Slope stability slab foundation

Chapter 4 (FEM-program) contains features:

1. Compact complete **Input Receipt** $\Rightarrow$ Less than 10 pages.
2. **Phi-c Reduction performs safety factor analysis for nonlinear material**.
   $\Rightarrow$ Safe factor is presented including associated deformations.
3. **Branch Analysis** enables performing several independent analyses within in same model.
4. **Material Modified Mohr-Coulomb (MMC) defines plastic soil material.**
   $\Rightarrow$ Useful when defining concrete structures.

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Appendix

1. Input receipt (FEM-program)

1. GENERAL

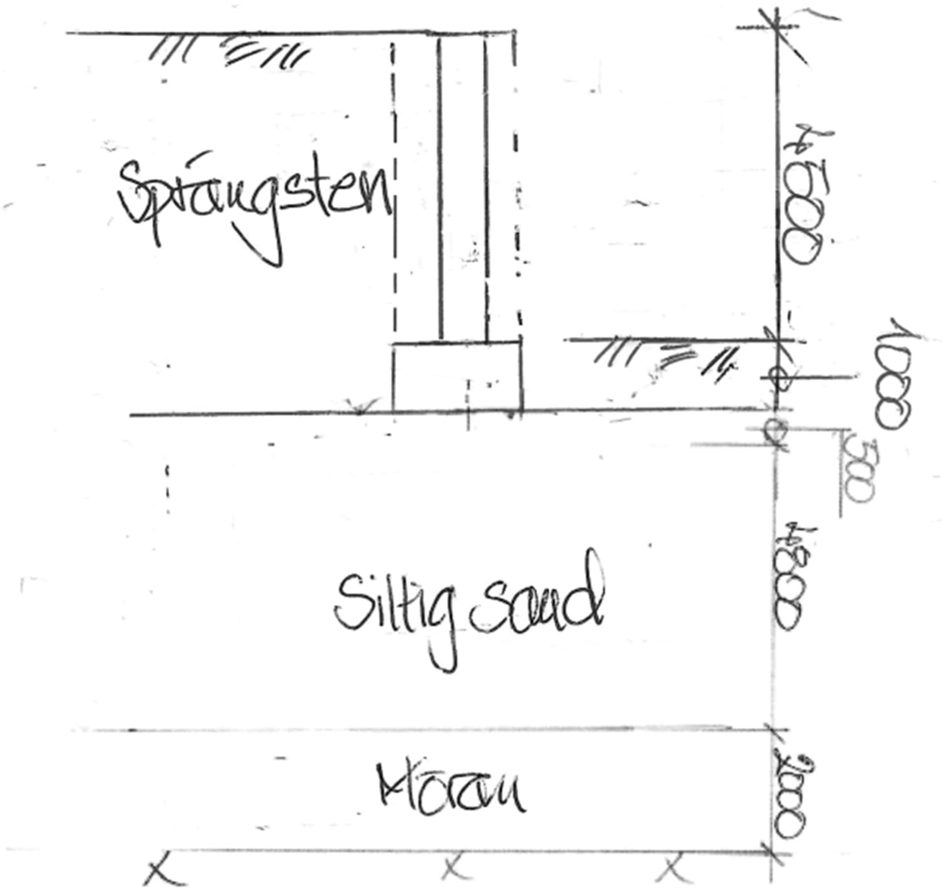
A slab foundation is evaluated using three different methods:

- General bearing capacity equation (”Allmäna bärighetsekvationen”)
- Circular slipe surface using SLOPE/W using ultimate limit safety.
- Slope stability analysis using FEM-program.

Summary of safety factors (SF):

Method	SF	Page
General bearing capacity equation	0.56	7
Circular slipe surface	1.17	7
Slope stability analysis	1.19	23

1.1 GEOTECHNICAL CROSSECTION

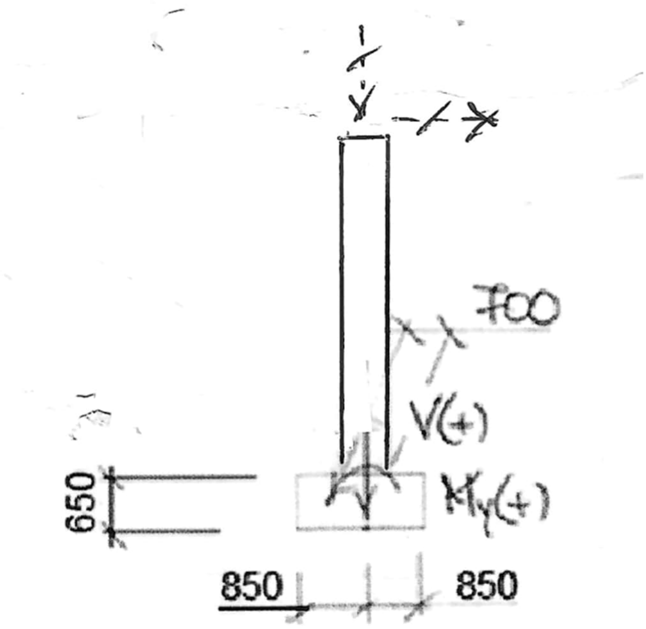


ELEVATION

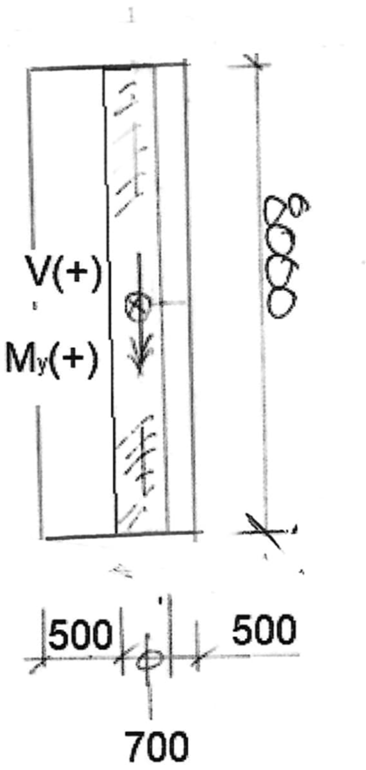
Geotechnical parameters:

Material	Level	ρ	ρ'	ϕ_k	E_k
”Sprängsten”	20.3-19.8	18	11	45	50
”Siltig sand”	19.8-15.0	20	11	38	35
”Morän”	15.0-13.0	20	11	39	45
”Berg”	13.0	-	-	-	-
-	m	kN/m^3	kN/m^3	deg	MPa

1.2 GEOMETRY



ELEVATION



PLAN
Bottom slab

1.3 DESIGN LOAD EFFECT

V_d = 3566kN

H_{xd} = 1570kN

H_{yd} = 39kN

M_{xd} = 386kNm

M_{yd} = 21kNm

2. GEOTECHNICAL BEARING CAPACITY EQUATION

General bearing capacity equation is determined using SS-EN 1997-1 annex D & TRVINFRA-002300 section 9.2.1.2.1 (“Allmänna bärighetsekvationen”), see other documentation.

3. CIRCULAR SLIPE SURFACE

Circular slipe surface safety is determined using SLOPE/W for ultimate limit (ULS) see other documentation.

4. SLOPE STABILITY ANALYSIS

4.1 GENERAL

Soil & abutment are modelled using 2D triangular quadric plain strain elements (TNP6).

FEM-program has function *Phi-c Reduction* performs a safety factor analysis on nonlinear material.

Plastic load model *Modified Mohr-Coulomb* (MMC) to define both soil and concrete.

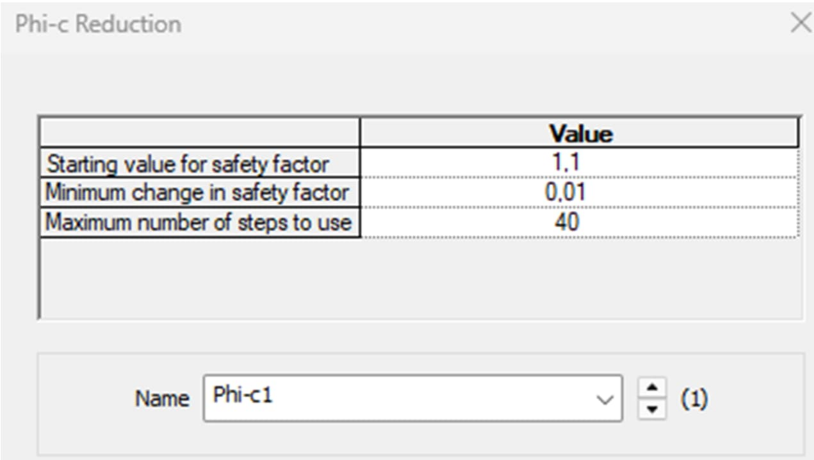
FEM-program has function *Branch Analysis* that enables performing several analyses within same model. This capability is used to perform a safety factor analysis on nonlinear material.

To model concrete abutment a fictious soil material is chosen. A cohesion material with very high cohesion (2 MPa) is used.

4.2 SYSTEM ANALYSIS

4.2.1 Safety factor analysis

Safety factor analysis is performed using function *Phi-c Reduction* with starting values seen below.

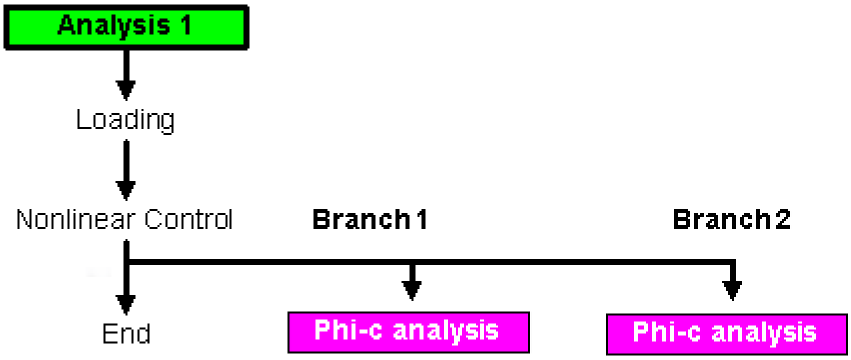


4.2.3 Branch Analysis

Branch Analysis seen below is used within same model.

Branch 1: Soil

Branch 2: Soil + Surface load



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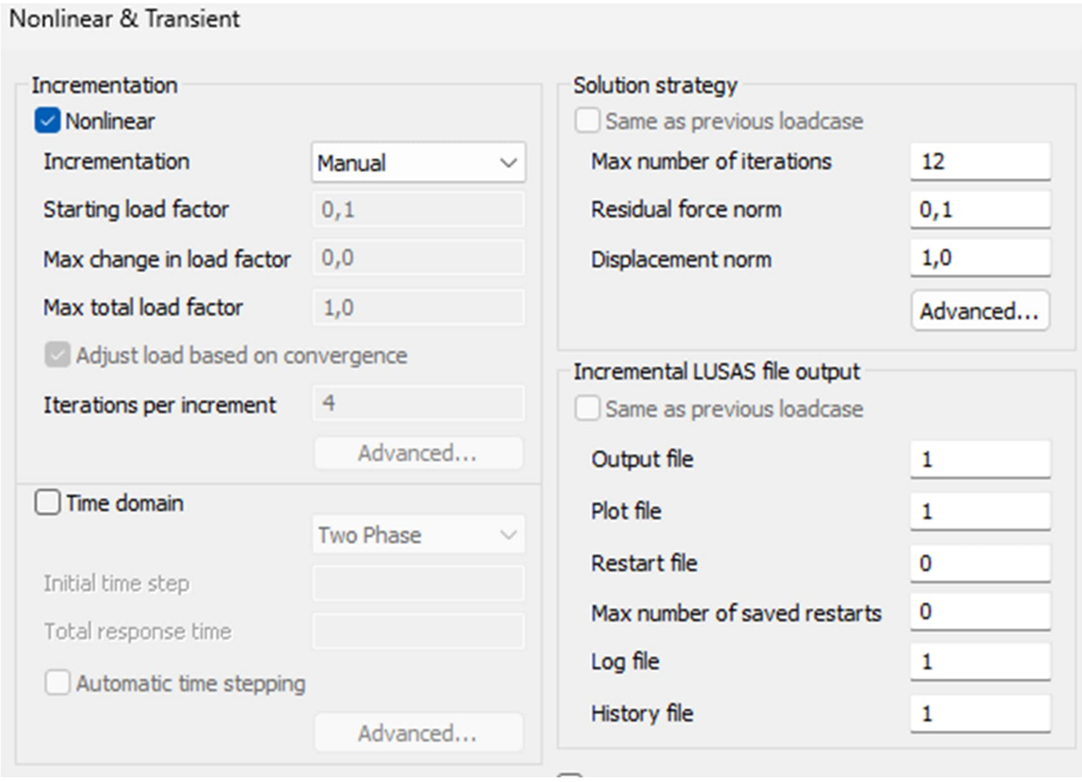
Schematic sketch

4.2.4 Nonelinear analysis

Nonelinear analysis is performed using increments using Newton_Raphson numerial procedure. These *Incrementation* as chosen to be performed *Manual* seen convergence generally more stable, see chosen parameters in dialogue box.



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

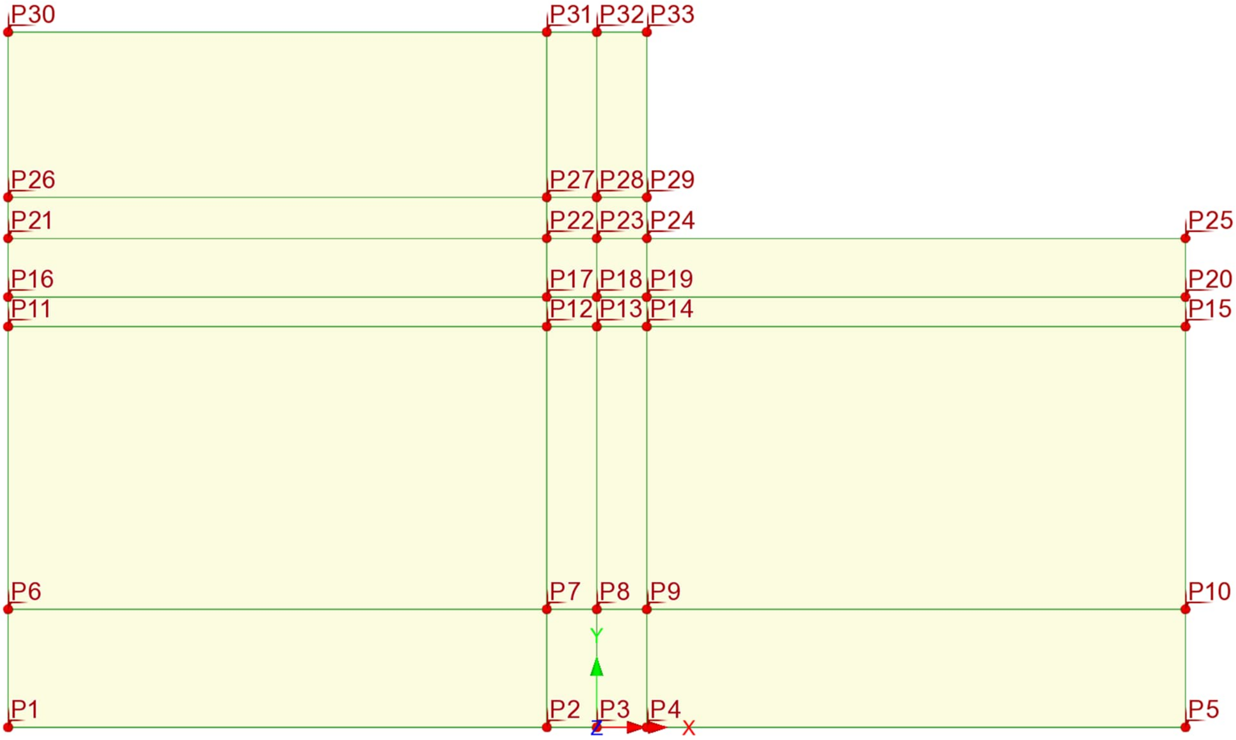
Residual force norm:
The limit for the sum of the squares of all residual forces as a percentage of the sum of the squares of all external forces, including reactions (rdnrm). By default only translation degrees of freedom are considered. So for a value of 0.1 the convergence of the solution at each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

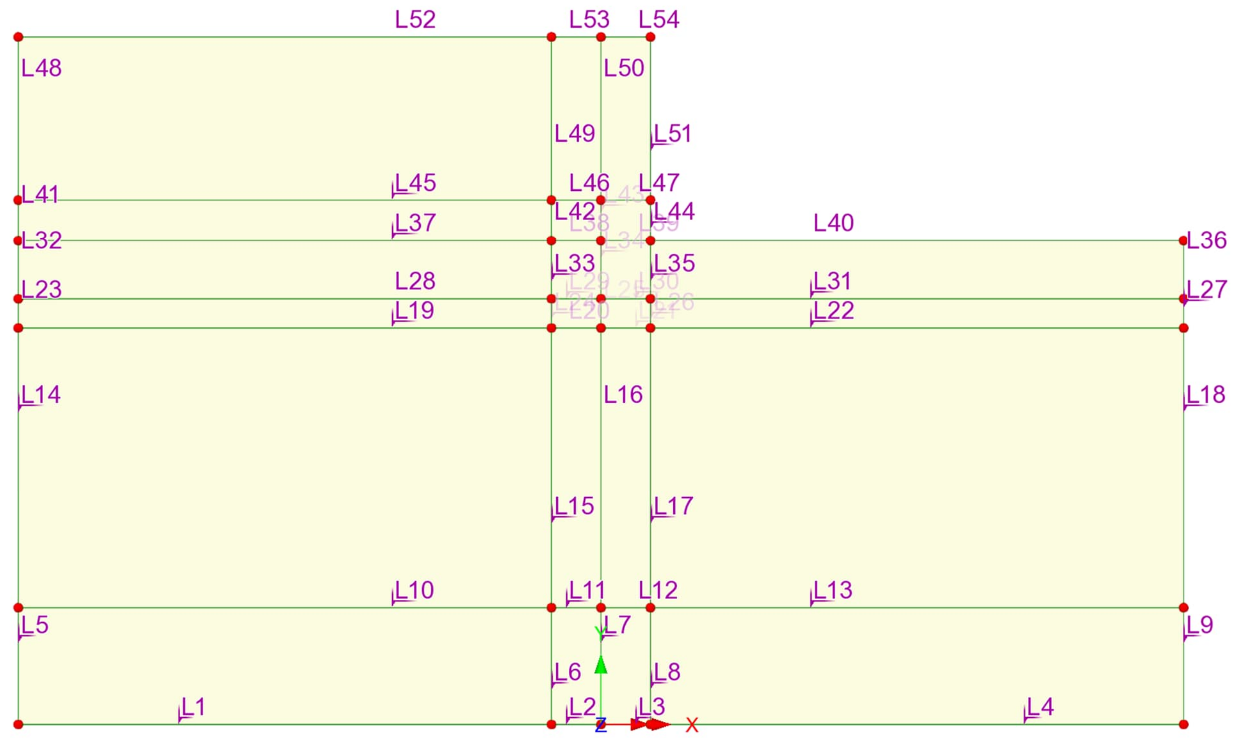
4.3 STATIC SYSTEM

4.3.1 Geometry

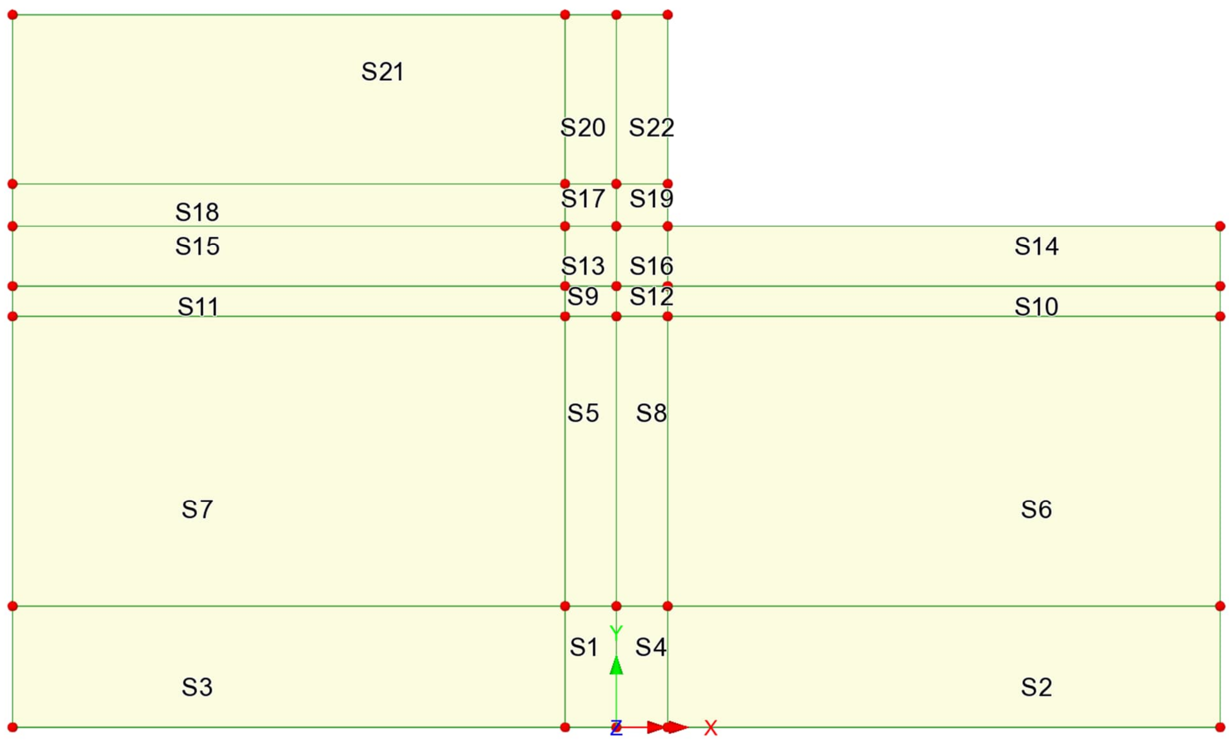
Points:



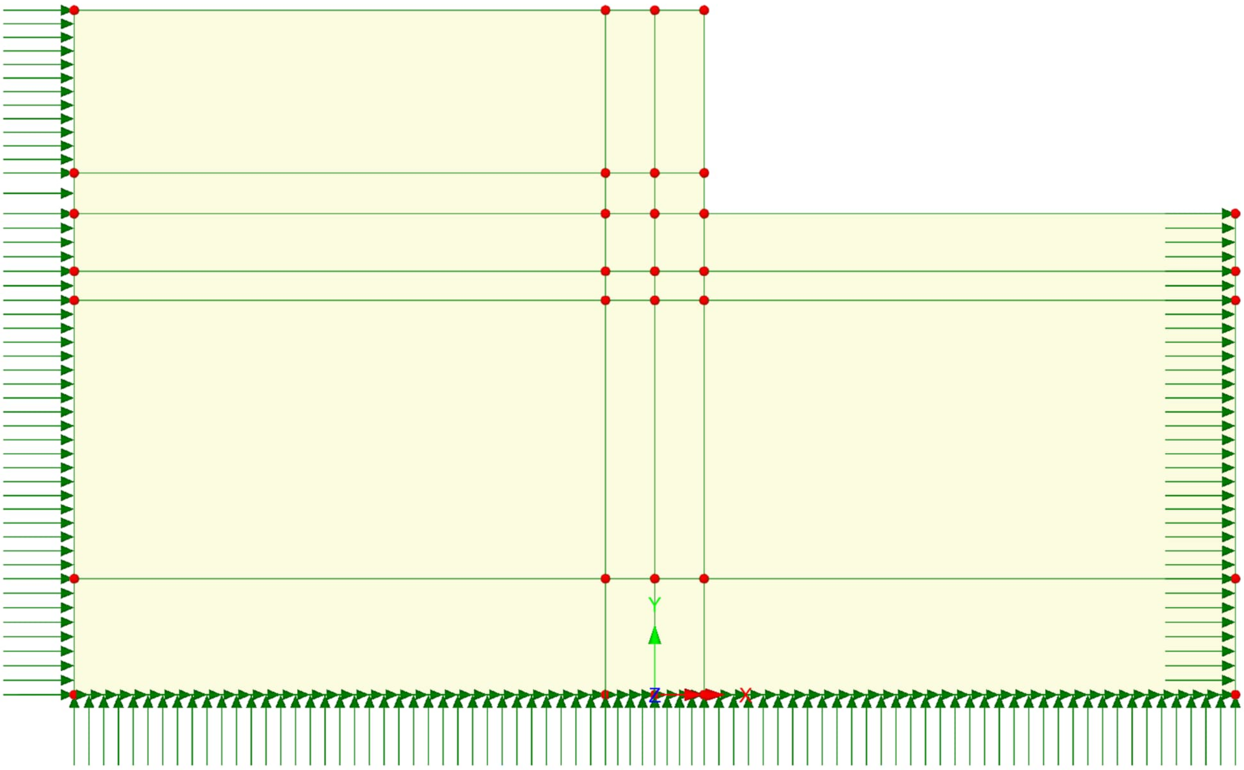
Lines:



Surface:

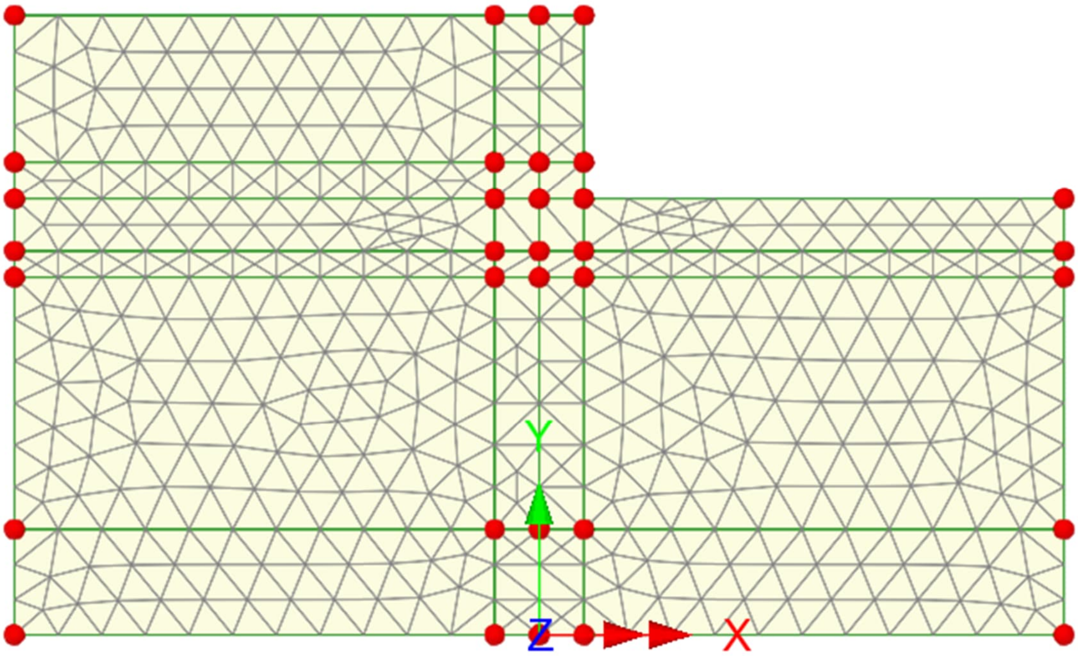


4.3.2 Boundary



4.3.3 MESH: Beam element (BMI2)

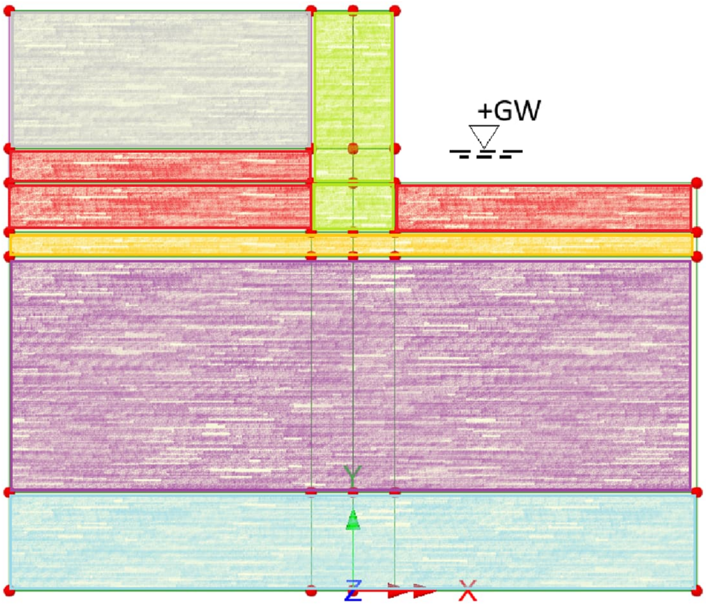
Soil & foundation are modelled as seen below.

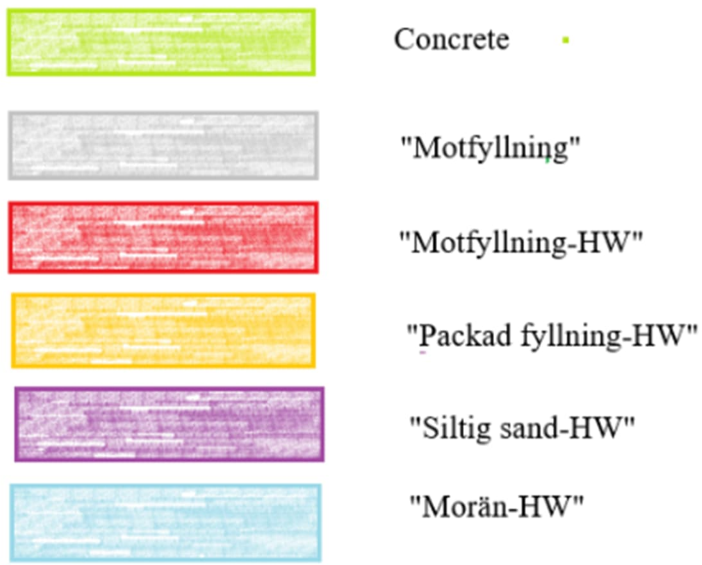


Name	Element size	Irregular mesh
TNP6	0.8 m	Yes

4.3.4 Material

All materials are isotropic plastic material using *Modified Mohr-Coulomb* as seen below.





Elastic properties:

Material	Below GW	Mass density	v	E-modulus
Concrete	-	0.5[1.)]	0,3	34000
"Motfyllning"	No	2.0	0,3	50
"Motfyllning - HW"	Yes	1.1	0,3	50
"Packad fyllning - HW"	Yes	1.1	0,3	50
"Siltig sand - HW	Yes	1.1	0,3	35
"Moran - HW"	Yes	1.1	0,3	45
-	-	ton/m^3	-	MPa

[1.)] Fictitious density.

Plastic properties (incl. K_0 initialisation):

Material	Plastic modell	$\phi_{friktion}$	$\phi_{dilation}$	c_u	$\sigma_{t,\ cut\text{-}off}$	$\sigma_{c,\ cut\text{-}off}$	K_0
Concrete	Modified Mohr Coulomb[2.)]	0	0	$2{\cdot}10^3$	-	-	1.0[4.)]
"Motfyllning"	Modified Mohr Coulomb[3.)]	38	38	0	0	109	1.0[4.)]
"Motfyllning - HW"	Modified Mohr Coulomb[3.)]	38	38	0	0	109	1.0[4.)]
"Packad fyllning - HW"	Modified Mohr Coulomb[3.)]	38	38	0	0	109	1.0[4.)]
"Siltig sand – HW”	Modified Mohr Coulomb[3.)]	31	31	0	0	109	1.0[4.)]
"Moran - HW"	Modified Mohr Coulomb[3.)]	32	32	0	0	0	1.0[4.)]
-	-	deg	deg	kPa	kPa	kPa	-

[2.)] No cut-off due to compression or tension stress.

[3.)] Rankine using cut-off stress at $\sigma_{t,\ cut\text{-}off}$ and $\sigma_{c,\ cut\text{-}off}$

[4.)] When non-linear analysis starts, initially K_0 is applied.
($K_0 = 1.0 \rightarrow \sigma_h = \sigma_v$ which is considered on safe side).

4.4 LOADS

4.4.1 Soil weight (Gravity)

Soil weight is determined material density.

4.4.2 Surfaced load

Surface load is defined as a global distributed load.

The vertical load is reduced due fictious weight of concrete.

V_d = 3566kN : see page 6

H_{xd} = 1570kN : see page 6

$H_{x.earth}$ = 515kN : see page 10

B = 1.70m : see page 5

L_{ef} = 8.28m : see page 8

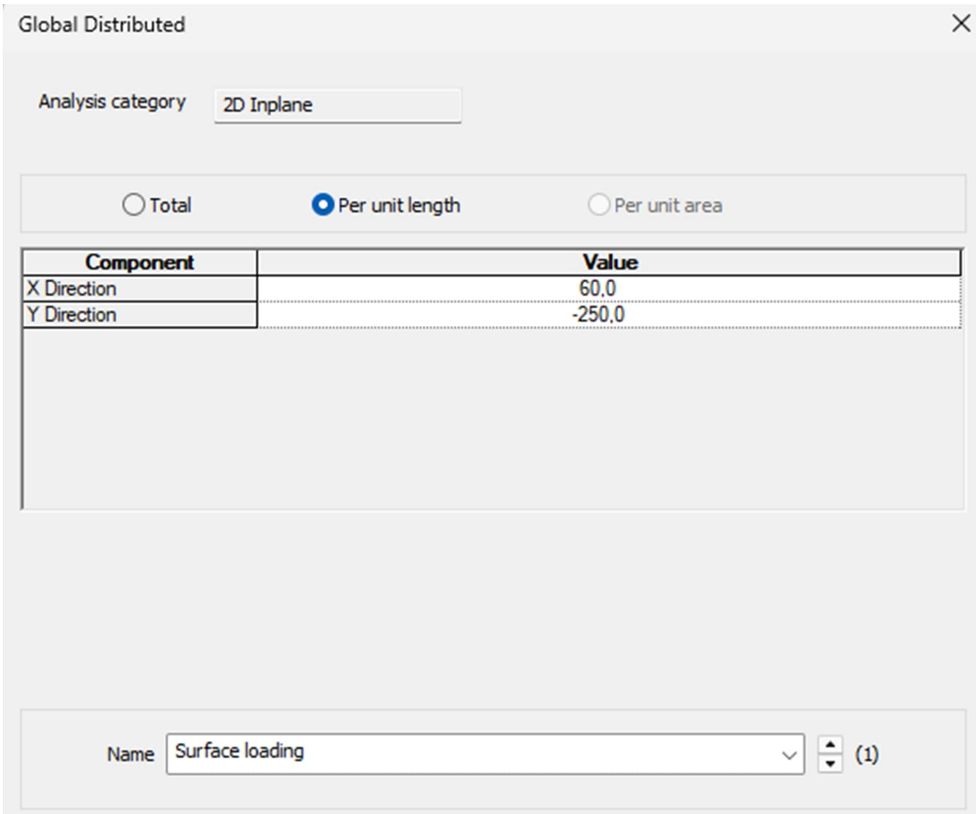
$$H_{xd.red} = H_{xd} - \psi\gamma_{earth} \cdot H_{x.earth} = 1570kN - 1.45 \cdot 515kN = 823kN$$

$$\rightarrow Px = \frac{H_{xd.red}}{B \cdot L_{ef}} = \frac{823kN}{1.70m \cdot 8.28m} = -60\frac{kN}{m^2}$$

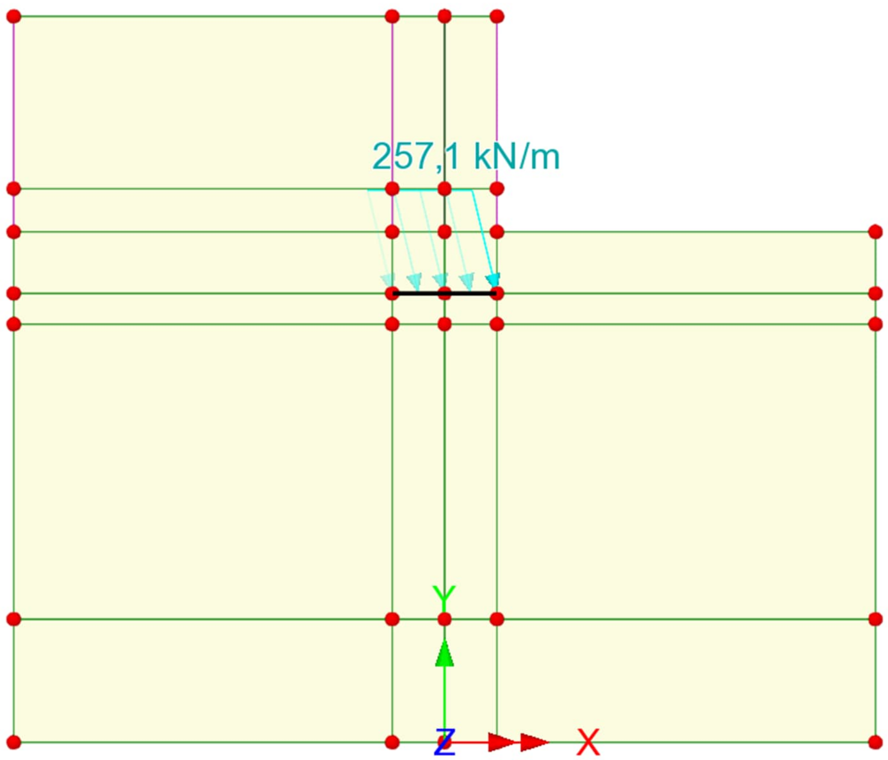
$$V_{d.red} = V_d - B \cdot H = 3566kN - 1.70m \cdot 4.5m \cdot 5\frac{kN}{m^3} = 3528kN$$

$$\rightarrow Py = -\frac{V_{d.red}}{B \cdot L_{ef}} = -\frac{3528kN}{1.70m \cdot 8.28m} = -250\frac{kN}{m^2}$$

$$P_d = \sqrt{Px^2 + Py^2} = 257\frac{kN}{m^2}$$



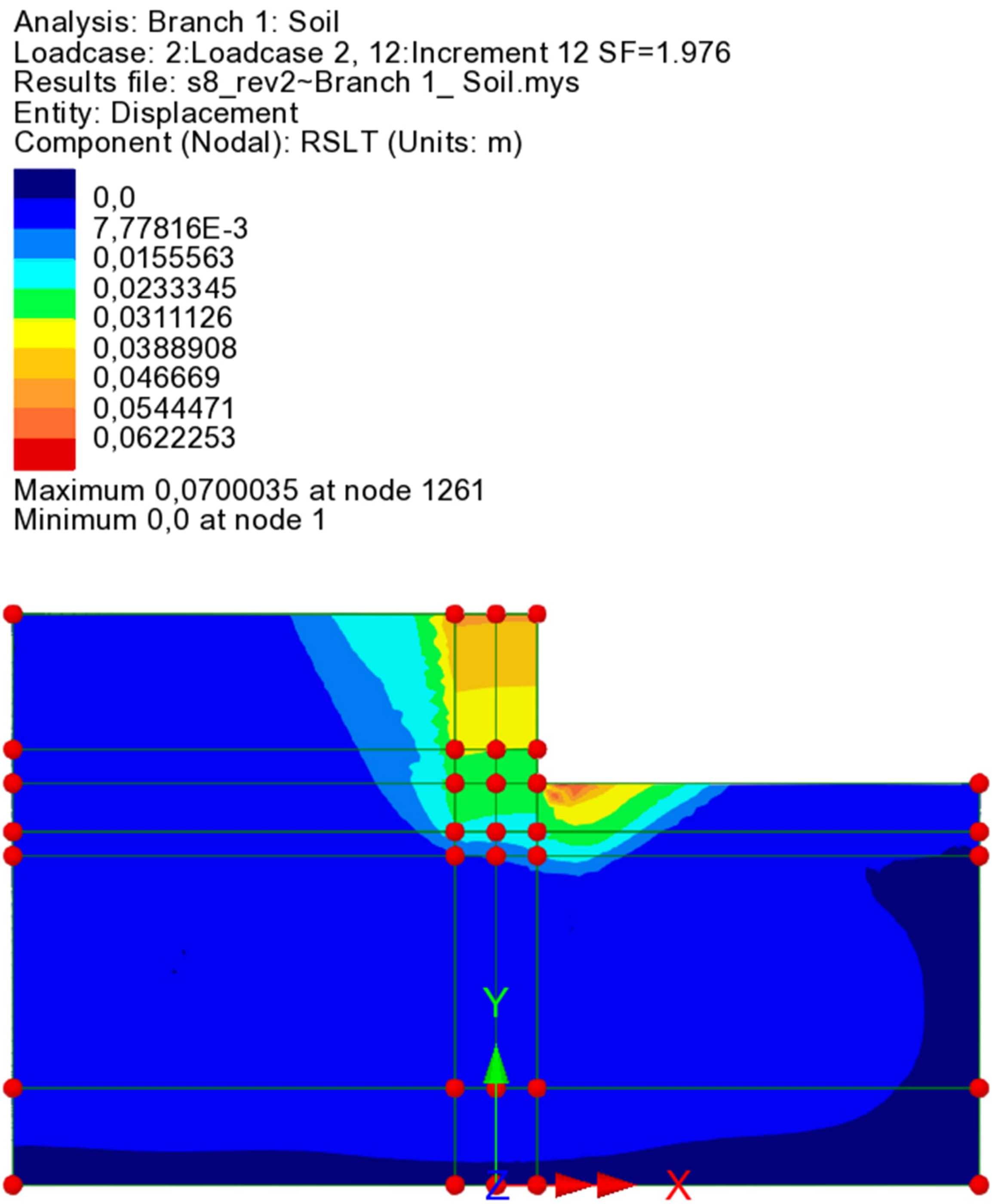
$$P_d = \sqrt{Px^2 + Py^2} = 257\frac{kN}{m^2}$$



4.4 RESULTS (FEM-program)

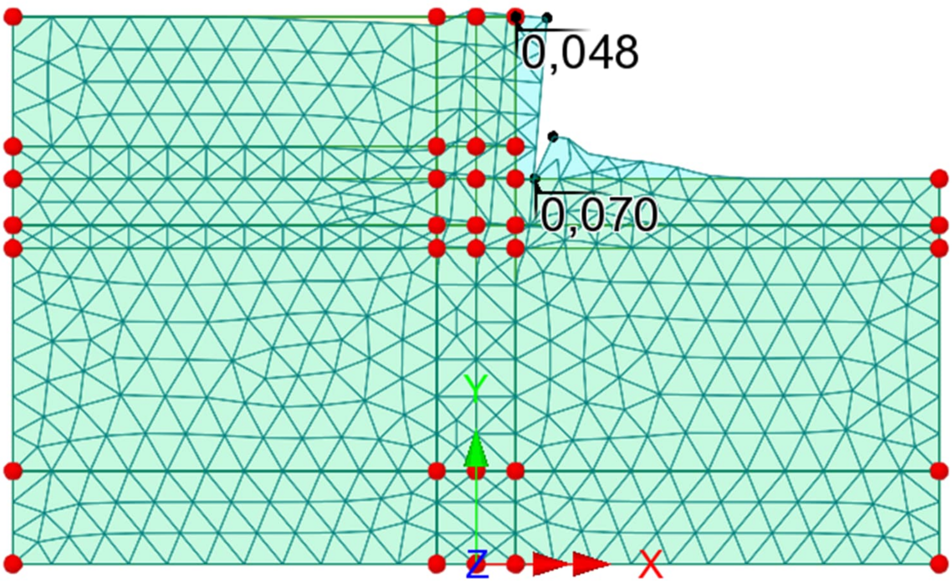
4.4.1 Branch 1: Soil

→ Safety factor FS = 1.98



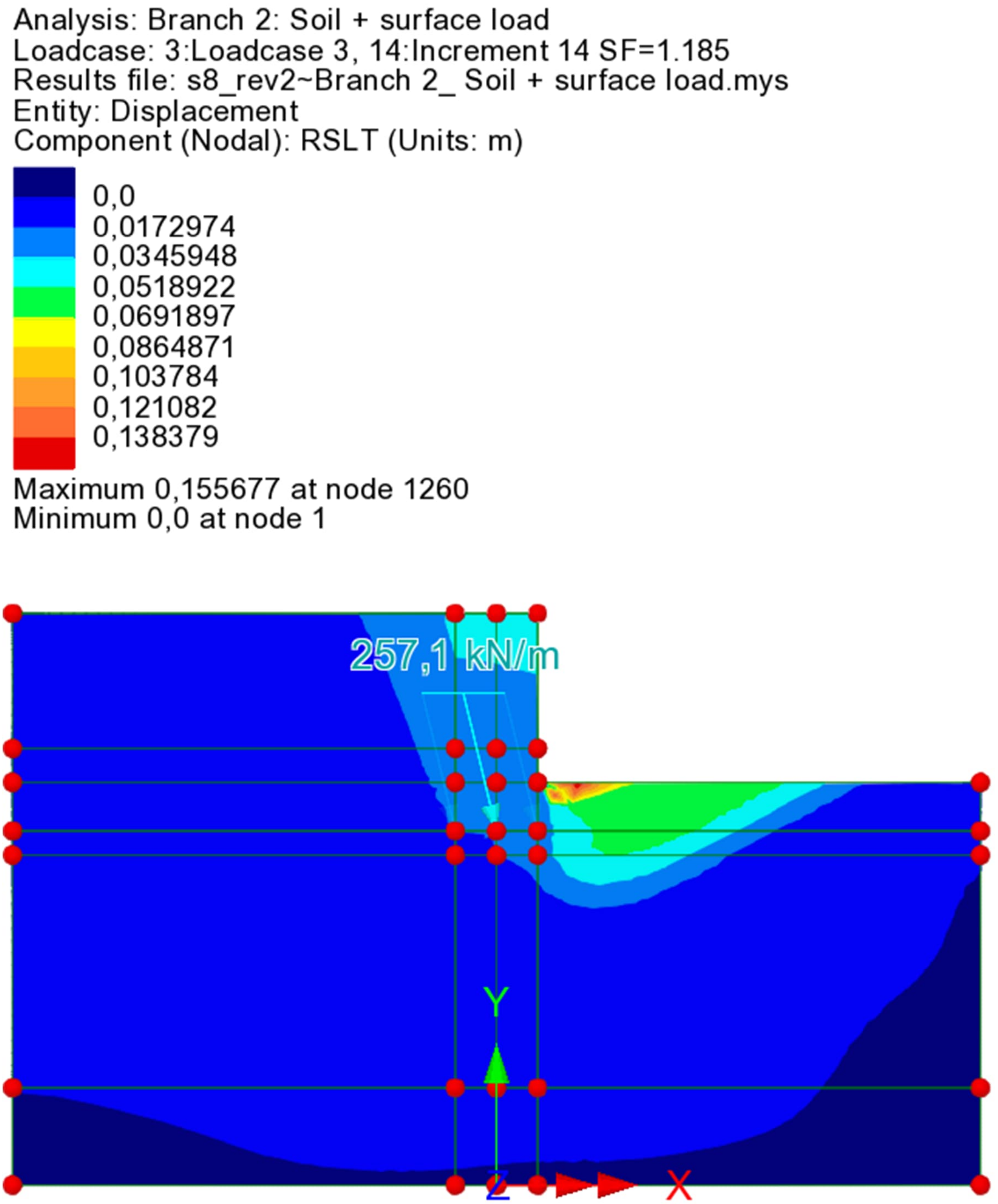
Scale: 1: 166,573
Zoom: 56,7427
Eye: (0,0; 0,0; 1,0)
Nonlinear analysis
Analysis: Branch 1: Soil
Loadcase: 2:Loadcase 2, 12:Increment 12 SF=1.976
Results file: s8_rev2~Branch 1_ Soil.mys
Maximum displacement 0,0700035 at node 1261
Deformation exaggeration: 14,2769

Peak/value entity: Displacement
Peak/value component: RSLT (Units: m)
Peak range(%): 100,0
Peak/value maximum 0,0700035 at node 1261
Peak/value minimum 0,0 at node 1



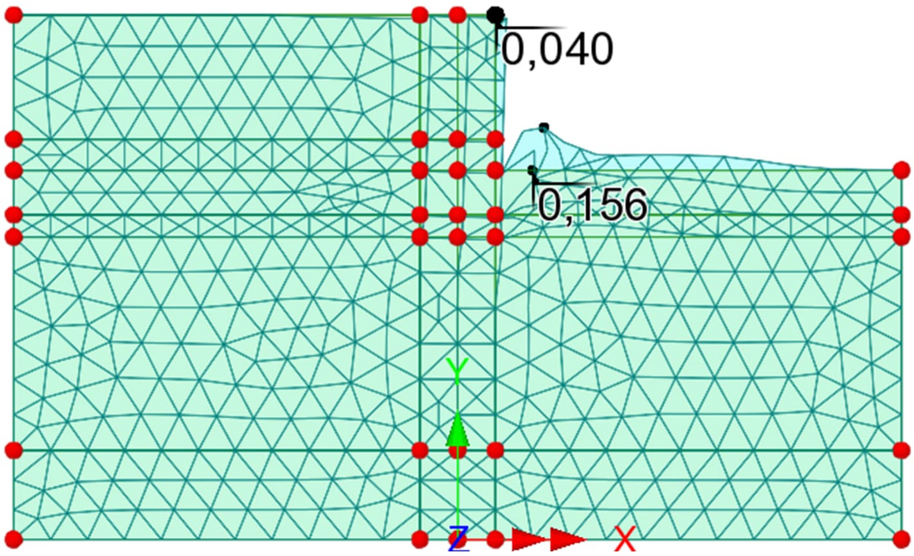
4.4.2 Branch 2: Soil + Surface load

→ Safety factor FS = 1.19



Scale: 1: 166,573
Zoom: 56,7427
Eye: (0,0; 0,0; 1,0)
Nonlinear analysis
Analysis: Branch 2: Soil + surface load
Loadcase: 3:Loadcase 3, 14:Increment 14 SF=1.185
Results file: s8_rev2~Branch 2_ Soil + surface load.mys
Maximum displacement 0,155677 at node 1260
Deformation exaggeration: 6,41994

Peak/value entity: Displacement
Peak/value component: RSLT (Units: m)
Peak range(%): 100,0
Peak/value maximum 0,155677 at node 1260
Peak/value minimum 0,0 at node 1



Title: Input receipt

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

Model Title:
Model File: s8

Table of Contents

1. Phi-c reduction

Attribute: 1 Title: Ph-c1
Sub Type = Phi-c reduction

Starting value:	1.1
Minimum change in safety factor:	0.01
Maximum number of steps in use:	60

2. Branch

Attribute: 1 Title: Branch 1: Soil
Sub Type = Branch

Analysis:	Analysis 1

Attribute: 2 Title: Branch 2: Soil + surface load
Sub Type = Branch

Analysis:	Analysis 1

3. Analysis

Analysis	Type	Branch	Phi-c reduction
1	Nonlinear & Transient	None	None
1	Nonlinear & Transient	1	Ph-c1
1	Nonlinear & Transient	2	Ph-c1

4. Points

Point	X coordinate	Y coordinate	Z coordinate
1	-10,0	0,0	0,0
2	-0,9	0,0	0,0
3	0,0	0,0	0,0
4	0,9	0,0	0,0
5	10,0	0,0	0,0
6	-10,0	2,0	0,0
7	-0,9	2,0	0,0
8	0,0	2,0	0,0
9	0,9	2,0	0,0
10	10,0	2,0	0,0
11	-10,0	6,8	0,0
12	-0,9	6,8	0,0
13	0,0	6,8	0,0
14	0,9	6,8	0,0
15	10,0	6,8	0,0
16	-10,0	7,3	0,0
17	-0,9	7,3	0,0
18	0,0	7,3	0,0
19	0,9	7,3	0,0
20	10,0	7,3	0,0
21	-10,0	8,3	0,0
22	-0,9	8,3	0,0
23	0,0	8,3	0,0
24	0,9	8,3	0,0
25	10,0	8,3	0,0
26	-10,0	9,0	0,0
27	-0,9	9,0	0,0
28	0,0	9,0	0,0
29	0,9	9,0	0,0
30	-10,0	11,8	0,0
31	-0,9	11,8	0,0
32	0,0	11,8	0,0
33	0,9	11,8	0,0

5. Lines

Line	Points	Line	Points
1	2;1	2	3;2
3	3;4	4	4;5
5	1;6	6	7;2
7	3;8	8	9;4
9	5;10	10	6;7
11	8;7	12	8;9
13	10;9	14	6;11
15	12;7	16	8;13
17	14;9	18	10;15
19	11;12	20	13;12
21	13;14	22	15;14
23	11;16	24	17;12
25	13;18	26	19;14
27	15;20	28	16;17
29	18;17	30	18;19
31	20;19	32	16;21
33	22;17	34	18;23
35	24;19	36	20;25
37	21;22	38	23;22
39	23;24	40	25;24
41	21;26	42	27;22
43	23;28	44	29;24
45	26;27	46	28;27
47	28;29	48	26;30
49	31;27	50	28;32
51	33;29	52	30;31
53	32;31	54	32;33

6. Surfaces

Surface	Lines	Surface	Lines
1	7;11;6;2	2	9;13;8;4
3	5;1;6;10	4	7;3;8;12
5	16;20;15;11	6	18;22;17;13
7	14;10;15;19	8	16;12;17;21
9	25;29;24;20	10	27;31;26;22
11	23;19;24;28	12	25;21;26;30
13	34;38;33;29	14	36;40;35;31
15	32;28;33;37	16	34;30;35;39
17	43;46;42;38	18	41;37;42;45
19	43;39;44;47	20	50;53;49;46
21	48;45;49;52	22	50;47;51;54

7. Mesh

Attribute: 1 Title: TPN6 1,0 m
Sub Type = Surface Mesh Element Type = TPN6

Property	Symbol	Value
Element size	size	0,8
Quadrilateral element angle limit	quadAngle	30,0
Size multiplier	sizeMultiplier	1,1
edge deviation	edgeDeviation	0,0
Element defined by name	DefinedByName	false
Single feature joint	isSingleFtrJnt	false

Assignment to Surfaces:
1T22

8. Material

Attribute: 2 Title: Motfylling
Sub Type = Isotropic Material
Assigned in: Analysis 1

Property	Symbol	Value
Young's modulus	E	50000,0
Poisson's ratio	nu	0,3
Density	rho	2,0
Type	type_8	"Rankine"
Friction angle	frc	38,0
Dilation angle	dil	38,0
Damping factor	dmpFct	0,0
Single cohesion value	CSngle	0,0
Single tensile value	QmaxSngle	0,0
Single compressive value	QminSngle	1000000000,0
Type	type_6	"elastic"
Model	model	"Elastic"
Calculate initial void ratio	calcVoid	false
Young's modulus for Ko	Eko	0,0
Coefficient of lateral earth pressure	Ko	1,0

~~**Loadcase ID: 1 Title: Loadcase 1**~~ (Information "Assigned in" seems sufficient)
Assignment to Surfaces:
21

Attribute: 3 Title: Packad fyllning - HW
Sub Type = Isotropic Material
Assigned in: Analysis 1

Property	Symbol	Value
Young's modulus	E	50000,0
Poisson's ratio	nu	0,3
Density	rho	1,1
Type	type_8	"Rankine"
Friction angle	frc	38,0
Dilation angle	dil	38,0
Damping factor	dmpFct	0,0
Single cohesion value	CSngle	0,0
Single tensile value	QmaxSngle	0,0
Single compressive value	QminSngle	1000000000,0
Type	type_6	"elastic"
Model	model	"Elastic"
Calculate initial void ratio	calcVoid	false
Young's modulus for Ko	Eko	0,0
Coefficient of lateral earth pressure	Ko	1,0

~~**Loadcase ID: 1 Title: Loadcase 1**~~
Assignment to Surfaces:
9T12

Attribute: 4 Title: Motfylling- HW
Sub Type = Isotropic Material
Assigned in: Analysis 1

Property	Symbol	Value
Young's modulus	E	50000,0
Poisson's ratio	nu	0,3
Density	rho	1,1
Type	type_8	"Rankine"
Friction angle	frc	38,0
Dilation angle	dil	38,0
Damping factor	dmpFct	0,0
Single cohesion value	CSngle	0,0
Single tensile value	QmaxSngle	0,0
Single compressive value	QminSngle	1000000000,0
Type	type_6	"elastic"
Model	model	"Elastic"
Calculate initial void ratio	calcVoid	false
Young's modulus for Ko	Eko	0,0
Coefficient of lateral earth pressure	Ko	0,5

~~**Loadcase ID: 1 Title: Loadcase 1**~~
Assignment to Surfaces:
14;15;18

Attribute: 6 Title: Concrete
Sub Type = Isotropic Material
Assigned in: Analysis 1

Property	Symbol	Value
Young's modulus	E	34000000,0
Poisson's ratio	nu	0,3
Density	rho	0,5
Type	type_8	"No cut-off"
Friction angle	frc	0,0
Dilation angle	dil	0,0
Damping factor	dmpFct	0,0
Single cohesion value	CSngle	2000,0
Single tensile value	QmaxSngle	0,0
Single compressive value	QminSngle	0,0
Type	type_6	"elastic"
Model	model	"Elastic"
Calculate initial void ratio	calcVoid	false
Young's modulus for Ko	Eko	0,0
Coefficient of lateral earth pressure	Ko	1,0

~~**Loadcase ID: 1 Title: Loadcase 1**~~
Assignment to Surfaces:
13;16;17;19;20;22

Attribute: 7 Title: Siltig sand - HW
Sub Type = Isotropic Material
Assigned in: Analysis 1

Property	Symbol	Value
Young's modulus	E	35000,0
Poisson's ratio	nu	0,3
Density	rho	1,1
Type	type_8	"Rankine"
Friction angle	frc	31,0
Dilation angle	dil	31,0
Damping factor	dmpFct	0,0
Single cohesion value	CSngle	0,0
Single tensile value	QmaxSngle	0,0
Single compressive value	QminSngle	1000000000,0
Type	type_6	"elastic"
Model	model	"Elastic"
Calculate initial void ratio	calcVoid	false
Young's modulus for Ko	Eko	0,0
Coefficient of lateral earth pressure	Ko	1,0

~~**Loadcase ID: 1 Title: Loadcase 1**~~
Assignment to Surfaces:
5T8

Attribute: 8 Title: Moran - HW
Sub Type = Isotropic Material
Assigned in: Analysis 1

Property	**Symbol**	**Value**
Young's modulus	E	45000,0
Poisson's ratio	nu	0,3
Density	rho	1,1
Type	type_8	"Rankine"
Friction angle	frc	32,0
Dilation angle	dil	32,0
Damping factor	dmpFct	0,0
Single cohesion value	CSngle	0,0
Single tensile value	QmaxSngle	0,0
Single compressive value	QminSngle	1000000000,0
Type	type_6	"elastic"
Model	model	"Elastic"
Calculate initial void ratio	calcVoid	false
Young's modulus for Ko	Eko	0,0
Coefficient of lateral earth pressure	Ko	1,0

~~**Loadcase ID: 1 Title: Loadcase 1**~~
Assignment to Surfaces:
1T4

9. Supports

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

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

~~**Loadcase ID: 1 Title: Loadcase 1**~~ Information "Assigned in" seems sufficient)

Assignment to Lines:
5;9;14;18;23;27;32;36;41;48

Attribute: 2 Title: Fixed in XY
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:
1T4

10. Loading

Attribute: 1 Title: Surface loading
Sub Type = Global Distributed Load

Property	Symbol	Value
Attribute type	type	"Length"
X Direction	WX	60,0
Y Direction	WY	-250,0
Z Direction	WZ	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	Hinge	0,0
Pore pressure flux	pwp	0,0
Keep global	keepGlobal	false

Loadcase ID: 1 Title: Loadcase 1 Factor = 1.0
Assignment to Lines:
29;30

Gravity (when chosen) is applied as a body force of -9,8m/s² in the Y direction

11. Loadcases

Loadcase	Gravity	Loading	Analysis	Branch
1	On	-	Analysis 1	None
2	On	-	Analysis 1	Branch 1: Soil
3	On	1: Surface loading	Analysis 1	Branch 2: Soil + surface load