Retaining wall with one level of tie back anchors

Table of content

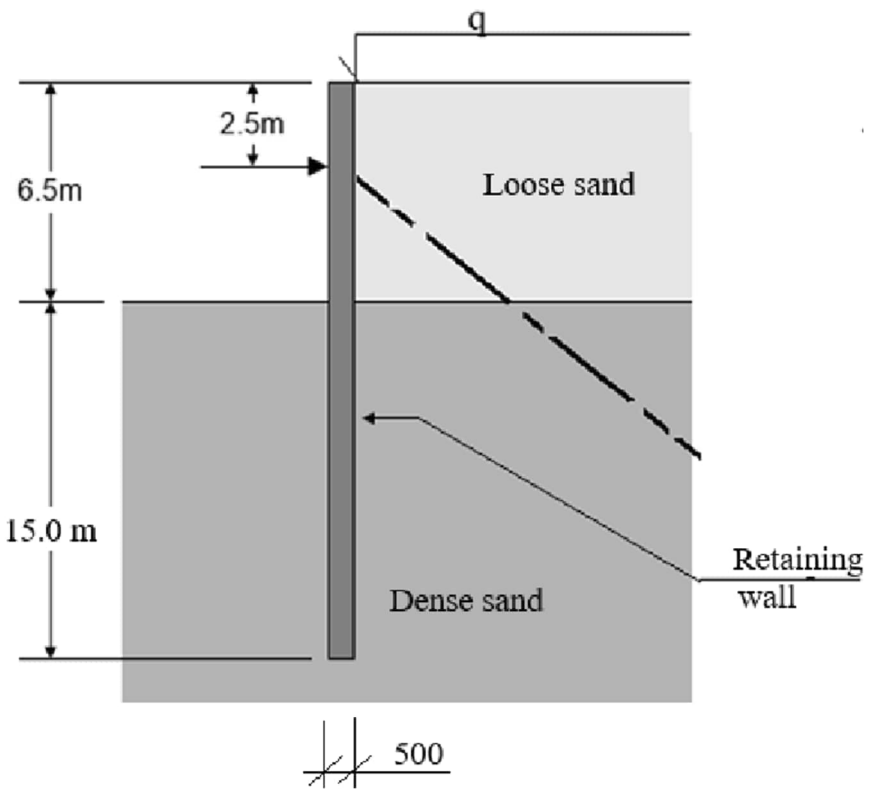
Appendix

1. Input receipt (FEM-program)

1. GENERAL

The retaining wall is modelled with and without one level of tie-back anchor.

1.1 GEOMETRY



ELEVATION

1.2 SOIL PROPRTIES

Ground water level: bellow bottom retaining wall

Geotechnical parameters:

Material	Level	ρ	ρ´	K_a	K_0	K_p
"Lose sand"	+20.0 →26.5	12	11	0.20	0.65	2.75
"Dense sand"	± 0→ 20.0	17	11	0.33	0.50	3.00
-	m	kN/m³	kN/m³	-	-	-

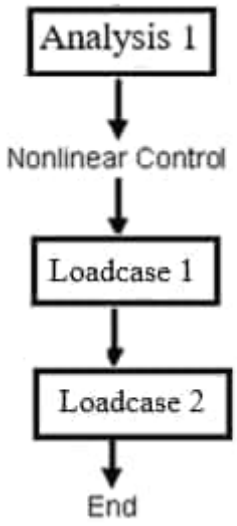
2. SYSTEM ANALYSIS

2.1 Analysis

Two nonlinear load cases are performed within same analysis.

LC 1: Soil + surcharge

LC 2: Soil + surface load + horizontal anchor force



Schematic sketch

2.2 Nonelinear analysis

Nonelinear analysis is performed using increments using Newton_Raphson numerial procedure.

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

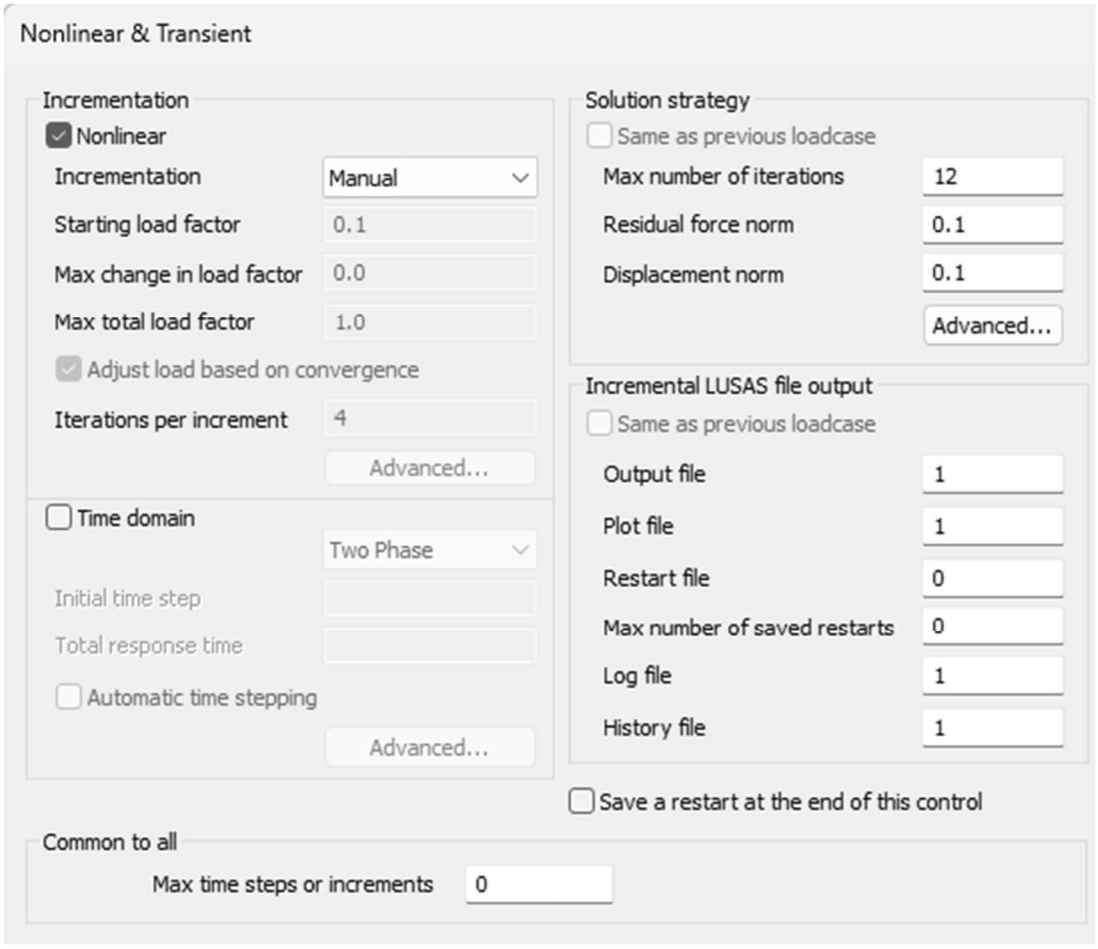
Residual force norm:
The limit for the sum of the squares of all residual forces as a percentage of the sum of the squares of all external forces, including reactions (rdnrm). By default only translation degrees of freedom are considered. So for a value of 0.1 the convergence of the solution at each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

2.2.1 Load case 1

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

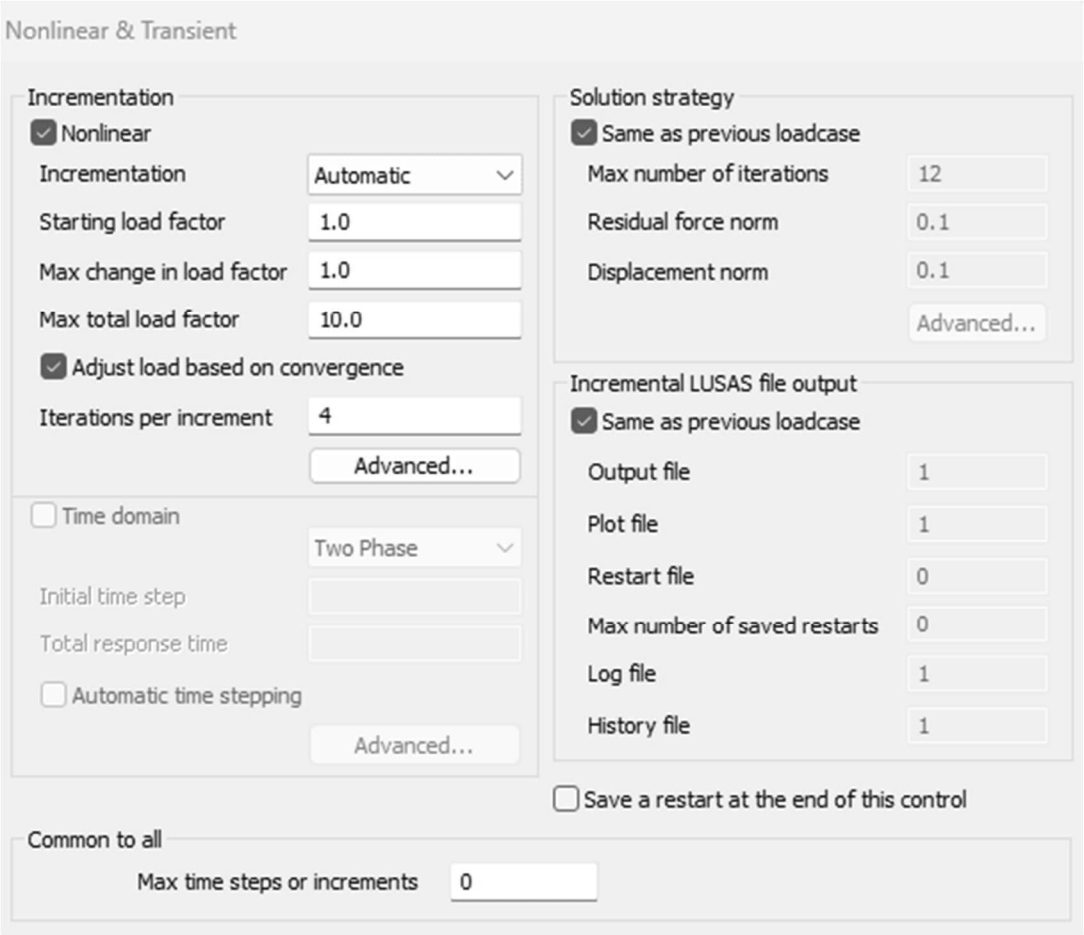
The need of nonlinear analysis is due to nonlinear material properties of soil equivalent joints.



2.2.2 Load case 2

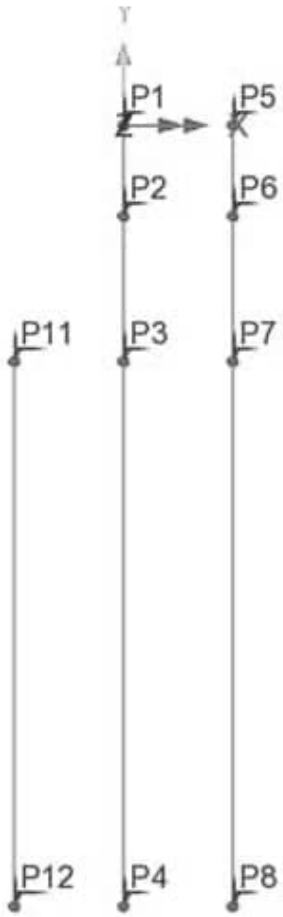
Incrementation as chosen to be performed *Automatic* with chosen parameters in dialogue box.

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



2.3 STATIC SYSTEM

2.3.1 Geometry

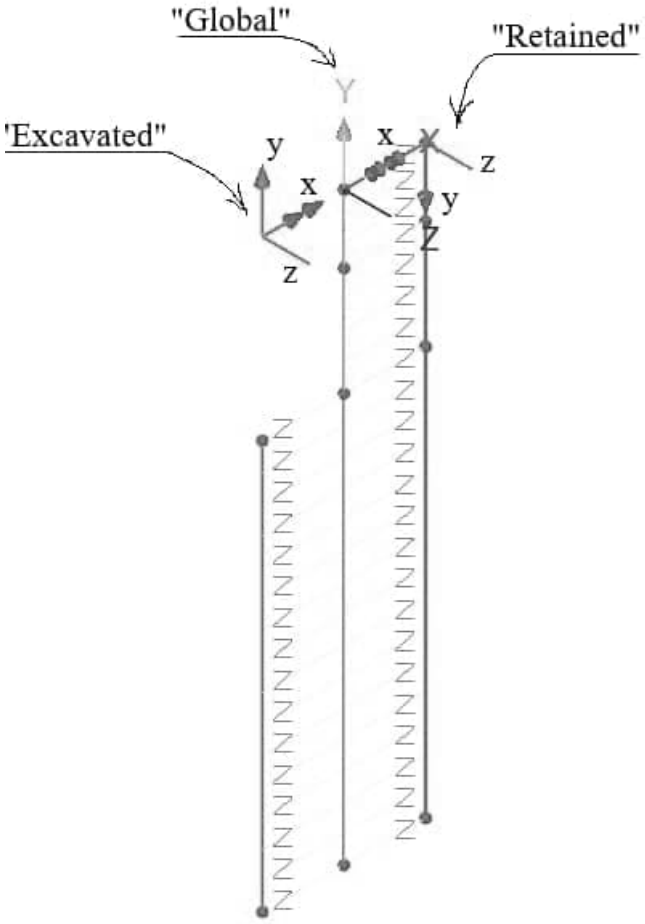


Points

Lines

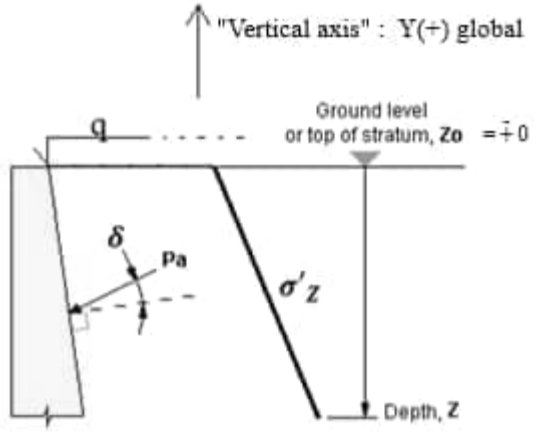
2.3.2 Local coordinate systems

There are two local coordinate systems as seen below. These are used when defining material properties associated to soil och either side of retaining wall.



2.3.3 Vertical axis

When defining trilinear earth pressure in a 2D analysis “vertical” axis is not Z as seen but Y. Important since otherwise load effect of gravity will act in faulty direction. Also defined material properties associated to soil will otherwise be incorrect.



Remark

In sketch above “Z” is replace with Y.

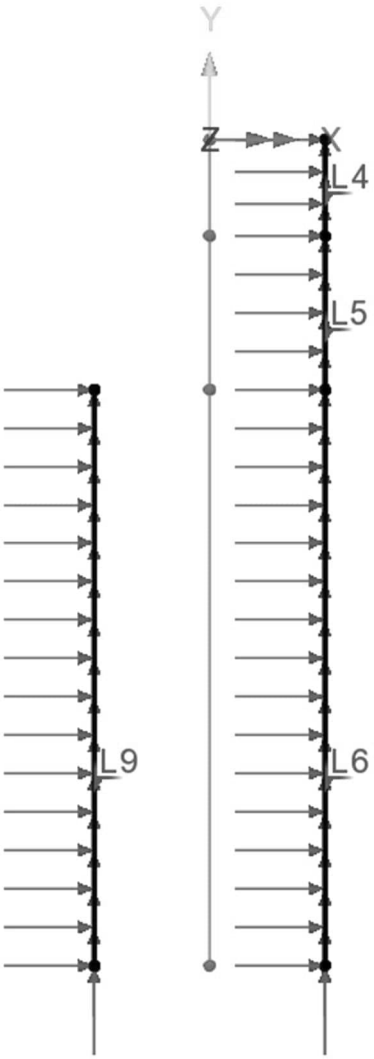
2.3.4 Boundary

2.3.4.1 Bottom of retaining wall: Fixed in Y

Applied to point P4.

2.3.4.2 Lines defining joint elements: Fixed in X &Y

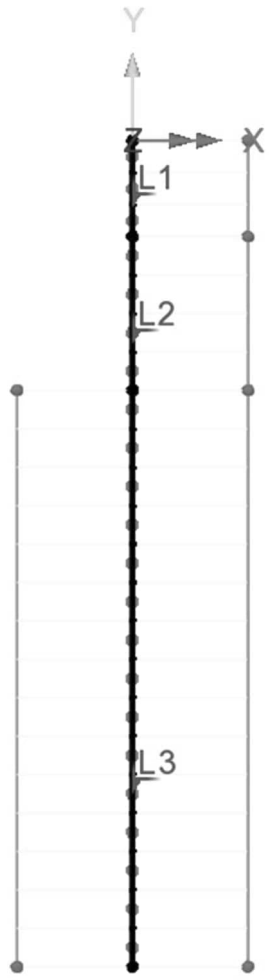
Applied to lines L4, L5, L6 and L9.



2.3.5 MESH

2.3.5.1 Beam element (BMI2)

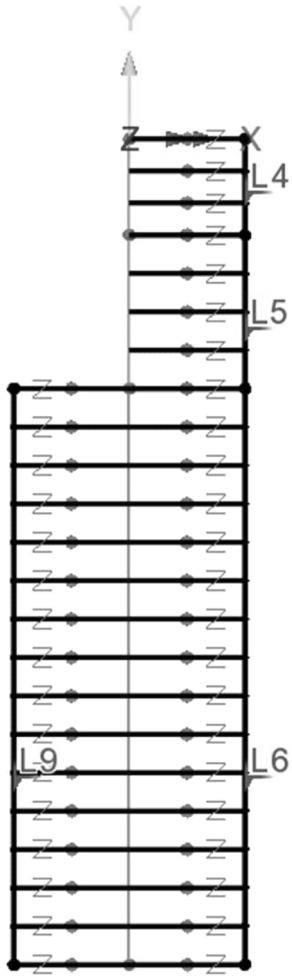
Retaining wall (L1, L2 and L3) is modelled as seen below.



Name	Element length	Type
BMI2	1.0	Thick beam 2D

2.3.5.2 Joint elements (JNT3)

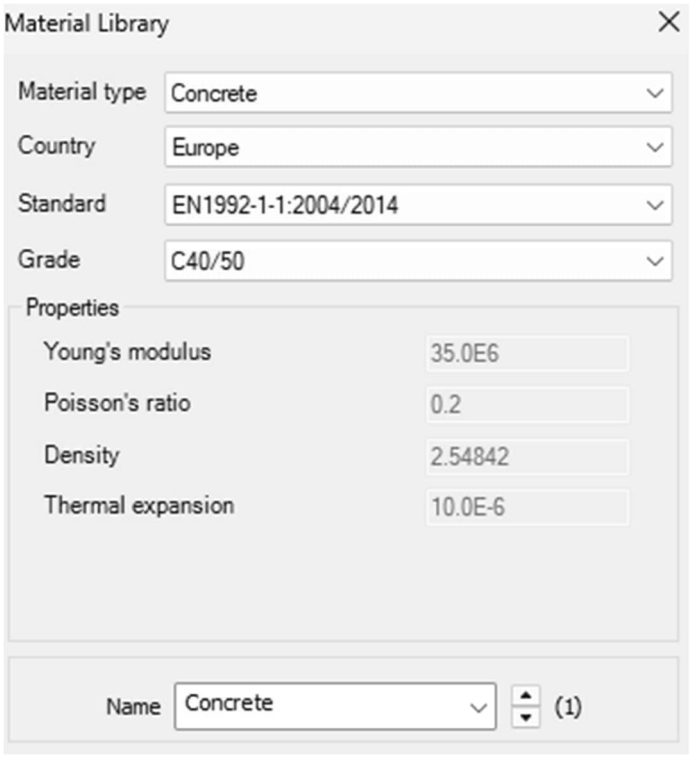
Soil is modelled using joints with no rotational stiffness along lines L4, L5, L6 och L9.



2.3.6 Material

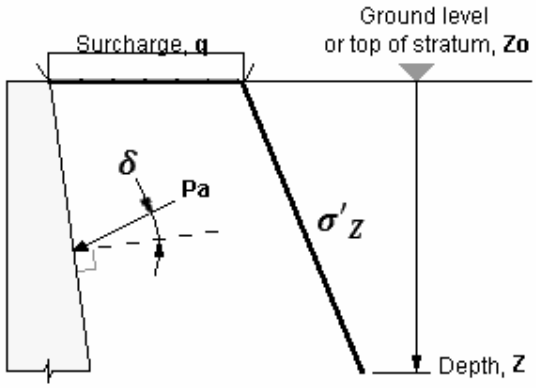
2.3.6.1 Retaining wall

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



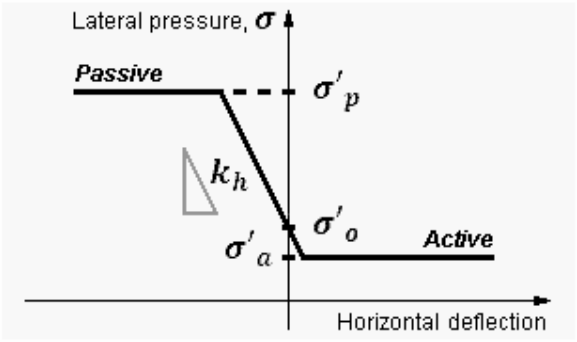
2.3.6.2 Soil material joints

Equivalent soil joints are defined using trilinear earth material as defined below.



$$\sigma'_Z = \int_{Z_o}^{Z} \gamma' dz + q$$

Vertical stress
($\therefore \sigma_y$ according to page 9)



$$\sigma'_a = K_a \sigma'_Z - 2c'K_{ac}$$
$$k_h = A + BZ^{\kappa}$$
$$\sigma'_o = K_o \sigma'_Z$$
$$\sigma'_p = K_p \sigma'_Z + 2c'K_{pc}$$

Lateral stress
($\therefore \sigma_x$ according to page 8)

Loose sand (side with filling → side towards filling):

σ_y (0 m) = 10 kPa : level $Z_o = \pm 0$ m

Trilinear Earth Pressure

Joint type: Two dimensional joint elements

Defining geometry: Lines

Vertical pressures

Parameter	Symbol	Value
Level of surcharge	Zo	0.0
Surcharge (vertical load per unit area)	q	10.0
Unit weight of soil	γ	12.0
Angle of shearing resistance between soil and structure	δ	0.0

Lateral pressures

Parameter	Symbol	Value
Coefficient of passive earth pressure	Kp	2.75
Coefficient of passive earth pressure due to cohesion	Kpc	0.0
Cohesion	c'	0.0
Coefficient of at-rest earth pressure	Ko	0.65
Coefficient of active earth pressure	Ka	0.2
Coefficient of active earth pressure due to cohesion	Kac	0.0
Empirical constant used in calculation of kh	A	1.0E3
Empirical constant used in calculation of kh	B	250.0
Empirical constant used in calculation of kh	κ	1.0
Soil width	Weff	1.0

Positive displacement of the local x axis mobilises
- (●) Active pressures
- ( ) Passive pressures

Positive direction of the local y axis
- ( ) Opposes gravity (points up)
- (●) Matches gravity (points down)

Name: Loose Sand Retained

Remark

On this side y-direction in local coordinate system points down, see page 8.

Dense sand (side with filling → side towards filling):

σ_y (-6.5 m) = 10 kPa + 6.5 m · 12 kN/m^3 = 88 kPa : level Z_o = -6.5 m

Trilinear Earth Pressure

Joint type: Two dimensional joint elements

Defining geometry: Lines

Vertical pressures

Parameter	Symbol	Value
Level of surcharge	Zo	-6.5
Surcharge (vertical load per unit area)	q	88.0
Unit weight of soil	γ	17.0
Angle of shearing resistance between soil and structure	δ	0.0

Lateral pressures

Parameter	Symbol	Value
Coefficient of passive earth pressure	Kp	3.0
Coefficient of passive earth pressure due to cohesion	Kpc	0.0
Cohesion	c'	0.0
Coefficient of at-rest earth pressure	Ko	0.5
Coefficient of active earth pressure	Ka	0.33
Coefficient of active earth pressure due to cohesion	Kac	0.0
Empirical constant used in calculation of kh	A	1.0E3
Empirical constant used in calculation of kh	B	250.0
Empirical constant used in calculation of kh	κ	1.0
Soil width	Weff	1.0

Positive displacement of the local x axis mobilises
- (●) Active pressures
- ( ) Passive pressures

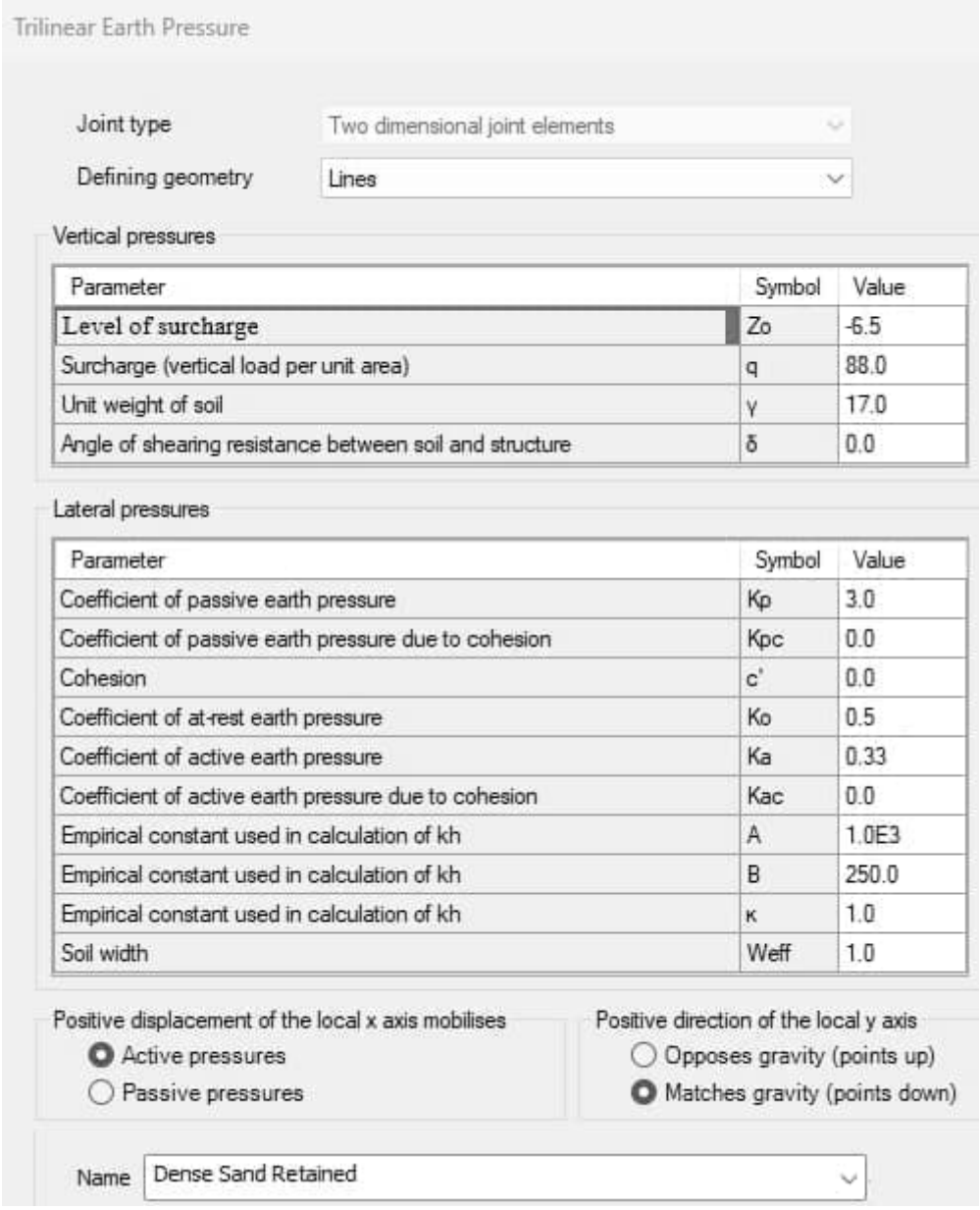
Positive direction of the local y axis
- ( ) Opposes gravity (points up)
- (●) Matches gravity (points down)

Name: Dense Sand Retained

Remark
On this side y-direction in local coordinate system points down, see page 8.

Dense sand (side from filling → side from filling):

σ_y (-6.5 m) = 0 kPa : level Z_o = -6.5 m



Remark

On this side y-direction in local coordinate system points up, see page 8.

3. LOADS

3.1 Soil weight (Gravity)

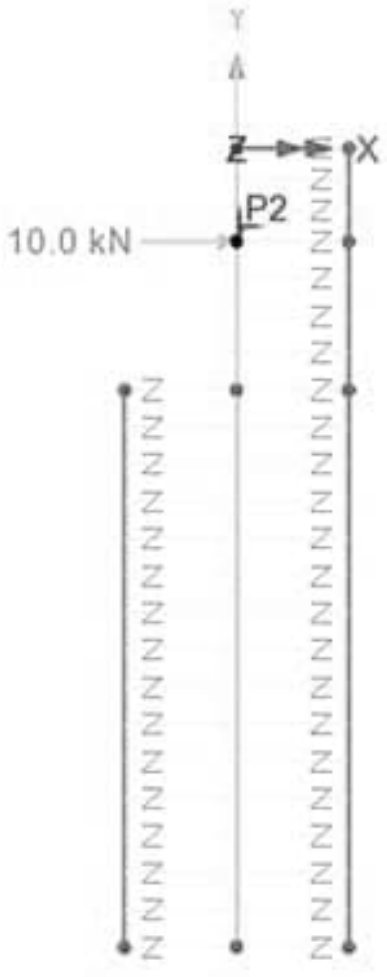
Soil weight is determined material density.

3.2 Surcharge

Surcharge (q = 10 kPa) on top if bank filling is not defined as load but as surcharge wihen defining soil properties.

3.3 Horizontal anchor load

A horizontal anchor load H_x = 10 kN is added a point P2.



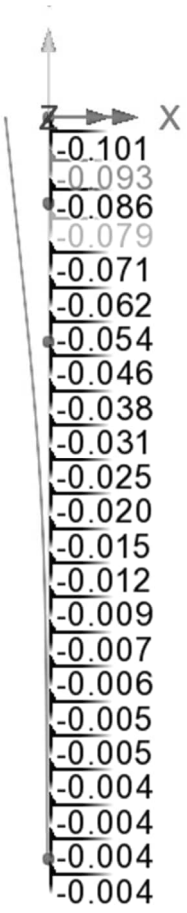
4. RESULTS (FEM-program)

4.1 Load case 1: Soil + surcharge

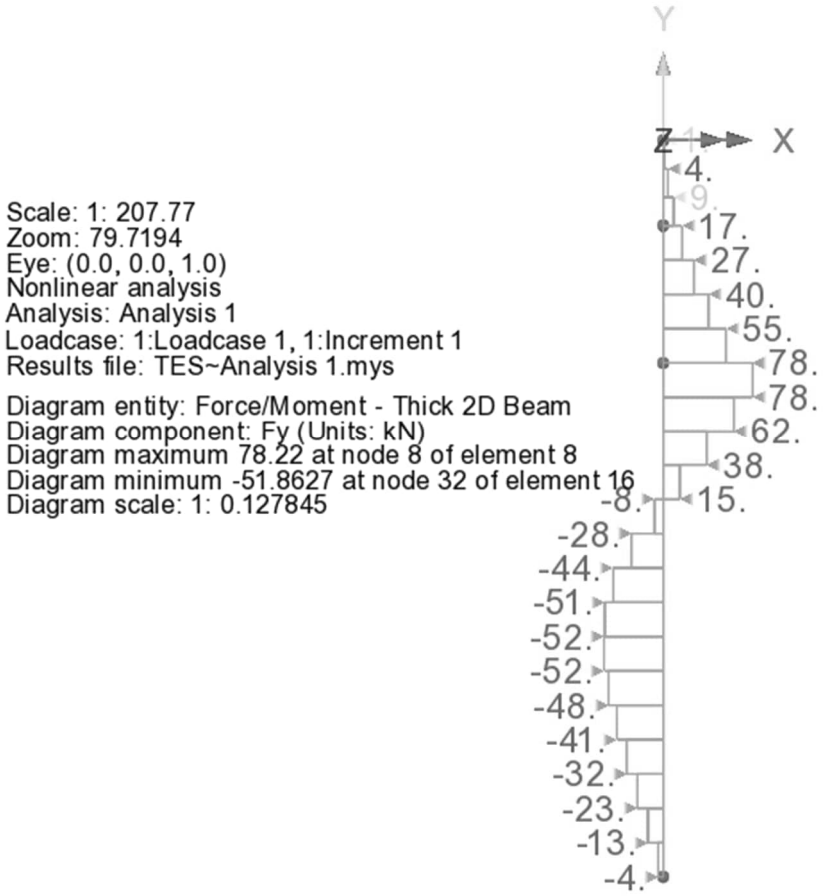
→ min Dx = -0.101 m

Scale: 1: 207.77
Zoom: 79.7194
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 1:Loadcase 1, 1:Increment 1
Results file: TES~Analysis 1.mys
Maximum displacement 0.100616 at node 1
Deformation exaggeration: 12.3898

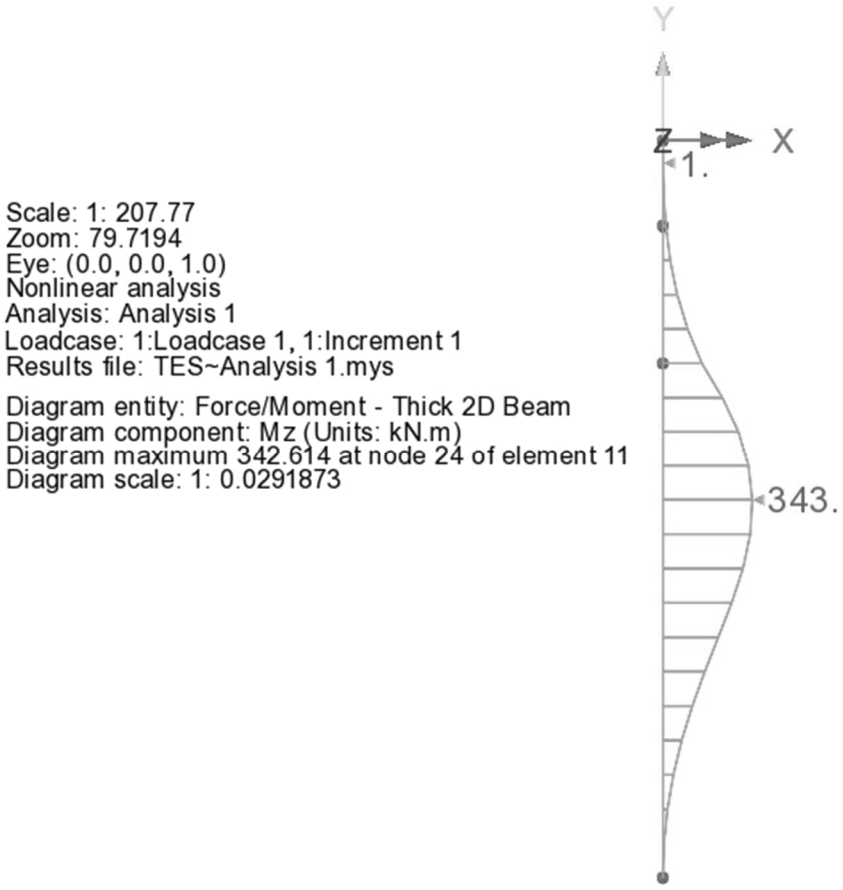
Peak/value entity: Displacement
Peak/value component: DX (Units: m)
Peak range(%): 100.0
Peak/value maximum -3.70749E-3 at node 16
Peak/value minimum -0.100616 at node 1



→ max Fy = 78 kN


Y
Z
X
Scale: 1: 207.77
Zoom: 79.7194
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 1:Loadcase 1, 1:Increment 1
Results file: TES~Analysis 1.mys
Diagram entity: Force/Moment - Thick 2D Beam
Diagram component: Fy (Units: kN)
Diagram maximum 78.22 at node 8 of element 8
Diagram minimum -51.8627 at node 32 of element 16
Diagram scale: 1: 0.127845
4.
9.
17.
27.
40.
55.
78.
78.
62.
38.
15.
-8.
-28.
-44.
-51.
-52.
-52.
-48.
-41.
-32.
-23.
-13.
-4.

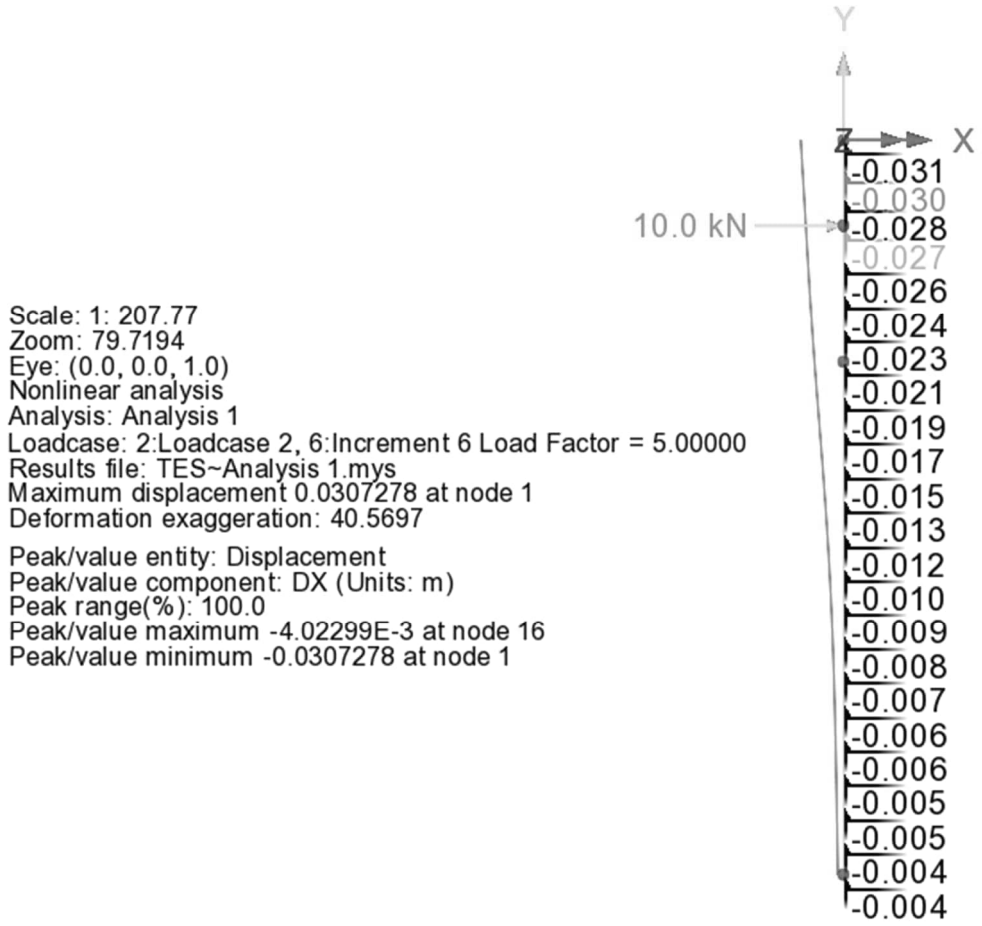
→ max Mz = 343 kNm



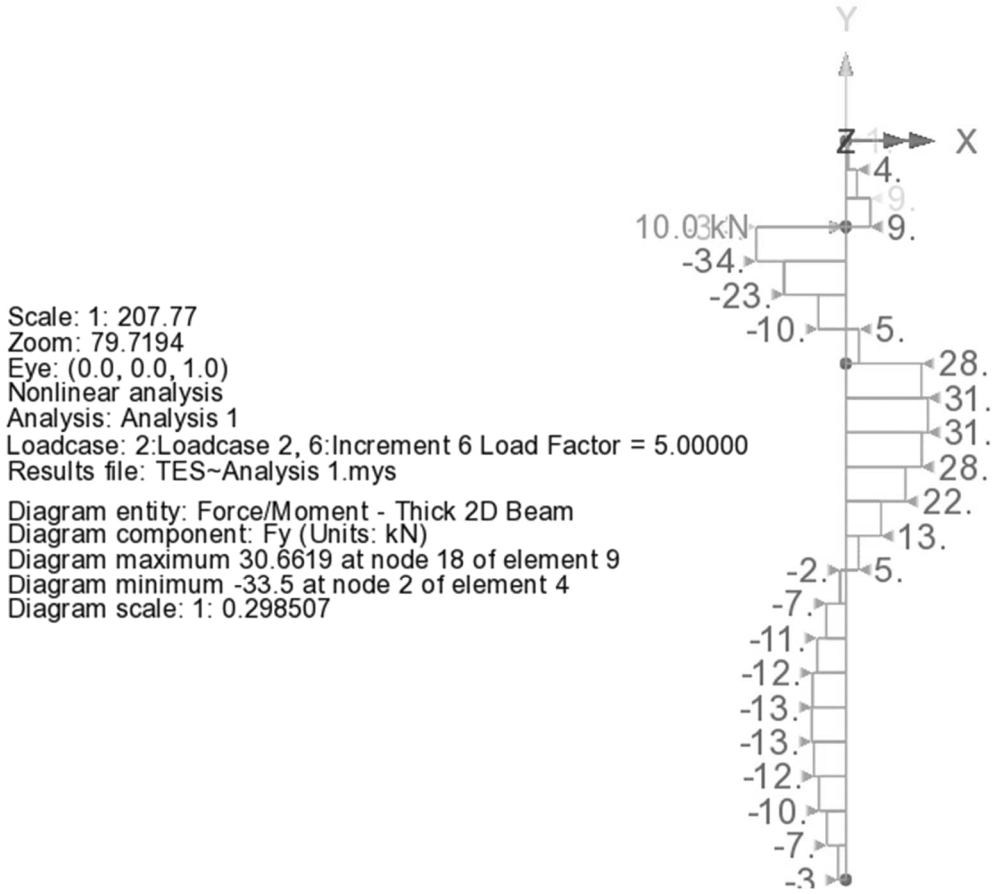
4.2 Load case 1: Soil + surcharge + anchor load (load factor 5)

Load factor 5 is chosen as best anchor load Hx = 50 kN (10 kN x 5) since gives small movement at level of anchor (Dx = -0.027 m).

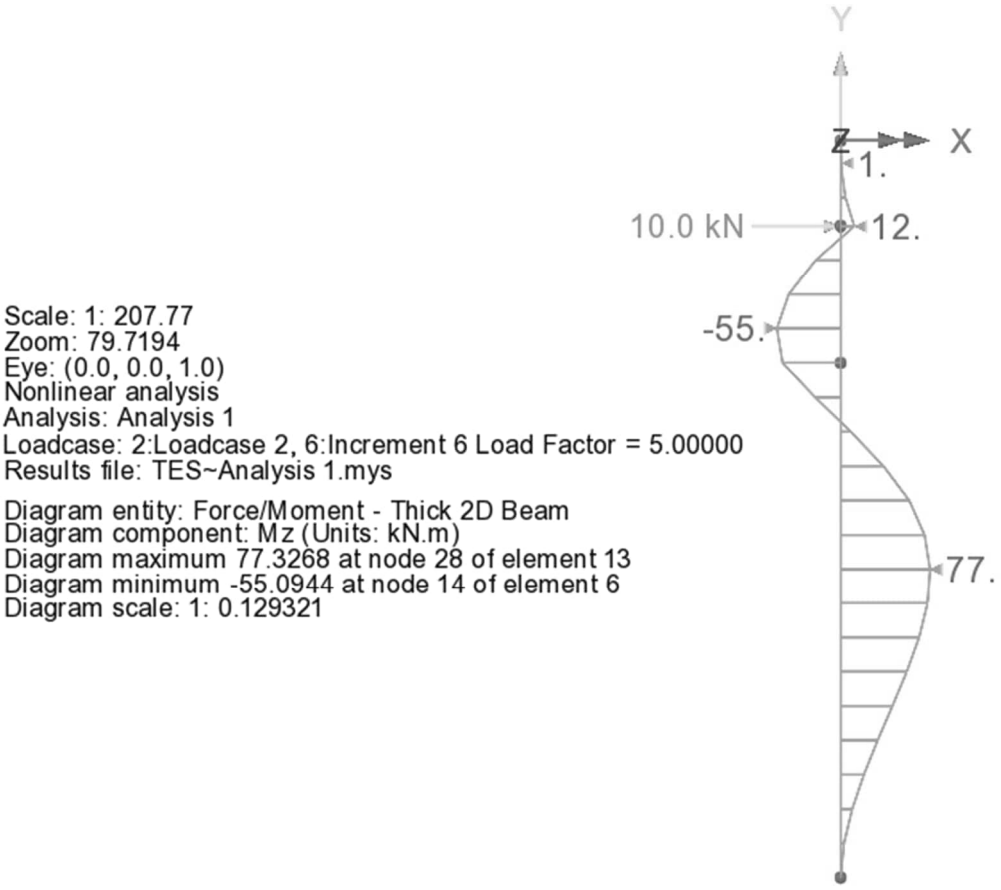
→ min Dx = -0.031 m



→ max Fy = 31 kN & min Fy = -34 kN



→ max Mz = 77 kNm


Y
Z
X
1.
10.0 kN
12.
-55.
77.
Scale: 1: 207.77
Zoom: 79.7194
Eye: (0.0, 0.0, 1.0)
Nonlinear analysis
Analysis: Analysis 1
Loadcase: 2:Loadcase 2, 6:Increment 6 Load Factor = 5.00000
Results file: TES~Analysis 1.mys
Diagram entity: Force/Moment - Thick 2D Beam
Diagram component: Mz (Units: kN.m)
Diagram maximum 77.3268 at node 28 of element 13
Diagram minimum -55.0944 at node 14 of element 6
Diagram scale: 1: 0.129321

Title: Input receipt

Model Units: kN,m,t,s,C
Report Units: kN,m,t,s,C

Model Title: System 001
Model File: System 001

Table of Contents

1. Analysis

Analysis	Type	Loadcase
1	Nonlinear & Transient	Load case 1
1	Nonlinear & Transient	Load case 2

2. Nonlinear analysis

Assigned in: Analysis 1
Assigned load case: Load case 1

Incrementation	Manual
Starting load factor	None
Max change in load factor	None
Max total load factor	None
Iteration per increment	None

Assigned in: Analysis 1
Assigned load case: Load case 2

Incrementation	Manual
Starting load factor1	1.0
Max change in load factor	1.0
Max total load factor	10.0
Iteration per increment	4

3. Points

Point	X coordinate	Y coordinate	Z coordinate
1	0.0	0.0	0.0
2	0.0	-2.5	0.0
3	0.0	-6.5	0.0
4	0.0	-21.5	0.0
5	3.0	0.0	0.0
6	3.0	-2.5	0.0
7	3.0	-6.5	0.0
8	3.0	-21.5	0.0
11	-3.0	-6.5	0.0
12	-3.0	-21.5	0.0

4. Lines

Line	Points	Line	Points
1	1,2	2	2,3
3	3,4	4	5,6
5	6,7	6	7,8
9	11,12		

5. Mesh

Attribute: 2 Title: Thick Beam
Sub Type = Line Mesh **Element Type = BMI2**

Mesh spacing	Element size	Start node end releases:	End node end releases:
Irregular	1.0	None	None

Assignment to Lines:
1T3

Attribute: 1 Title: Soil Mesh
Sub Type = Line Mesh **Element Type = JNT3**

Mesh spacing	Element size	Start node end releases:	End node end releases:
Irregular	1.0	None	None

Assignment to Lines: Local Coordinates = Excavated (Local x is joint x), Interface secondary Line 3, Mesh from primary to secondary
4T6;9

6. Material isotropic

Attribute: 1 Title: Concrete (C40/50 | Concrete | EN1992-1-1:2004/2014)
Sub Type = Isotropic Material
Assigned in: Analysis 1

Property	Symbol	Value
Young's modulus	E	35000000.0
Poisson's ratio	nu	0.2
Density	rho	2.5
Coefficient of thermal expansion	alpha	0.0
Characteristic compressive cylinder strength of concrete at 28 days	fck	40000.0
Mean value of axial tensile strength of concrete	fctm	3500.0
Ultimate compressive strain limit 3	ecu3	0.0
Design compressive strength 3	fcd3	26666.7
Compressive strain limit 3	ec3	0.0
Modulus of elasticity 3	E3	15238095.2

Loadcase ID: 1 Title: Loadcase 1
Assignment to Lines:
1T3

7. Joint material

Attribute: 2 Title: Loose Sand Retained (2D Line: GL=0 g=12 q=10)
Sub Type = Trilinear joint material
Assigned in: Analysis 1

Joint type dimensions	Two
Defining geometry	Line
Datum used for the calculation of effective overburden pressure	0.0
Surcharge (vertical load per unit area)	10.0
Bulk density of soil	12.0
Angle of shearing resistance between soil and structure	0.0
Coefficient of passive earth pressure	2.75
Coefficient of passive earth pressure due to cohesion	0.0
Cohesion	0.0
Coefficient of at-rest earth pressure	0.65
Coefficient of active earth pressure	0.2
Coefficient of active earth pressure due to cohesion	0.0
Empirical constant used in calculation of kh, A	1.0E3
Empirical constant used in calculation of kh, B	250.0
Empirical constant used in calculation of kh, k	1.0
Soil width	1.0
Positive displacement of the local x axis mobilises	Active
Positive direction of the local y axis	Negative
Consider angle of structure	False

K[0]	K[1]	M[0]	M[1]	StiffnessFactor[0]	StiffnessFactor[1]
0.0	0.0	0.0	0.0	0.0	0.0
Force 1[0]	**Force 1[1]**	**Displacement 1[0]**	**Displacement 1[1]**	**Force 2[0]**	**Force 2[1]**
{-MAX((2.75	{-1.0 * -MAX	{-1.0 * (2.1 *	{-1.0 * (2.1 *	{-MAX(0.65 *	{-MAX(0.65 *
Displacement 2[0]	**Displacement 2[1]**	**Force 3[0]**	**Force 3[1]**	**Displacement 3[0]**	**Displacement 3[1]**
0.0	0.0	{-MAX((0.2 *	{-MAX((0.2 *	{-1.0 * (-0.45	{-1.0 * (-0.45

Loadcase ID: 1 Title: Loadcase 1
Assignment to Lines:
4;5

Attribute: 3 Title: Dense Sand Retained (2D Line: GL=-6.5 g=17 q=88)
Sub Type = Trilinear joint material
Assigned in: Analysis 1

Joint type dimensions	Two
Defining geometry	Line
Datum used for the calculation of effective overburden pressure	-6.5
Surcharge (vertical load per unit area)	88.0
Bulk density of soil	17.0
Angle of shearing resistance between soil and structure	0.0
Coefficient of passive earth pressure	3.0
Coefficient of passive earth pressure due to cohesion	0.0
Cohesion	0.0
Coefficient of at-rest earth pressure	0.5
Coefficient of active earth pressure	0.33
Coefficient of active earth pressure due to cohesion	0.0
Empirical constant used in calculation of kh, A	1.0E3
Empirical constant used in calculation of kh, B	250.0
Empirical constant used in calculation of kh, k	1.0
Soil width	1.0
Positive displacement of the local x axis mobilises	Active
Positive direction of the local y axis	Negative
Consider angle of structure	False

K[0]	K[1]	M[0]	M[1]	StiffnessFactor[0]	StiffnessFactor[1]
0.0	0.0	0.0	0.0	0.0	0.0
Force 1[0]	**Force 1[1]**	**Displacement 1[0]**	**Displacement 1[1]**	**Force 2[0]**	**Force 2[1]**
{-MAX((3.0 *	{-1.0 * -MAX	{-1.0 * (2.5 *	{-1.0 * (2.5 *	{-MAX(0.5 *	{-MAX(0.5 *
Displacement 2[0]	**Displacement 2[1]**	**Force 3[0]**	**Force 3[1]**	**Displacement 3[0]**	**Displacement 3[1]**
0.0	0.0	{-MAX((0.33	{-MAX((0.33	{-1.0 * (-0.17	{-1.0 * (-0.17

Loadcase ID: 1 Title: Loadcase 1
Assignment to Lines:
6

Attribute: 4 Title: Dense Sand Excavated (2D Line: GL=-6.5 g=17 q=0)
Sub Type = Trilinear joint material
Assigned in: Analysis 1

Joint type dimensions	Two
Defining geometry	Line
Datum used for the calculation of effective overburden pressure	-6.5
Surcharge (vertical load per unit area)	0.0
Bulk density of soil	17.0
Angle of shearing resistance between soil and structure	0.0
Coefficient of passive earth pressure	3.0
Coefficient of passive earth pressure due to cohesion	0.0
Cohesion	0.0
Coefficient of at-rest earth pressure	0.5
Coefficient of active earth pressure	0.33
Coefficient of active earth pressure due to cohesion	0.0
Empirical constant used in calculation of kh, A	1.0E3
Empirical constant used in calculation of kh, B	250.0
Empirical constant used in calculation of kh, k	1.0
Soil width	1.0
Positive displacement of the local x axis mobilises	Active
Positive direction of the local y axis	Positive
Consider angle of structure	False

K[0]	K[1]	M[0]	M[1]	StiffnessFactor[0]	StiffnessFactor[1]
0.0	0.0	0.0	0.0	0.0	0.0
Force 1[0]	**Force 1[1]**	**Displacement 1[0]**	**Displacement 1[1]**	**Force 2[0]**	**Force 2[1]**
{-MAX((3.0 *	{-MAX((3.0 *	{-1.0 * (2.5 * (	{-1.0 * (2.5 * (	{-MAX(0.5 *	{-1.0 * -MAX
Displacement 2[0]	**Displacement 2[1]**	**Force 3[0]**	**Force 3[1]**	**Displacement 3[0]**	**Displacement 3[1]**
0.0	0.0	{-MAX((0.33	{-1.0 * -MAX	{-1.0 * (-0.17	{-1.0 * (-0.17

Loadcase ID: 1 Title: Loadcase 1
Assignment to Lines:
9

8. Supports

Attribute: 1 Title: Fixed in Y
Sub Type = Structural Support
Assigned in: Analysis 1

Property	Symbol	Value
Translation in X	U	"F"
Translation in Y	V	"R"
Rotation about Z	THZ	"F"
Pore pressure	pore	"C"

Loadcase ID: 1 Title: Loadcase 1
Assignment to Points:
4

Attribute: 2 Title: Fixed in X & Y
Sub Type = Structural Support
Assigned in: Analysis 1

Property	Symbol	Value
Translation in X	U	"R"
Translation in Y	V	"R"
Rotation about Z	THZ	"F"
Pore pressure	pore	"C"

Loadcase ID: 1 Title: Loadcase 1
Assignment to Lines:
4T6;

9. Loading

Attribute: 1 Title: Px = 10 kN
Sub Type = Concentrated Load

Property	Symbol	Value
Concentrated load in X Dir	PX	10.0
Concentrated load in Y Dir	PY	0.0
Concentrated load in Z Dir	PZ	0.0
Moment about X axis	MX	0.0
Moment about Y axis	MY	0.0
Moment about Z axis	MZ	0.0
Moment about hinge nodes	L2	0.0
Pore pressure flux	PorePressure	0.0
Bi moment	Mb	0.0

Loadcase ID: 2 Title: Loadcase 2 Factor = 1.0
Assignment to Points:
2

10. Loadcases

Loadcase	Gravity	Loading	Analysis
1	On	Surcharge	Analysis 1
2	On	Surcharge + Px	Analysis 1