analysis: Analysis 1
Loadcase: 1:LC 1: Initial conditions
Entity: Material
Component (Element nodal): E (Units: kN/m²)

	10000 (Soil:1)
	12300 (Soil:2)
	34500 (Soil:3)
	38300 (Soil:4)



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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.

Mohr-Coulomb friction interface

Soil structure interface

Tangential slip

☐ Specify cut-off tension limit

	Value
Angle of friction	35.0
Dilatancy angle	0.0
Cohesion	1.0

Advanced...

☐ Angle of friction curve

☐ Dilatancy angle curve

☐ Cohesion curve

	Tangential slip	Angle of friction
1		
2		
3		
4		
5		
6		

	Tangential slip	Dilatancy angle
1		
2		
3		
4		
5		
6		

	Tangential slip	Cohesion
1		
2		
3		
4		
5		
6		

Name

Wall/soil

(8)

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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.

Geometric Line

Analysis category
2D Inplane

Definition

☐ From library / calculator
☒ Enter properties

Usage
Plane Strain Beam

EU Sections
HE Shapes (EN53-62)
HE 1000 M

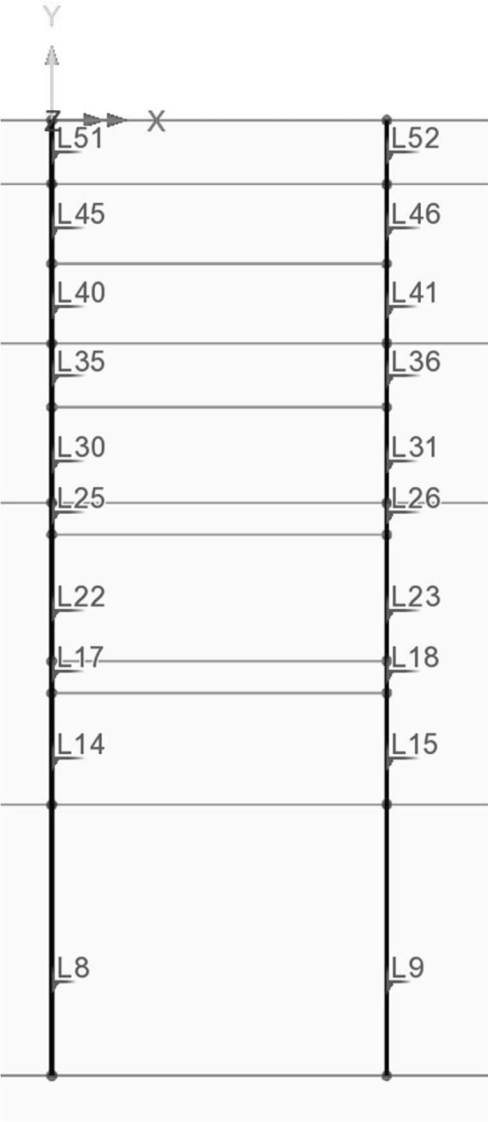
100%

	Value
In-plane thickness	0.1

Visualise...
Section details...

Name
Wall
(1)

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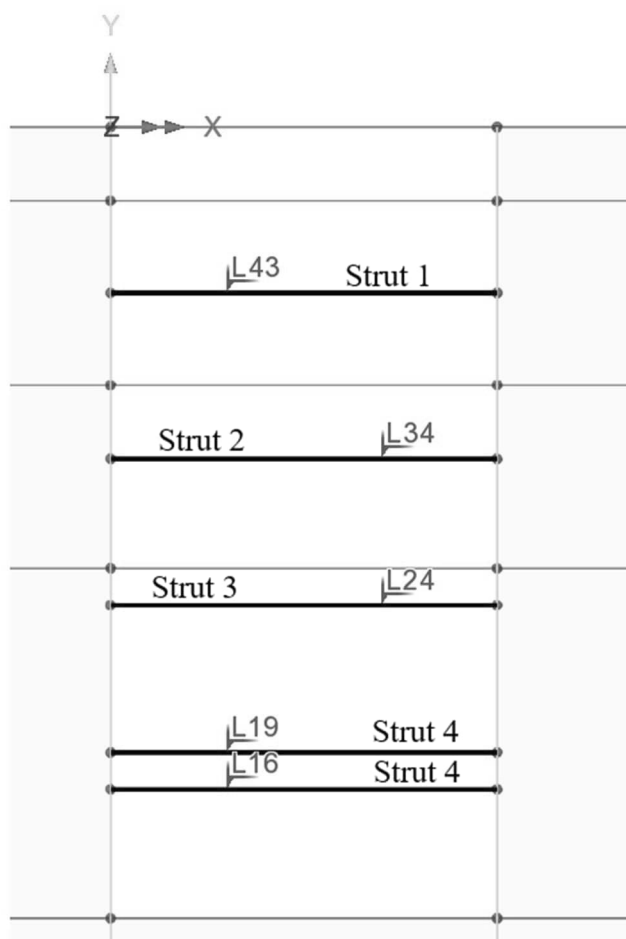
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2.8.2 Struts

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



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3. LOADS

Only gravity loads and surcharge are considered in this example.

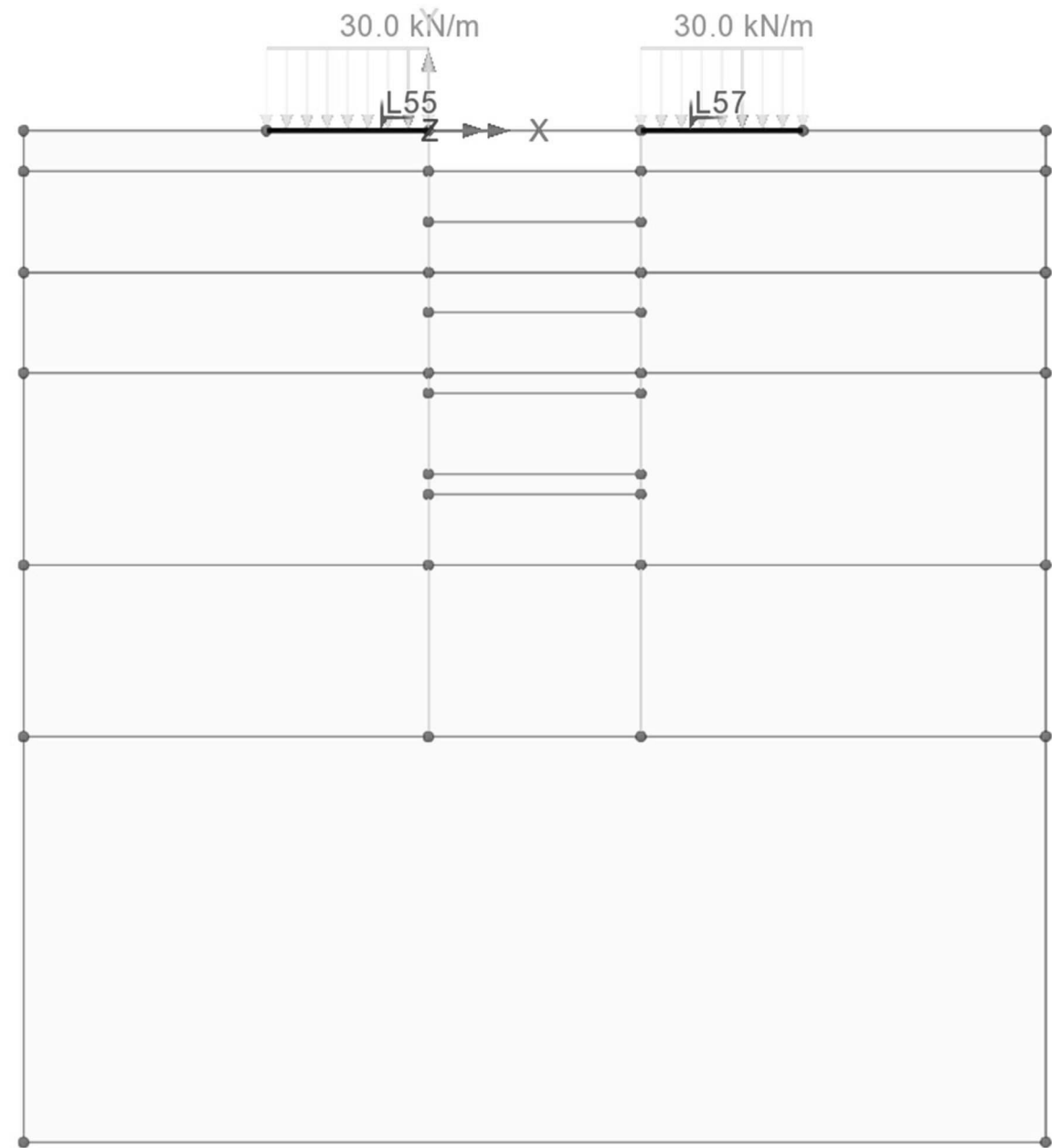
3.1 Soil weight (Gravity)

Soil weight is determined material density.

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3.2 Surcharge

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



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Overall

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4. RESULTS (FEM-program)

4.1 Earth pressure

Standard 2D Continuum Element

Direct stress

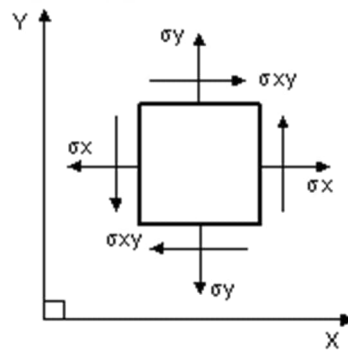
(+ve) Tension

(-ve) Compression

Shear stress

(+ve) Shear into XY quadrant

(-ve) Shear into XY quadrant

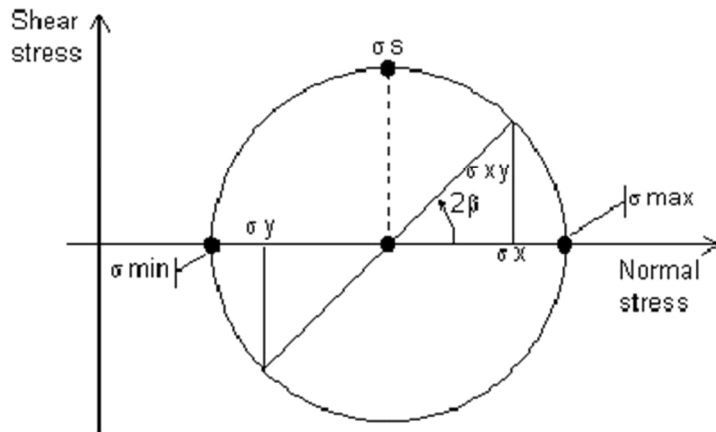


Note. Positive stress values are shown.

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Output Notation for Principal Stresses

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



where:

σ_{max} is the maximum principal stress.

σ_{min} is the minimum principal stress

σ_s is the maximum shear stress

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

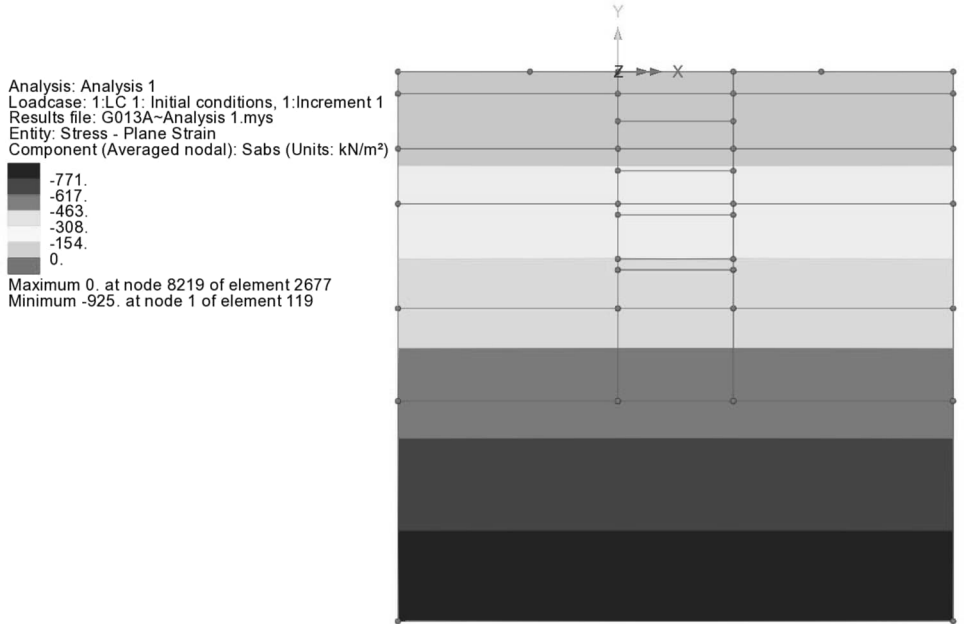
σ_x, σ_y, σ_{xy} represent an arbitrary two dimensional stress state.

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

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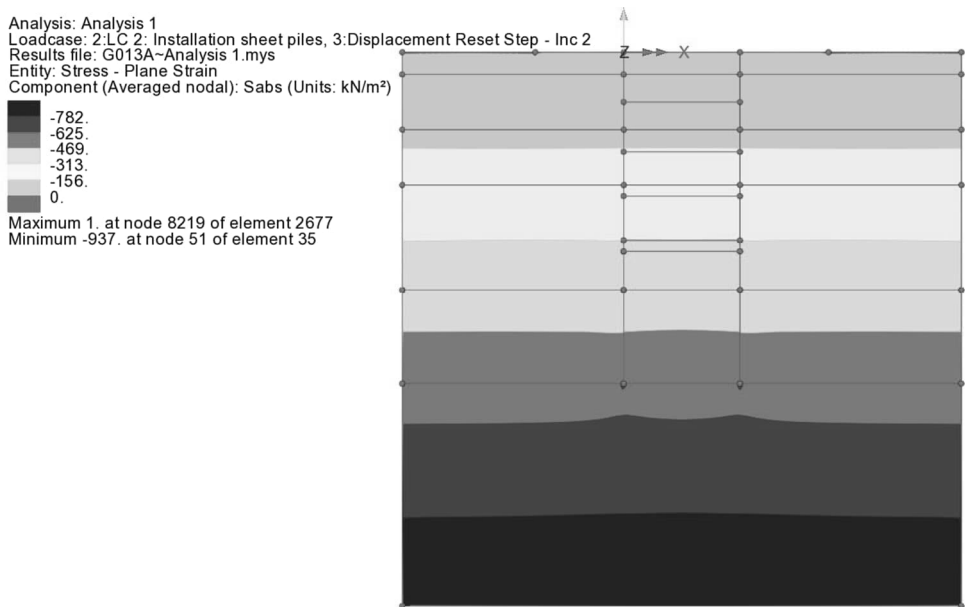
4.1.1 LC 1

→ Min Sabs = -925 kPa



4.1.2 LC 2

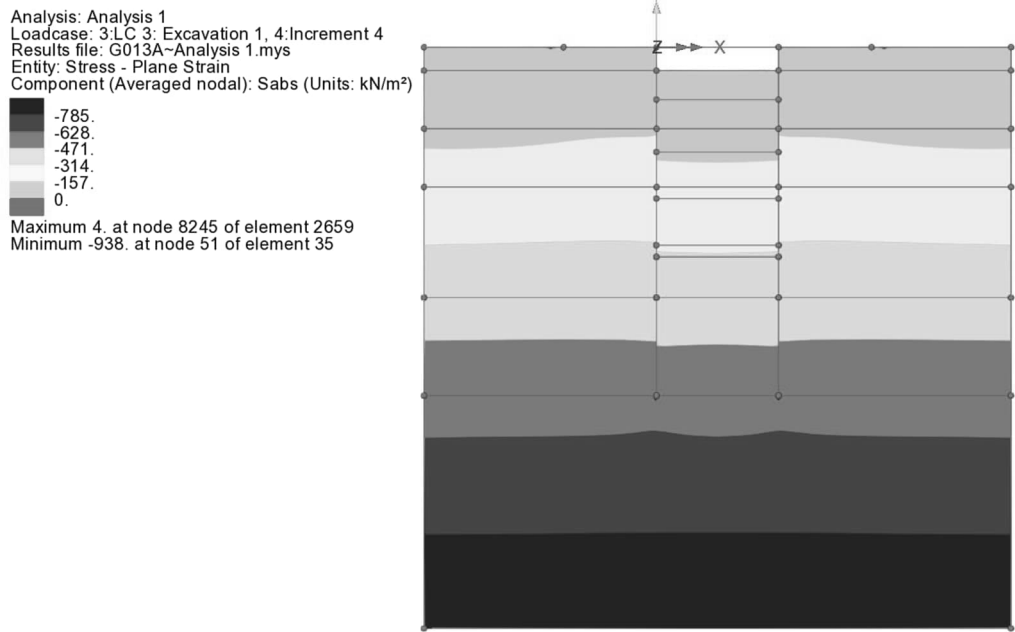
→ Min Sabs = -1089 kPa



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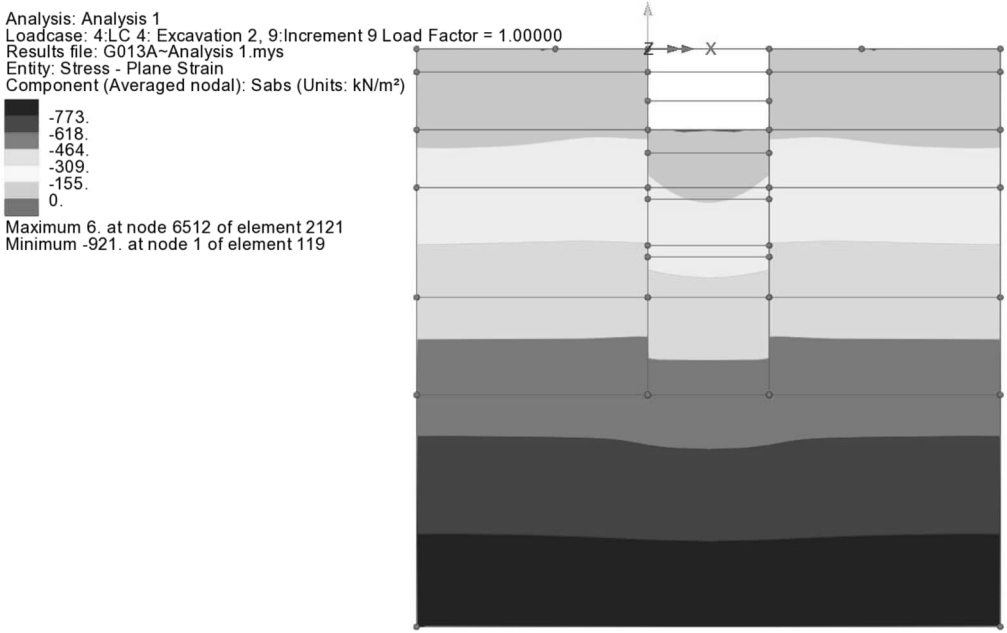
4.1.3 LC 3

→ Min Sabs = -938 kPa



4.1.4 LC 4

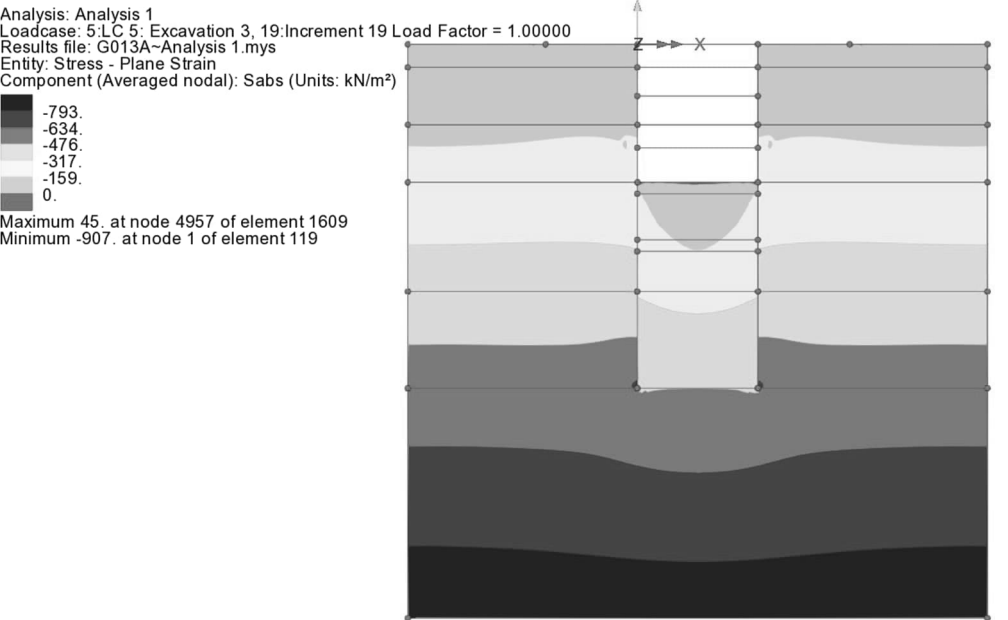
→ Min Sabs = -921 kPa



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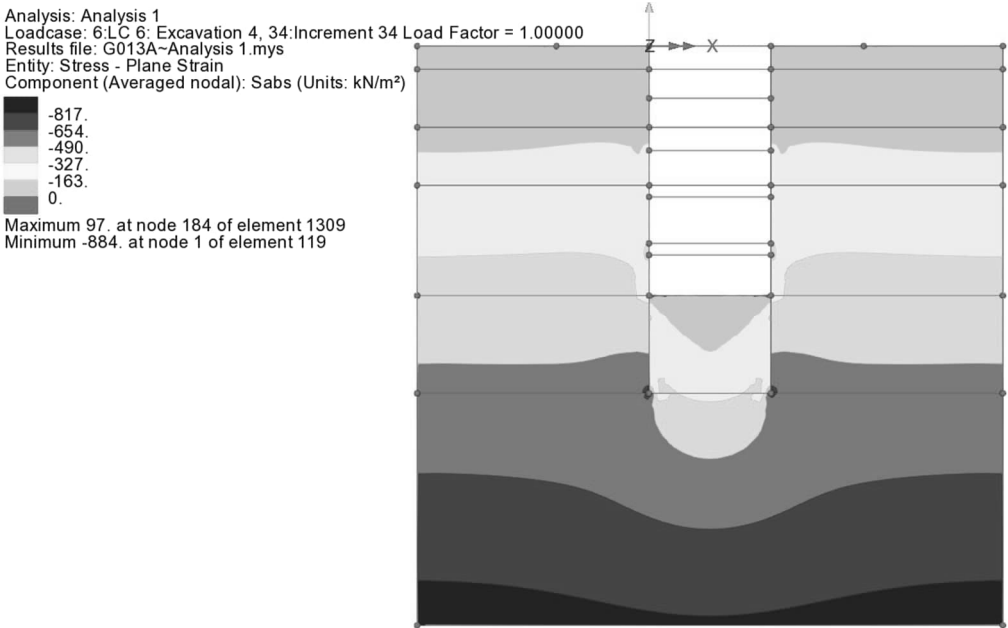
4.1.5
LC 5

→
Min Sabs = -907 kPa



4.1.6
LC 6

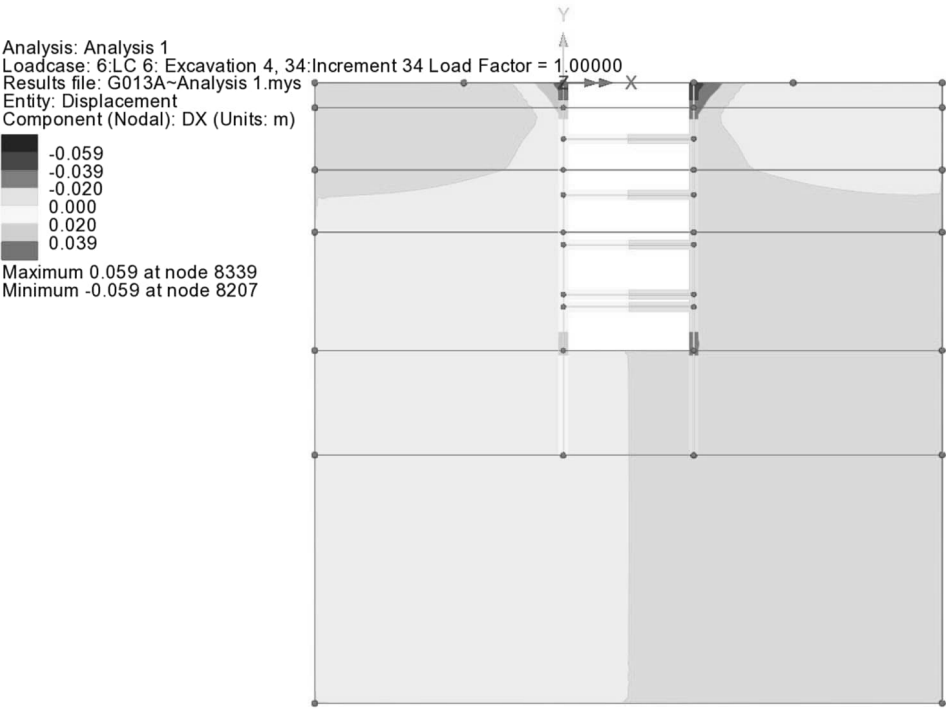
→
Min Sabs = -884 kPa



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4.2
Horizontal displacement after completed excavation (LC 6)

→
Max Dx = +0.059 m
Min Dx = -0.059 m

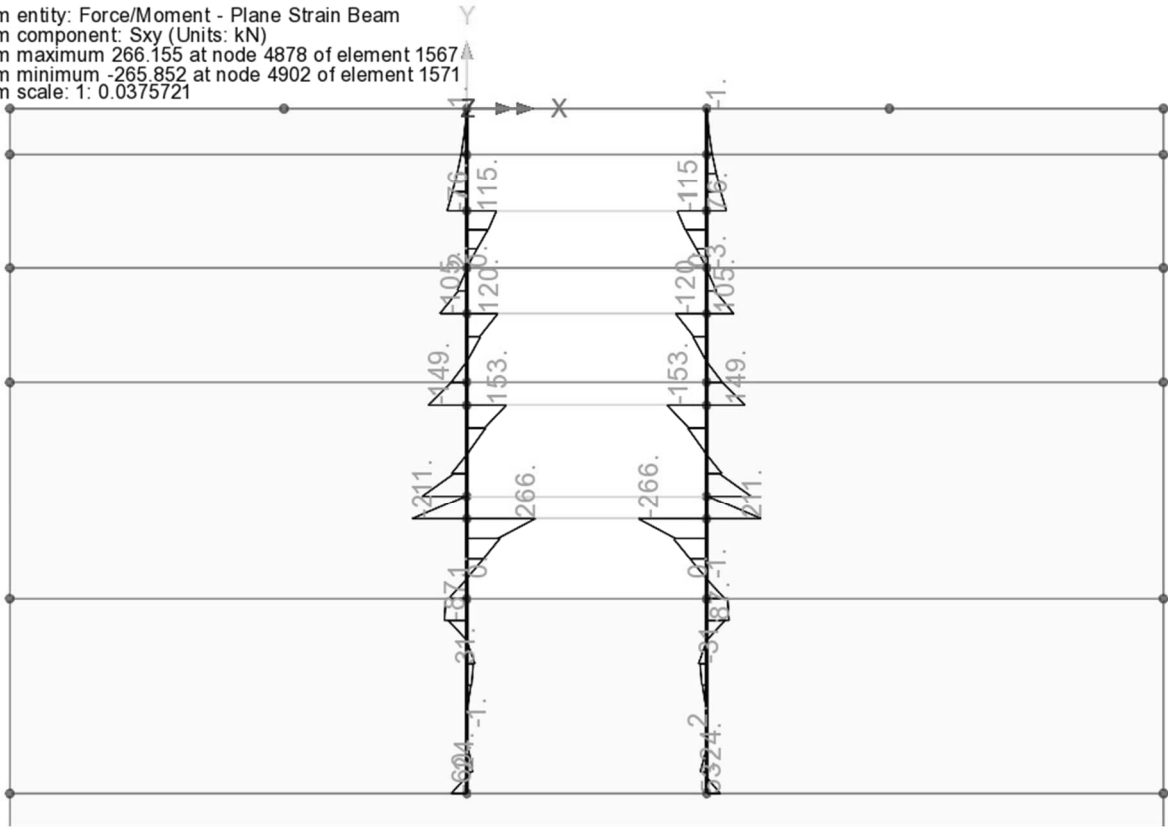


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4.3
Shear force sheet pile after completed excavation (LC 6)

→
Max Sxy = +266kN
Min Sxy = -266kN

Scale: 1: 405.877
Zoom: 135.028
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 6:LC 6: Excavation 4, 34:Increment 34 Load Factor = 1.00000
Results file: G013A~Analysis 1.mys
Diagram entity: Force/Moment - Plane Strain Beam
Diagram component: Sxy (Units: kN)
Diagram maximum 266.155 at node 4878 of element 1567
Diagram minimum -265.852 at node 4902 of element 1571
Diagram scale: 1: 0.0375721

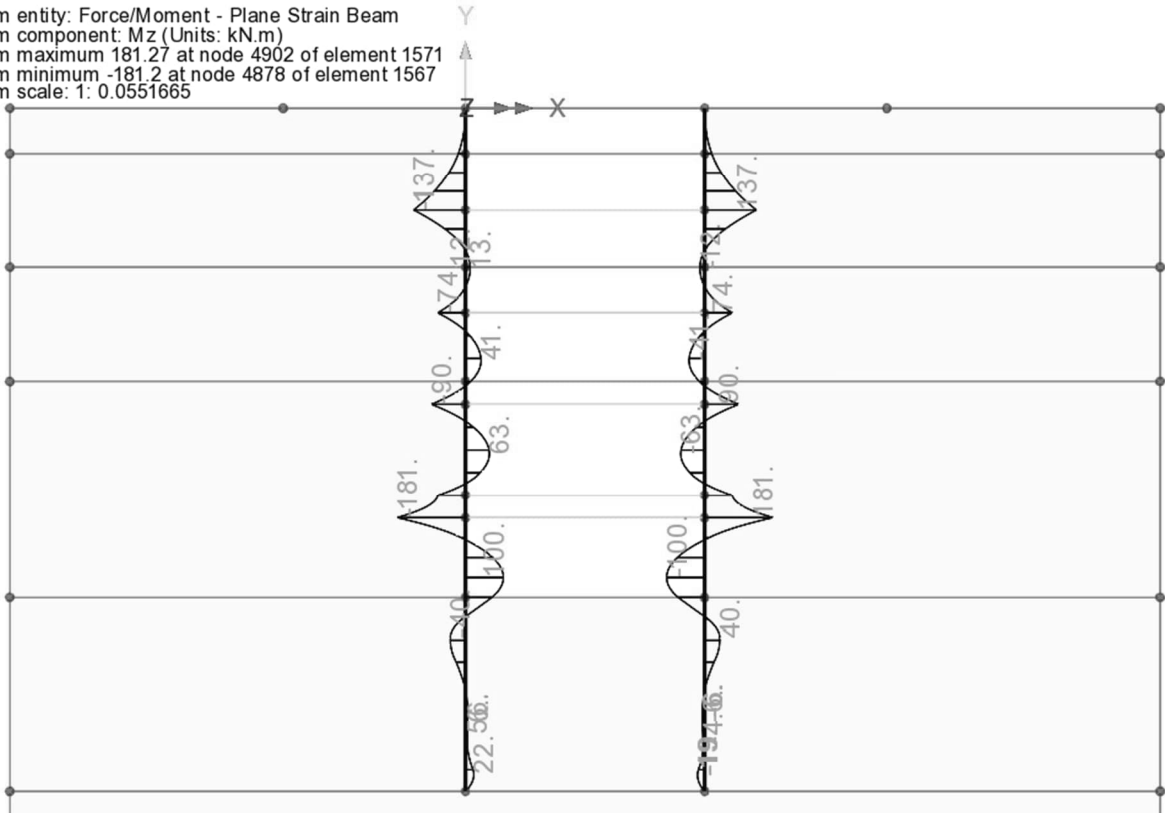


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4.4 Bending moment sheet pile after completed excavation (LC 4)

→ Max Mz = +181 kNm
 Min Mz = -181 kNm

Scale: 1: 405.877
 Zoom: 135.028
 Eye: (0.0, 0.0, 1.0)
 Nonlinear analysis
 Analysis: Analysis 1
 Loadcase: 6:LC 6: Excavation 4, 34:Increment 34 Load Factor = 1.00000
 Results file: G013A~Analysis 1.mys
 Diagram entity: Force/Moment - Plane Strain Beam
 Diagram component: Mz (Units: kN.m)
 Diagram maximum 181.27 at node 4902 of element 1571
 Diagram minimum -181.2 at node 4878 of element 1567
 Diagram scale: 1: 0.0551665



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4.5 Normal axial struts (LC 4)

→ Max Fx = -174 kN
 Min Fx = -492 kN

Scale: 1: 405.877
Zoom: 221.501
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 6:LC 6: Excavation 4, 34:Increment 34 Load Factor = 1.00000
Results file: G013A~Analysis 1.mys

