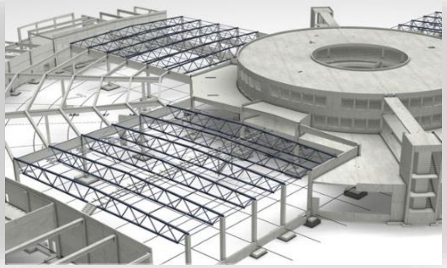
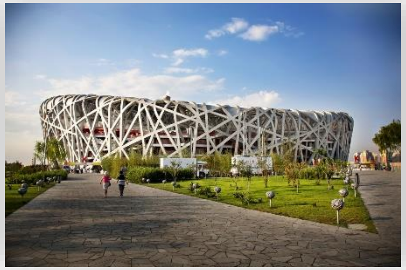
GeoStruktur Sistem Solusindo

Your Trusted Partner for Digital Transformation



Deep Excavation using PLAXIS 2D

GeoStruktur

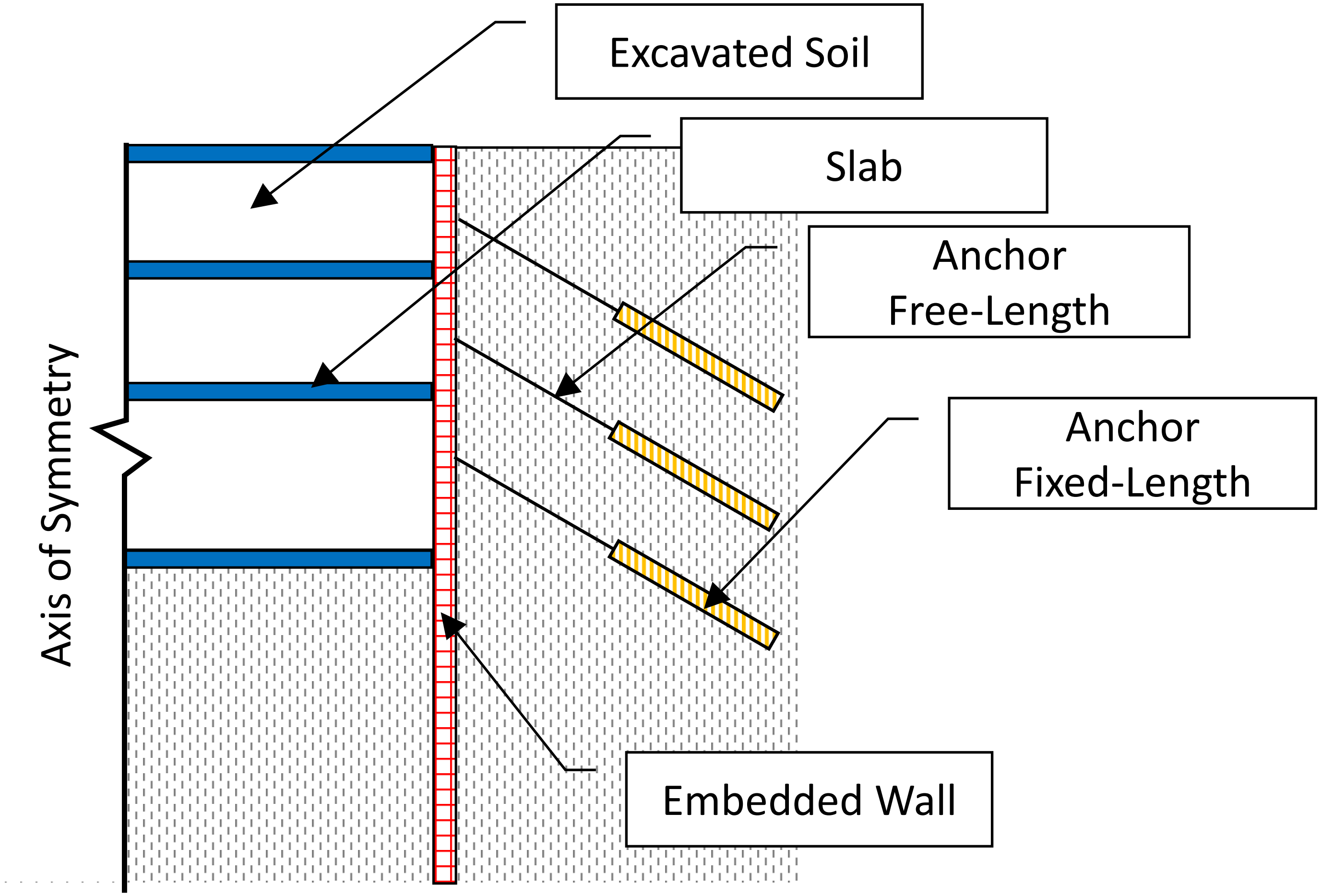
Deep Excavation using PLAXIS 2D

1. Design Criteria
2. Soil Model in Deep Excavation
3. Structural Elements
4. PLAXIS 2D Simulation
5. Results

Part 1: Design Criteria

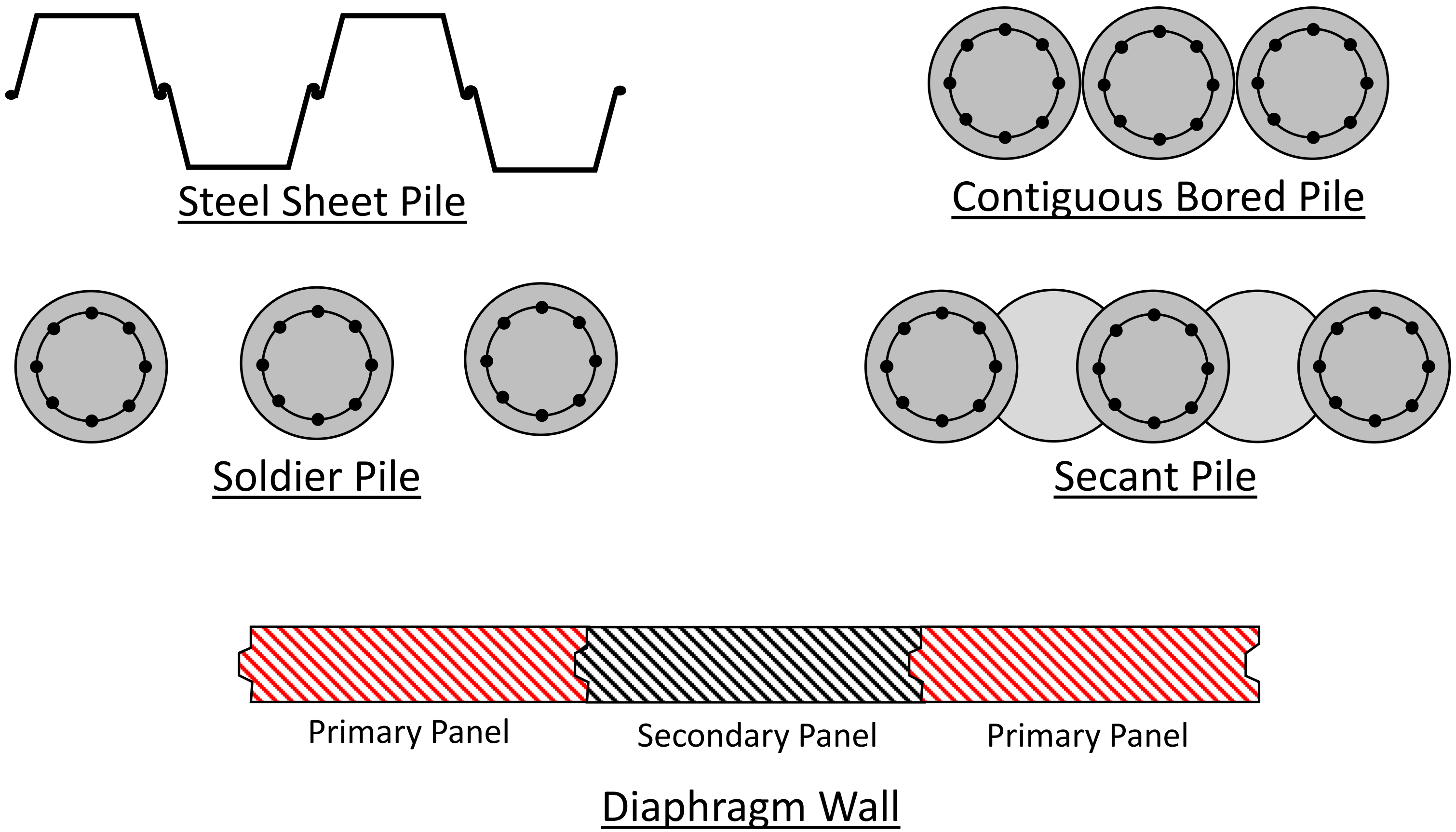
Deep Excavation

- Definition: An excavation with depth of 3 m or more (SNI 8460 Sect. 11.1).



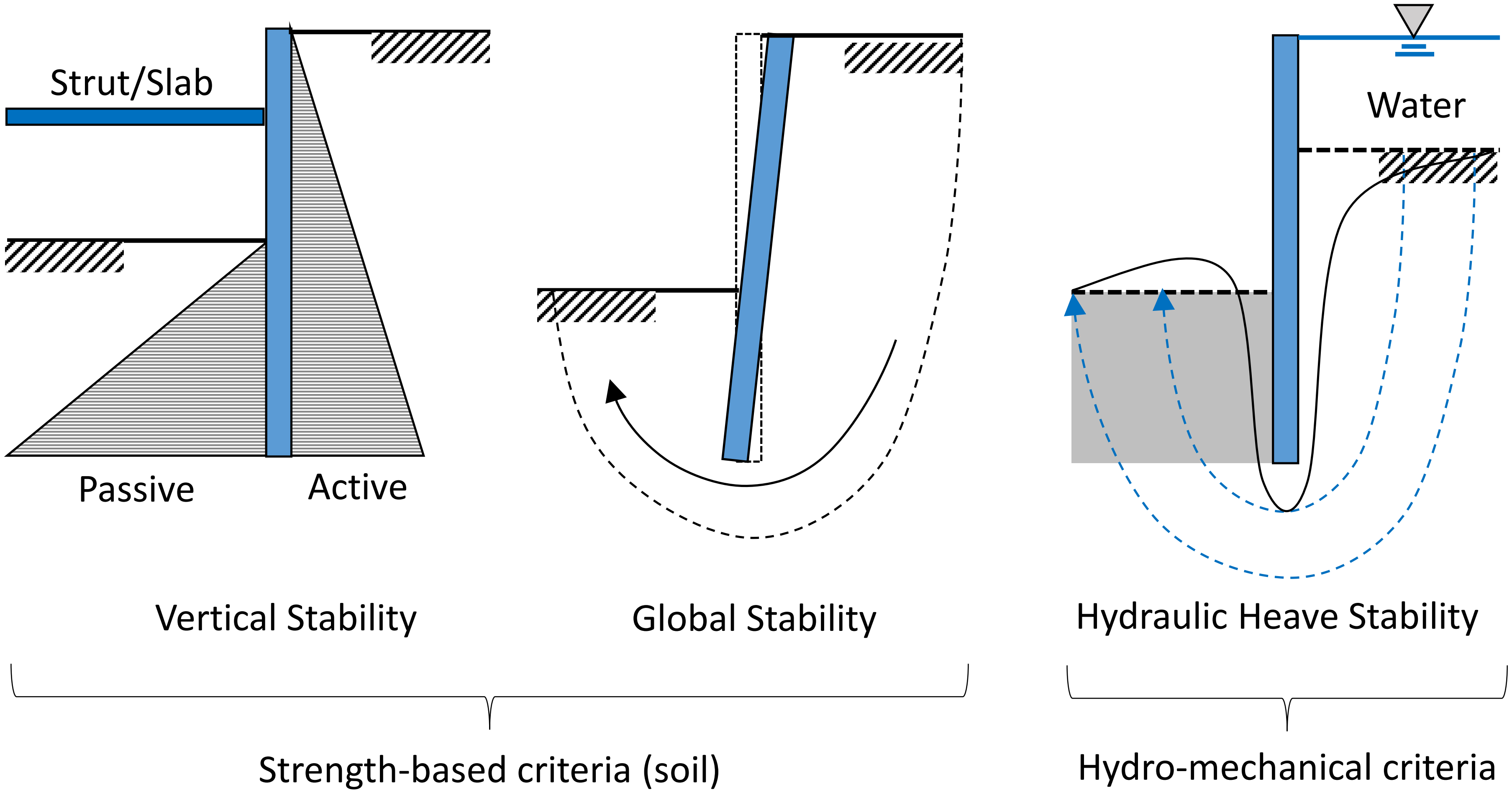
Schematic of deep excavations

Types of Embedded Wall



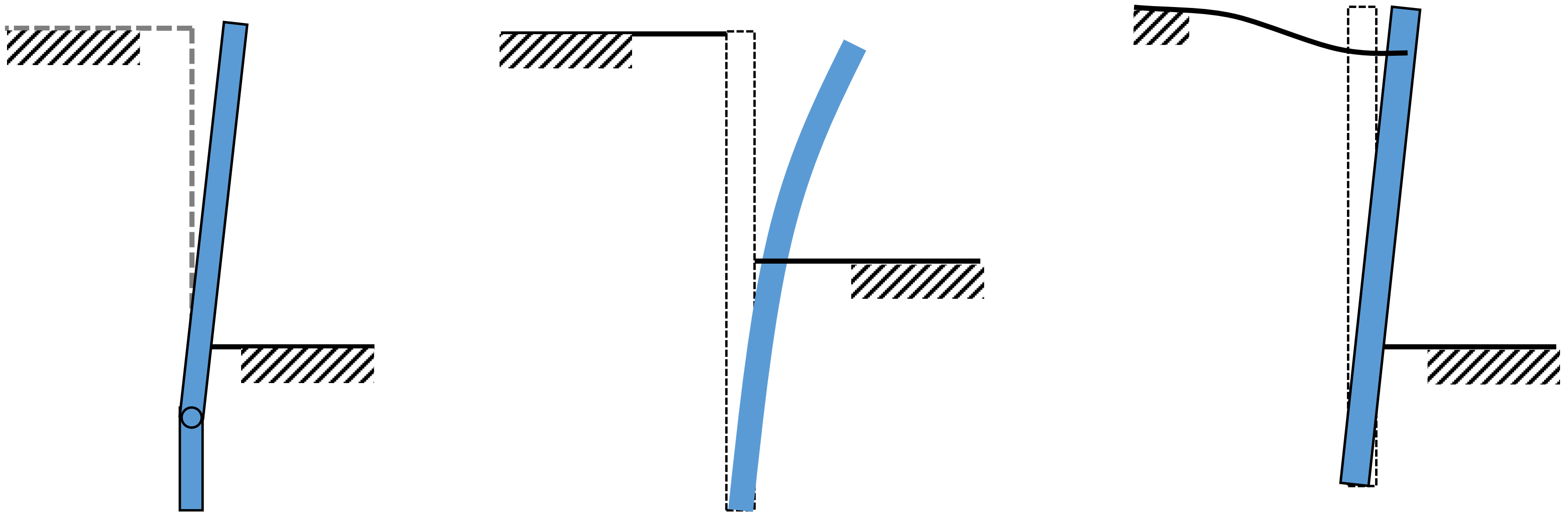
GeoStruktur

Design Criteria (1/2) – Stability Criteria



GeoStruktur

Design Criteria (2/2) – Other Criteria



Plastic Limit

Deflection Limit
(Embedded Wall)

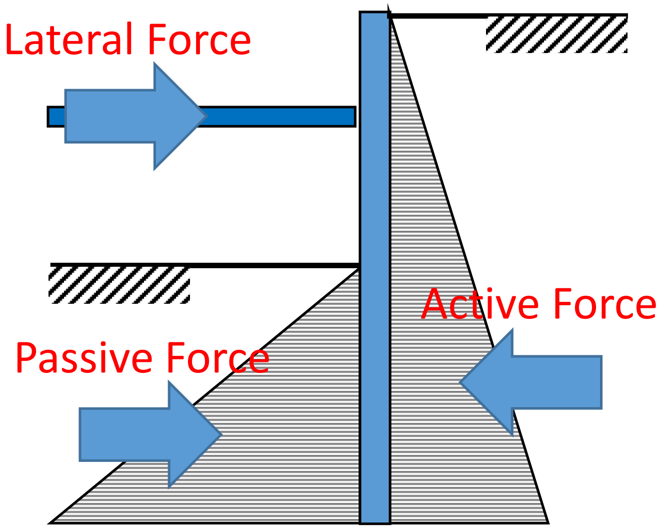
Settlement Limit

Strength-based criteria
(structural elements)

Displacement-based criteria

GeoStruktur

Vertical Stability



Schematic of forces contributing to vertical stability

Vertical stability criteria :

1. Against sliding.

$$SF = \frac{F\_act}{F\_pas} \geq 1.5$$

2. Against overturning.

$$SF = \frac{M\_mob}{M\_sta} \geq 2.0$$

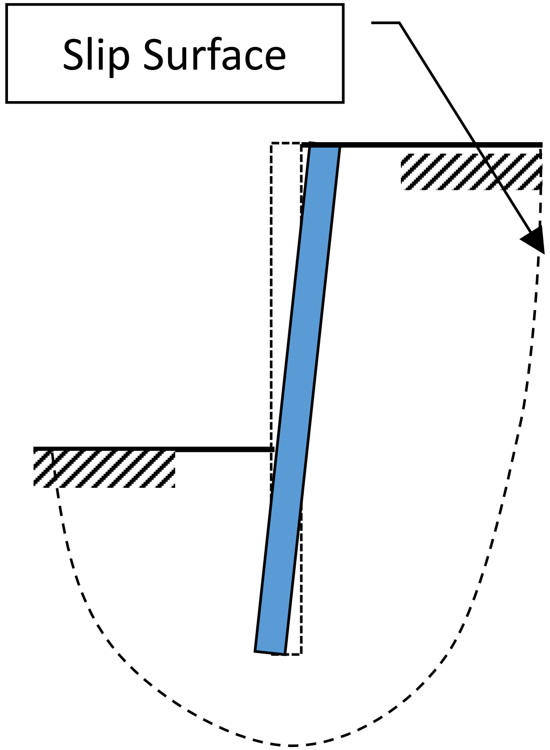
Approaches for checking vertical stability:

- Plastic yield strength: Rankine/Coulomb method.
- Beam on elastic foundation.
- Finite element / finite difference software.

When struts and/or ground anchors are required → Difficult to be solved with hand calculation.

→ PLAXIS2D will be used for simulation.

Global Stability



Slip surface in global stability

Global stability criteria :

1. Static condition.

$$SF = \frac{F\_mob}{F\_sta} \geq 1.5$$

2. Seismic condition.

$$SF = \frac{F\_mob}{F\_sta} \geq 1.1$$

Approaches for checking global stability:

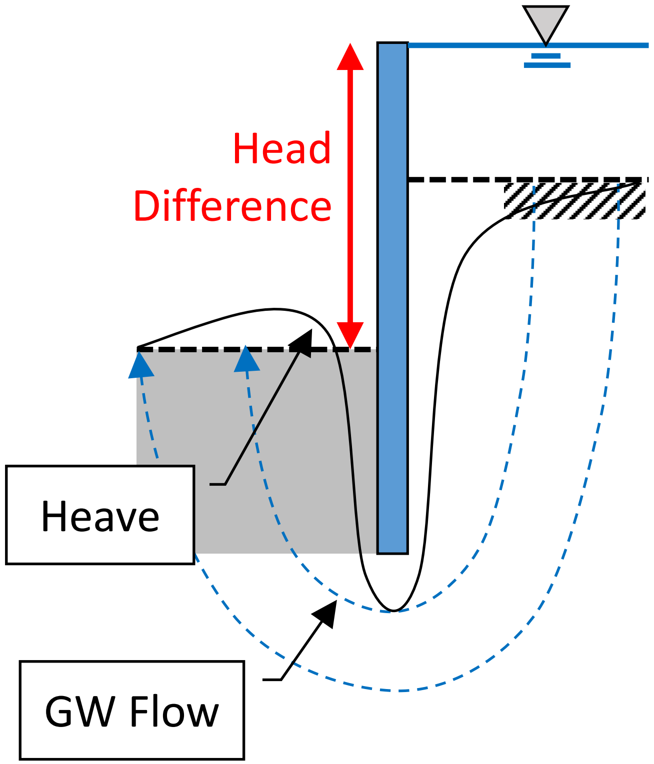
- Limit equilibrium analysis.
- Finite element / finite difference software.

Both vertical stability and global stability can be checked in PLAXIS2D using safety analysis (a.k.a phi-c reduction analysis in older version).

→ PLAXIS2D does not separate vertical stability check and global stability check, safety analysis will yield only the SF for governing mechanism.

GeoStruktur

Hydraulic Heave Stability



Hydraulic Heave Stability

Heave stability criteria (SNI 8460 Sect. 10.3.6.7):

1. Basal heave stability → SF ≥ 1.25.
2. Blow-in SF → SF ≥ 1.25.
3. Piping SF → SF ≥ 1.5.

Basal heave failure is the heaving of soil at the bottom of excavation due to uplift pressure.

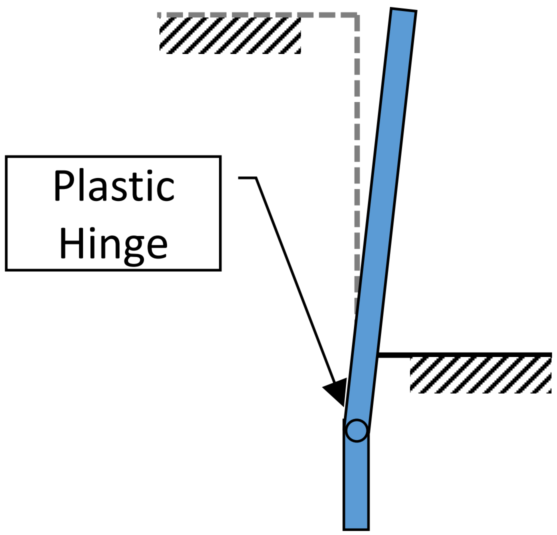
Blow-in failure is the "puncture" of aquifer due to high head pressure at the aquifer which is situated below an aquitard layer.

Piping failure materialize as an internal erosion process which depletes the fine soils or in an extreme case unfolds as sand boiling case; it is caused by high exit gradient flow.

→ PLAXIS2D may simulate the pore water pressure using either phreatic, steady-state, or transient condition.

GeoStruktur

Plastic Limit (Structural Elements)



Plastic Limit

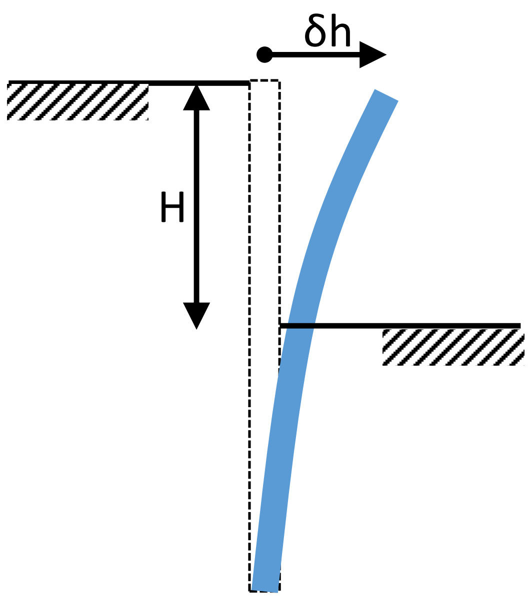
Embedded Wall
Criteria: The exerted moment force shall not be greater than the embedded wall moment capacity.

Struts
Criteria: The exerted axial force shall not be greater than the strut axial compressive capacity (usually governed by strut buckling capacity).

Anchors
Criteria: The axial tensile force shall not be greater than the steel bar axial tensile capacity and the grout frictional resistance.

→ Using PLAXIS2D, internal forces in structural elements can be checked after each step of staged-construction simulations.

Deflection Limit (Embedded Wall)



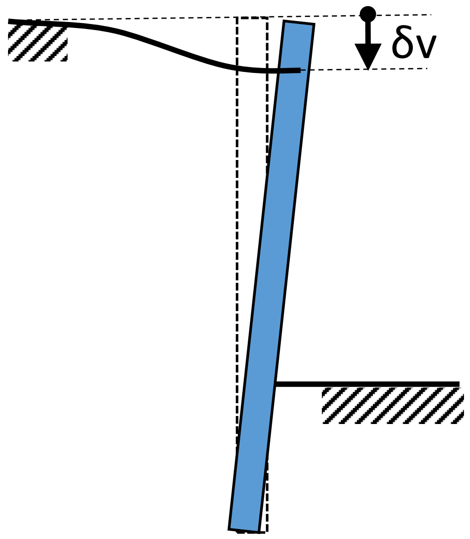
Deflection Limit
(Embedded Wall)

Criteria: Within allowable wall lateral deflection δh → 0.5% H (SNI 8460 Sect. 10.3.8.2) and between 0.5% to 1.0% H depending on the proximity of excavation with other buildings/infrastructures (SNI 8460 Table 51).

Sometimes stricter criteria should apply, especially if there are existing facilities/buildings in the vicinity of pit excavation).

→ In PLAXIS2D, deflection of some selected points can be tracked during the staged-construction simulations.

Settlement Limit



Settlement Limit
(Upstream Face)

Criteria: Settlement δv shall be within allowable limit, the limiting value usually depends on the facilities/buildings in the vicinity of pit excavation.

Settlements are contributed by:

1. Settlement due to wall lateral movement.
2. Settlement due to a reduction of ground water level (e.g. seepage, dewatering).

As per SNI 8460 Sect. 10.3.8.1, in order to avoid adverse effect of settlement caused by GWL reduction; the decrease of GWL shall be no greater than 2.0 m (unless it can be proven otherwise is safe).

→ The performance of displacement prediction largely depends on the selected soil model; MC model is typically inaccurate for predicting displacement.

GeoStruktur

Summary of Design Criteria

Criteria	Criteria	Remarks for PLAXIS Simulation
Vertical Stability	Sliding: SF ≥ 1.5 Overturning: SF ≥ 2.0	Checked through safety analysis.
Global Stability	Static: SF ≥ 1.5 Seismic: SF ≥ 1.1	Checked through safety analysis.
Hydraulic Heave Stability	Basal Heave → SF ≥ 1.25 Blow-in SF → SF ≥ 1.25 Piping SF → SF ≥ 1.5	Basal heave → Checked through safety analysis; certain deflection criterion may also be used. Blow-in shall be checked for confined aquifer with high hydraulic head. Piping shall be checked for seepage through loose cohesionless soil.
Plastic Limit	Load < Plastic Limit	Verified in staged-CST phases.
Deflection Limit	δh < Deflection Limit	Verified in staged-CST phases.
Settlement Limit	δv < Settlement Limit	Verified in staged-CST phases.

GeoStruktur

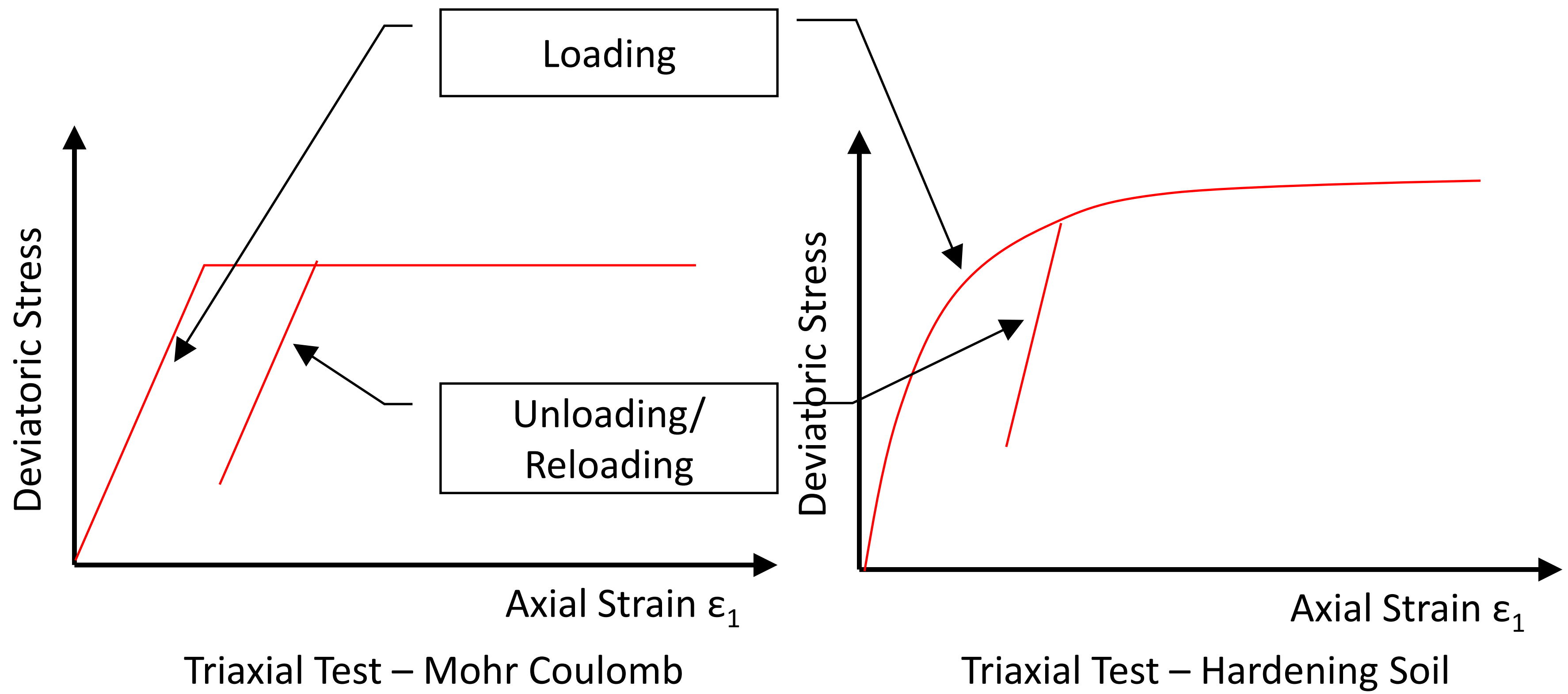
Part 2: Soil Model in Deep Excavation

GeoStruktur

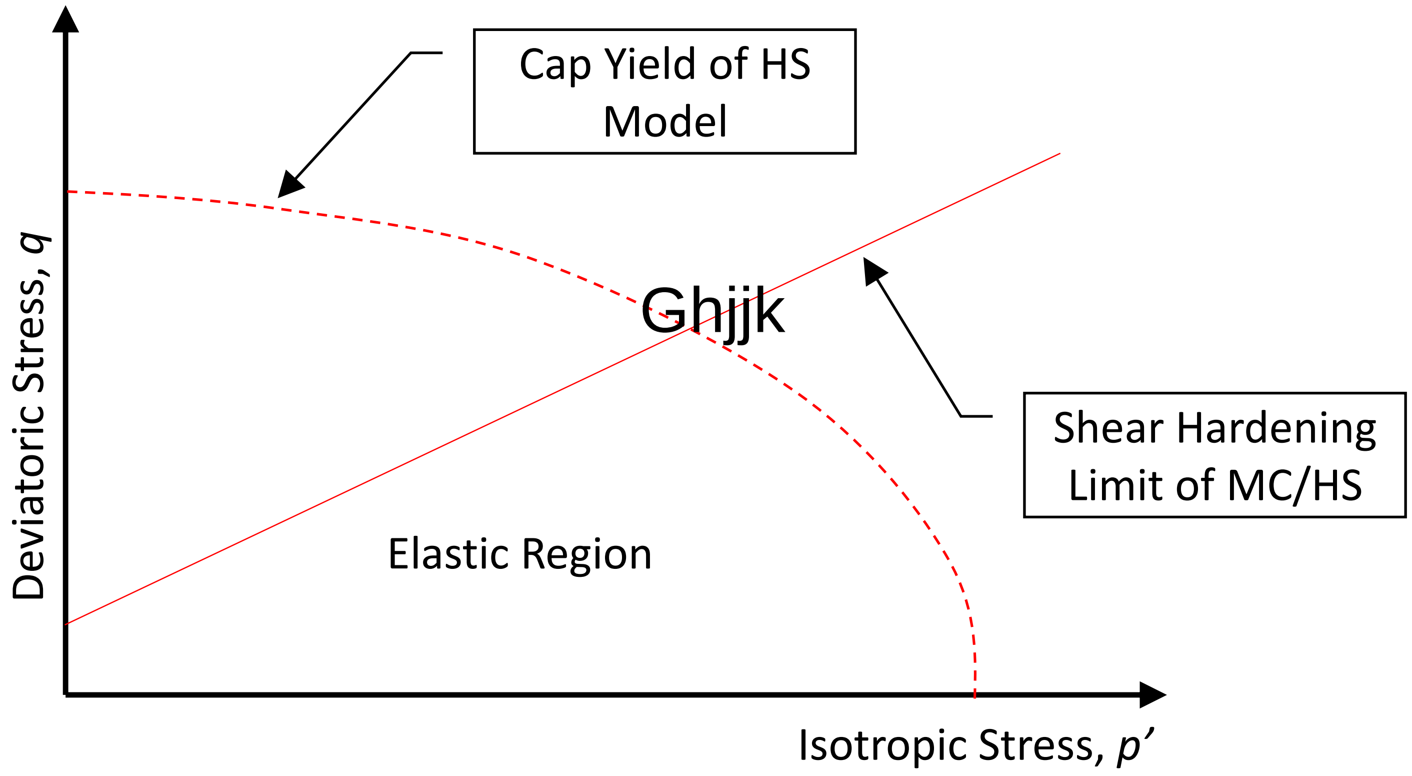
Soil Model

- Key limitations of Mohr-Coulomb model:
  - Soil is linear-elastic before failure, without compression/shear hardening.
  - Non stress-dependent stiffness.
  - Elastic modulus is typically taken as E_{50}, which will produce lots of unrealistic heave in unloading case.
- Considering that the deflection limit will be checked; soil layers that are expected to be part of global stability failure mode; they will be modeled with Hardening Soil (HS) Model (Duncan-Chang hyperbolic model).
  - HS model provides both isotropic hardening and shear hardening, as well as stress-dependent stiffness.
  - HS model has two extra plastic parameters for simulating isotropic and shear hardening: E_{oed}^{ref} and E_{50}^{ref}.
  - Dominant failure mode in excavation case: Shear failure → E_{50}^{ref} in HS model is important !
- For simplicity, the deep underlying soil (deeper than 23.8m), they will simply be modeled with Mohr-Coulomb (MC) Model.

MC and HS: Key Differences



MC and HS: Key Differences



Boring Log (1/3)

SAMPLE	DEPTH (m)	USCS SYMBOL	ROCK / SOIL DESCRIPTION	DEPTH (m)	PENETROMETER qu (kg/cm²)	SPT DEPTH (m)	SPT Blows/ Penetr.
	0.00	CH	FAT CLAY, reddish brown colored 5YR 4/4, high plasticity, high dry strength, none dilatancy, high toughness, moist trace sand with medium to coarse grained, fill material, soft. **Fill Soil**	1.00	0.50		
				1.55	0.50	1.70	4/30
				2.00	0.50		
3.00 – 3.70				3.00	0.50		
	3.70	SP	POORLY GRADED SAND, dark gray colored 5YR 4/1, fine sand grained moist, loose to medium dense. **Loose-Medium Dense Sand**	3.70	0.50	3.85	2/30
				4.15	0.25		
				5.00	0.25		
				5.40	0.25		
				6.00	0.25	6.15	13/30
				6.45	1.50		
				7.00	1.50		
	8.00	CH	FAT CLAY, gray colored 5YR 5/1, medium plasticity, medium dry strength, slow dilatancy, medium tougness, moist, very soft. **Very Soft Clay**	8.00	1.50	8.00	1/45
				8.45	< 0.25		
9.00 – 10.00				9.00	< 0.25		
				10.00	< 0.25		
				11.00	< 0.25	11.00	1/45
				11.45	< 0.25		
				12.00	< 0.25		
				13.00	< 0.25	13.00	1/45
				13.45	< 0.25		
14.00 – 15.00				14.00	< 0.25		
				15.00	< 0.25	15.15	1/45
				15.45	< 0.25		
				16.00	< 0.25		
	16.30	CH	FAT CLAY, gray colored 5YR 5/1, medium plasticity, medium dry	16.40	< 0.25		

STANDARD PENETRATION TEST — SPT Graphic Blows/30 cm: 10 20 30 40; Recovery (%): 40 80

Boring Log (2/3)

SAMPLE	DEPTH (m)	USCS SYMBOL	ROCK / SOIL DESCRIPTION	Annotation
	16.30 – 17.00	CH	FAT CLAY, gray colored 5YR 5/1, medium plasticity, medium dry strength, slow dilatancy, medium toughness, slighty shell fragmen, moist.	Medium Stiff Clay
	17.00 – 18.00	CH	FAT CLAY, olive brown colored 2.5 4/4, high plasticity, high dry strength, none dilatancy, high toughness, stiff.	Medium Stiff Clay
	18.00 – 20.40	CL	SANDY CLAY, dark yellowish brown colored 10YR 4/4, medium plasticity, medium dry strength, slow dilatancy, medium toughness, moist, soft.	Medium Stiff Clay
21.00 – 21.70	20.40 – 23.80	CH	FAT CLAY, light yellowish brown colored 2.5Y 6/3 streak with light red colored 10YR 6/6, high plasticity, high dry strength, none dilatancy, high toughness, stiff.	Medium Stiff Clay
	23.80 – 25.45		TUFFACEOUS SAND WITH SILT, yellowish brown colored 10YR 5/6, fine sand grained, moist, v…	Very Loose Sand
26.00 – 26.70	25.45 – 27.50	CH	FAT CLAY, brownish yellow colored 10YR 6/6, high plasticity, high dry strength, none dilatancy, high toughness, stiff.	Medium Stiff Silt/Clay
	27.50 – 29.00	CL	SANDY SILT, yello… …city, low dry strength, slow rap…	Medium Stiff Silt/Clay
	29.00 – 29.55	CH	FAT CLAY, pale yellow colored 5Y 7/4, high plasticity, high dry strength, none dilatancy, high toughness, stiff.	Medium Stiff Silt/Clay
	29.55 – 31.00	SM	SILTY SAND, olive yellow colored 2.5Y 6/6, fine sand grained, moist, medium dense.	Medium Stiff Silt/Clay
	31.00	ML	SILT, strong brown colored 7.5YR 4/6, low plasticity, low dry strength, slow dilatancy, low toughness, some cemented silt, very stiff.	

DEPTH (m)	PENETROMETER qu (kg/cm²)
16.40	< 0.25
17.00	1.25
17.45	1.25
18.00	1.25
19.00	1.25
19.45	1.25
20.00	1.25
21.00	1.25
21.70	1.50
22.15	1.50
23.00	1.50
23.45	1.25
24.00	1.50
25.00	1.50
25.45	< 0.25
26.00	< 0.25
26.70	< 0.25
27.15	1.25
28.00	1.25
28.55	1.25
29.00	1.00
30.00	1.00
30.55	1.00
31.00	1.75

STANDARD PENETRATION TEST	
DEPTH (m)	Blows/ Penetr.
17.15	10/30
19.15	4/30
21.85	12/30
23.15	10/30
25.00	1/45
26.85	11/30
28.70	9/30
30.70	15/30

SPT Graphic Blows/30 cm: 10 20 30 40

Recovery (%): 40 80

CS GeoStruktur

Boring Log (3/3)

SAMPLE	DEPTH (m)	USCS SYMBOL	GRAPHIC LOG	ROCK / SOIL DESCRIPTION
	32.55 – 35.00	ML		SILT, very dark gray colored 5YR 5/1, low plasticity, low dry strength, slow dilatancy, low toughness, some cemented silt, moist, hard.
	35.00 – 36.00	CH		FAT CLAY, dark gray colored 5YR, high plasticity, high sry strength, none dilatancy, high
	36.00 – 39.50	CL		LEAN CLAY, dark gra ticity, medium dry strength, none dilatancy, high toughness,few silt, stiff to hard.
	39.50 – 50.00	CH		FAT CLAY, dark gray colored 5YR 4/1, high plasticy, high dry strength, none dilatancy, high toughness, stiff to very stiff.
	50.00 – 50.45	SP		POORLY GRADED SAND, dark gray colored 4/1, fine sand grained, moist, very dense.

Very Stiff Silt/Clay (32.55 – 39.50 m)

Stiff Silt/Clay (39.50 – 50.00 m)

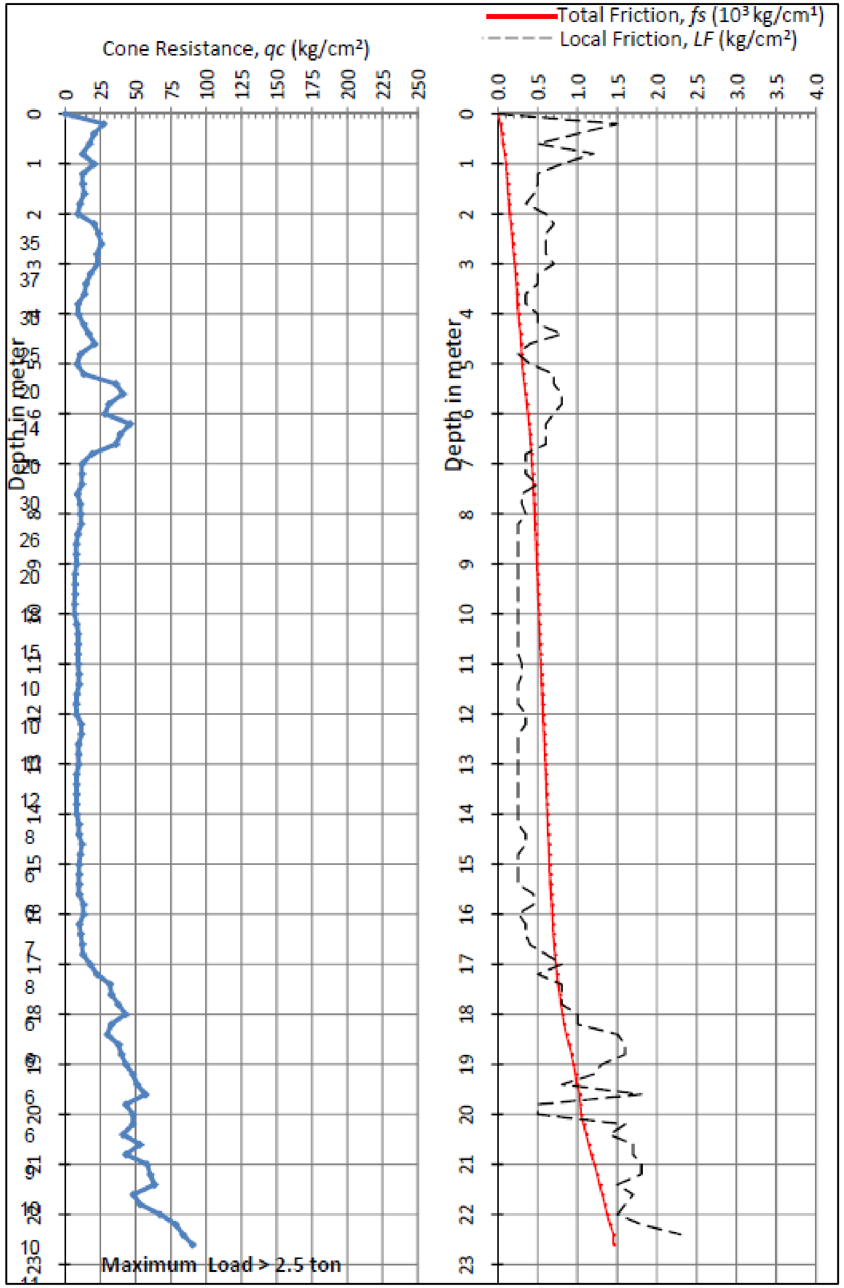
DEPTH (m)	PENETROMETER qu (kg/cm²)
32.55	1.75
33.00	4.50
34.00	4.50
34.55	4.50
35.00	1.75
36.00	1.75
36.55	3.00
37.00	4.50
38.00	4.50
38.55	1.25
39.00	1.25
40.00	1.25
40.55	1.25
41.00	1.00
42.00	1.00
42.55	1.00
43.00	1.25
44.00	1.25
44.55	1.25
45.00	1.25
46.00	1.50
46.55	1.50
47.00	2.00
48.00	2.00
48.55	1.75
49.00	1.75
50.00	4.50
50.45	4.50

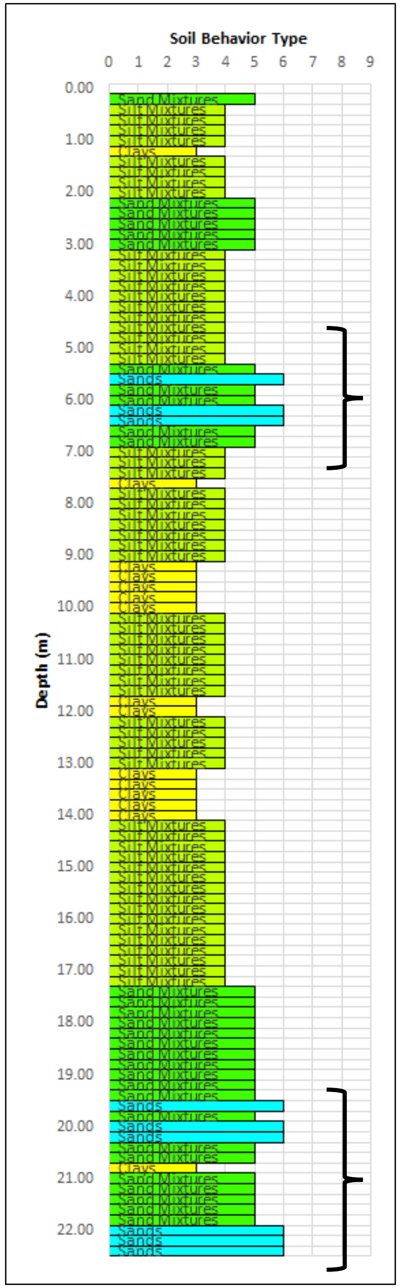
STANDARD PENETRATION TEST

DEPTH (m)	Blows/ Penetr.	SPT Graphic Blows/30 cm (10 20 30 40)	Recovery (%) (40 80)
32.70	45/30		
34.70	14/30		
36.70	47/30		
38.70	10/30		
40.70	9/30		
42.70	11/30		
44.70	10/30		
46.70	16/30		
48.70	14/30		
50.15	64/30	N > 50	

GeoStruktur

CPT Log





SBT based on [Robertson, 2010]

Sandy Soil

Sandy Soil

Index Property Tests

Depth in meter	Sample Type	Description	USCS CHART	Specific Gravity G_s	Density Wet ρ_m	Density Dry ρ_d	Water Content w_n	Atterberg limits: Liquid Limit LL	Atterberg limits: Plastic Limit PL	Atterberg limits: Plasticity Index PI	Liquidity Index LI	Void Ratio e	Porosity n	Degree of Saturation Sr
-	-	-	-	-	t/m^3	t/m^3	%	%	%	%	-	-	%	%
3.00-3.70	UDS	Fat Clay	CH	2.64	1.76	1.23	43.1	77.9	33.1	44.9	0.22	1.14	53	100
9.00-10.00	UDS	Fat Clay	CH	2.40	1.48	0.81	82.1	97.0	38.9	58.1	0.74	1.96	66	100
14.00-15.00	UDS	Fat Clay	CH	2.38	1.41	0.71	99.6	135.0	43.1	92.0	0.62	2.38	70	100
21.00-21.70	UDS	Fat Clay	CH	2.46	1.62	1.06	52.8	102.0	37.2	64.8	0.24	1.32	57	98
26.00-26.70	UDS	Fat Clay	CH	2.44	1.52	0.90	68.5	104.5	41.6	63.0	0.43	1.70	63	98

Low SG

High PI

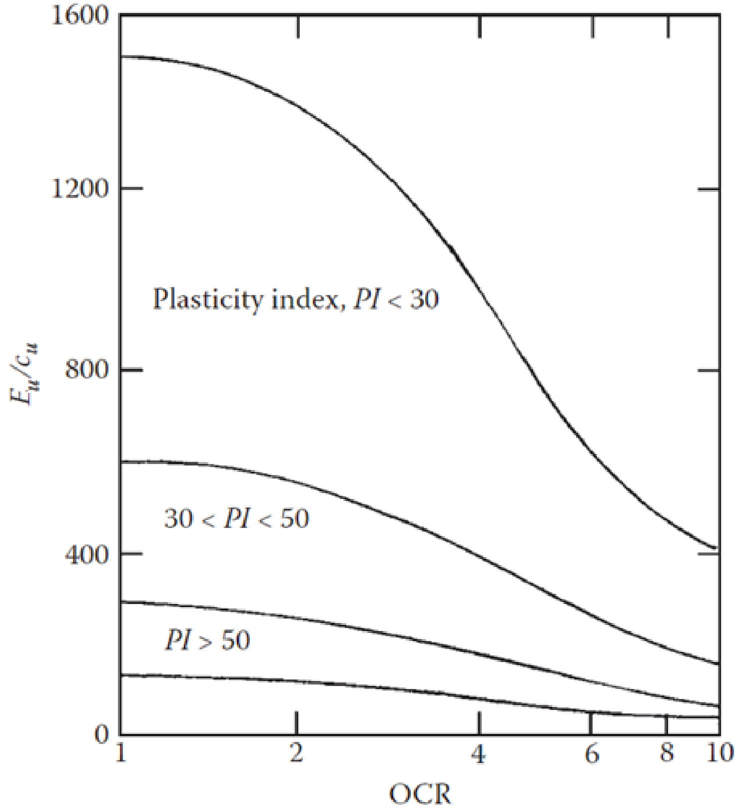
Overview of Soil Properties

Depth	Soil	SPT	Soil Model	Analysis*
0.0 – 3.7	Fill soil	4	Hardening Soil	Undrained A
3.7 – 8.0	Loose-to-medium dense sand	2-13	Hardening Soil	Drained
8.0 – 16.3	Very soft clay	1	Hardening Soil	Undrained A
16.3 – 23.8	Medium stiff clay	4-12	Hardening Soil	Undrained A
23.8 – 25.5	Very loose sand	1	Mohr-Coulomb	Drained
25.5 – 31.0	Medium stiff clay	9-15	Mohr-Coulomb	Undrained B
31.0 – 39.5	Very stiff silt/clay	10-47	Mohr-Coulomb	Undrained B
39.5 – 50.0	Stiff silt/clay	9-16	Mohr-Coulomb	Undrained B

* Only short-term condition is shown in current example.

Layer 1: Soil Data
Fill Soil (0.0 – 3.7)

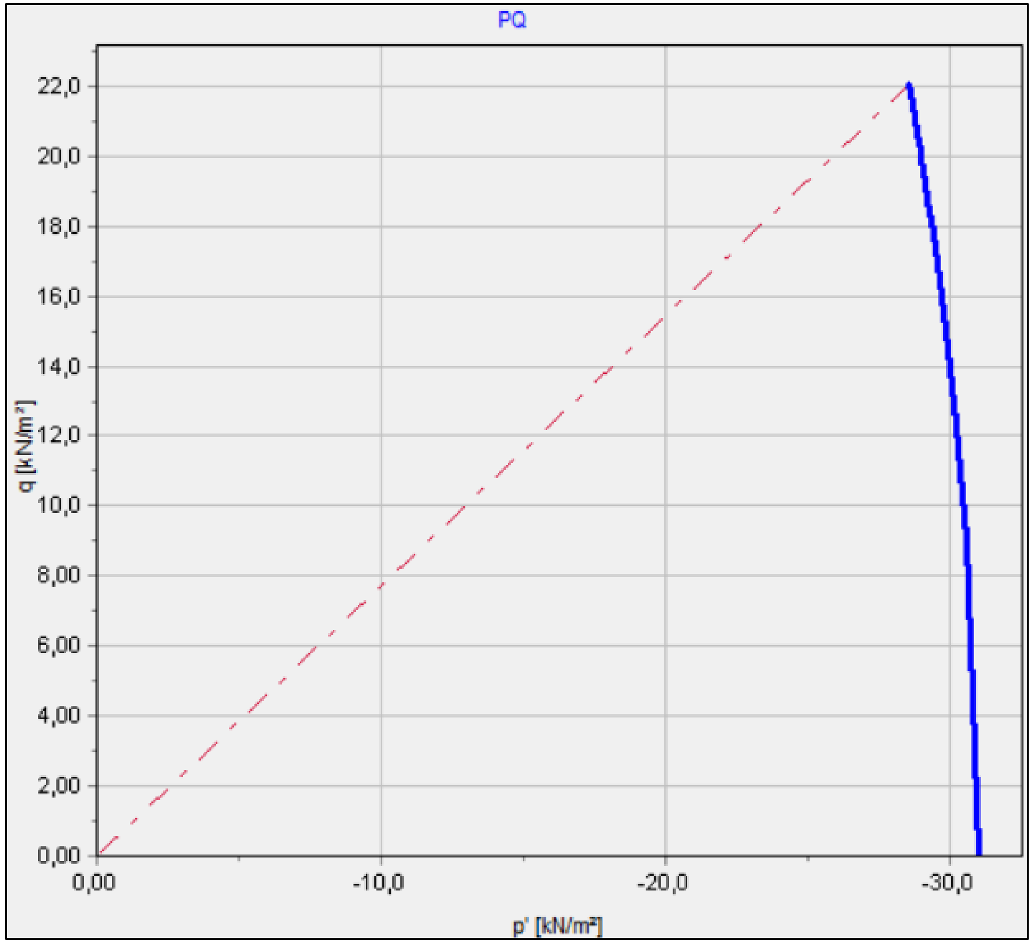
- Soil Model: Hardening Soil Model.
- Soil data:
  - SPT → N-value = 4.
  - Atterberg limits → $I_p = 45\%$.
  - Degree of saturation → SR = 100%
  - Triaxial UU → $c_u = 20$ kPa.
  - Consolidation test → $OCR \approx 3$.
- Plastic parameters:
  - $E_u^{50} \approx 250c_u = 5000$ kPa (see chart).
  - $E_{50} \approx 0.7E_u^{50} = 3500$ kPa.
  - $E_{50}^{ref} = E_{50}\left(\frac{p_{ref}}{\sigma_3'}\right)^1 = 3500\left(\frac{100}{(2)(7)+17}\right) = 11290$ kPa.
  - $E_{oed}^{ref} \approx \frac{50000}{I_p\%} = 1111$ kPa.
- For soft clay: $E_{ur}^{ref} \approx 20E_{oed}^{ref} = 22220$ kPa.
- Assume $\varphi' = 25°$ (to be adjusted).



[Duncan and Buchignani, 1976]

Layer 1: Soil Parameter
Fill Soil (0.0 – 3.7)

Var	Unit	Value
E_{50}^{ref}	kPa	11290
E_{oed}^{ref}	kPa	6938
$E_{ur,oed}^{ref}$	kPa	23000
p_{ref}	kPa	100
υ'_{ur}	-	0.2
c'_{ref}	kPa	0
φ'	°	20
ψ	°	0
m	-	1
K_0^{NC}	-	0.6580



PLAXIS SoilTest, undrained TX, PQ-plane, p' = 31 kPa

GeoStruktur

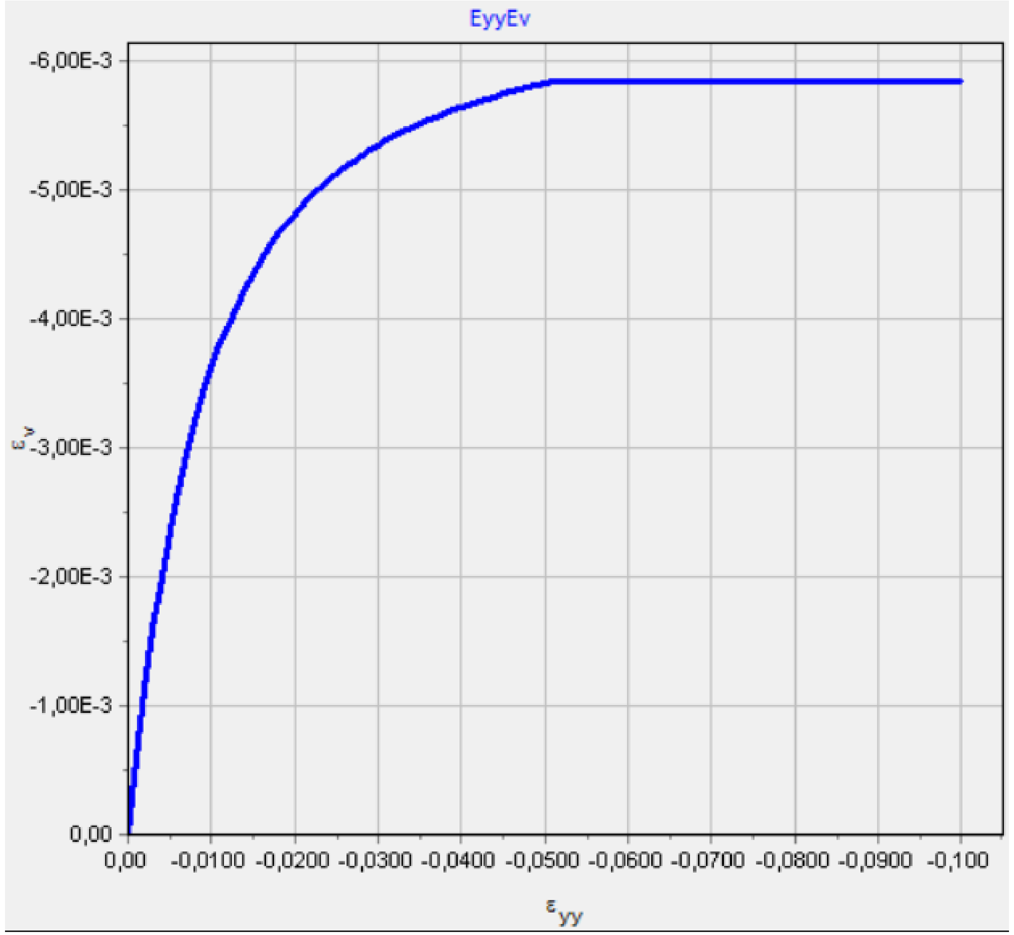
Layer 2: Soil Data
Loose-Medium Sand (3.7 – 8.0)

- Soil Model: Hardening Soil Model.
- Soil data:
  - SPT → N-value = 2-13.
  - CPT → Avg $q_c = 27$ kg/cm^2.
- Plastic parameters:
  - $E_{oed} \approx 4q_c = 10800$ kPa → [Lunne and Christoffersen, 1983].
  - $E_{oed}^{ref} = E_{oed}\left(\frac{p_{ref}}{\sigma_3'}\right)^{0.5} = 10800\left(\frac{100}{17+(2.5)(7)+(1.5)(17)}\right)^{0.5} = 13943$ kPa.
  - $E_{50}^{ref} \approx E_{oed}^{ref}$.
- For sand: $E_{ur}^{ref} \approx 5E_{oed}^{ref} = 69714$ kPa.
- Assume: $\varphi' = 30°$ (low relative density)

GeoStruktur

Layer 2: Soil Parameter
Loose-Medium Sand (3.7 – 8.0)

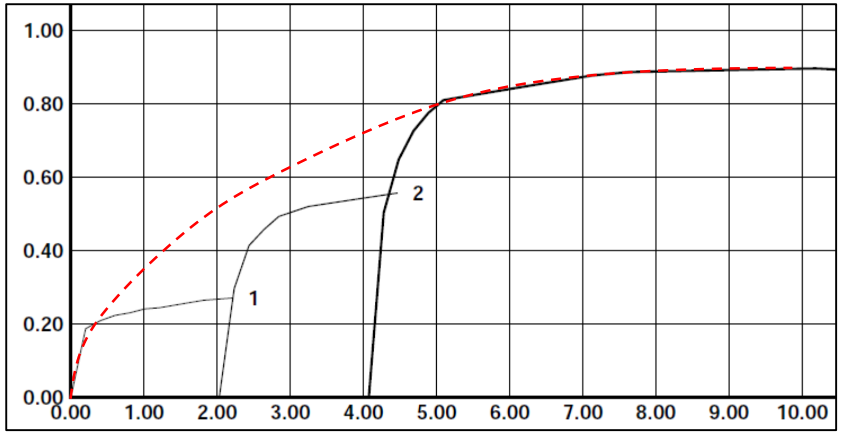
Var	Unit	Value
E_{50}^{ref}	kPa	13943
E_{oed}^{ref}	kPa	13943
$E_{ur,oed}^{ref}$	kPa	69714
p_{ref}	kPa	100
υ'_{ur}	-	0.2
c'_{ref}	kPa	0
φ'	°	30
ψ	°	0
m	-	0.5
K_0^{NC}	-	0.5



PLAXIS SoilTest, drained TX, p' = 60 kPa
Contraction during shearing

Layer 3: Soil Data
Very Soft Clay (8.0 – 16.3)

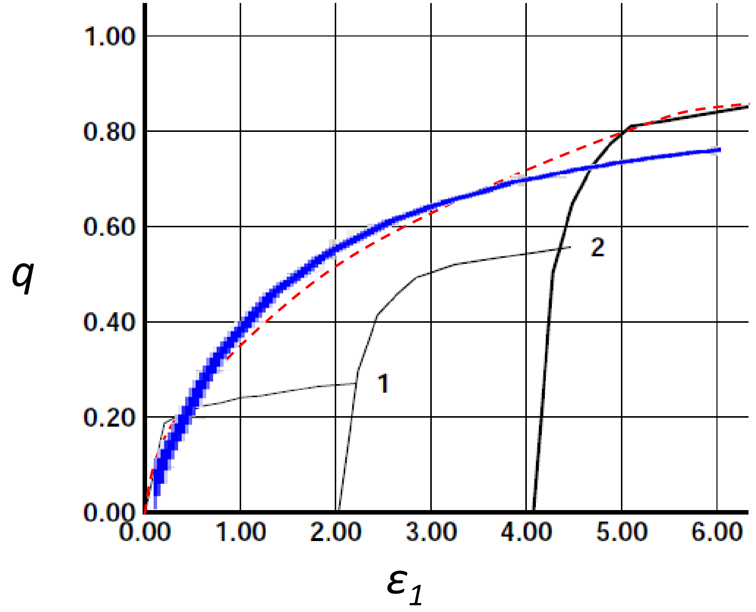
- Soil Model: Hardening Soil Model.
- Soil data:
    - SPT N-value → 1.
    - Multistage Triaxial CU → $\varphi' = 22.8$.
    - Atterberg limits → $I_p = 58\%$.
    - Vane shear → $S_u(16m) = 88$ kPa.
- Plastic parameters:
    - $E^{50}_{u,lab} = (90/2)/0.02 = 2250$ kPa.
    - $E_{50} \approx 0.7E^{50}_{u} = 1575$ kPa.
    - $E^{ref}_{50} = E_{50}\left(\frac{p_{ref}}{\sigma'_3}\right)^1 = 1575\left(\frac{100}{120}\right) = 1313$ kPa.
    - $E^{ref}_{oed} \approx \frac{50000}{I_p\%} = 862$ kPa.
- For soft clay: $E^{ref}_{ur} \approx 15E^{ref}_{oed} = 12930$ kPa.



Deviatoric-axial strain curve of multistage CU-TX using confinement stress of 30, 60 and 120 kPa

Layer 3: Soil Parameter Very Soft Clay (8.0 – 16.3)

Var	Unit	Value
E_{50}^{ref}	kPa	1313
E_{oed}^{ref}	kPa	862
$E_{ur,oed}^{ref}$	kPa	12930
p_{ref}	kPa	100
υ'_{ur}	-	0.2
c'_{ref}	kPa	0
φ'	°	22.8
ψ	°	0
m	-	1
K_0^{NC}	-	0.6125

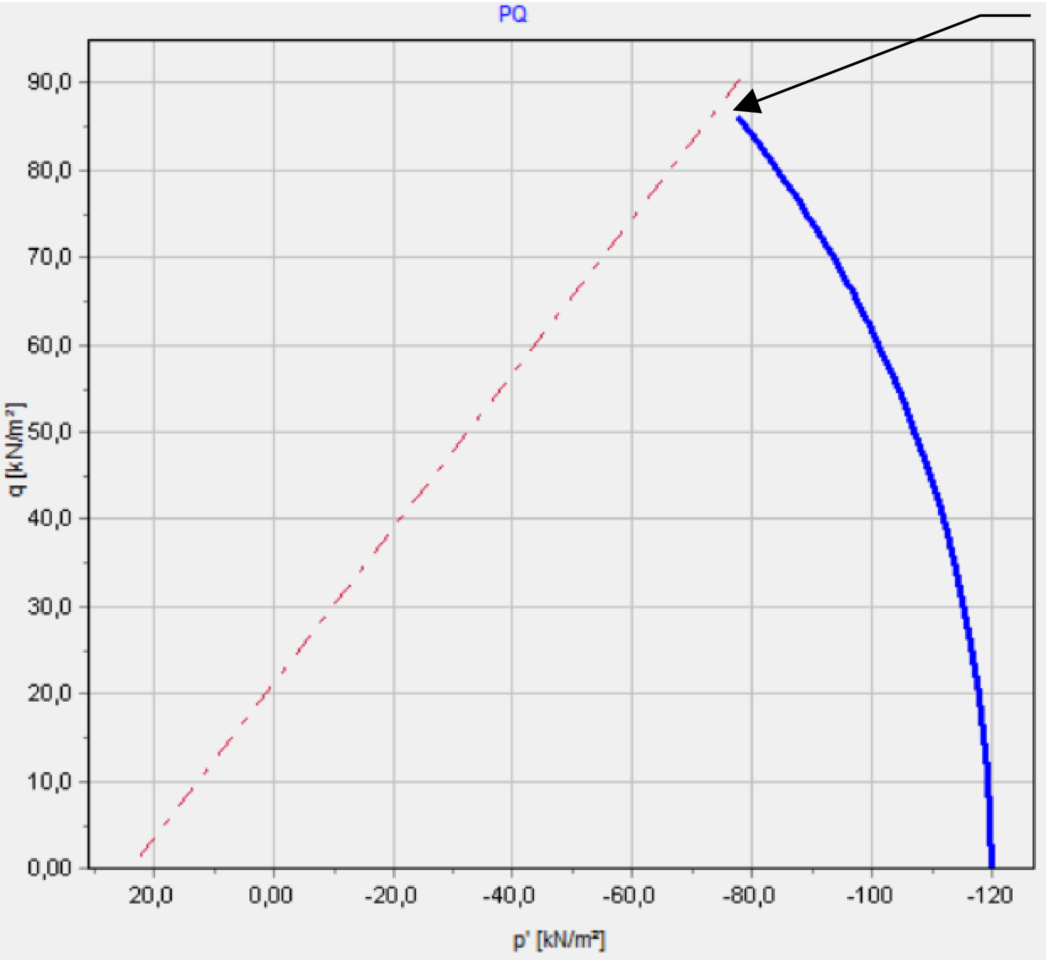


PLAXIS SoilTest (blue), undrained TX, p' = 120 kPa in deviatoric stress vs axial strain

- For axial strain less than 5%, blue curve fits quite well with red curve.
- At large strain, the deviatoric stress of blue curve is smaller than red curve → Conservative.

GeoStruktur

Layer 3: Comparison with Vane Shear



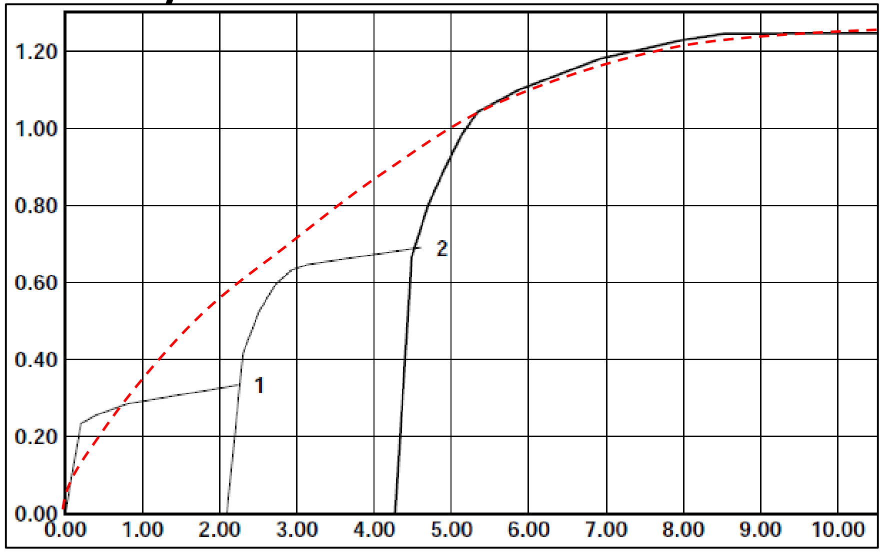
Match pretty well with vane shear test at depth of 16m of which $S_u(16m) = 88$ kPa

PLAXIS SoilTest, undrained TX, PQ-plane, p' = 120 kPa

CS GeoStruktur

Layer 3: Soil Data
Medium Stiff Clay (16.3 – 23.8)

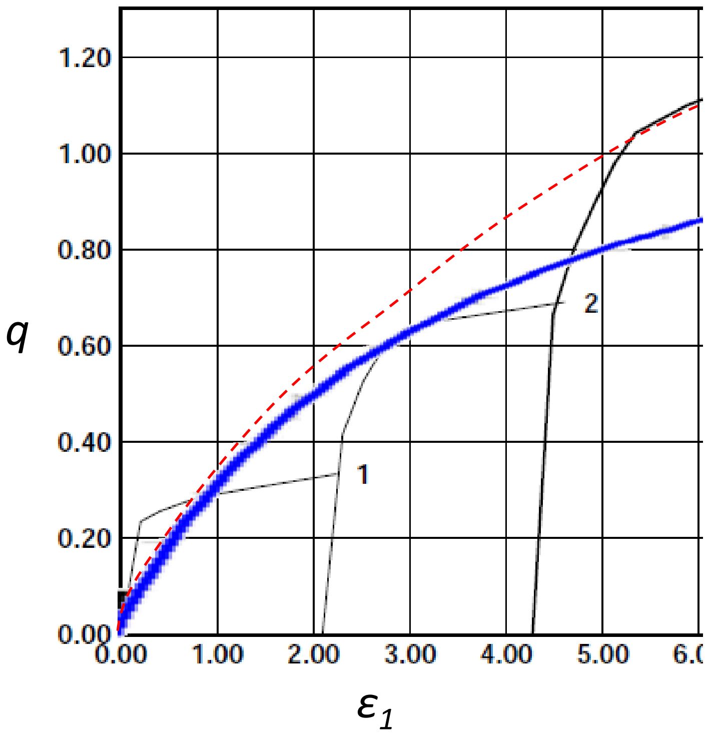
- Soil Model: Hardening Soil Model.
- Soil data:
  - SPT N-value → 4-12.
  - Multistage Triaxial CU → $\varphi' = 17.7$.
  - Atterberg limits → $I_p = 51\%$.
- Plastic parameters:
  - $E_{u,lab}^{50} = (125/2)/0.025 = 2500$ kPa.
  - $E_{50} \approx 0.7E_u^{50} = 1750$ kPa.
  - $E_{50}^{ref} = E_{50}\left(\frac{p_{ref}}{\sigma_3'}\right)^1 = 1750\left(\frac{100}{200}\right) = 875$ kPa.
  - $E_{oed}^{ref} \approx \frac{50000}{I_p\%} = 980$ kPa.
- For stiff clay: $E_{ur}^{ref} \approx 5E_{oed}^{ref} = 4900$ kPa.



Deviatoric-axial strain curve of multistage CU-TX using confinement stress of 50, 100 and 200 kPa

Layer 4: Soil Data
Medium Stiff Clay (16.3 – 23.8)

Var	Unit	Value
E_{50}^{ref}	kPa	875
E_{oed}^{ref}	kPa	1704
$E_{ur,oed}^{ref}$	kPa	4900
p_{ref}	kPa	100
υ'_{ur}	-	0.2
c'_{ref}	kPa	0
φ'	°	17.7
ψ	°	0
m	-	1
K_0^{NC}	-	0.6960



PLAXIS SoilTest (blue), undrained TX, p' = 200 kPa in deviatoric stress vs axial strain

Layer 5-8: Soil Parameter (Mohr-Coulomb) Deep Underlaying Layer

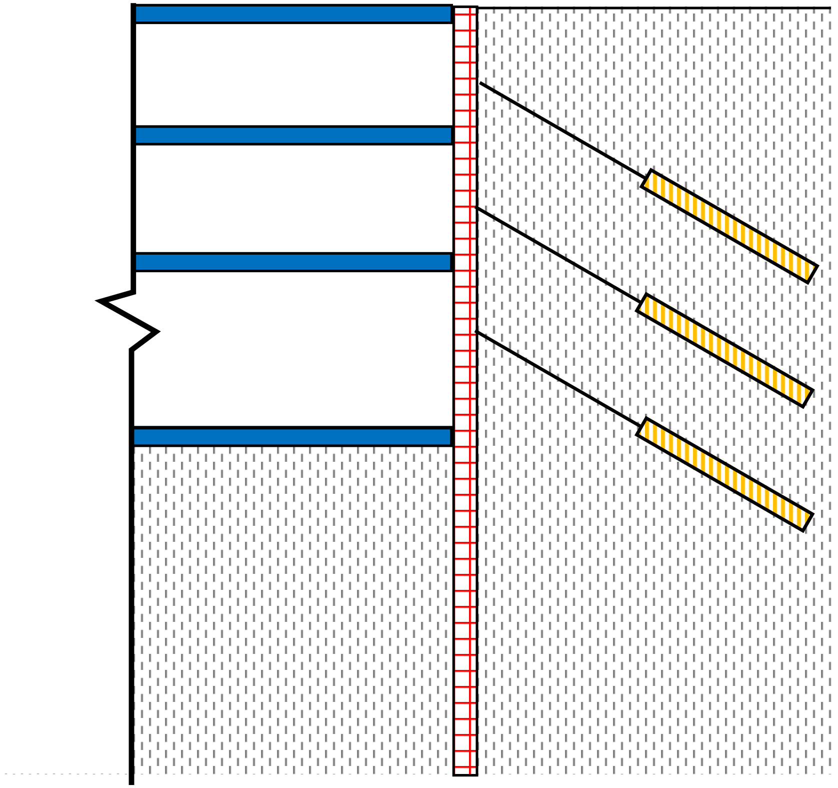
Var	Unit	Layer 5	Layer 6	Layer 7	Layer 8
Soil	-	Loose Sand	Medium stiff clay	Very stiff silt/clay	Stiff silt/clay
SPT	-	1	9-15	10-47	9-16
E'	kPa	15000	18000	42000	20000
υ'	-	0.2	0.2	0.2	0.2
c'_{ref}	kPa	1	72	168	78
φ'	°	25	0	0	0
ψ	°	0	0	0	0

CS GeoStruktur

Part 3: Structural Elements: Plate, Anchor, EBR

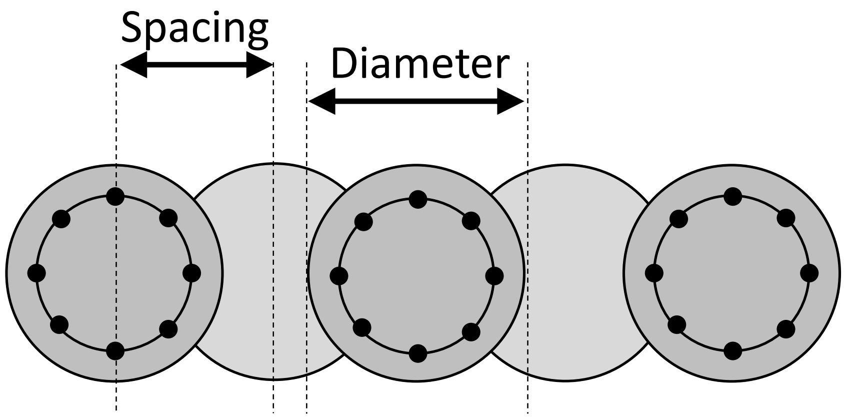
Structural Elements in PLAXIS

Structural Element	Common Application in Deep Excavation Simulation	Features
Plate	Embedded wall	Axial and flexural rigidity
Node-to-Node Anchor	Unbonded length of anchor	Axial rigidity
Fixed-End Anchor	Strut	Axial rigidity
Embedded Beam Row	Bonded length of anchor	Axial and flexural rigidity with user-defined skin and toe resistance



Schematic of deep excavations

Structure: Embedded Wall (Plate)



Secant Pile

Pile diameter = 1.0 m
Pile spacing = 0.8 m

Concrete strength
$f_c' = 35$ MPa.

Young Modulus (Concrete)
$E = 4700\sqrt{f_c'} = 25743$ MPa.

Area of secant pile
$A = 0.703648$ m^2/m

Inertia of secant pile
$I = 0.047578$ m^4/m

Model: Plate Element
Material: Elastoplastic

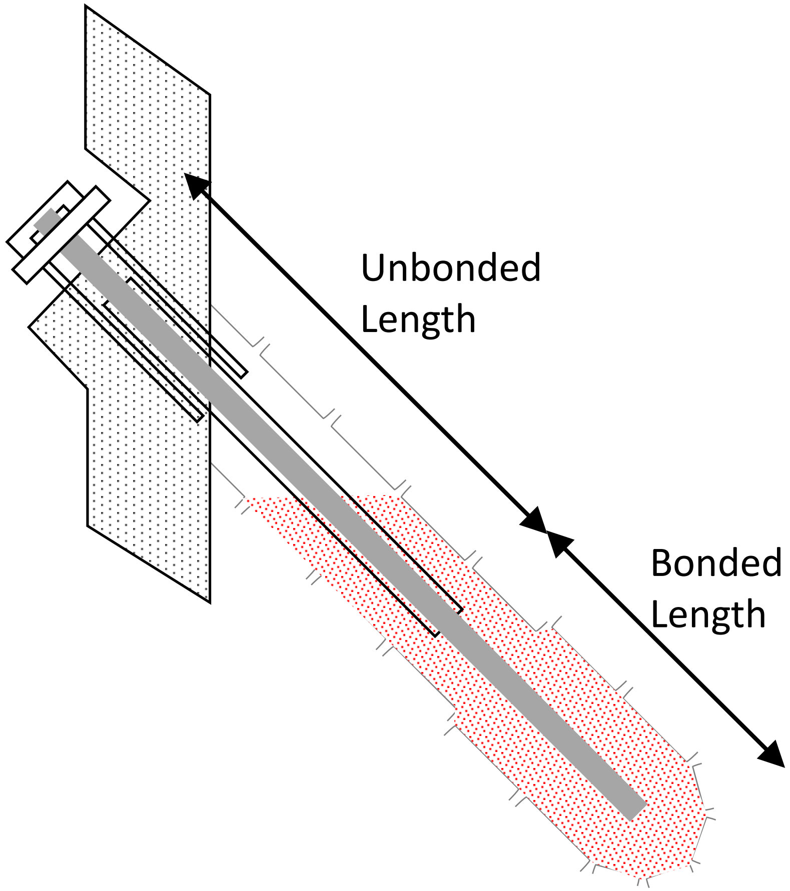
Plate Properties:

- $EA = 22.642.10^6$ kN/m
- $EI = 1.531.10^6$ kN-m^2/m
- $\upsilon = 0.15$
- $w = 21$ kN/m/m
- $M_p = 750$ kN-m/m

Ground Anchor: Pullout Capacity

- Ground anchor pullout capacity (SNI 8460 Sect. 10.6.4.4) is calculated as follows :
  - Cohesive soil: $P_u = \alpha A_s L_s S_u$
  - Non-cohesive soil: $P_u = \sigma'_v A_s L_s K_s$

- Where:
  - P_u = Pull-out resistance.
  - A_s = Unit shaft area of anchor fixed length.
  - L_s = Anchor effective length.
  - α = Adhesion factor.
  - S_u = Avg und. shear strength along fixed length.
  - σ'_v = Eff. ver. stress at the midpoint of fixed length.
  - K_s = Anchorage coefficient.



Ground Anchor Overview

GeoStruktur

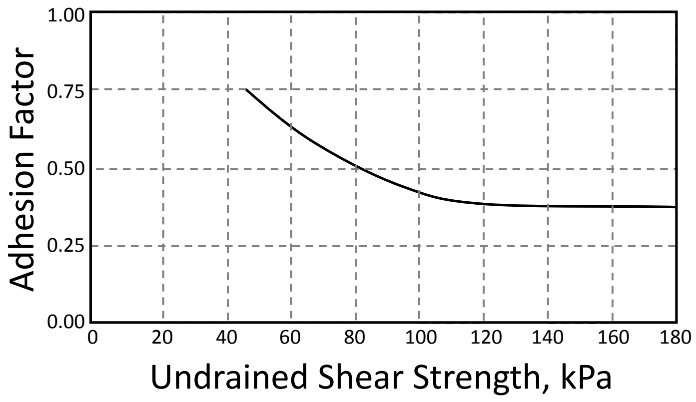
Structure: Anchor UL (Node-to-Node Anchor)

- Prestressing bar properties:
  - Diameter 36 mm.
  - ASTM A722 Grade 150.
- Prestressing bar capacity:
  - Ultimate Capacity → $F_u = f_{pu}A_s = (1035MPa)(1018mm^2) = 1053$ kN.
  - Prestressed to 80% of capacity → 80% x 1053 kN = 843 kN.
  - Allowable capacity, SF = 1.4 (Table 49 SNI 8460) → 843 kN / 1.4 = 602 kN.

Model: Node-to-Node Anchors.
Material: Elastoplastic

Input for PLAXIS2D:
- $EA = 214.10^3$ kN
- $Spacing = 1.5$ m
- $F_{max,tens} = 602$ kN

Structure: Anchor BL (EBR)



- Anchor properties:
  - Anchor diameter = 150 mm.
  - Undrained shear strength = 180 kPa.
  - Adhesion factor = 0.4.
- Anchor pullout capacity:
  - Ultimate capacity (cohesive soil) → $P_u = \alpha A_s L_s S_u = 34$ kN/m.
  - Allowable capacity SF = 2.0 (Table 49 SNI 8460) → $P_a = 17$ kN/m.

Model: Embedded beam rows.
Input for PLAXIS2D:
- Material: Elastic
- $E = 2.1.10^8$ kN/m^2
- $Dia = 36$ mm
- $\gamma = 50$ kN/m^3
- $Spacing = 1.5$ m
- $T_{skin} = \frac{127}{6} = 17$ kN/m
- $F_{max} = 0$ kN

GeoStruktur

Ground Anchor: Other Requirements

- Minimum free length shall be 3 m for tendon bar and 4.5 m for strand (SNI 8460 Sect. 10.6.4.3).

- Minimum fixed length shall be 3 m with a maximum fixed length of 13 m; a length > 13 m can be used if it can be proven through pullout test (SNI 8460 Sect. 10.6.4.3).

- Ground anchor fixed length shall be installed at least 5 m from ground elevation (SNI 8460 Sect. 10.6.4.2a).

- Anchor fixed-length shall be embedded in a competent soil layer: (1) Sand with SPT N-value ≥ 25; (2) Clay with SPT N-value ≥ 20 elevation (SNI 8460 Sect. 10.6.3.1).

- Horizontal spacing shall be at least 1.5 m for anchor with diameter ≤ 0.2 m (SNI 8460 Sect. 10.6.4.2c).

Structure: Slab/Strut (Fixed-End Anchor)

- Slab properties:
    - Concrete strength = 30 MPa.
    - Slab thickness = 200 mm.

Model: Fixed-end anchor.
Input for PLAXIS2D:
- Material: Elastic
- $EA = 5.15.10^6$ kN/m^2

GeoStruktur

Other Design Requirements

- Additional load (1 ton/m^2) of 10 m width shall be given in the upstream face of embedded wall (SNI 8460 Sect. 10.3.5.4.1 and 10.3.6.4).

- Over-excavation shall be considered → 10% $H_{unbraced} \leq 0.5$ m (SNI 8460 Sect. 10.3.5.3.2(a-b)).

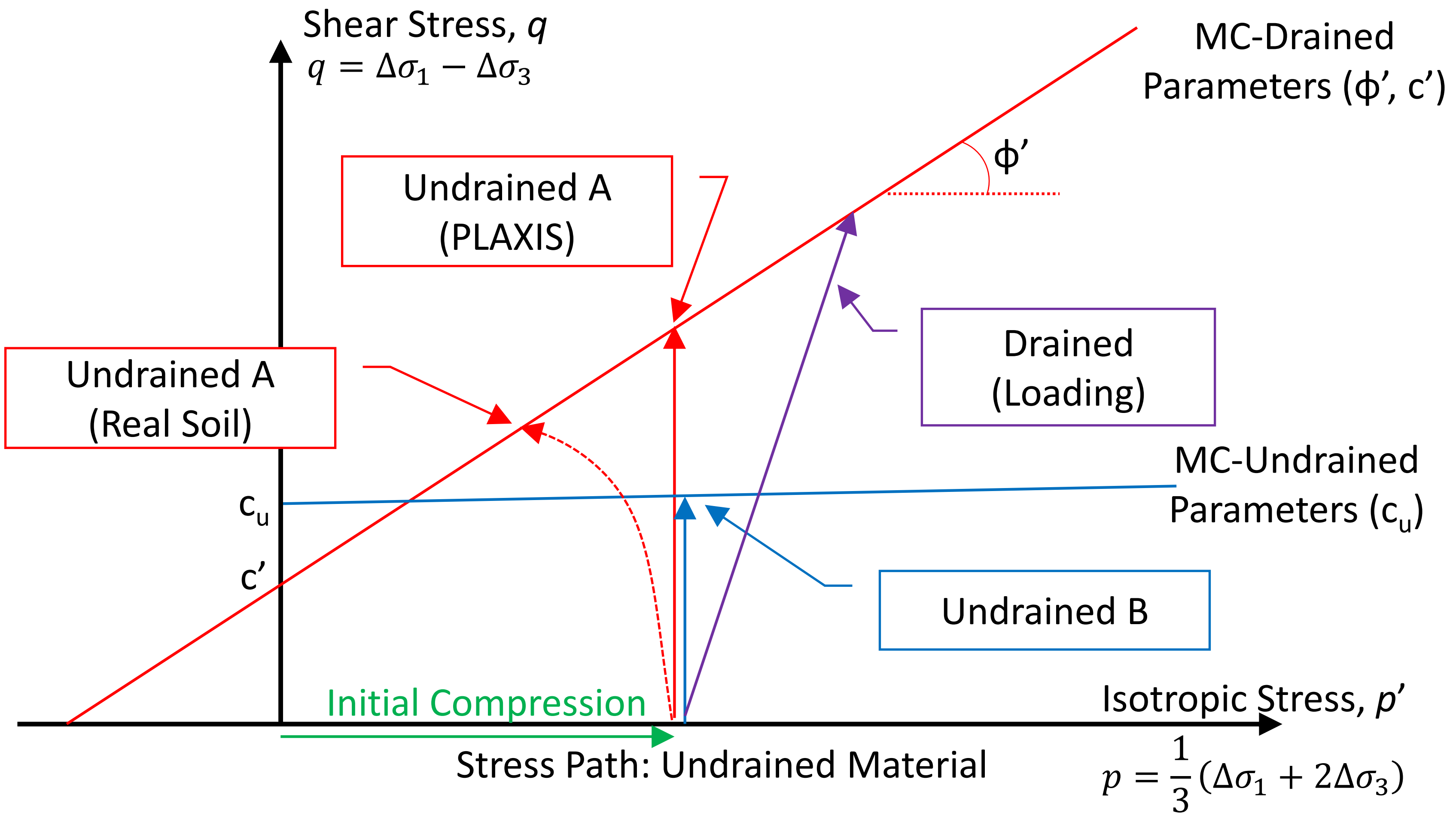
- In principle, analysis has to be performed using soil parameters that will produce the most critical condition. If it is not known, either undrained condition or drained condition, is the most critical condition; analysis has to be performed for both conditions (SNI 8460 Sect. 10.3.6.5).

CS GeoStruktur

Part 4: PLAXIS 2D Simulation
Short-Term Condition

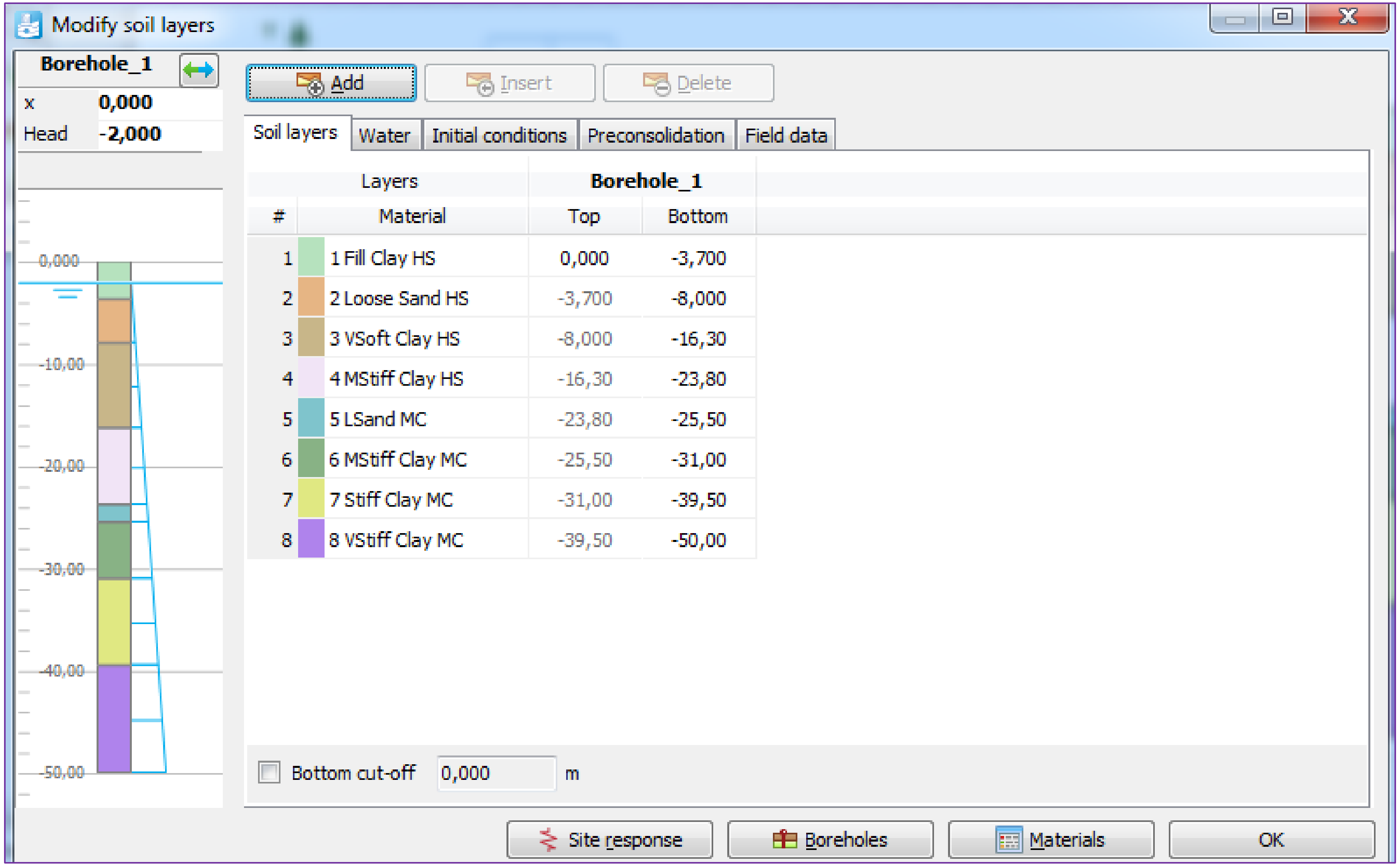
GeoStruktur

Stress Path: Drained vs Undrained



Drained parameters → Determine the failure surface.
Drained material → Determine the stress path.

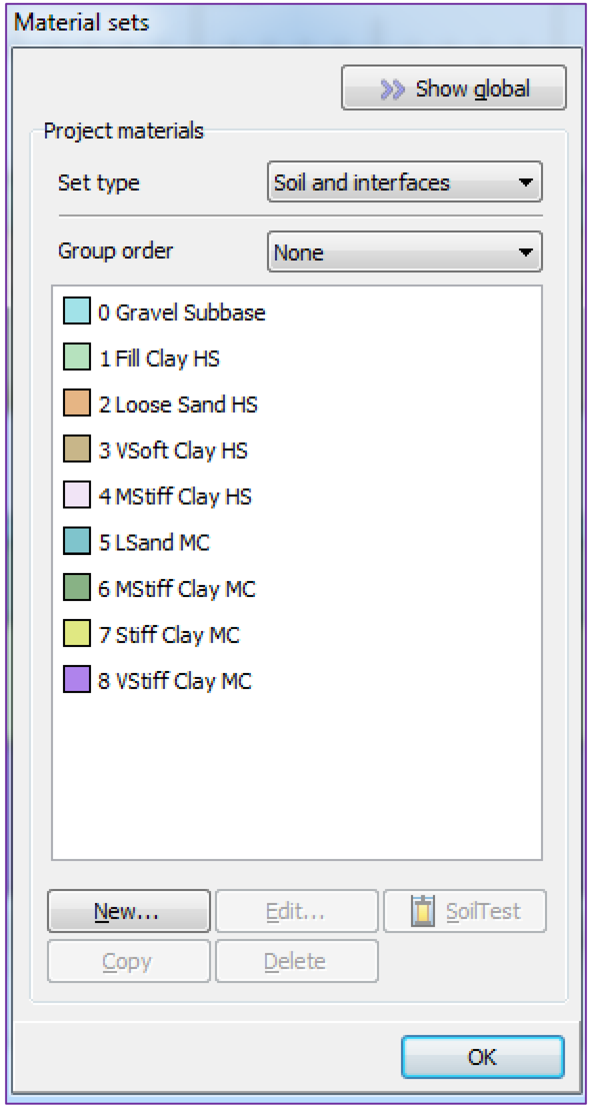
Set Borehole Data

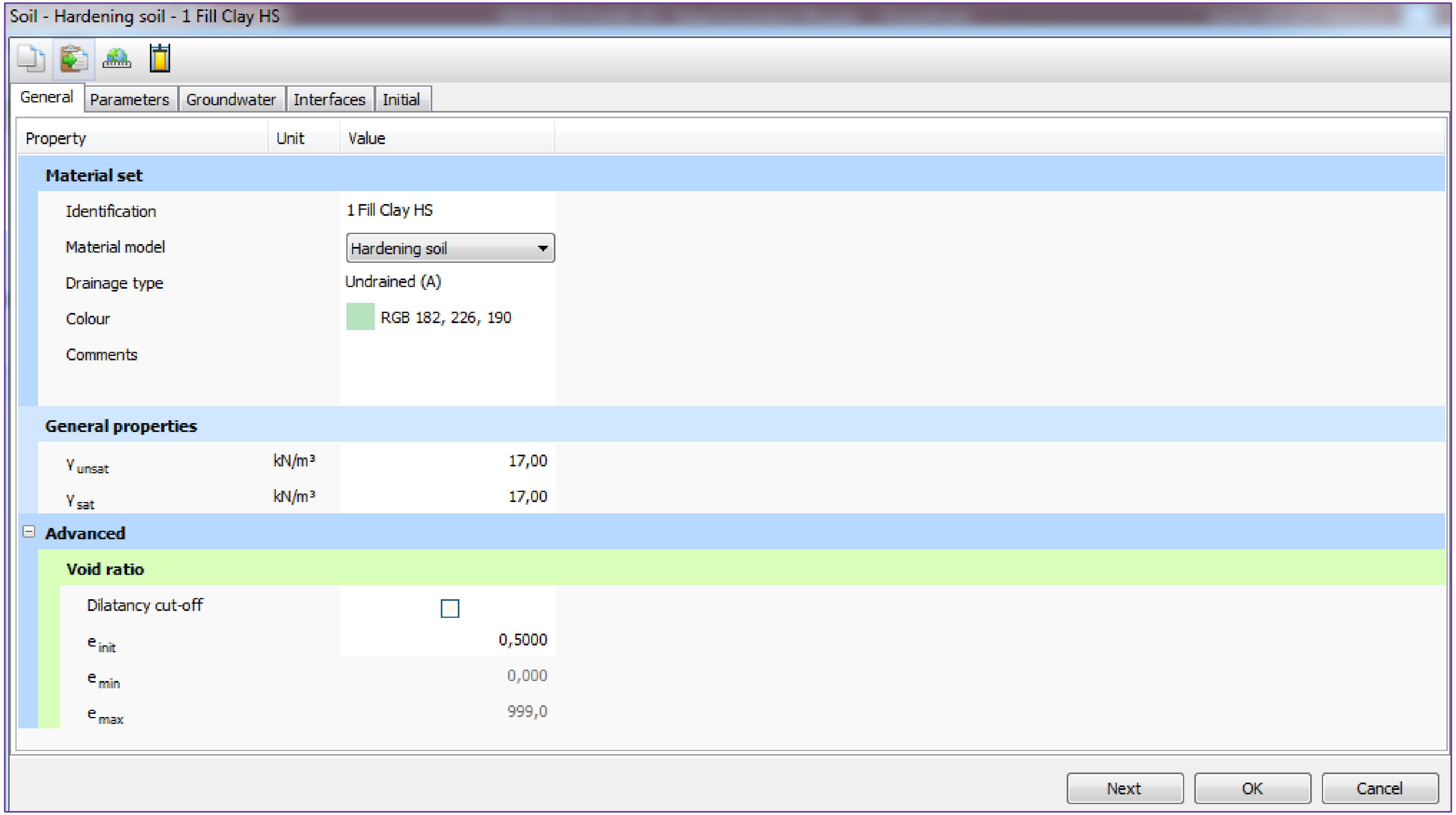


#	Material	Top	Bottom
1	1 Fill Clay HS	0,000	-3,700
2	2 Loose Sand HS	-3,700	-8,000
3	3 VSoft Clay HS	-8,000	-16,30
4	4 MStiff Clay HS	-16,30	-23,80
5	5 LSand MC	-23,80	-25,50
6	6 MStiff Clay MC	-25,50	-31,00
7	7 Stiff Clay MC	-31,00	-39,50
8	8 VStiff Clay MC	-39,50	-50,00

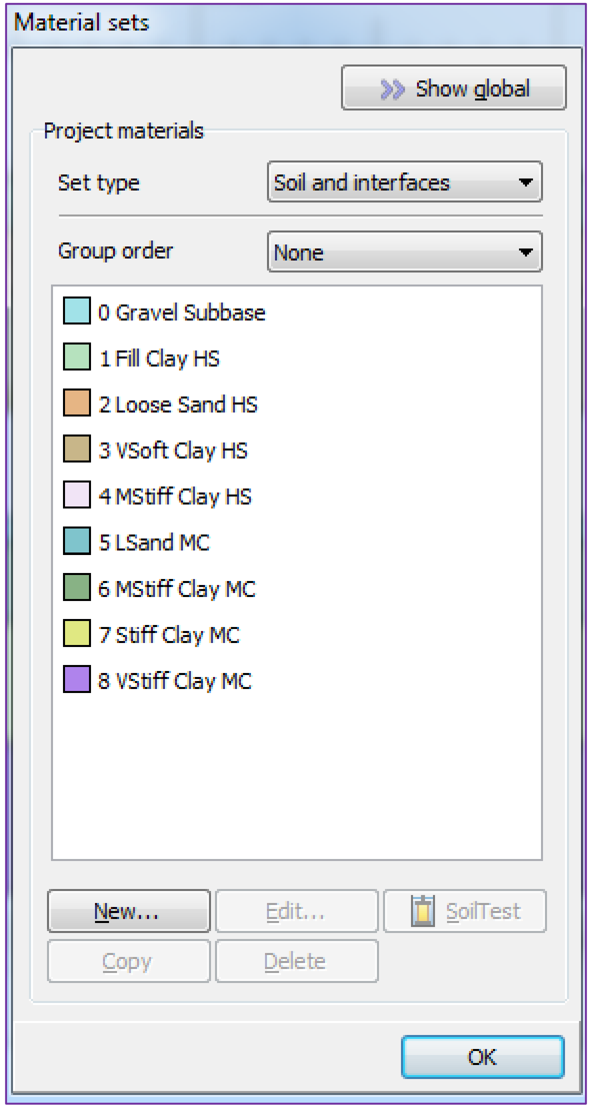
CS GeoStruktur

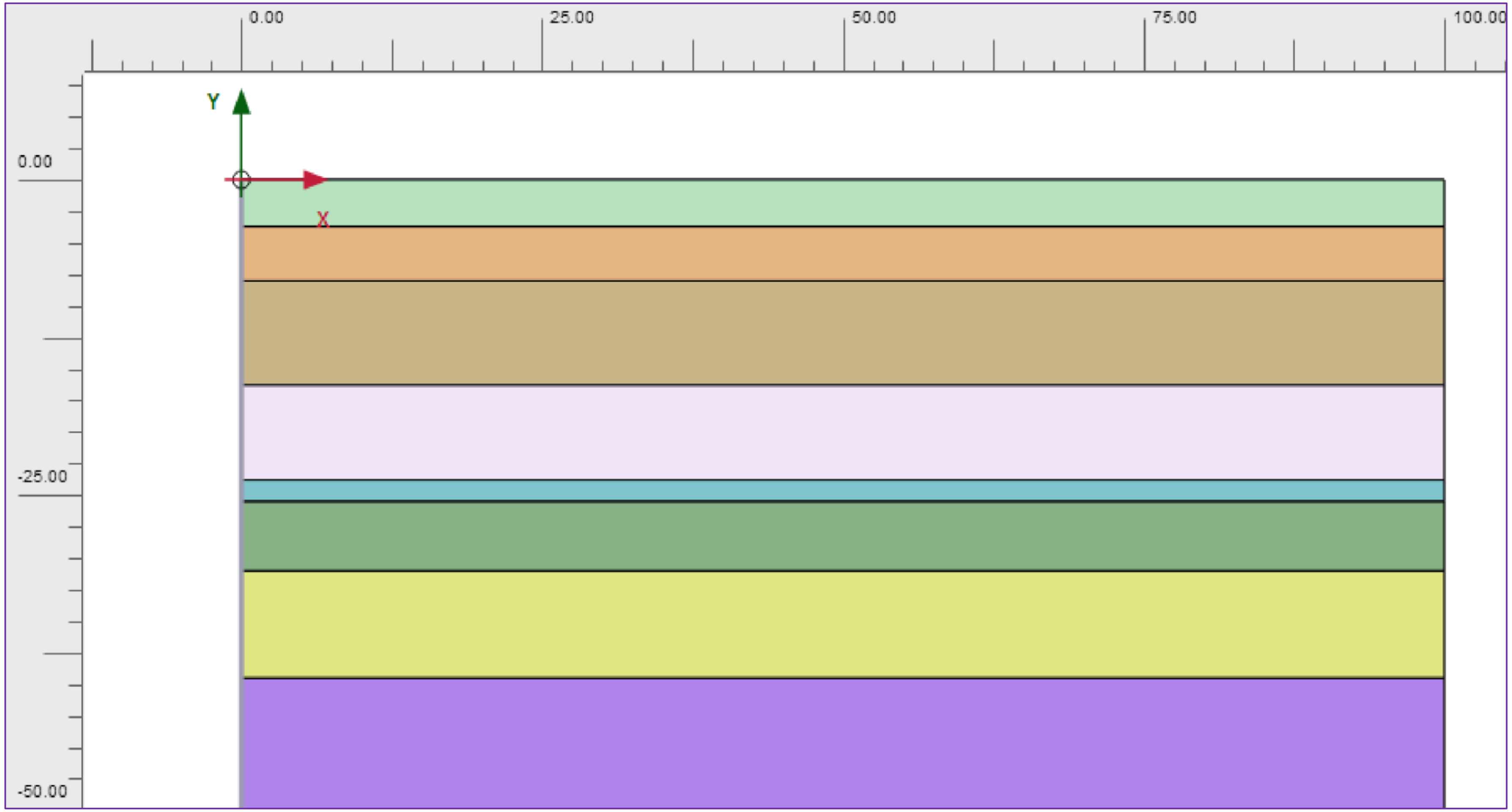
Set Material Data





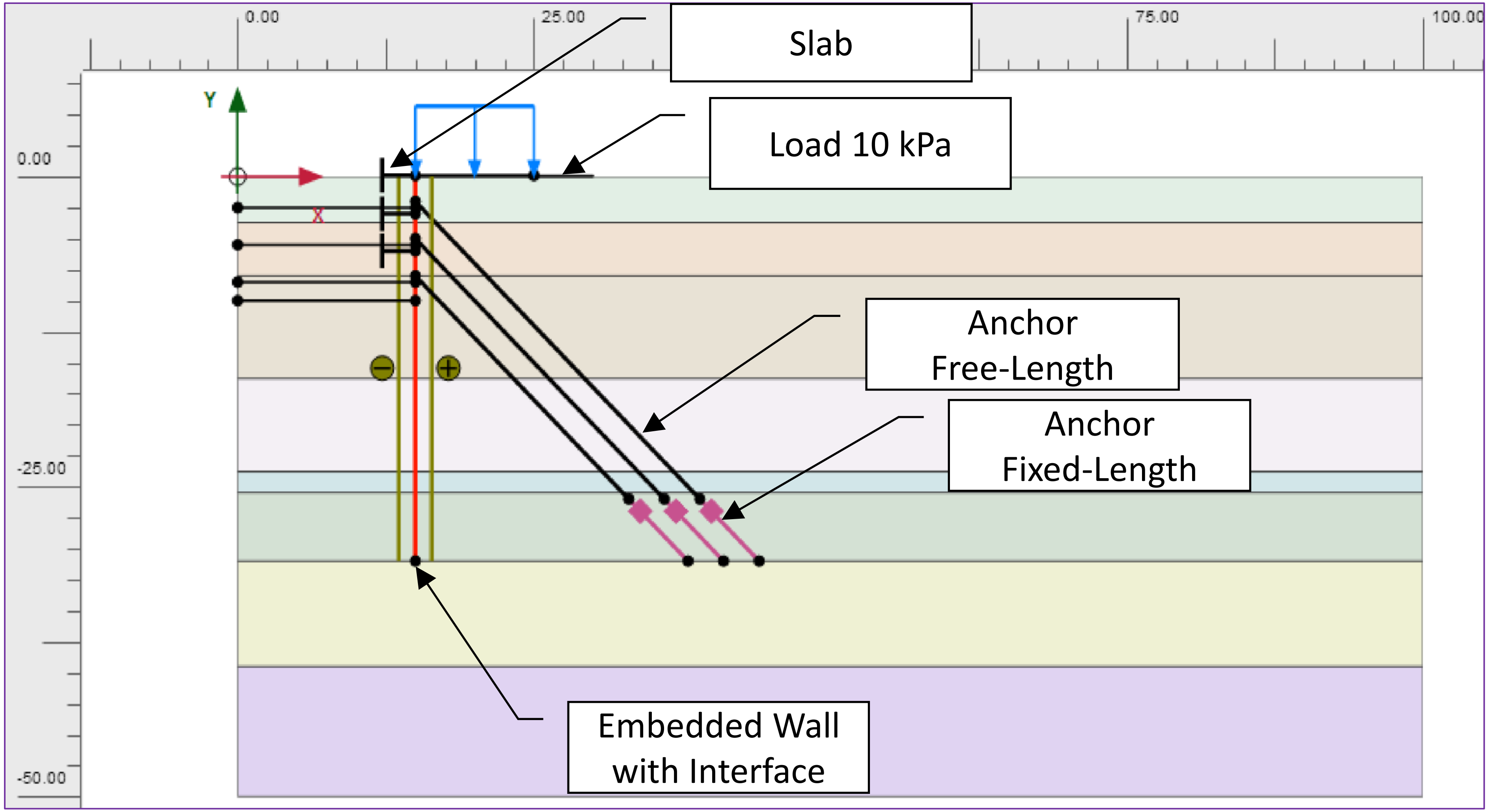
Assign Soil Data





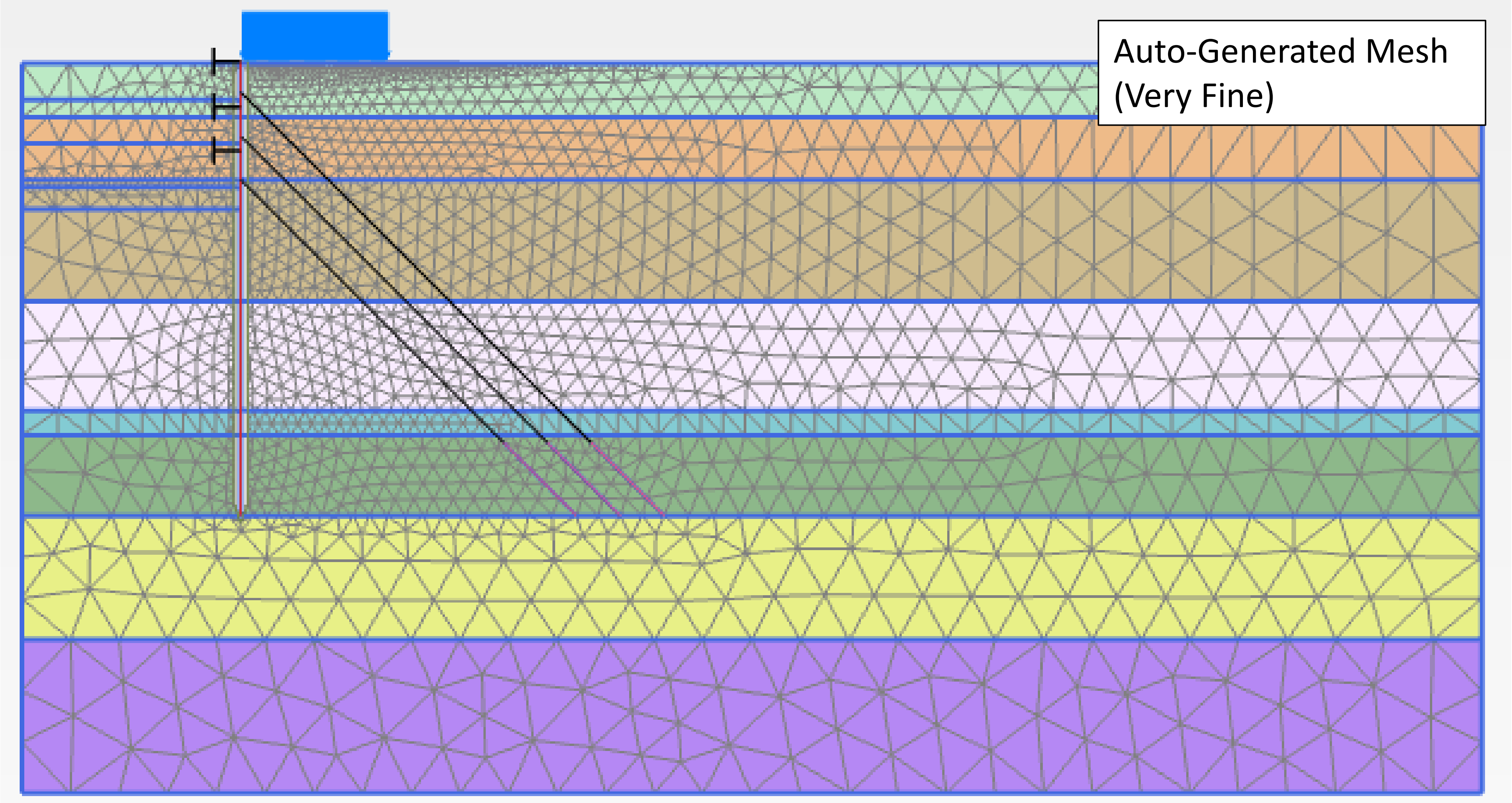
GeoStruktur

Create Structural Element

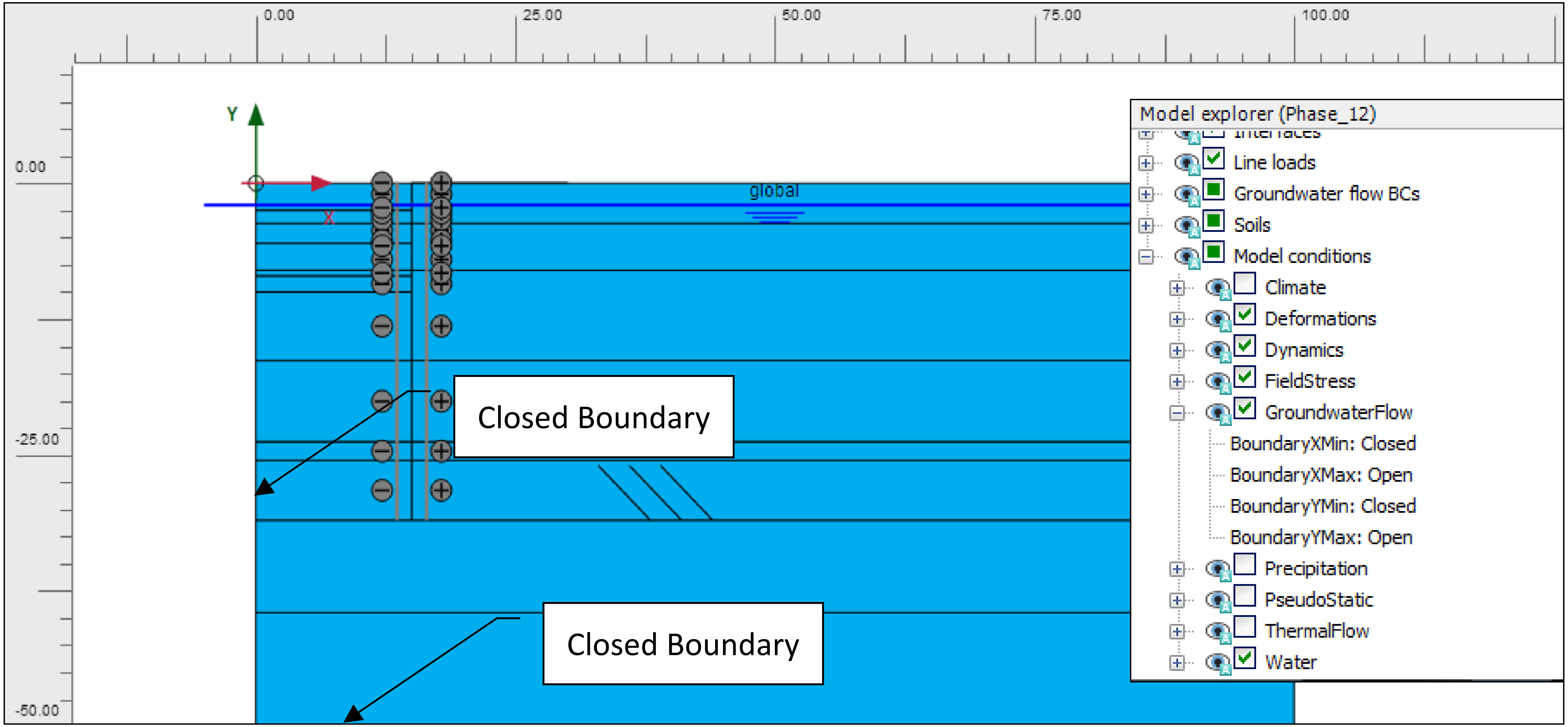


GeoStruktur

Generate Mesh

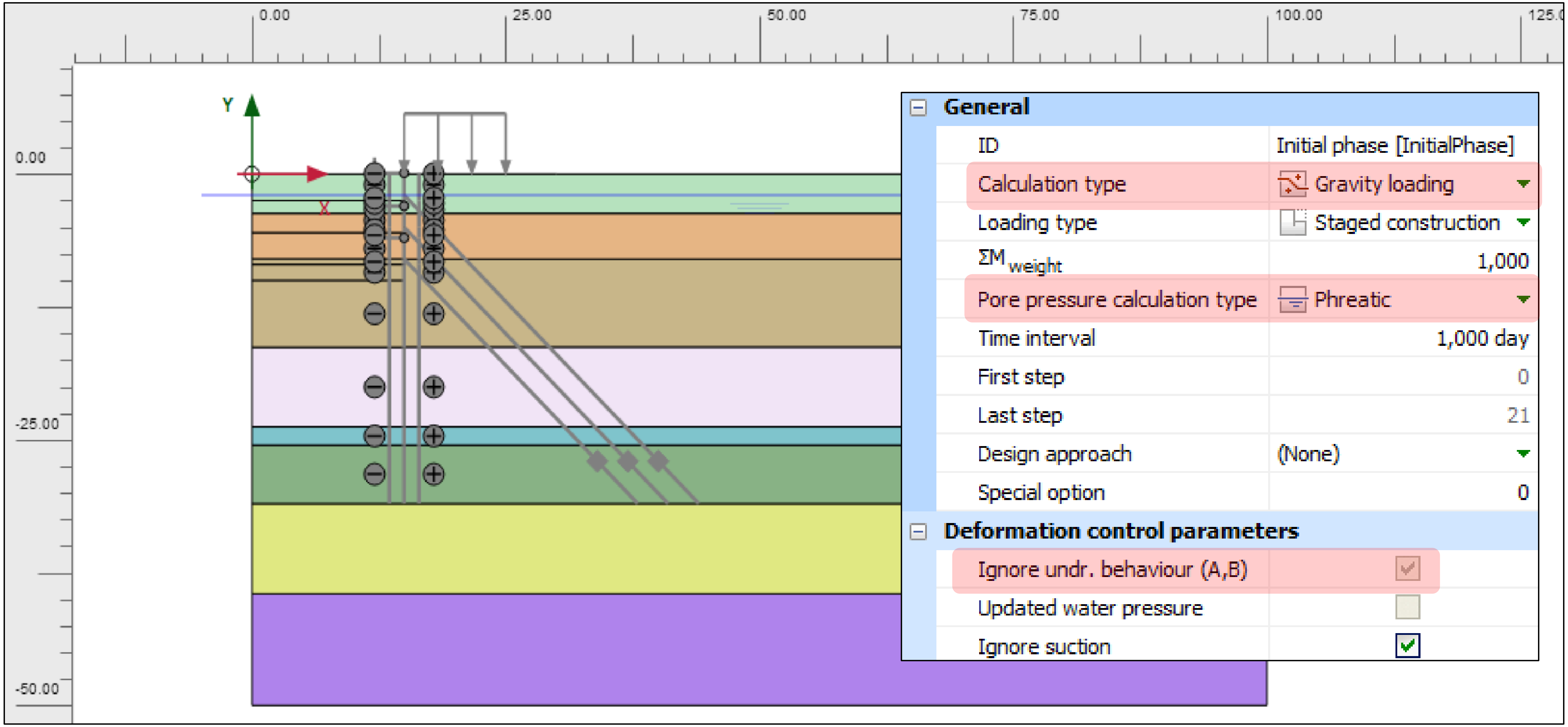


Initial Flow Condition



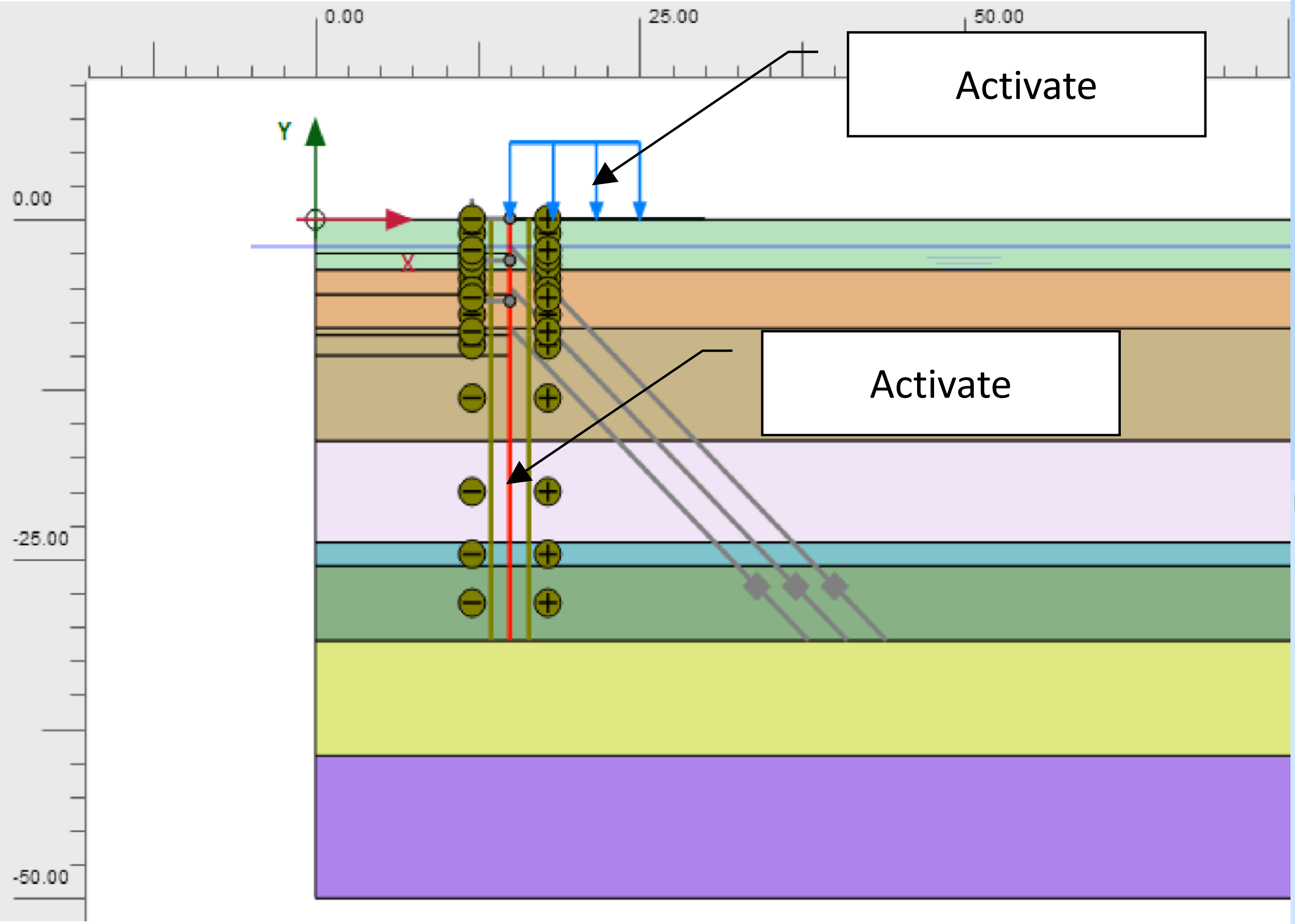
GeoStruktur

Initial Cond: Gravity Loading



CS GeoStruktur

Phase 1: Embedded Wall + CST Load

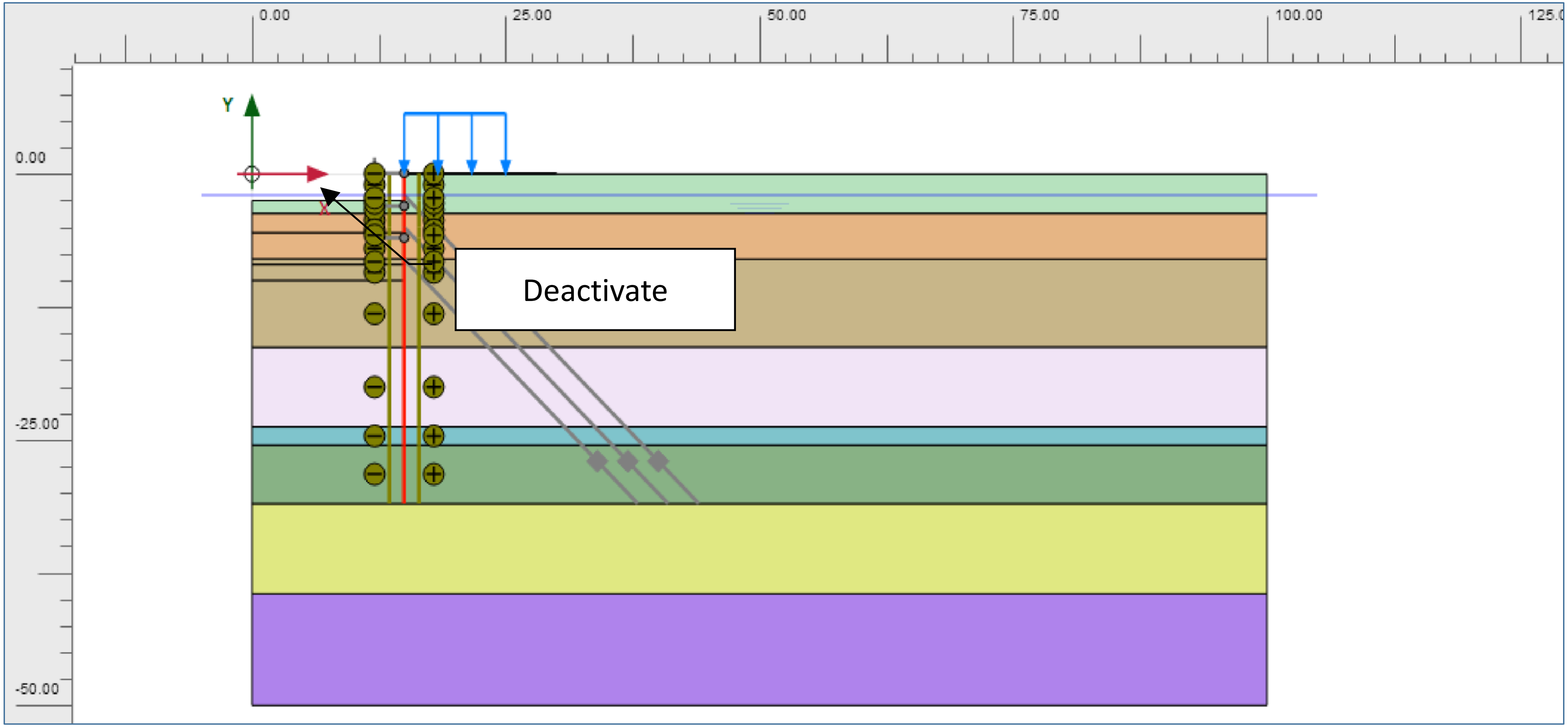


General	
ID	SecWall [Phase_1]
Start from phase	Initial phase
Calculation type	Plastic
Loading type	Staged construction
ΣM_{stage}	1,000
ΣM_{weight}	1,000
Pore pressure calculation type	Phreatic
Time interval	1,000 day
First step	22
Last step	26
Design approach	(None)
Special option	0

Deformation control parameters	
Ignore undr. behaviour (A,B)	☐
Reset displacements to zero	☑
Reset small strain	☑
Reset state variables	☐
Reset time	☐
Updated mesh	☐
Updated water pressure	☐
Ignore suction	☑
Cavitation cut-off	☐
Cavitation stress	100,0 kN/m²

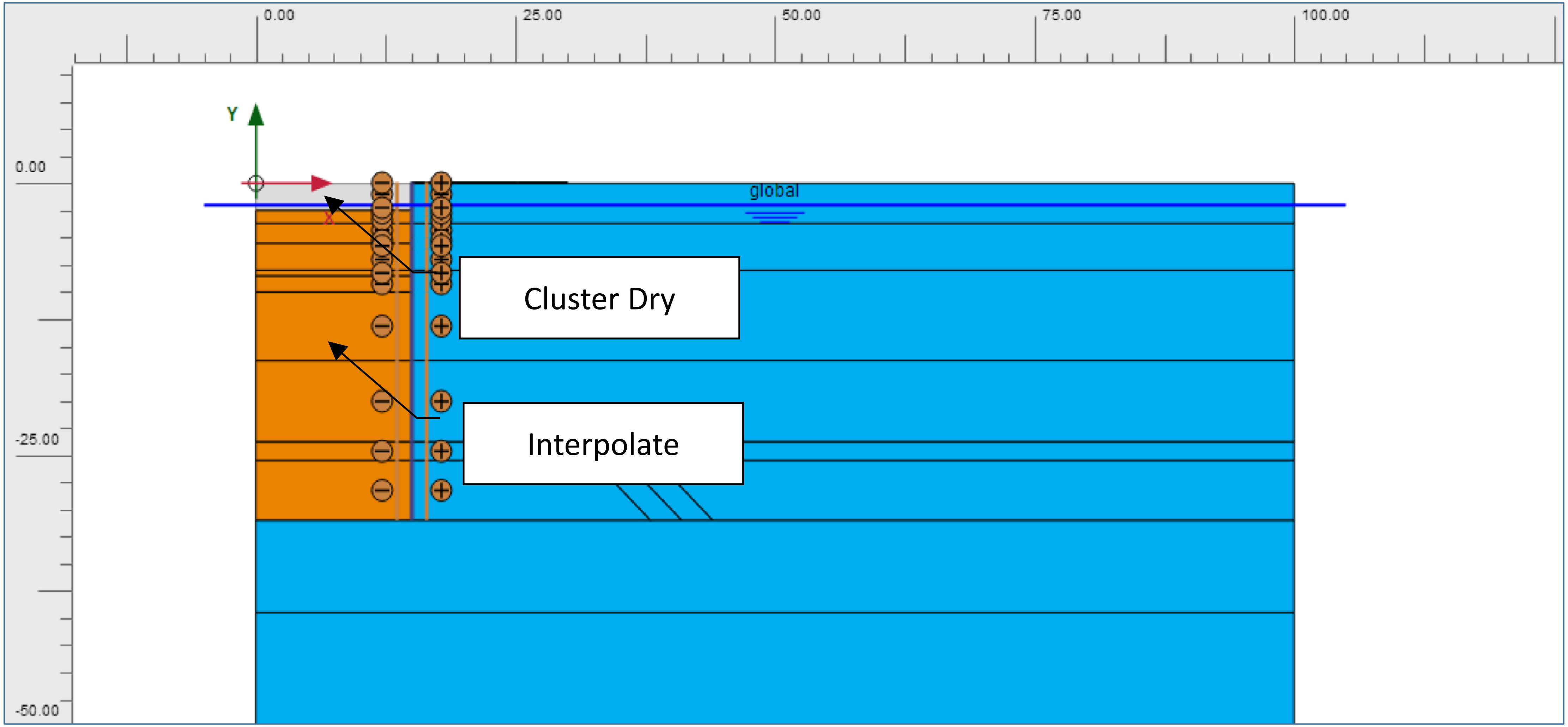
GeoStruktur

Phase 2: Excavation (1)

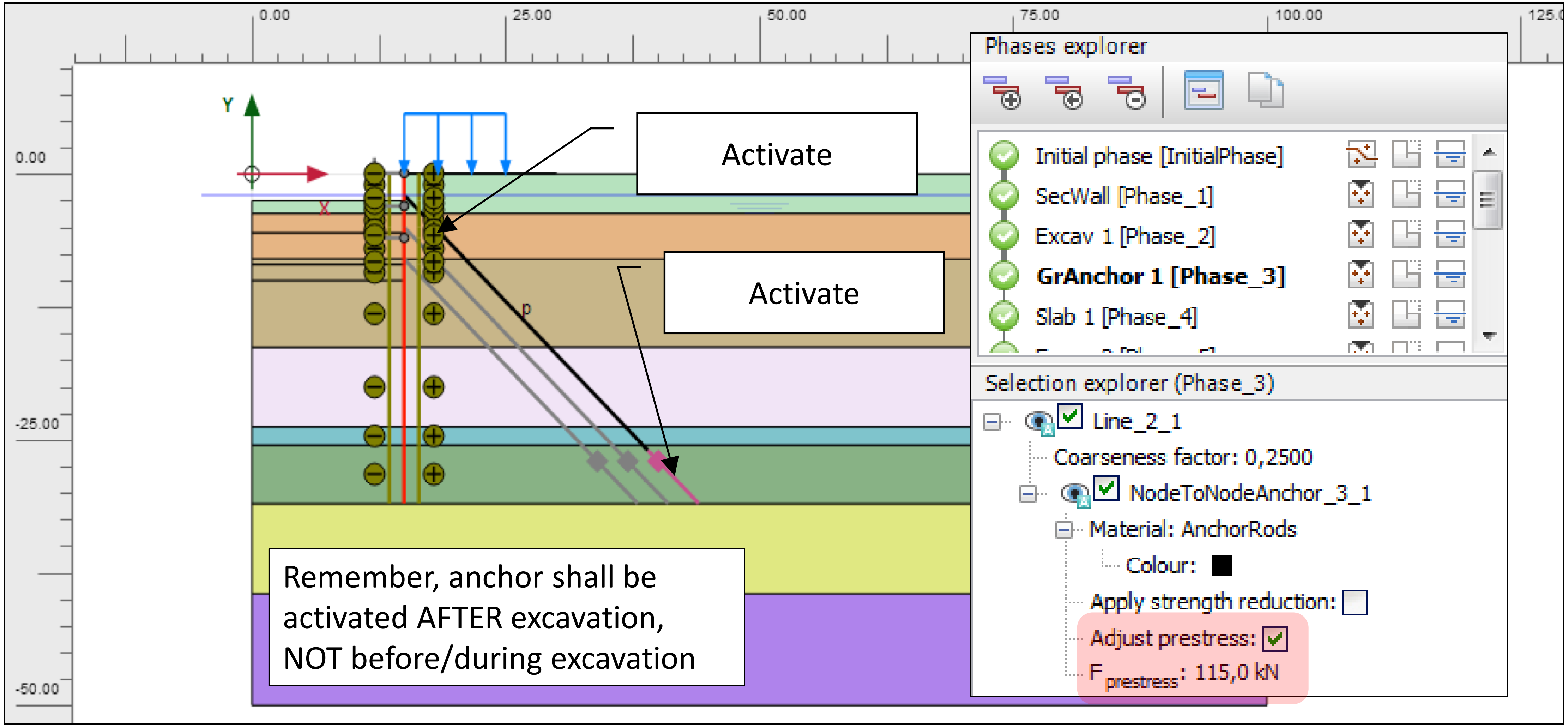


GeoStruktur

Phase 2: Excavation (1) – Flow Condition

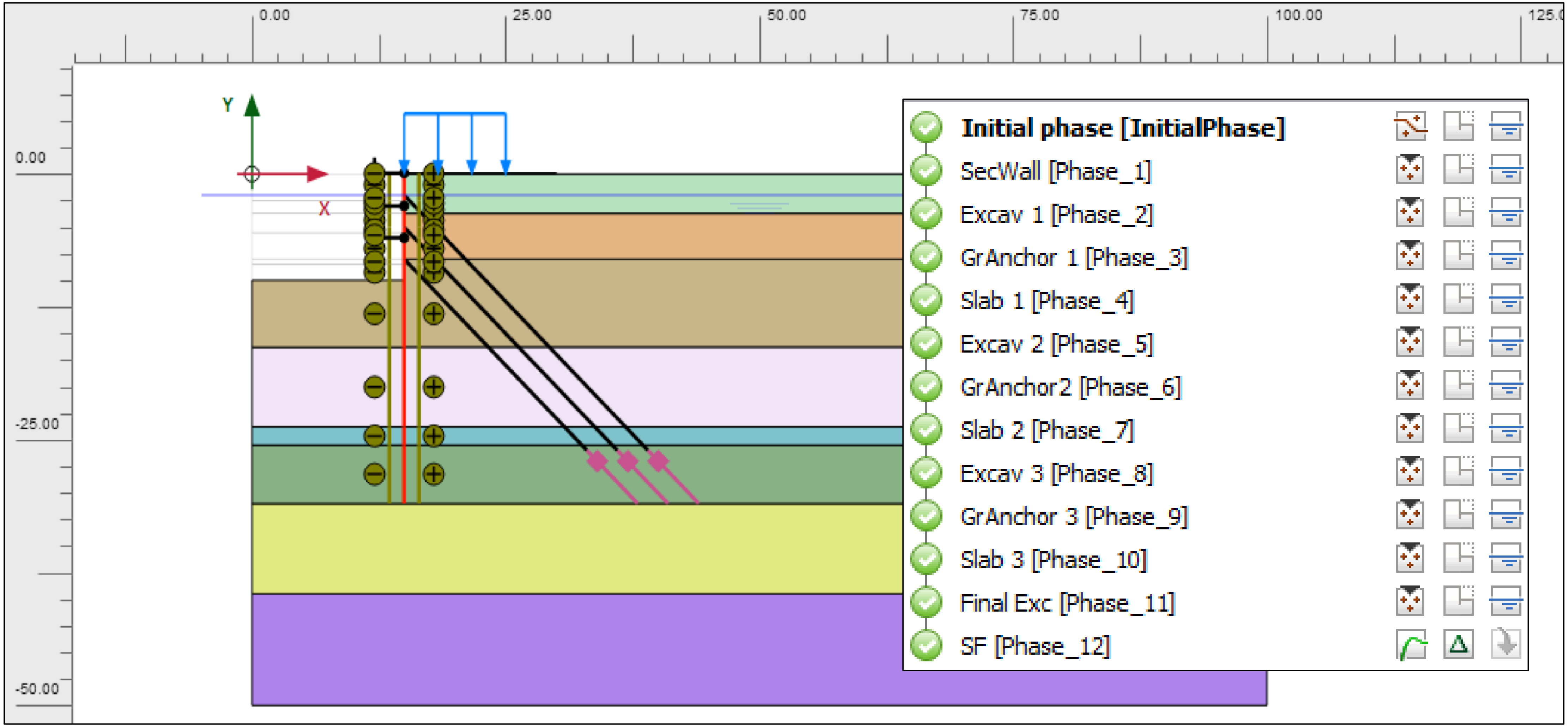


Phase 3: Ground Anchor (1)



GeoStruktur

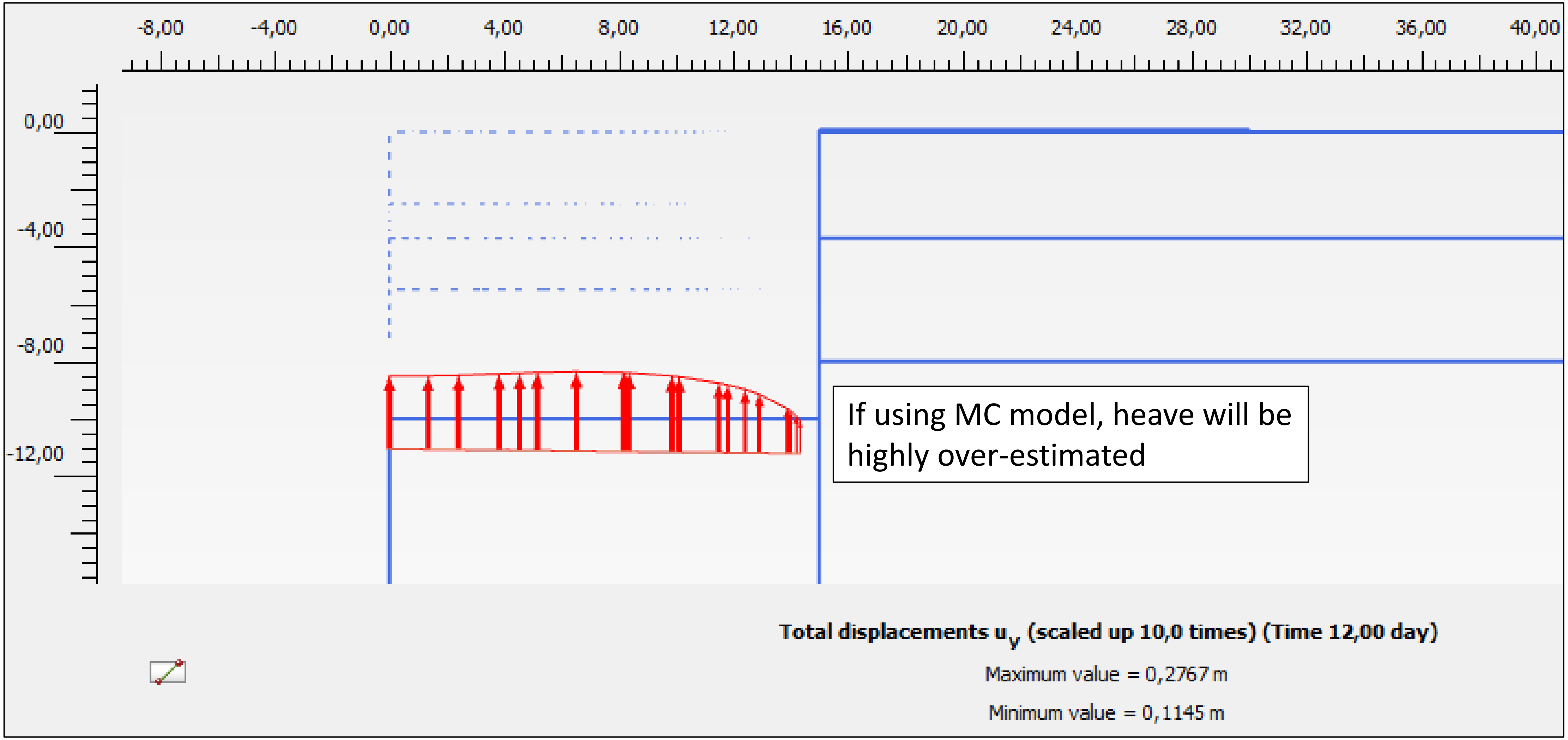
Final Phase



GeoStruktur

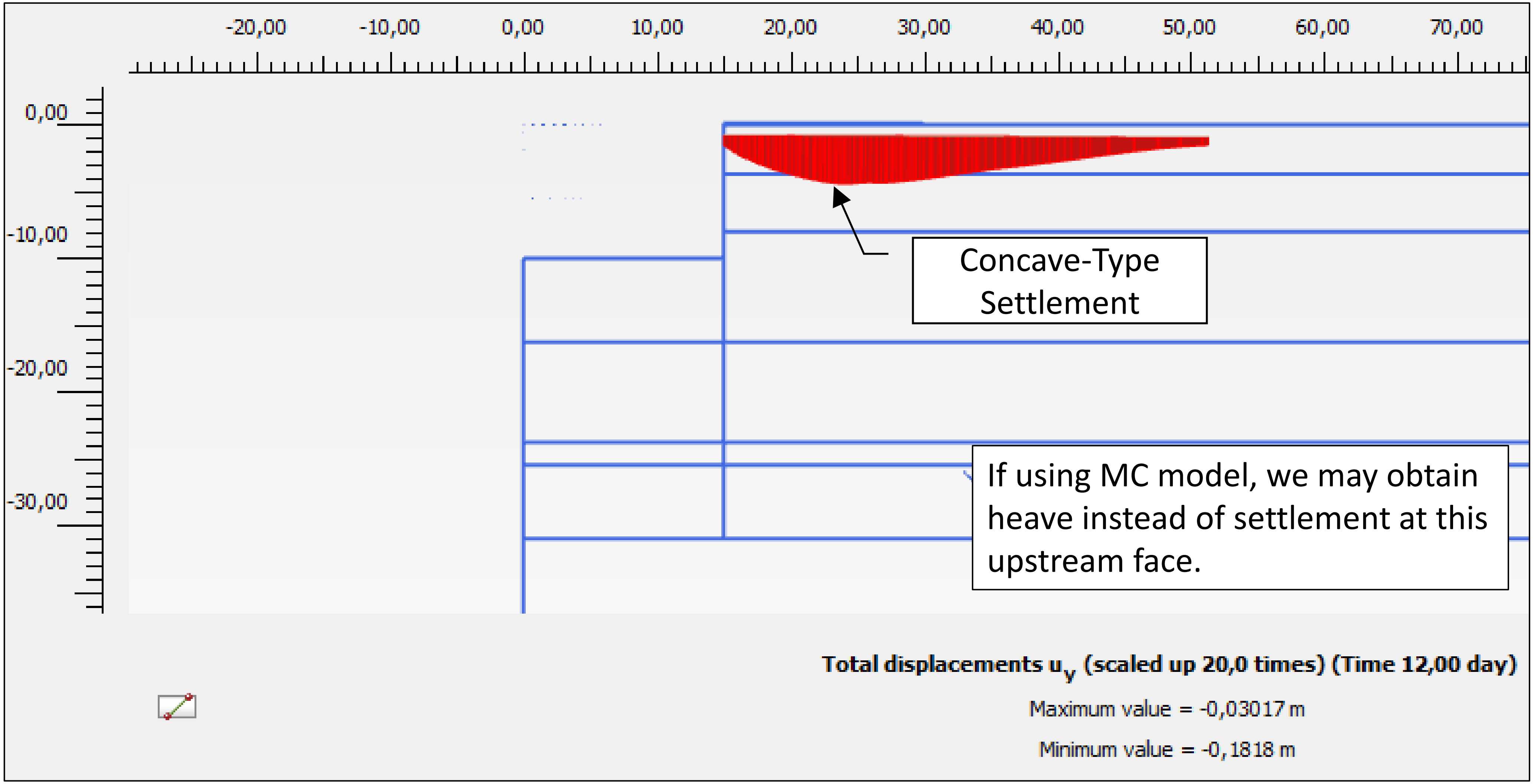
Part 5: Results
Short-Term Condition

Results: Heave Displacement

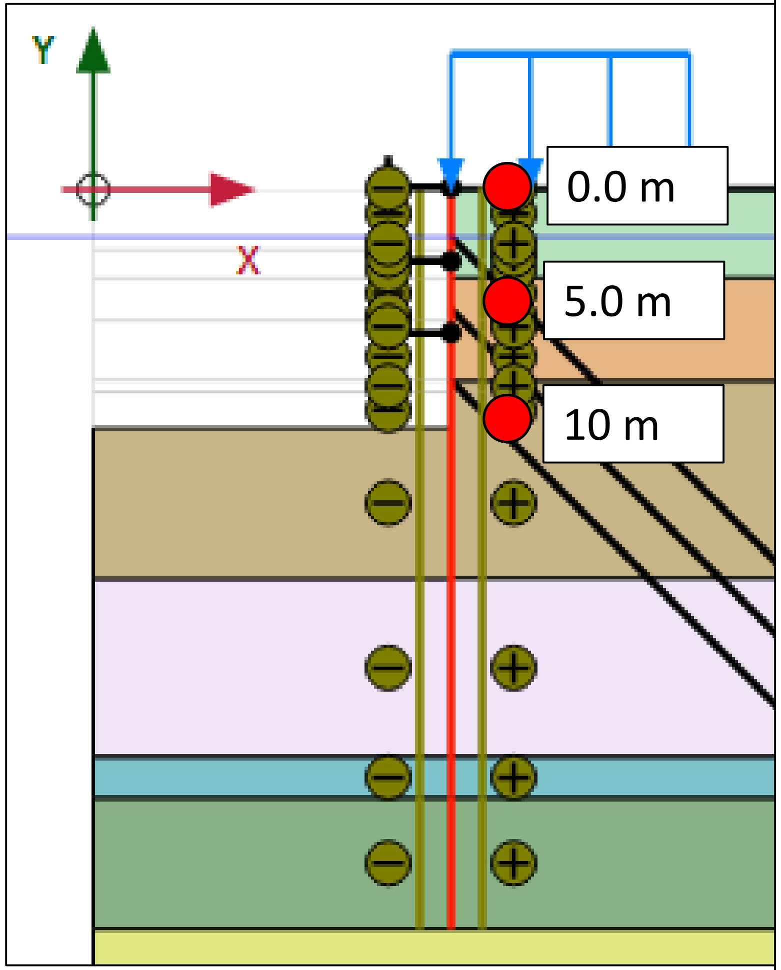


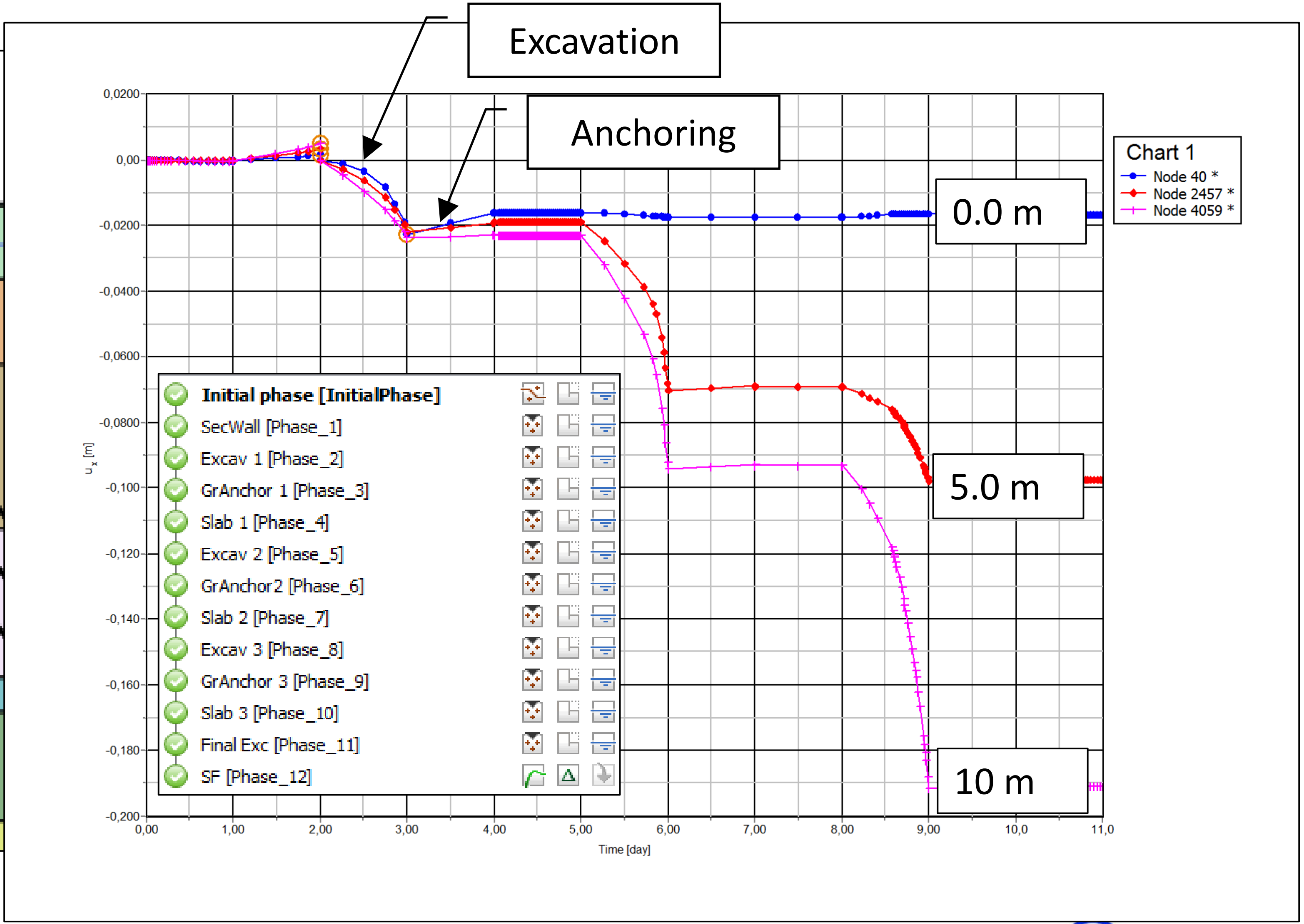
GeoStruktur

Results: Settlement at Upstream Face



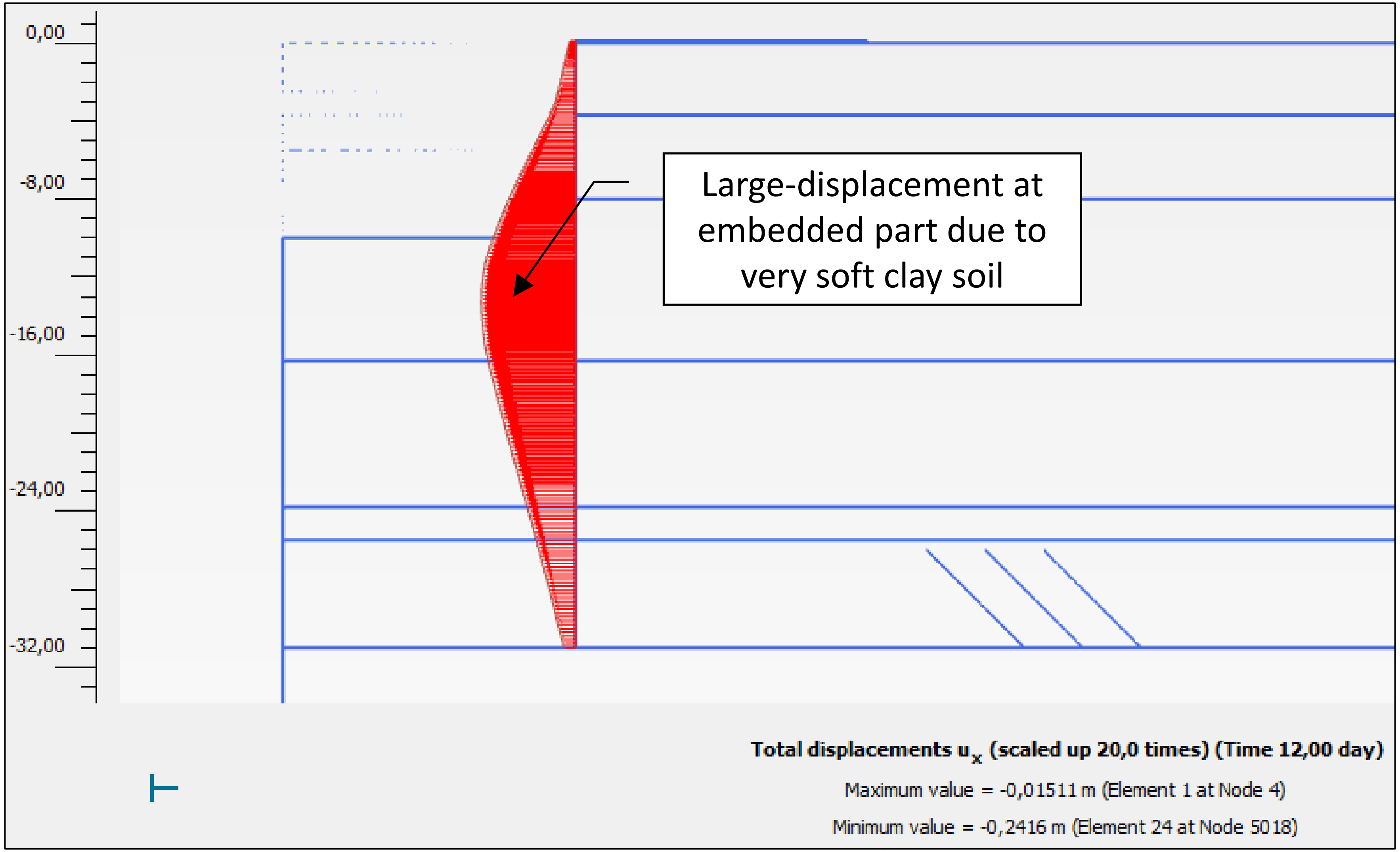
Point Tracking: Lat. Displacement



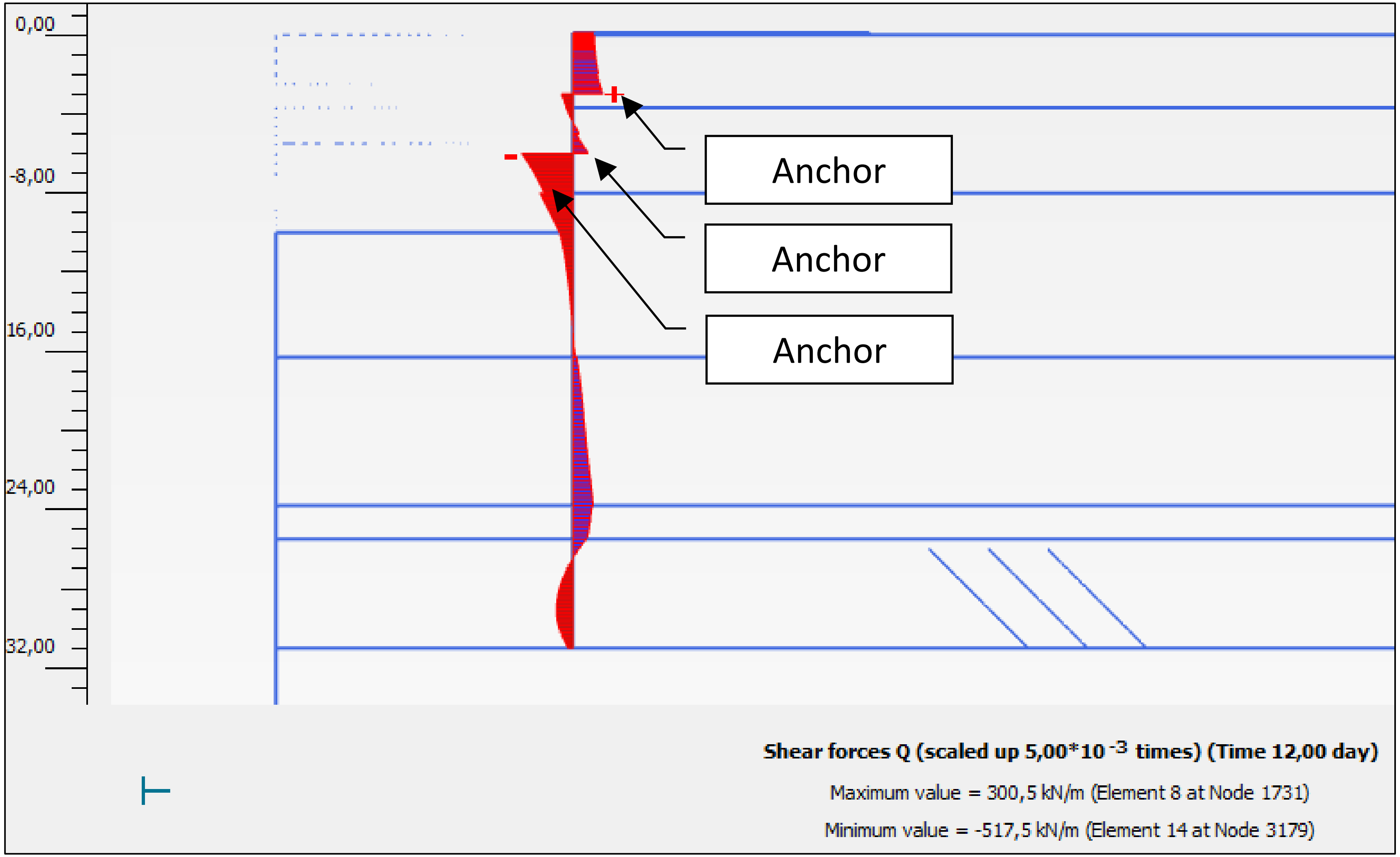


GeoStruktur

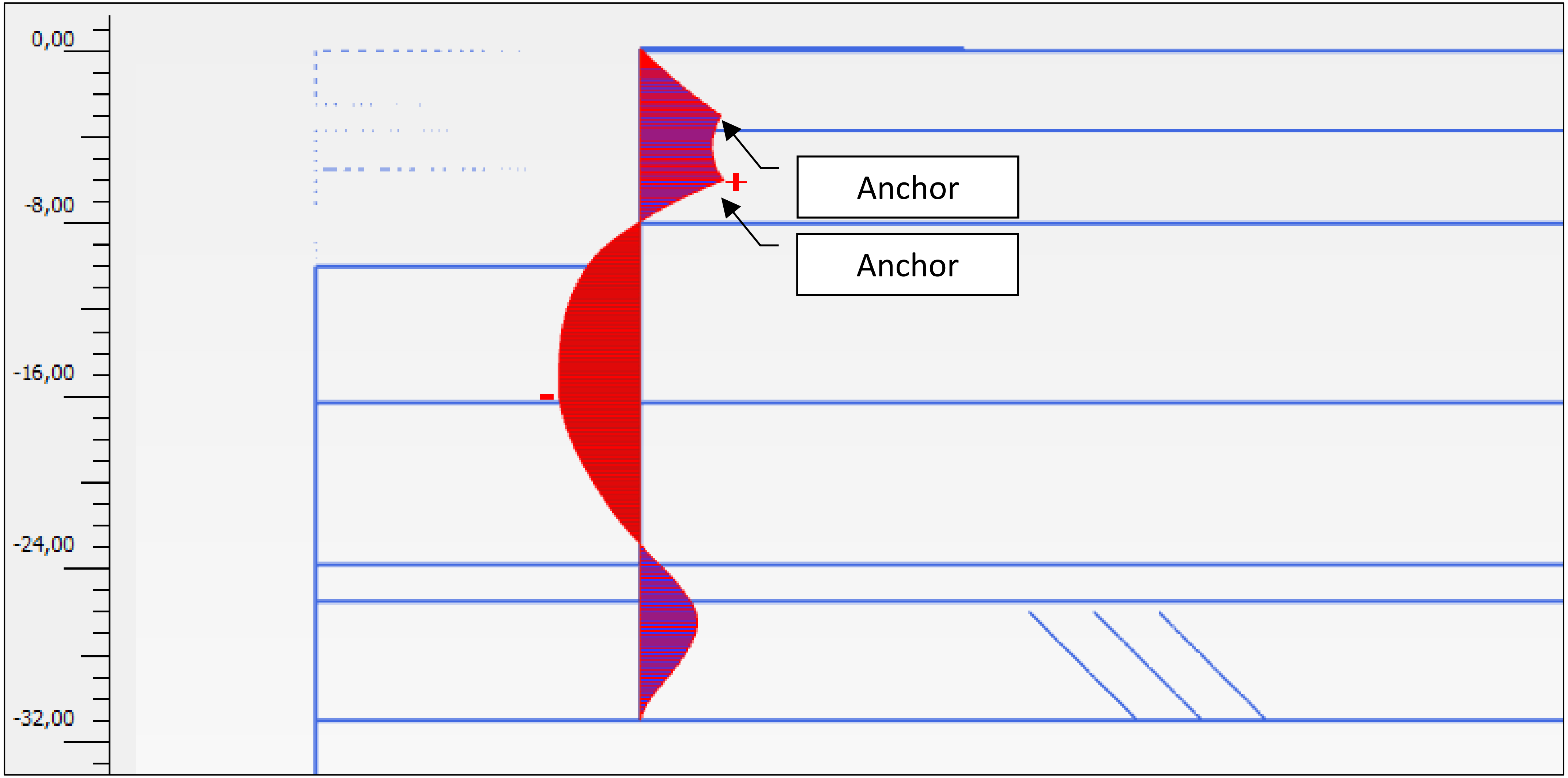
Embedded Wall: Lateral Displacement



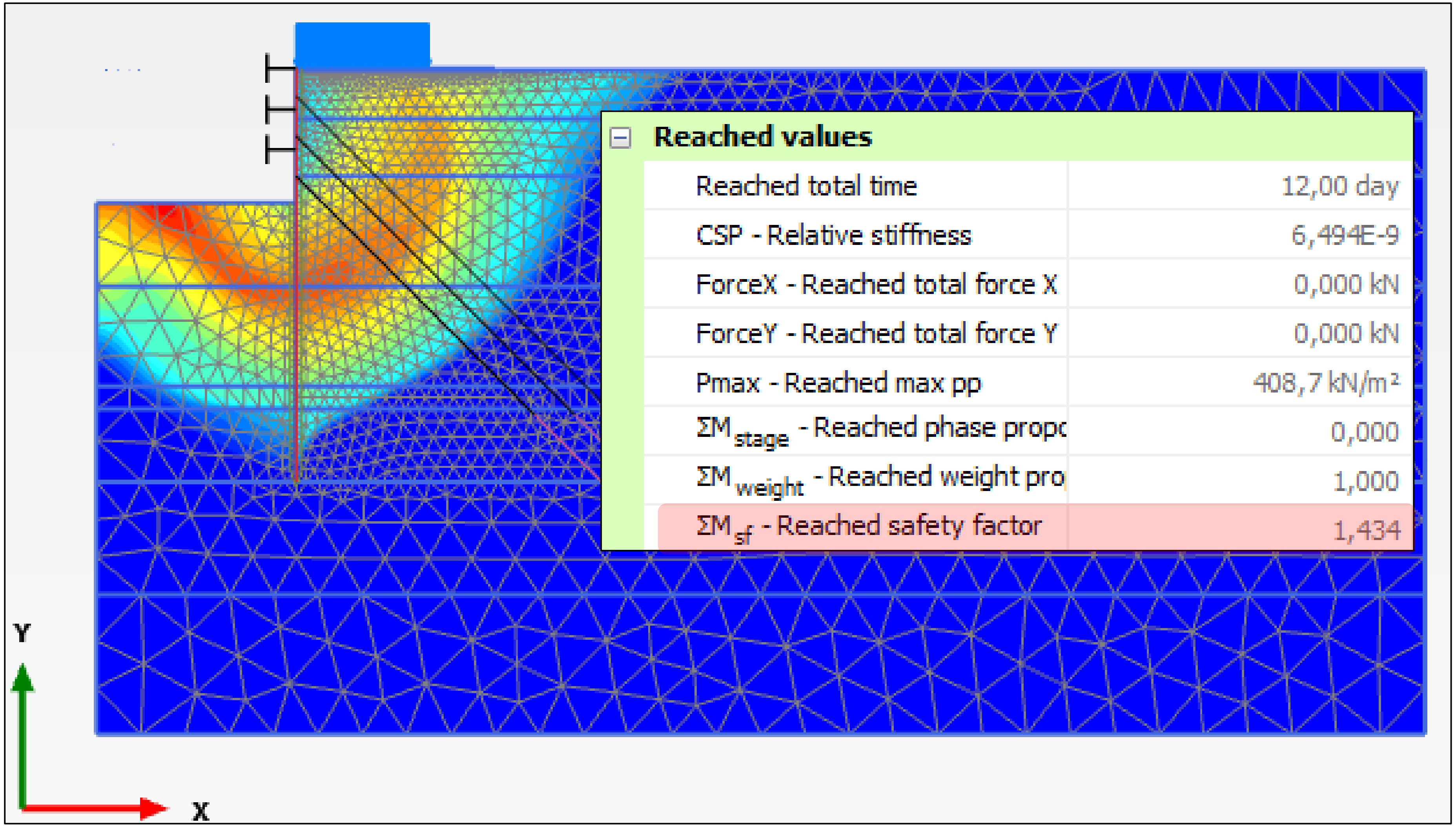
Embedded Wall: Shear Force



Embedded Wall: Moment Force

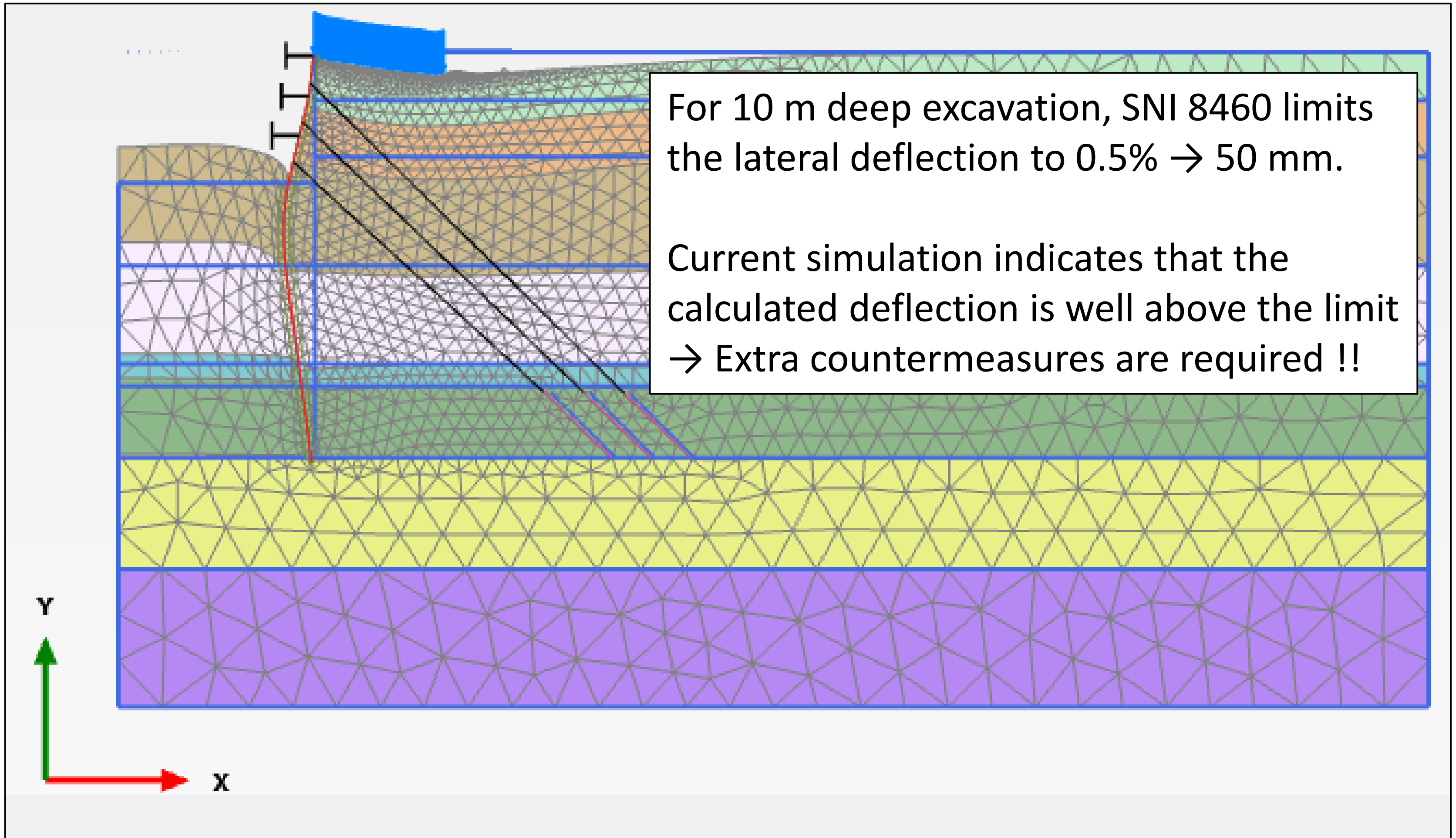


Safety Analysis



GeoStruktur

Results: Deformed Mesh



For 10 m deep excavation, SNI 8460 limits the lateral deflection to 0.5% → 50 mm.

Current simulation indicates that the calculated deflection is well above the limit → Extra countermeasures are required !!

Deformed mesh |u| (scaled up 10,0 times) (Time 12,00 day)

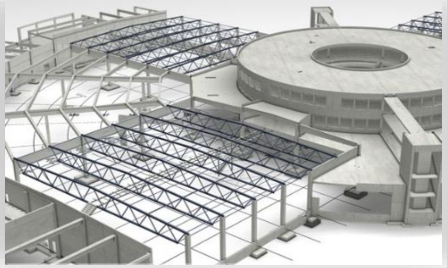
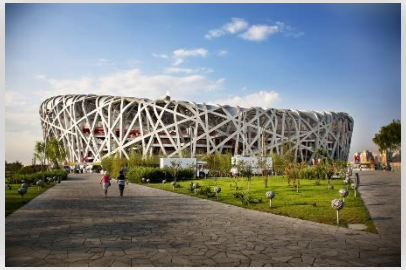
Maximum value = 0,3154 m (Element 2036 at Node 8328)

GeoStruktur

GeoStruktur Sistem Solusindo

Your Trusted Partner for Digital Transformation



Thank you for your attention!

GeoStruktur