Use of geogrids to anchor sheet pile walls

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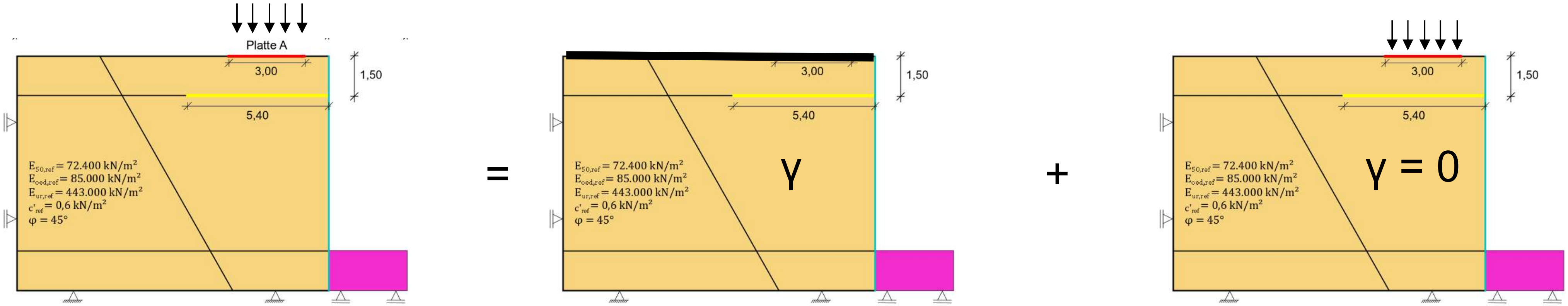
- Introduction



- German design concept for sheet pile walls for construction pits and water ways
- Numerical studies based on the small scale model tests at DELTARES
- Numerical studies on a simplified real system
- Summary

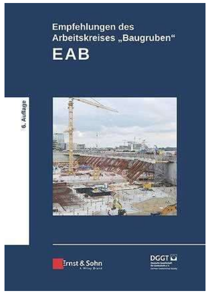
German design concept for sheet pile walls for construction pits and water ways

- EC7 - DIN EN 1997-1 (09/2009) [German version EN 1997-1:2004 + AC:2009] Geotechnical design – Part 1: General rules
- NAD - DIN EN 1997-1/NA (12/2010) National Annex – Nationally determined parameters – Eurocode 7: Geotechnical design – Part 1
- DIN 1054 (12/2010) Subsoil – Verification of the safety of earthworks and foundations – Supplementary rules to DIN EN 1997-1

These three documents are summarized in “Handbuch Eurocode 7 – Band 1: Allgemeine Regeln”

DIN 1054 (12/2010) is referring to other standards and guidelines, e.g.

- DIN 4085 (08/2017) Subsoil – Calculation of earth-pressure
- EAB – Recommendations on excavations (2021)
- EAU – Recommendations on bank stabilizations, harbor constructions and water ways (2020)
- EBGEO – Recommendations for design and analysis of earth structures using geosynthetic reinforcements (2010)

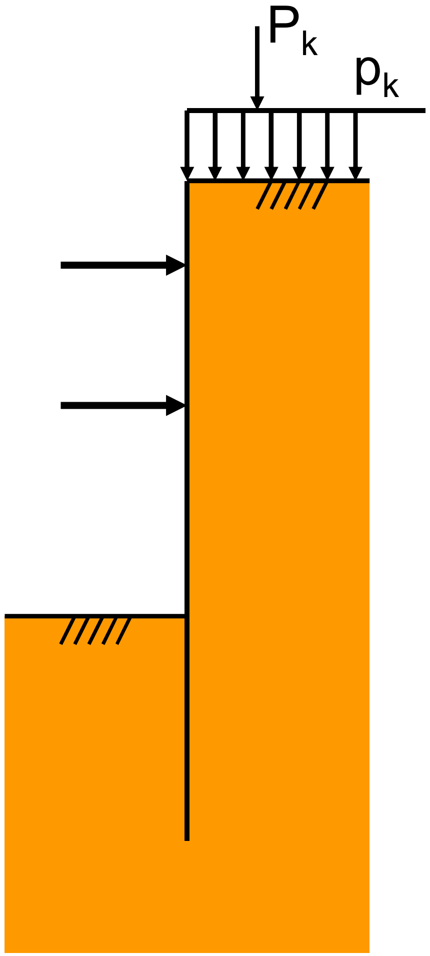


German design concept for sheet pile walls for construction pits and water ways

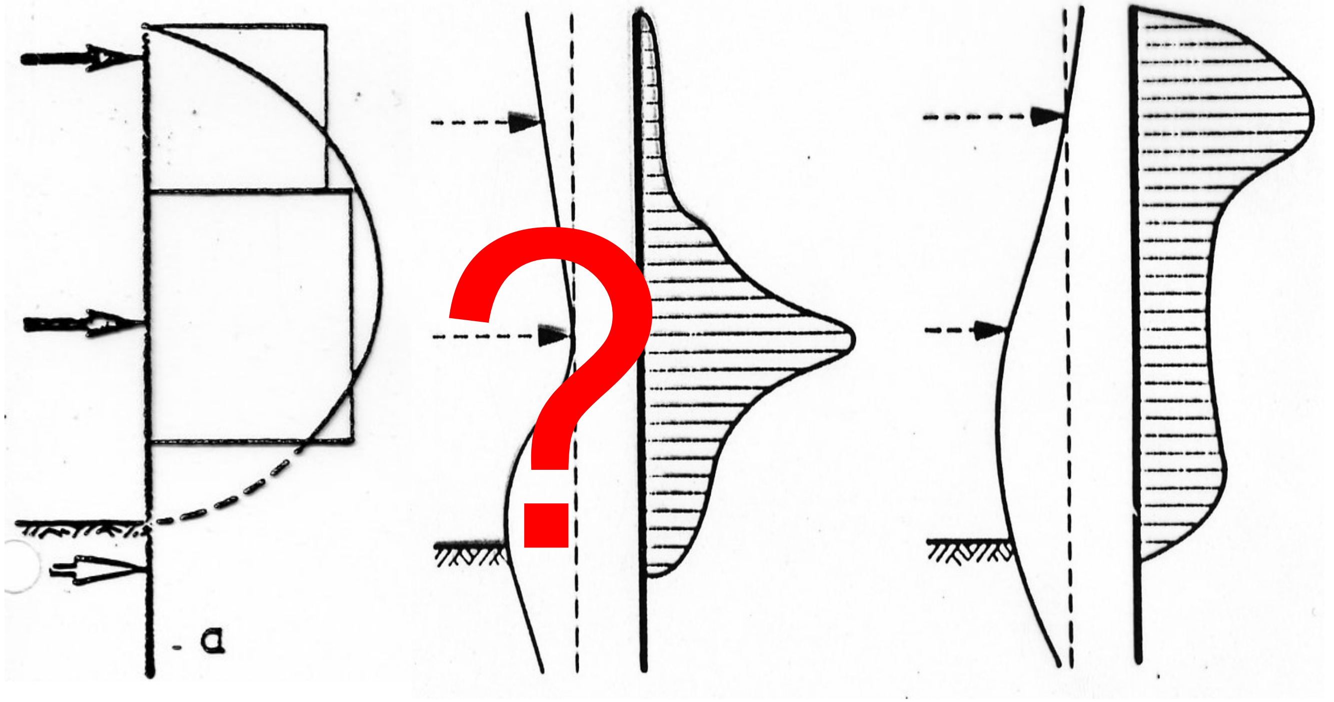
- Concept of EAB related to excavation pits:

>>> construction from top to bottom

>>> use of grouted anchors or struts



Calculation of active earth pressure?



Measurement at the site (strut forces)

Results from small scale model tests

German design concept for sheet pile walls for construction pits and water ways

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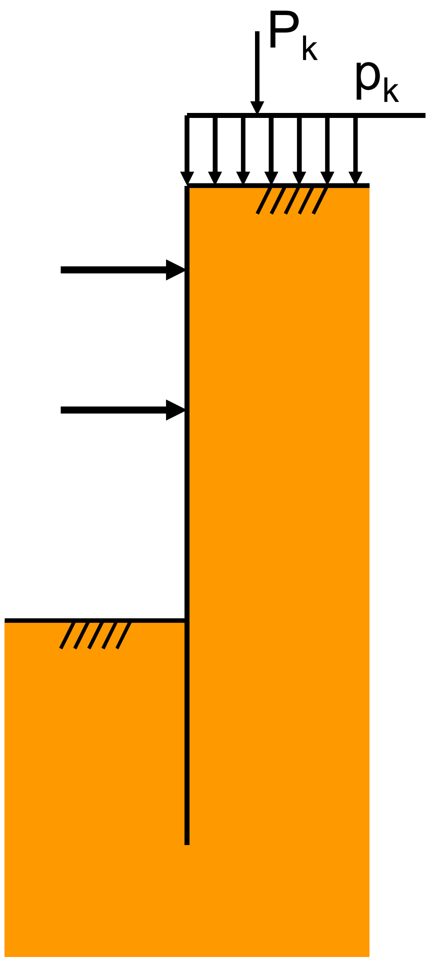
Classical earth pressure distribution valid for a wall turning around a deep point >> typical for unsupported walls

Supports change type of wall movement >> influence on earth pressure distribution



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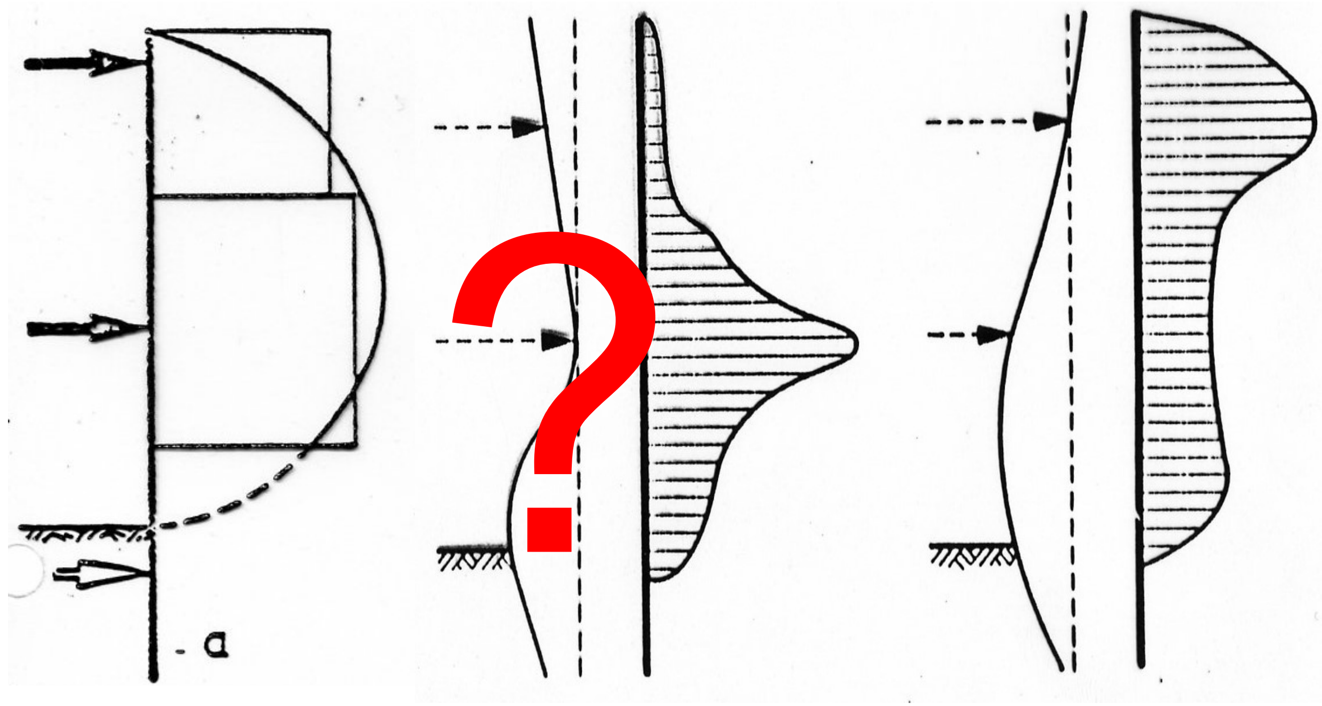

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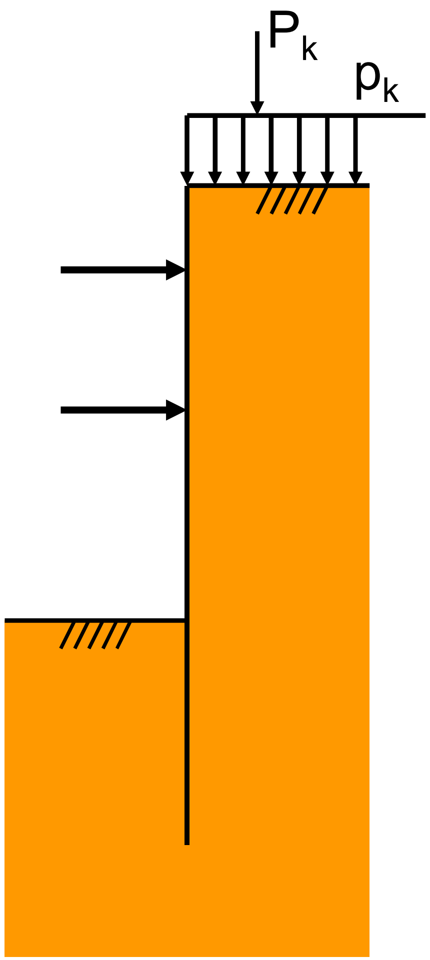
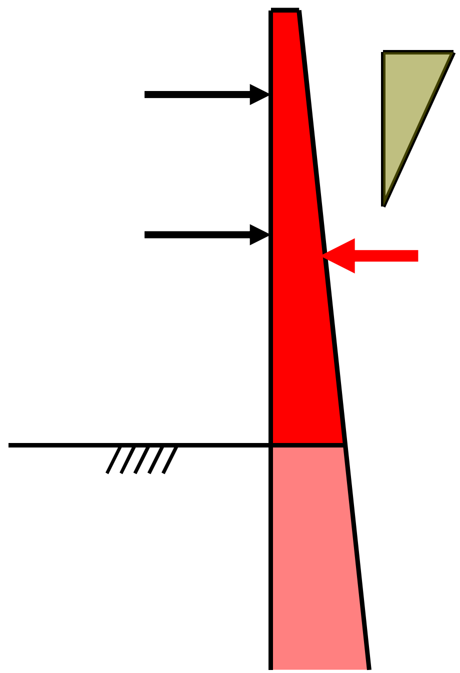
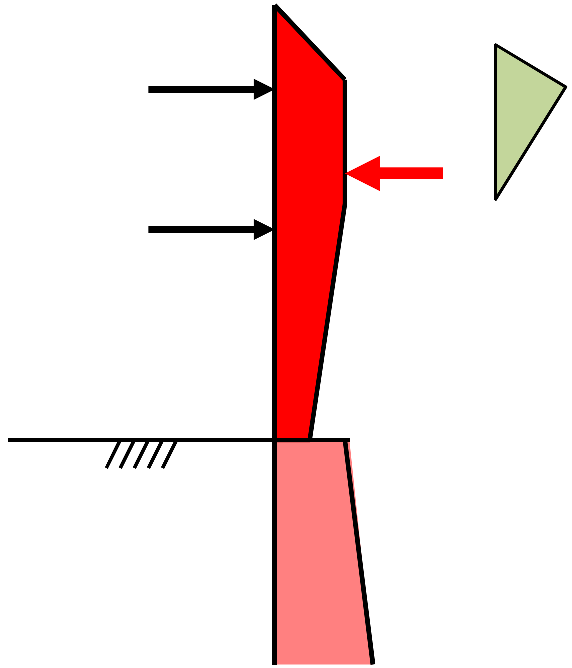


Classical earth pressure (distribution not realistic for supported walls)



Redistributed earth pressure (more realistic for supported walls)



Assumption: Earth pressure force is independent of type of wall movement

German design concept for sheet pile walls

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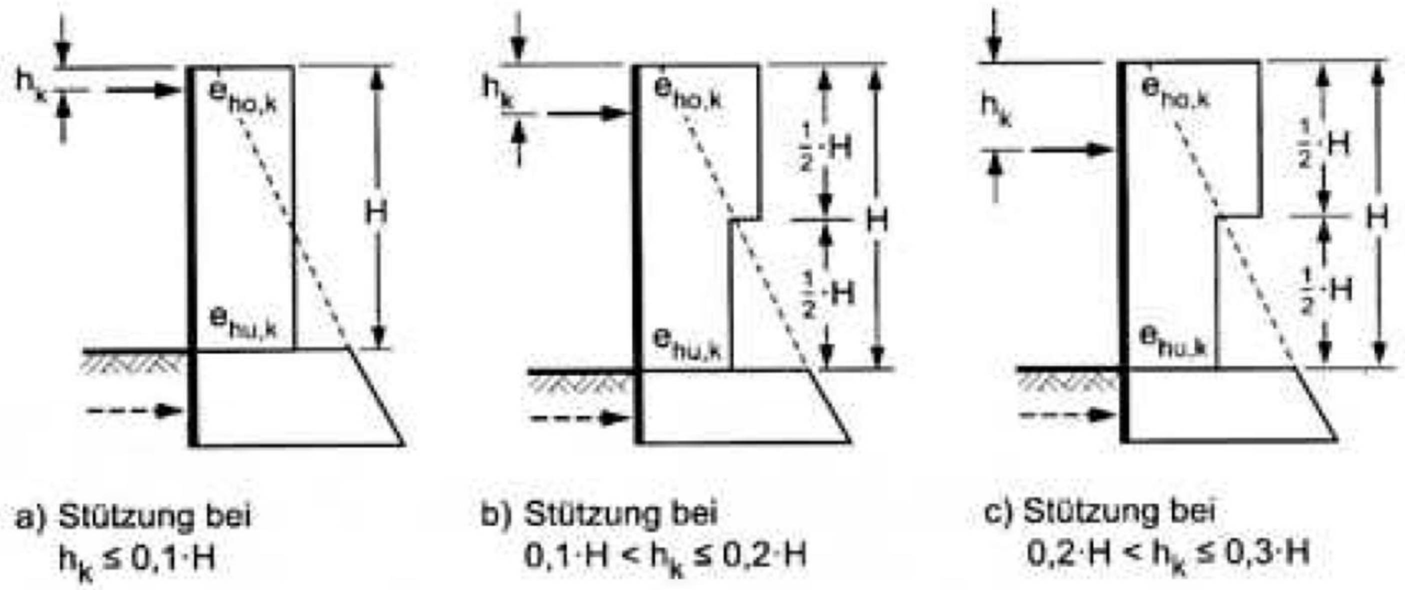

Bild EB 70-1. Lastfiguren für einmal gestützte Spundwände und Ortbetonwände

Bild EB 70-2. Lastfiguren für zweimal gestützte Spundwände und Ortbetonwände

German design concept for sheet pile walls for construction pits and water ways

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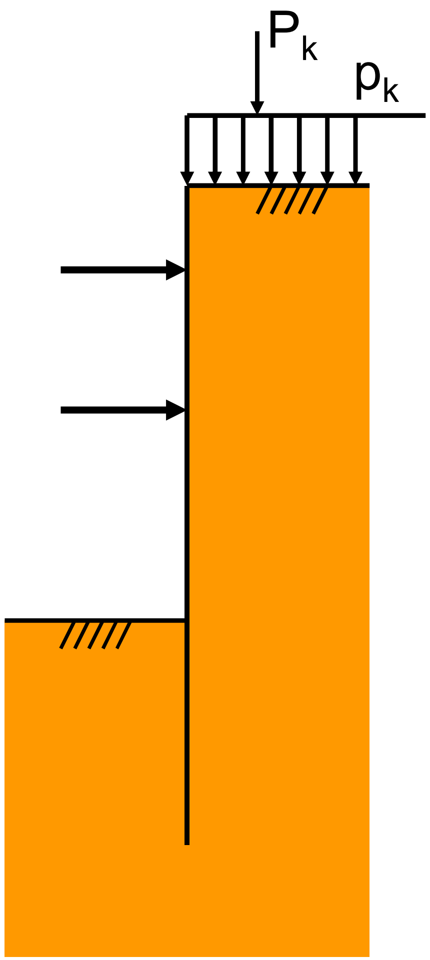

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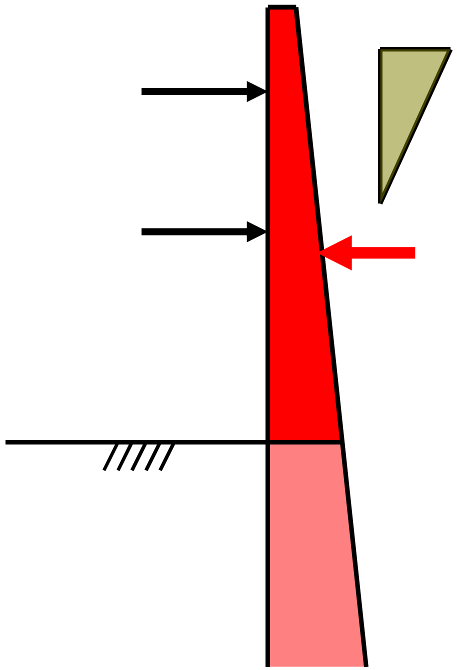

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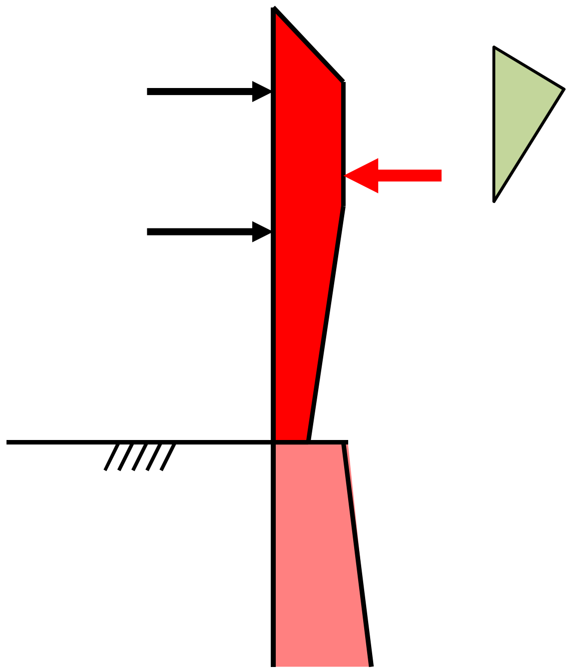

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German design concept for sheet pile walls for construction pits and water ways

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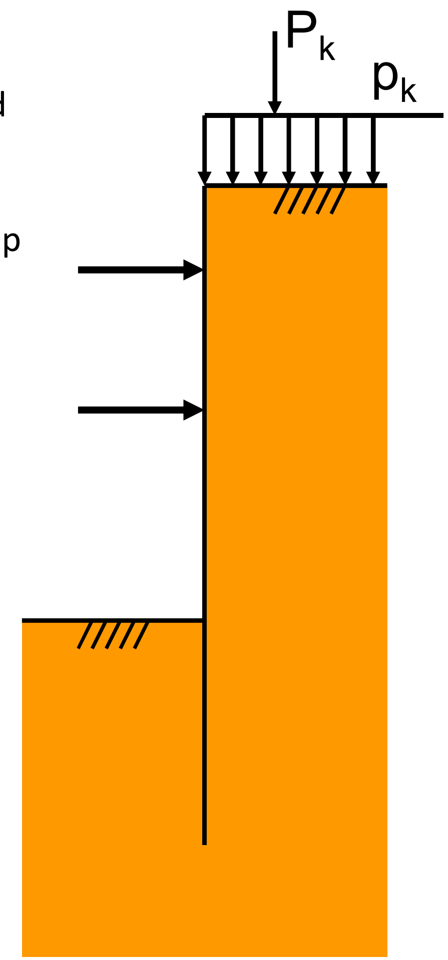
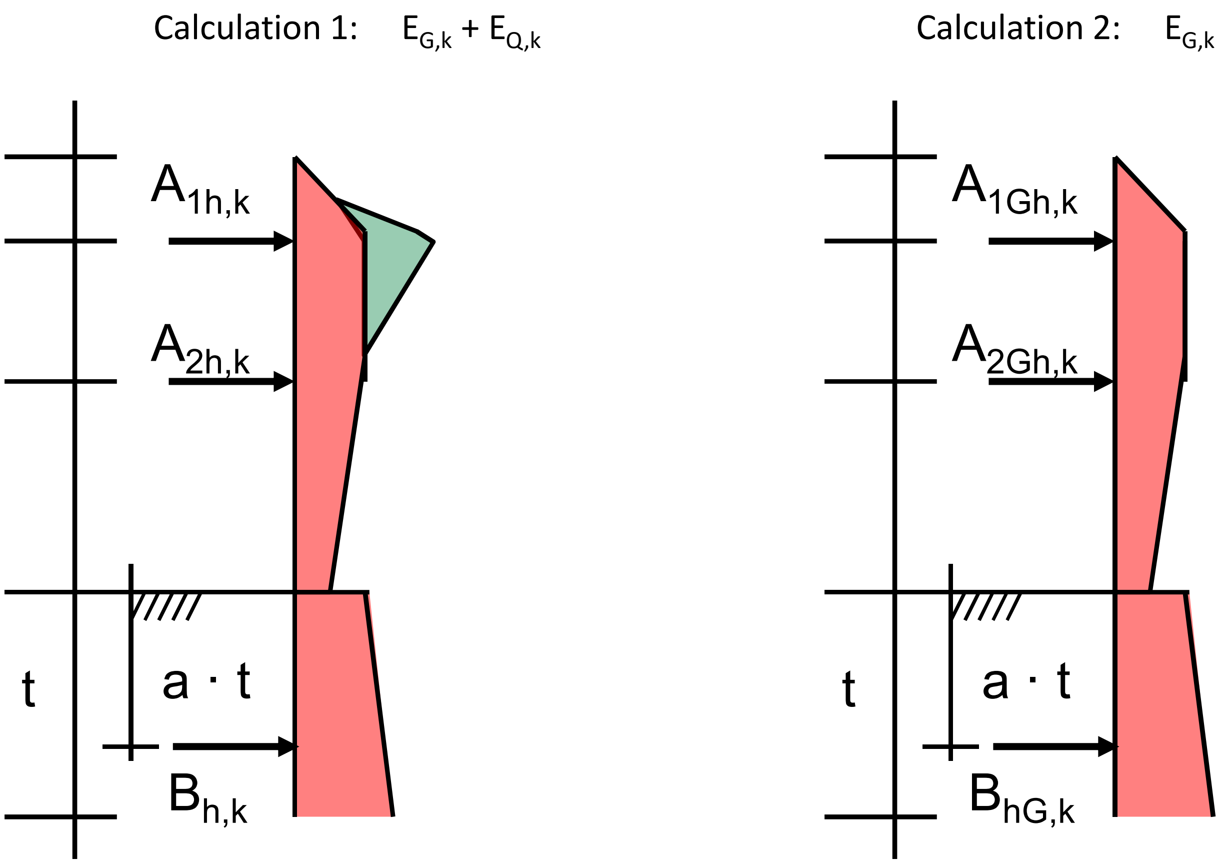
Equilibrium in horizontal direction





Support forces and stress resultants

German design concept for sheet pile walls for construction pits and water ways

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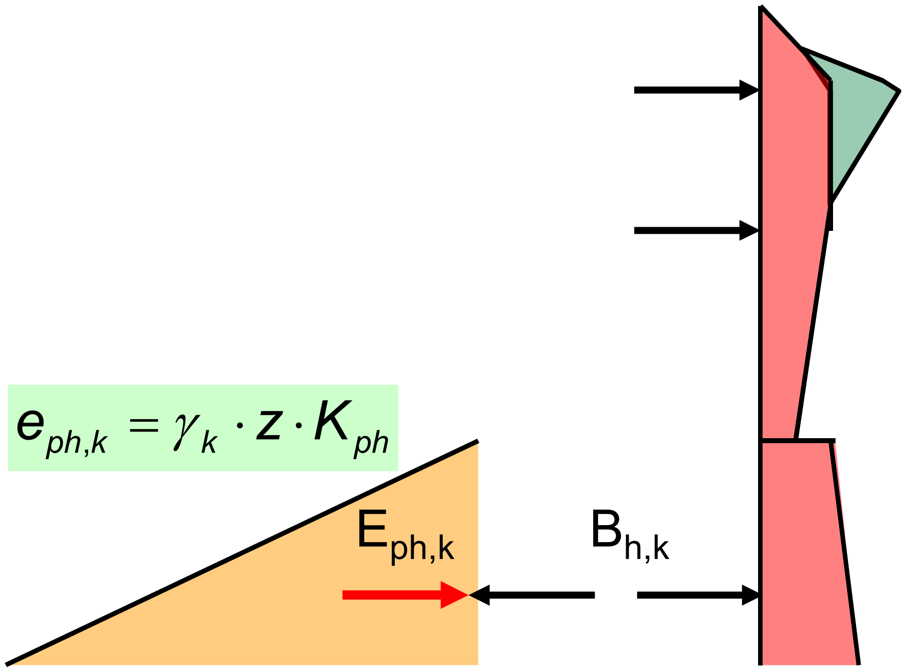
Equilibrium in horizontal direction

$$e_{ph,k} = \gamma_k \cdot z \cdot K_{ph}$$



$$B_{h,d} = B_{hG,k} \cdot \gamma_G + B_{hQ,k} \cdot \gamma_Q$$

$$E_{ph,d} = E_{ph,k}\, \eta \,/\, \gamma_{R,e}$$

$$E_{ph,d} = \tfrac{1}{2}\, \gamma_k\, z^2\, K_{ph}\, \eta \,/\, \gamma_{R,e}$$

$$E_{ph,d} \geq B_{h,d}$$

German design concept for sheet pile walls for construction pits and water ways

- Concept of EAB related to excavation pits:

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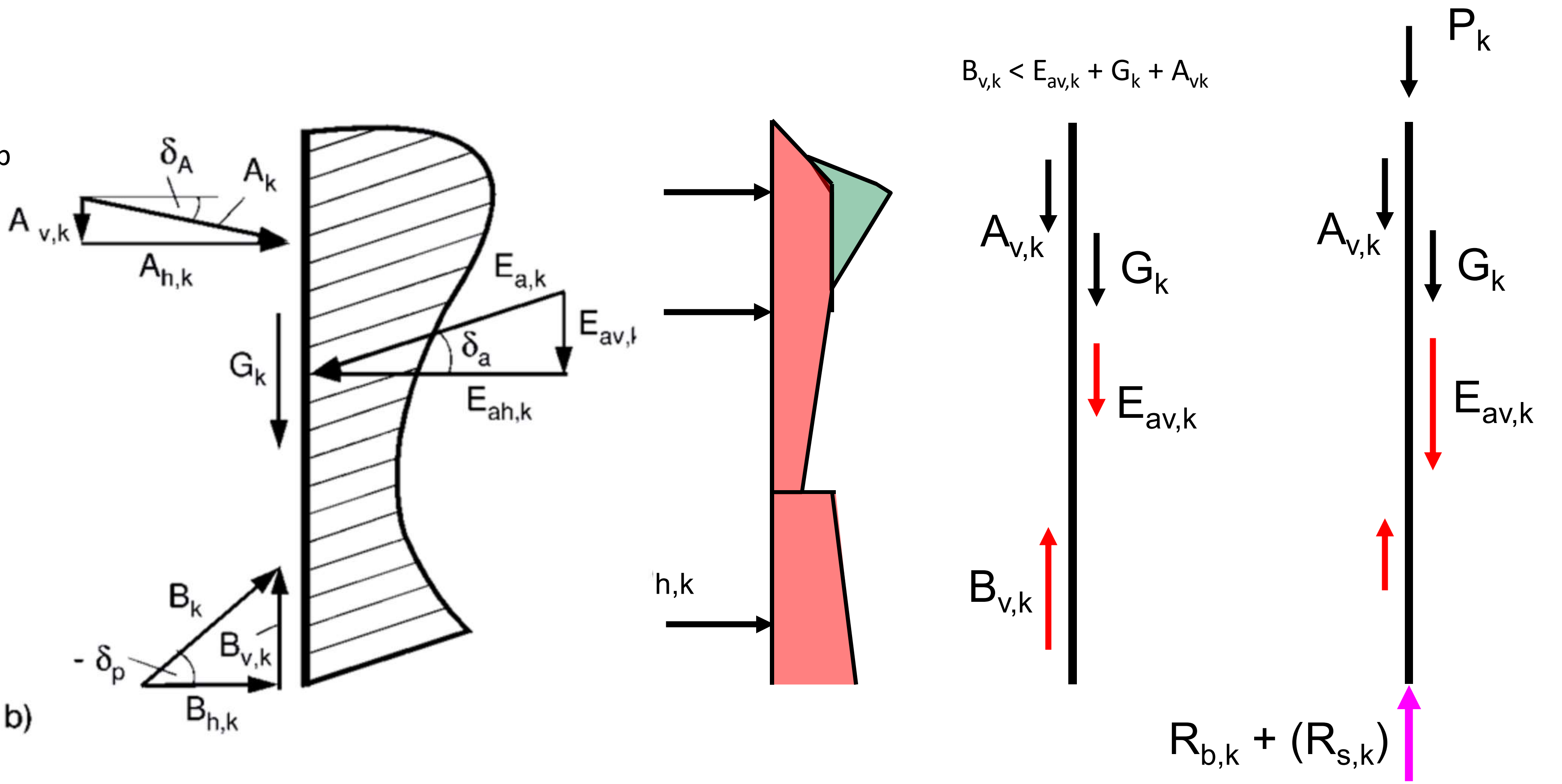
Equilibrium in vertical direction

$E_{av,k} + G_k + A_{v,k} + P_k > R_{B,k} + R_{b,k} + (R_{s,k})$



German design concept for sheet pile walls for construction pits and water ways

- Concept of EAB related to excavation pits:

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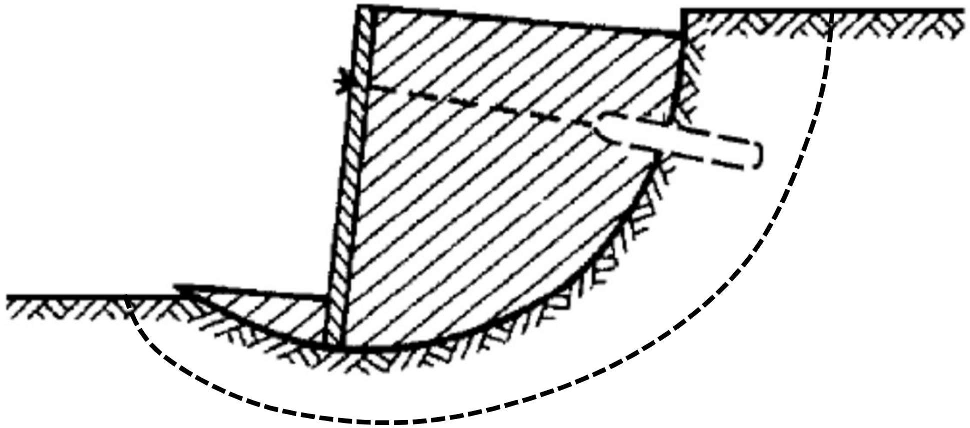
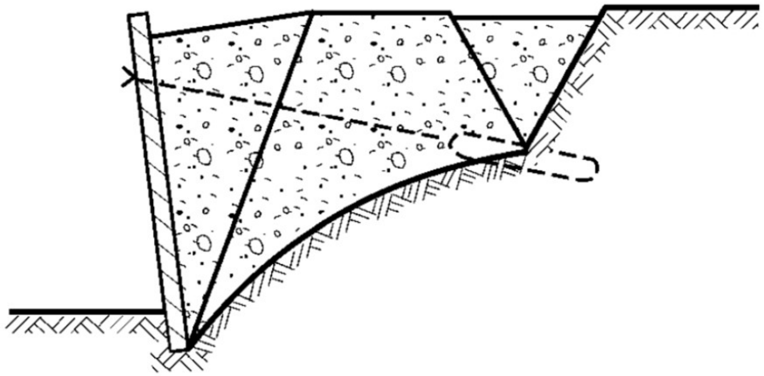
Verification of anchor length

Analysis of global stability



Analysis following Kranz (1953)



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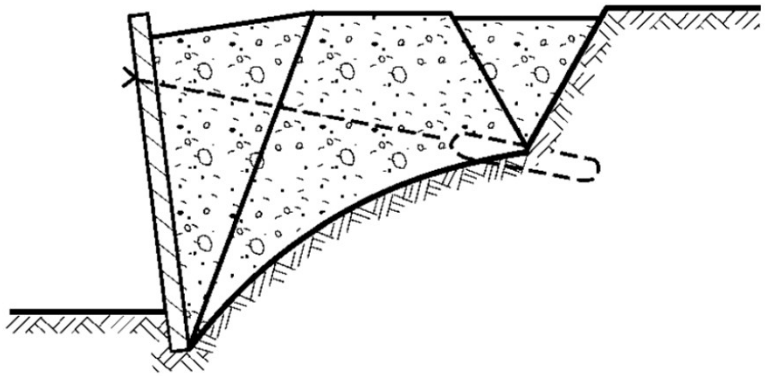

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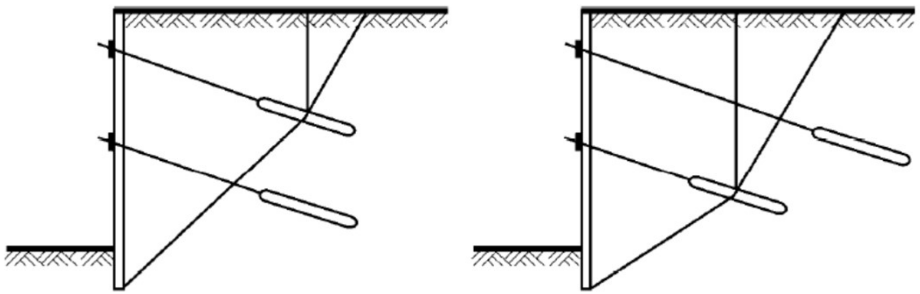

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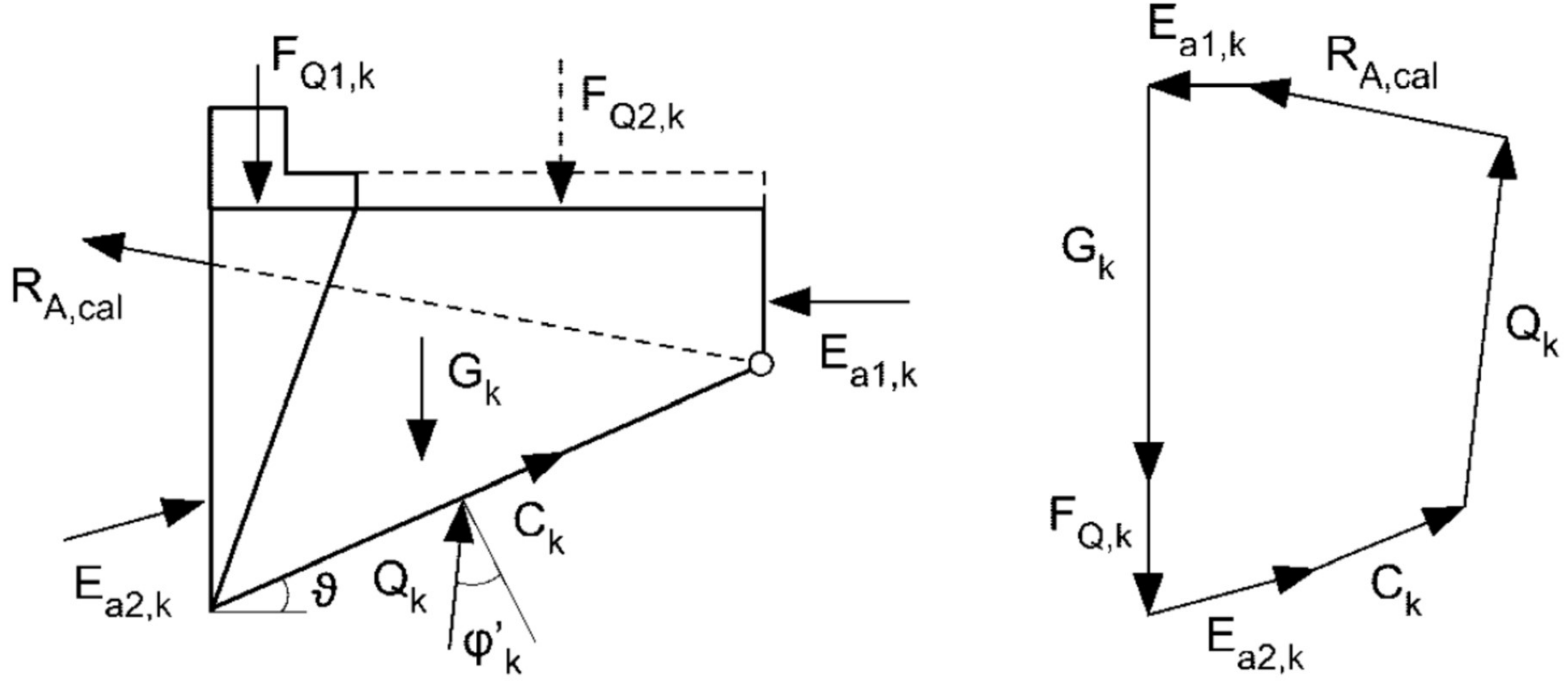


$$E_d = A_{G,k} \cdot \gamma_G + A_{Q,k} \cdot \gamma_Q \leq \frac{R_{A,cal}}{\gamma_{Ep}} = R_d$$

German design concept for sheet pile walls for construction pits and water ways

- Concept of EAU related to quay walls, sea walls, bank stabilization:

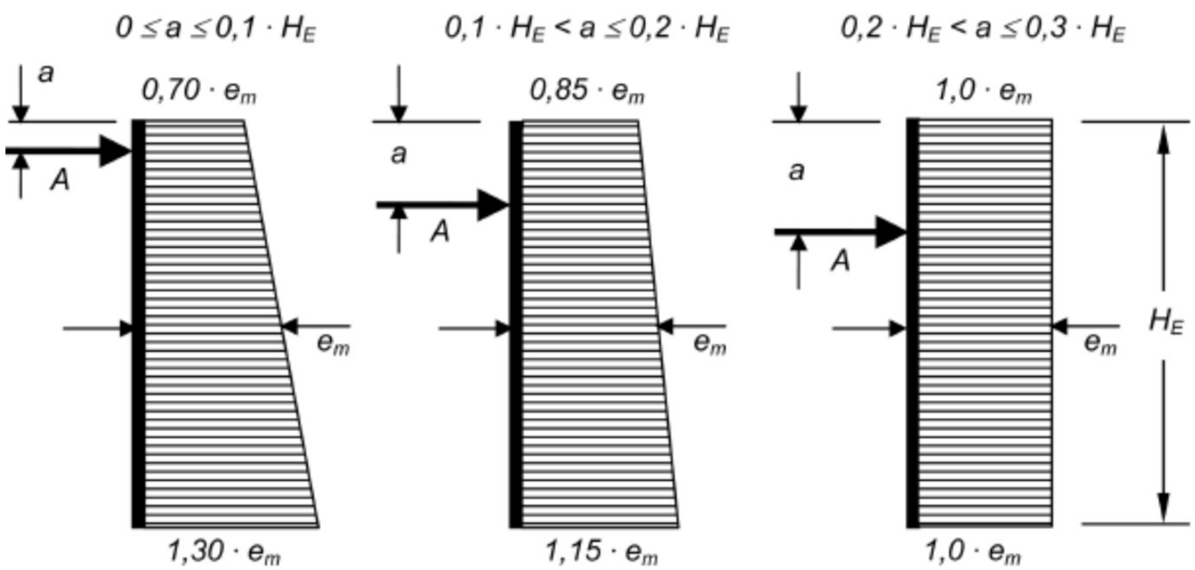
>>> construction from top to bottom as well as from bottom to top

>>> use of different types of anchor systems

Design concept for sheet pile walls follows EAB concept.

Differences in assumptions related to earth pressure distribution.

Excavation in front of the wall



Assumption: Earth pressure force is independent of type of wall movement

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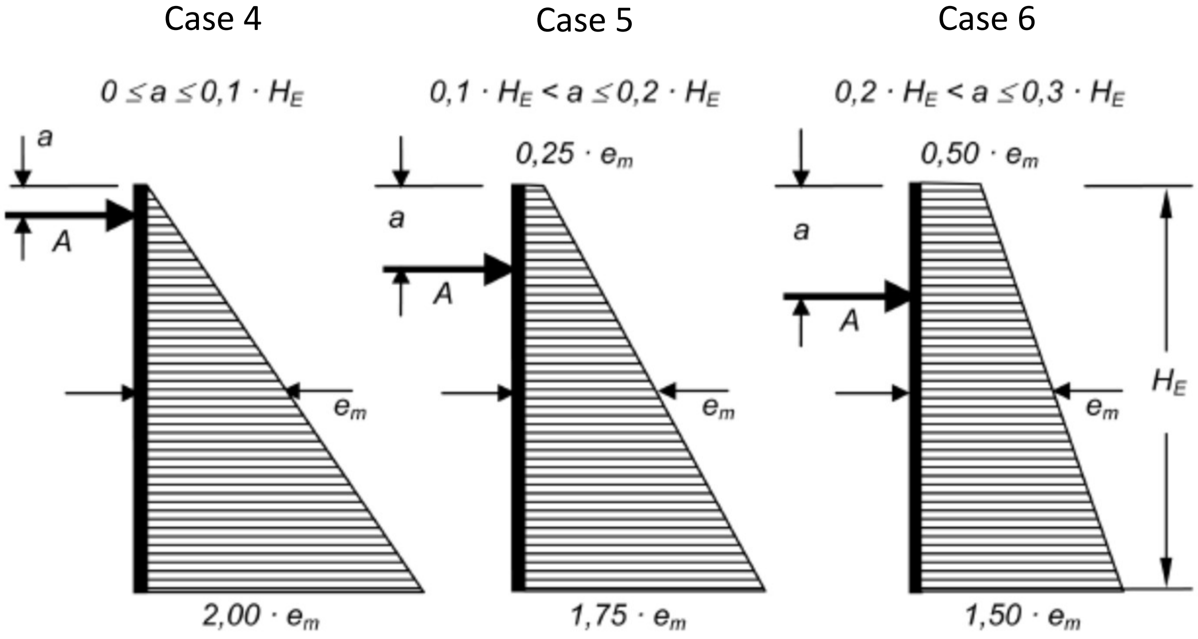
Backfilled wall



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German design concept for sheet pile walls for construction pits and water ways

- Primary questions using geogrids for anchoring sheet pile walls

What is the earth pressure force due to self weight of the soil acting on the sheet pile wall depending on positions, lengths and number of geogrids?

How earth pressure due to self weight of the soil is distributed over the depth of the wall depending on position, lengths and number of geogrids?

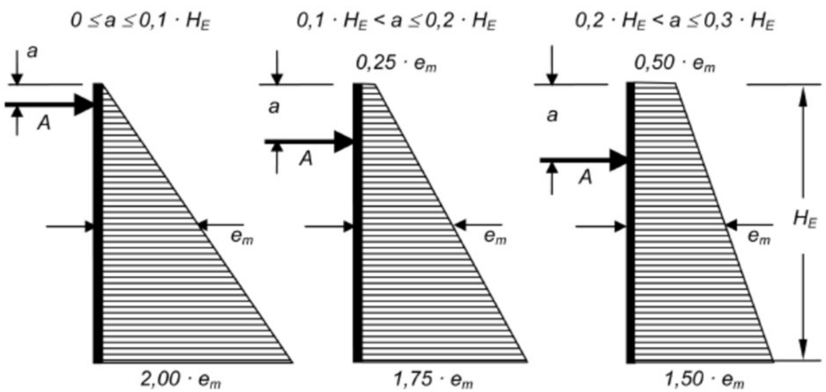
- Other questions using geogrids for anchoring sheet pile walls

What about earth pressure related to surface loads?

How to verify the length of geogrids (can we adopt the calculation method based on Kranz, 1953)?

How surface loads have to be taken into account using the concept of Kranz (1953)?

Assumption: Earth pressure force is independent of type of wall movement



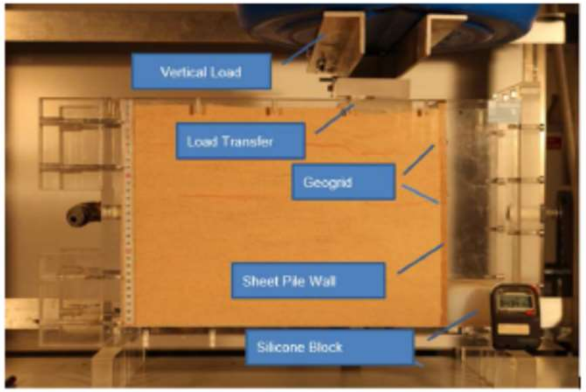
Numerical studies based on the small scale model tests at DELTARES

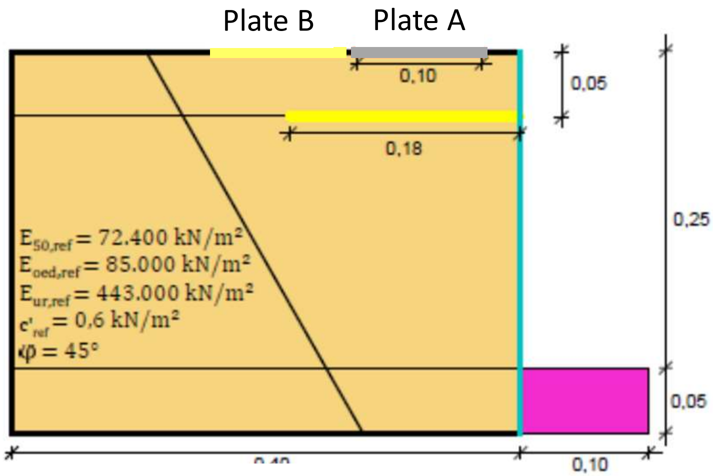
- FE-simulations in model scale

Earth pressure due to self weight of the soil is small.

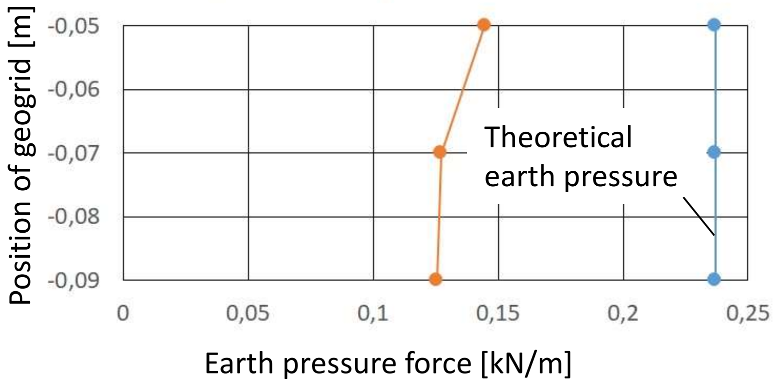
Wall movement at top of the wall is allowed after filling.

Evaluation of earth pressure force and earth pressure distribution for infinite and local surface loads at different positions.

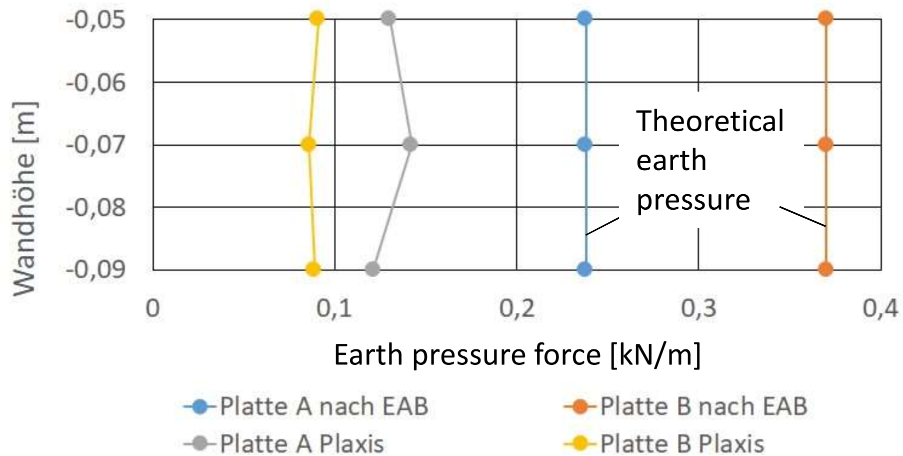




Earth pressure force with infinite surface load of 2.5 kN/m²



Earth pressure force with strip surface load



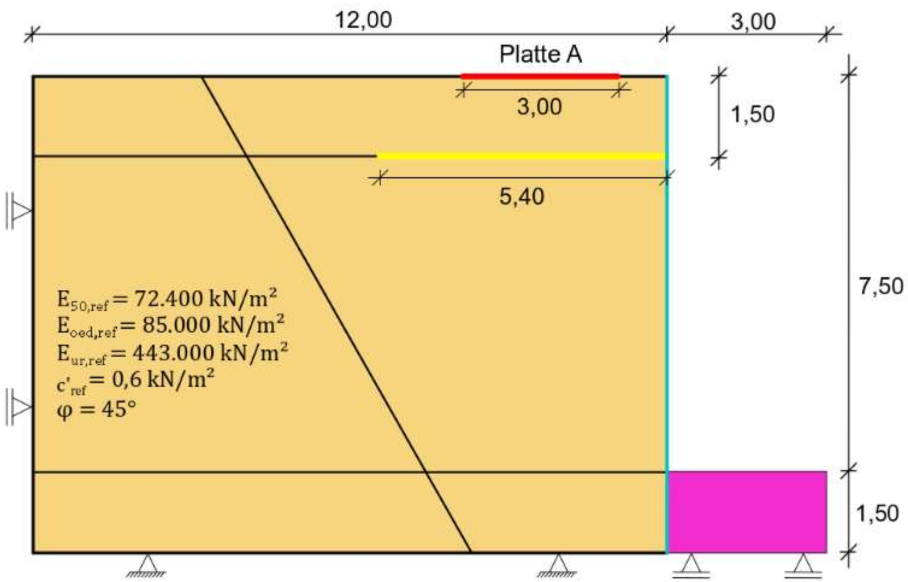
Numerical studies based on the small scale model tests at DELTARES

- FE-simulations in real scale

Earth pressure due to self weight of the soil is relevant.

Evaluation of earth pressure due to self weight of the soil.

	kleines Modell	hochskaliertes Modell
Geogitter	$EA = 190\ kN/m$	$EA = 190 \cdot 30^2 = 171.000\ kN/m$
Silikonblock	$E' = 130 kN/m^2$	$E' = 130 \cdot 30 = 3900 kN/m^2$
PVC Wand	$EA = 29.000\ kN/m$	$EA = 29.000 \cdot 30^2 = 216.100.000\ kN/m$
	$EI = 0{,}242\ kNm^2/m$	$EI = 0{,}242 \cdot 30^4 = 196.020\ kNm^2/m$
Platte	$EA = 300.000\ kN/m$	$EA = 300.000 \cdot 30^2 = 270.000.000 kN/m$
	$EI = 2{,}5\ kNm^2/m$	$EI = 2{,}5 \cdot 30^4 = 2.025.000\ kNm^2/m$
Feder (am Wandfuß)	$EA = 10.000 kN$	$EA = 10.000 \cdot 30^2 = 90.000.000 kN$
Steife	$EA = 190\ kN/m$	$EA = 190 \cdot 30^2 = 171.000\ kN/m$



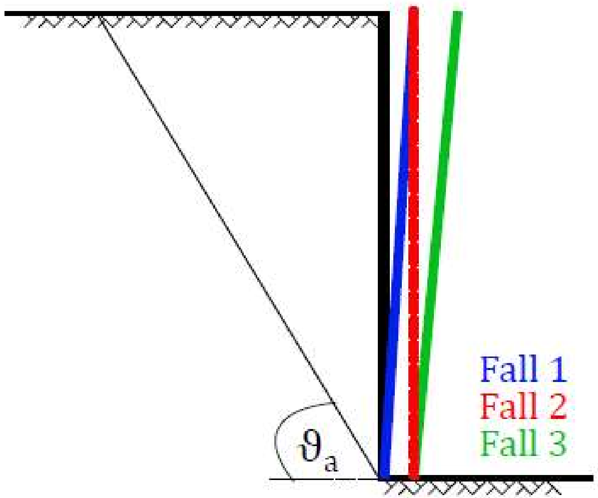
Numerical studies based on the small scale model tests at DELTARES

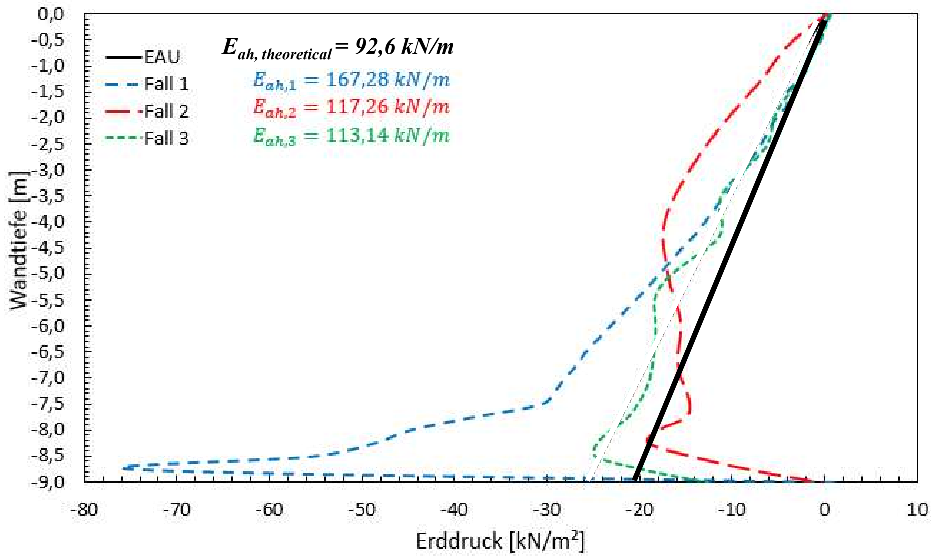
- FE-simulations in real scale

Earth pressure due to self weight of the soil is relevant.

Evaluation of earth pressure due to self weight of the soil.

Earth pressure due to self weight of the soil on a wall showing
- pure rotation
- pure parallel movement
- parallel movement plus rotation





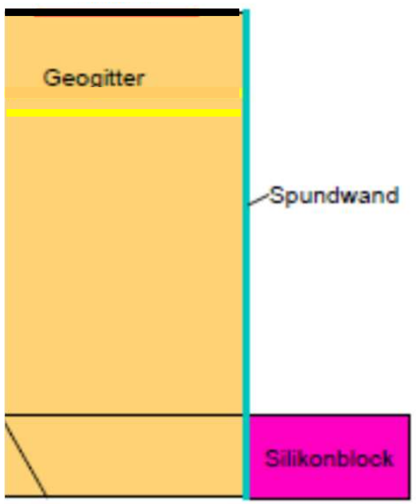
Numerical studies based on the small scale model tests at DELTARES

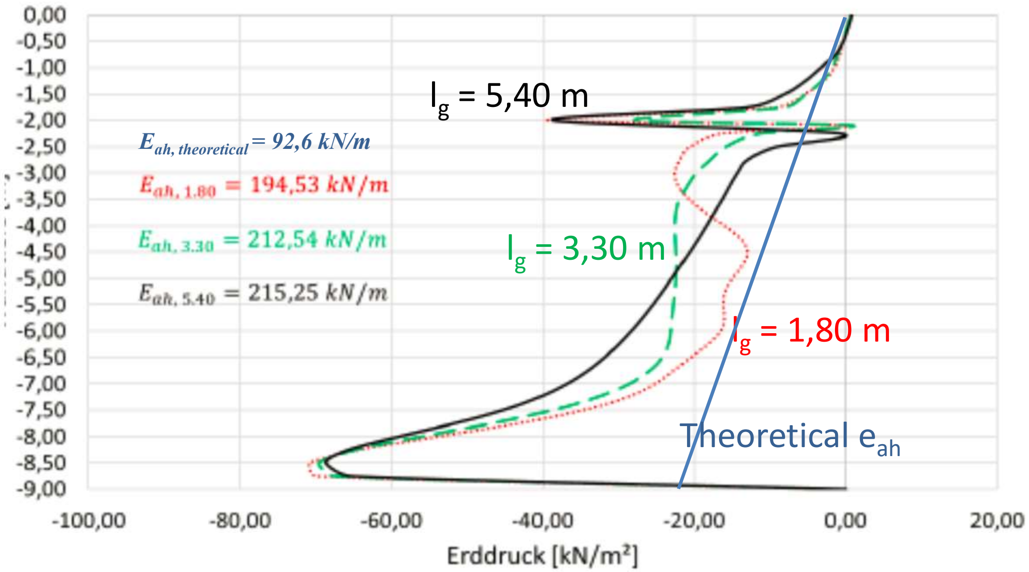
- FE-simulations in real scale

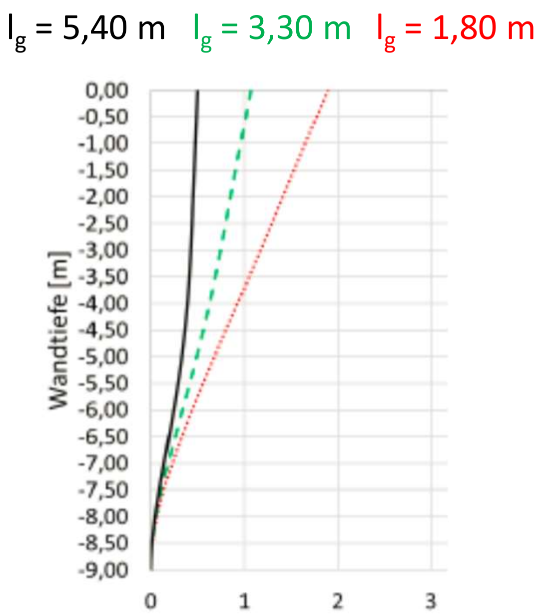
Earth pressure due to self weight of the soil is relevant.

Evaluation of earth pressure due to self weight of the soil.

Earth pressure due to self weight of the soil on a wall anchored with geogrids of different length l_g







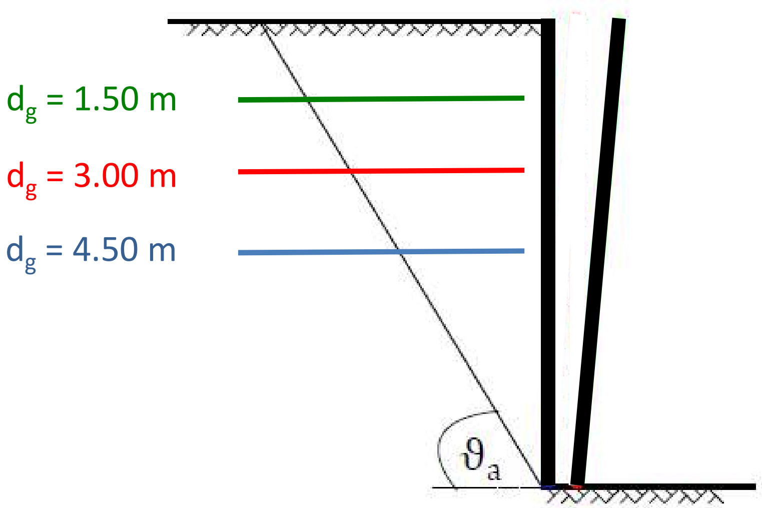
Numerical studies based on the small scale model tests at DELTARES

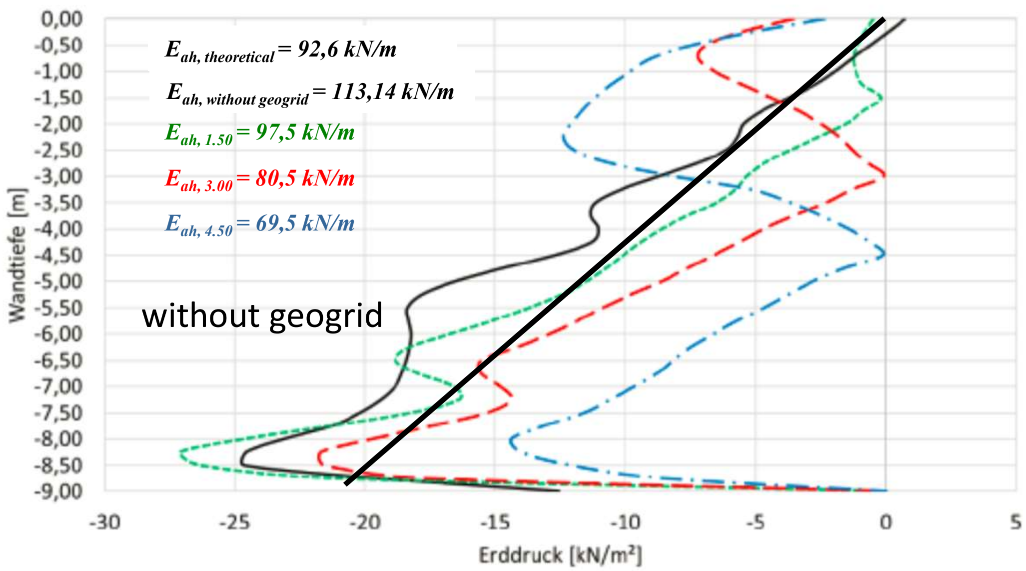
- FE-simulations in real scale

Earth pressure due to self weight of the soil is relevant.

Evaluation of earth pressure due to self weight of the soil.

Earth pressure due to self weight of the soil on a wall with geogrids of a length of 5.40 m placed in the soil without connection to the wall in different depth d_g.





Numerical studies based on the small scale model tests at DELTARES

- FE-simulations in real scale; base small scale model tests - Summary

Earth pressure magnitude depends on wall movement type and magnitude.

Earth pressure forces on geotextile anchored walls seem to be high compared to theoretical earth pressure.

Earth pressure distribution is influenced strongly closely above and below geogrid connection.

Earth pressure force on walls backfilled with soil including one geogrid not connected to the wall is small compared to theoretical earth pressure.

Earth pressure distribution on walls backfilled with soil including one geogrid not connected to the wall is influenced by the grid.

Numerical studies on a simplified real system

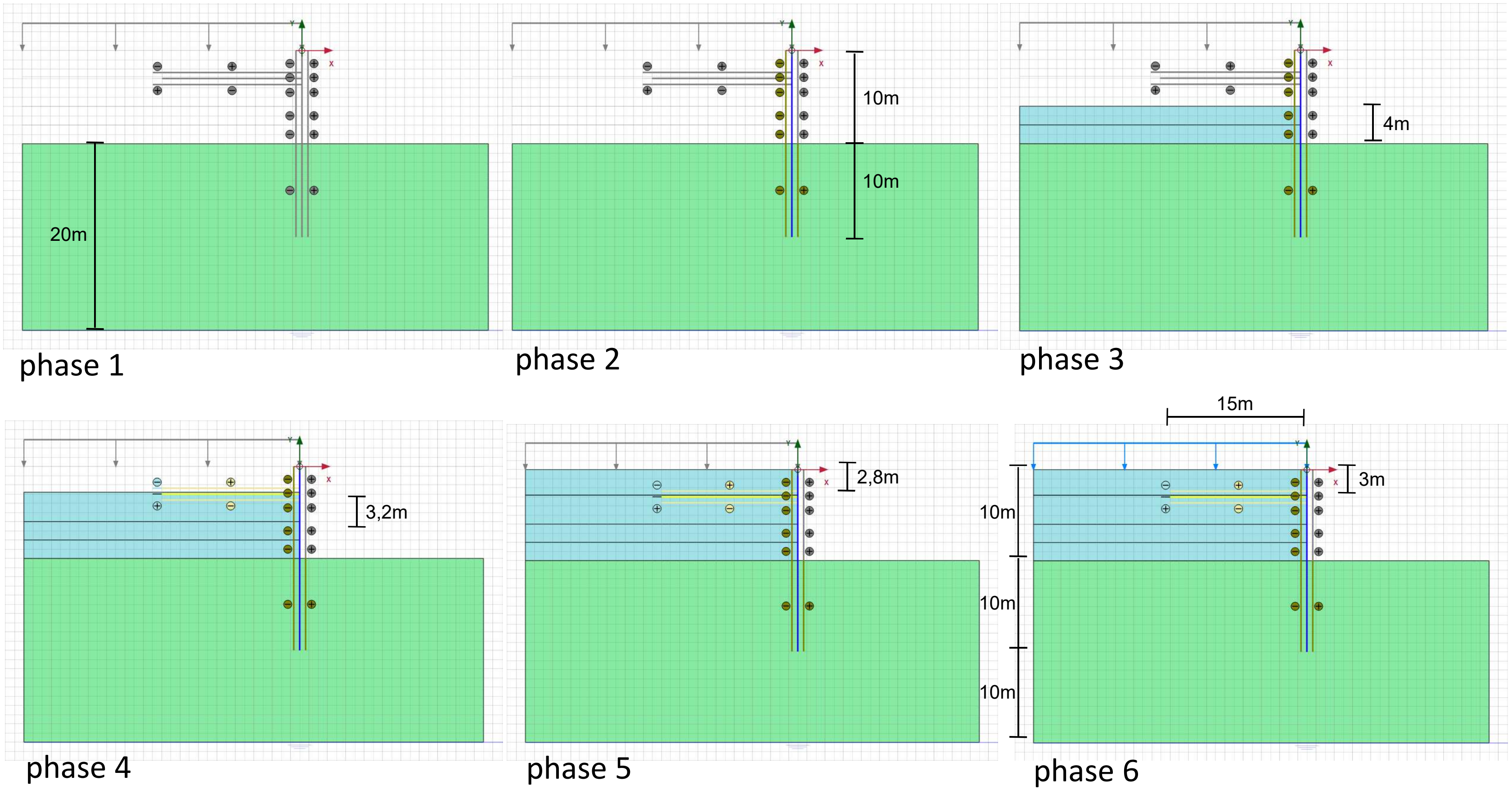
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay (phase 2)

Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m with activated geogrid at 3 m (phase 4)
- third layer 2.8 m after activation of geogrid (phase 5)

Total backfill 10 m

Surface load of 10 kPa (phase 6)



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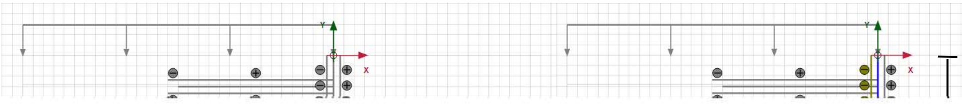
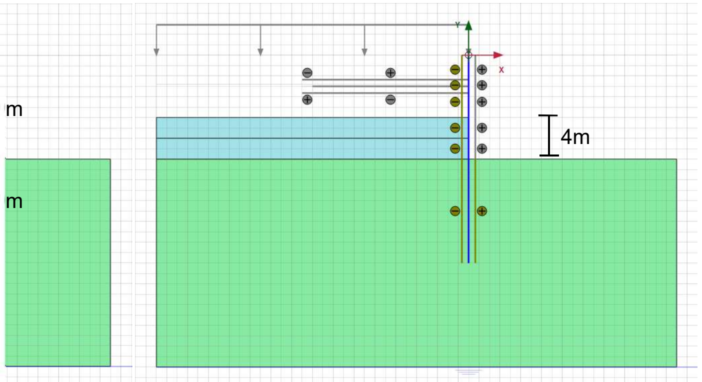
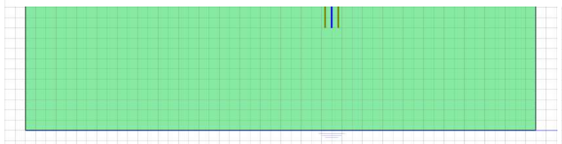


Bodenschicht	Ton	Sand
Materialmodell	Mohr-Coulomb	Mohr-Coulomb
E $[kN/m^2]$	40.000	20.000
γ $[kN/m^3]$	20	19
ϕ $[°]$	20	30
δ $[°]$	$0,667 * \phi$	$0,667 * \phi$
c' $[kN/m^2]$	30	0,1

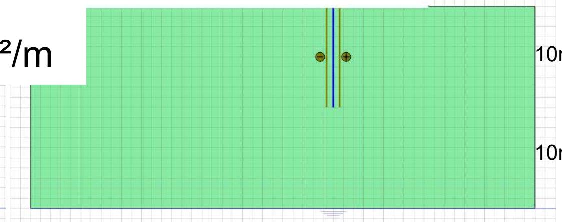
EA Geogrid 25,000 kN/m
EI Sheet pile wall 254,200 kNm²/m



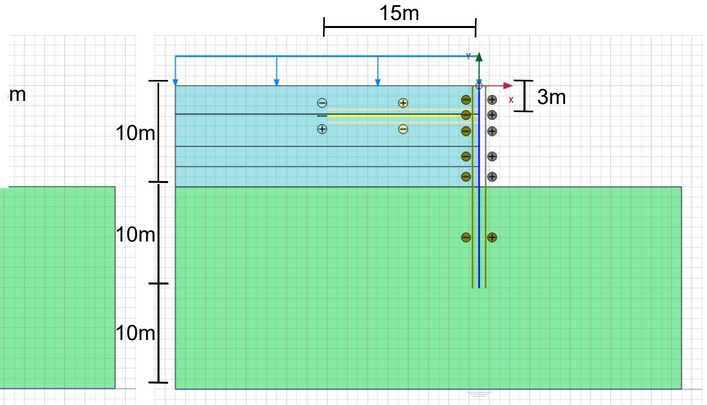
phase 3



phase 4



phase 5



phase 6

Numerical studies on a simplified real system

This peak is influenced by the connection force of the geogrid and should not be interpreted as earth pressure. Taking the earth pressure values from the interface elements it can not be distinguished between earth pressure and contact force.

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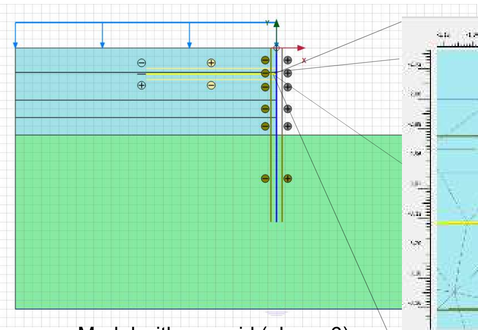
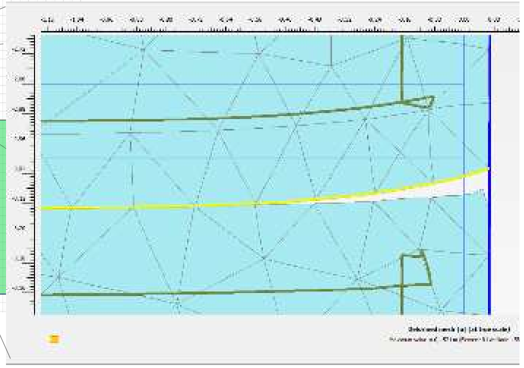
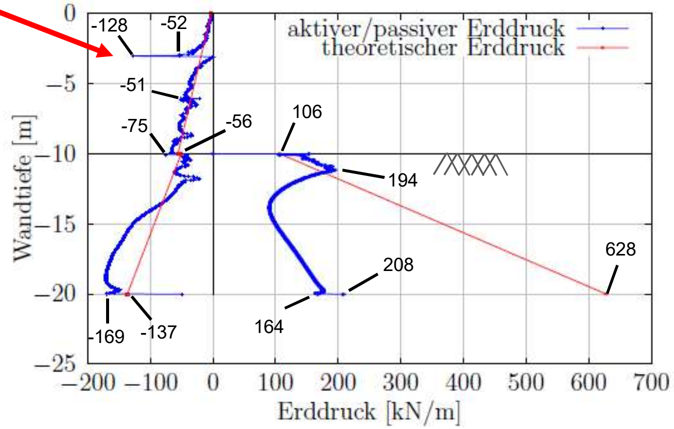


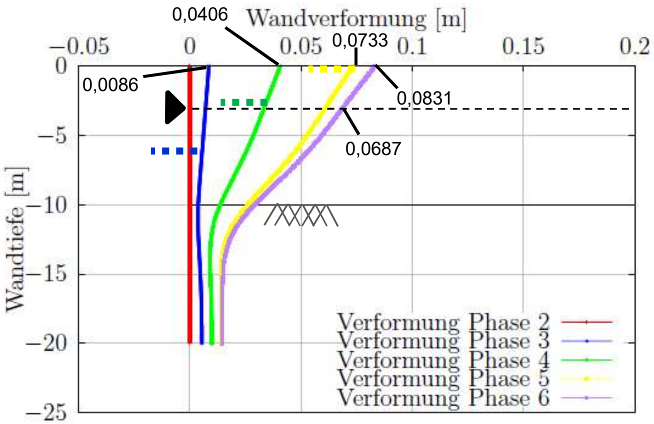
Model with geogrid (phase 6)



Detail: Deformations at connection point (phase 6)

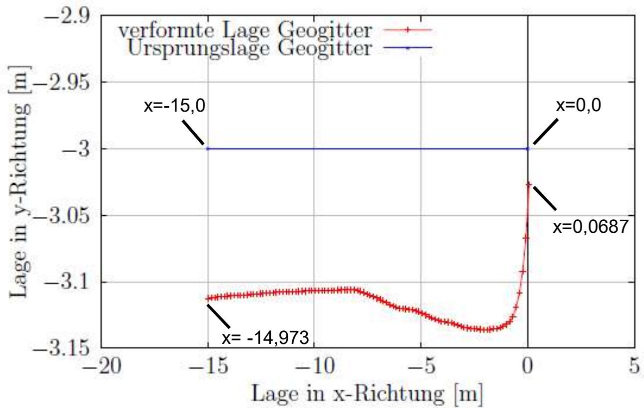


Earth pressure on right and left side of the wall (phase 6)



Wall deformations phases 2 to 6

Phase	Horizontal connection force
4	29 kN/m
5	115 kN/m
6	133 kN/m



Position of geogrid after filling (phase 6)

Numerical studies on a simplified real system

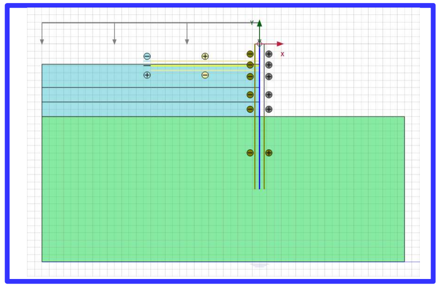
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay (phase 2)

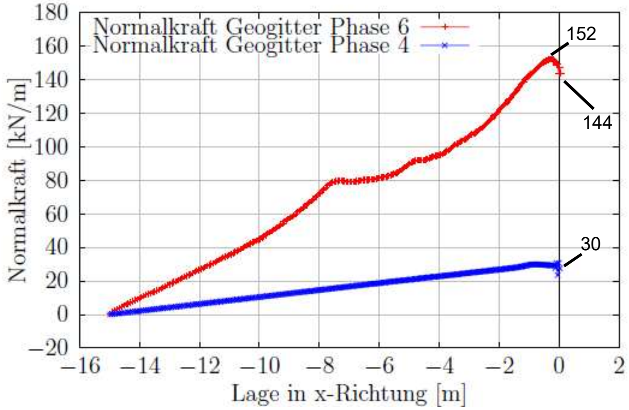
Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m with activated geogrid at 3 m (phase 4)
- third layer 2.8 m after activation of geogrid (phase 5)

Total backfill 10 m

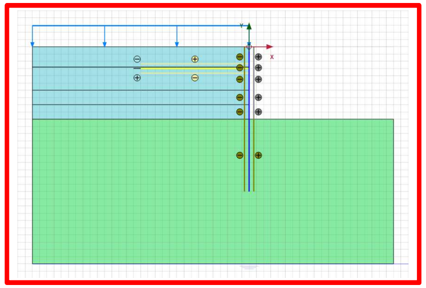
Surface load of 10 kPa (phase 6)



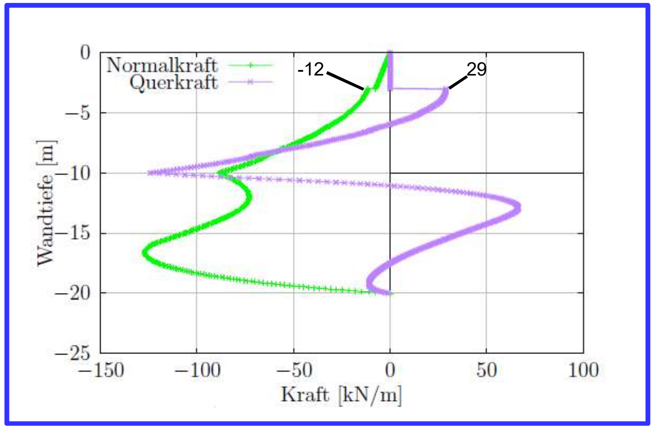
Model phase 4



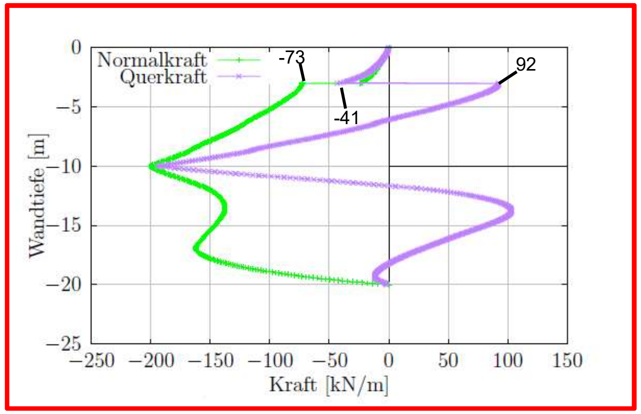
Geogrid force in phases 4 (blue) und 6 (red)



Model phase 6



Normal force (green) and shear force (purple) in phase 4



Normal force (green) and shear force (purple) in phase 6

Numerical studies on a simplified real system

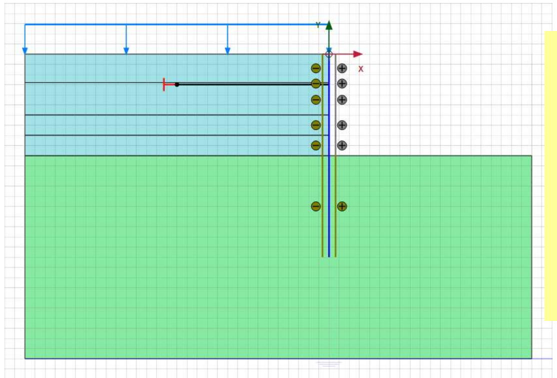
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay (phase 2)

Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m with activated **node to node anchor** at 3 m (phase 4)
- third layer 2.8 m after activation of **anchor** (phase 5)

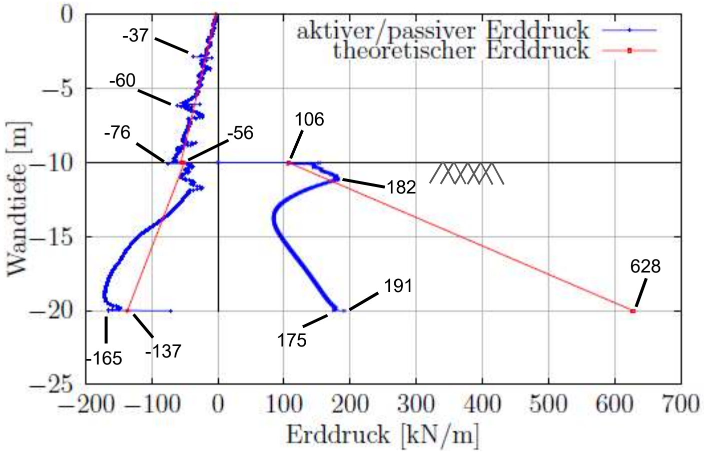
Total backfill 10 m

Surface load of 10 kPa (phase 6)

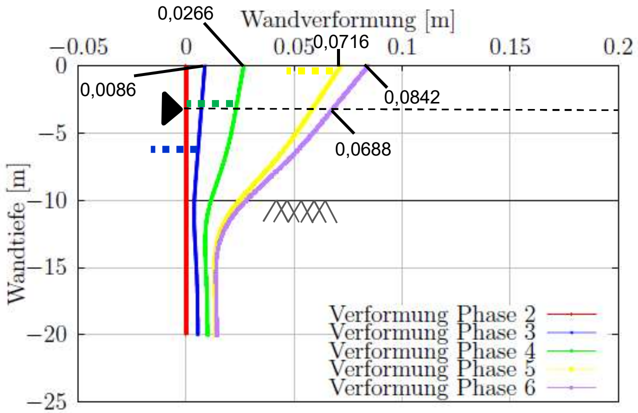


Model with anchor (phase 6)

Stiffness of anchor chosen in a way that deformation at connection point is similar to the one with geogrid.

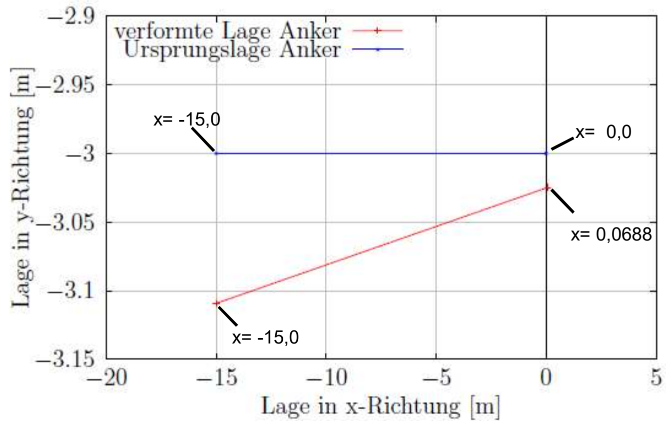


Earth pressure on right and left side of the wall (phase 6)



Wall deformations phases 2 to 6

Phase	Anschlusskraft horizontal
4	32 kN/m
5	83 kN/m
6	125 kN/m



Position of anchor after filling (phase 6)

Numerical studies on a simplified real system

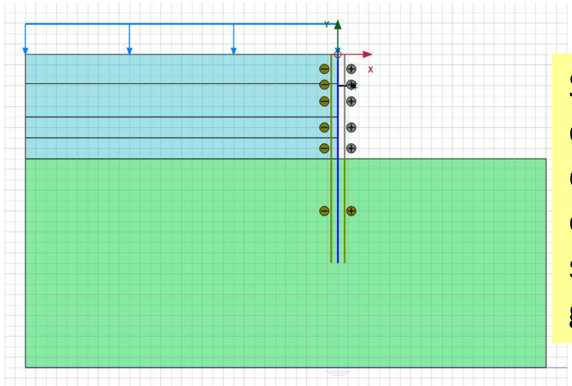
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay and **activated strut** (phase 2)

Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m (phase 4)
- third layer 2.8 m (phase 5)

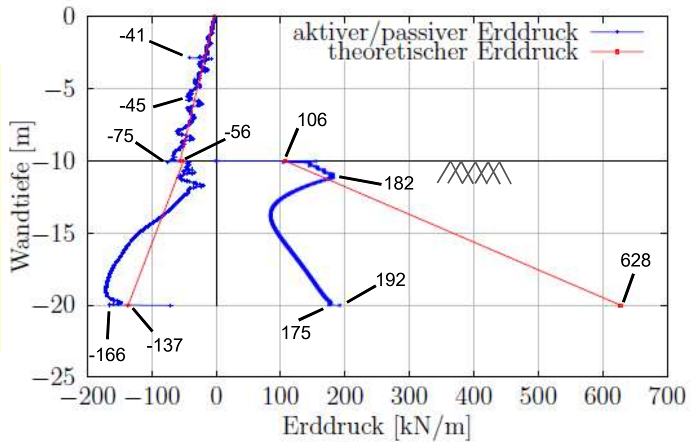
Total backfill 10 m

Surface load of 10 kPa (phase 6)

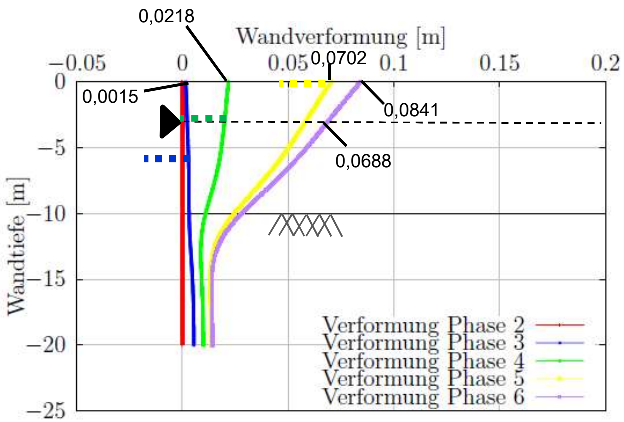


Model with strut (phase 6)

Stiffness of strut chosen in a way that deformation at connection point is similar to the one with geogrid.

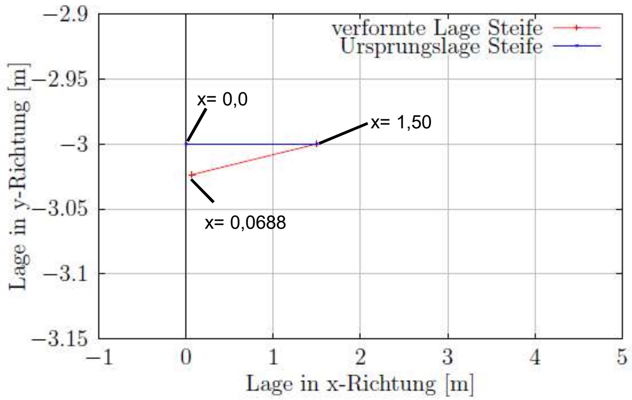


Earth pressure on right and left side of the wall (phase 6)



Wall deformations phases 2 to 6

Phase	Anschlusskraft horizontal
2	0
3	4 kN/m
4	35 kN/m
5	106 kN/m
6	125 kN/m



Position of anchor after filling (phase 6)

Numerical studies on a simplified real system

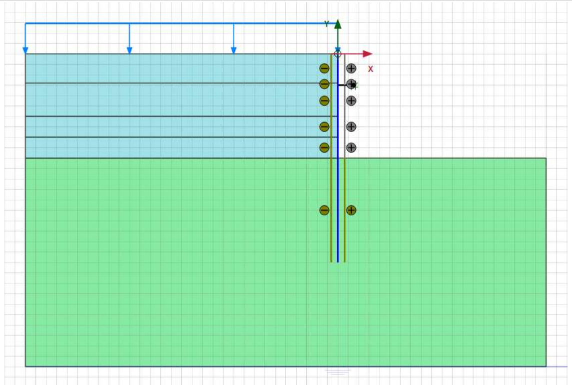
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay and **activated strut** (phase 2)

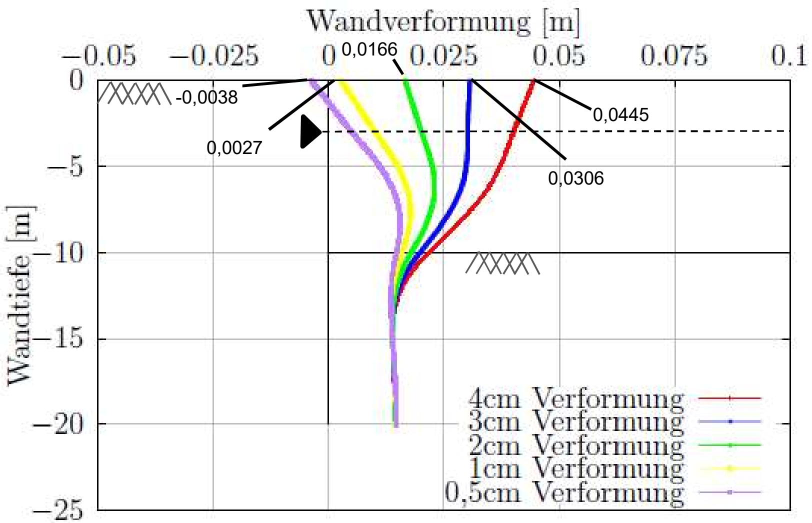
Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m (phase 4)
- third layer 2.8 m (phase 5)

Total backfill 10 m

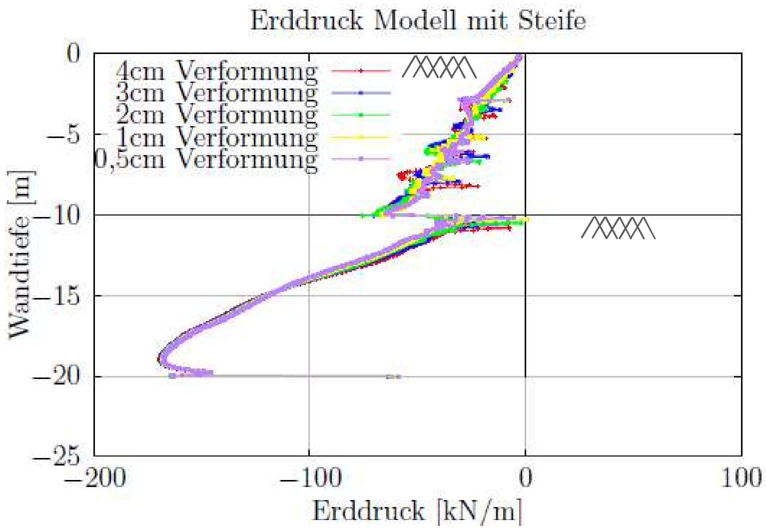
Surface load of 10 kPa (phase 6)



Prescribed deformation at level of the strut



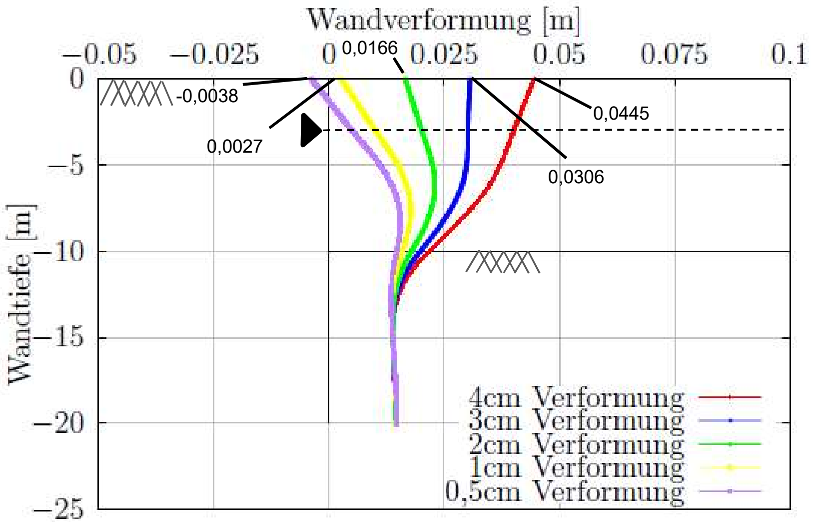
Wall deformations by prescribed displacement in depth of the strut (phase 6)



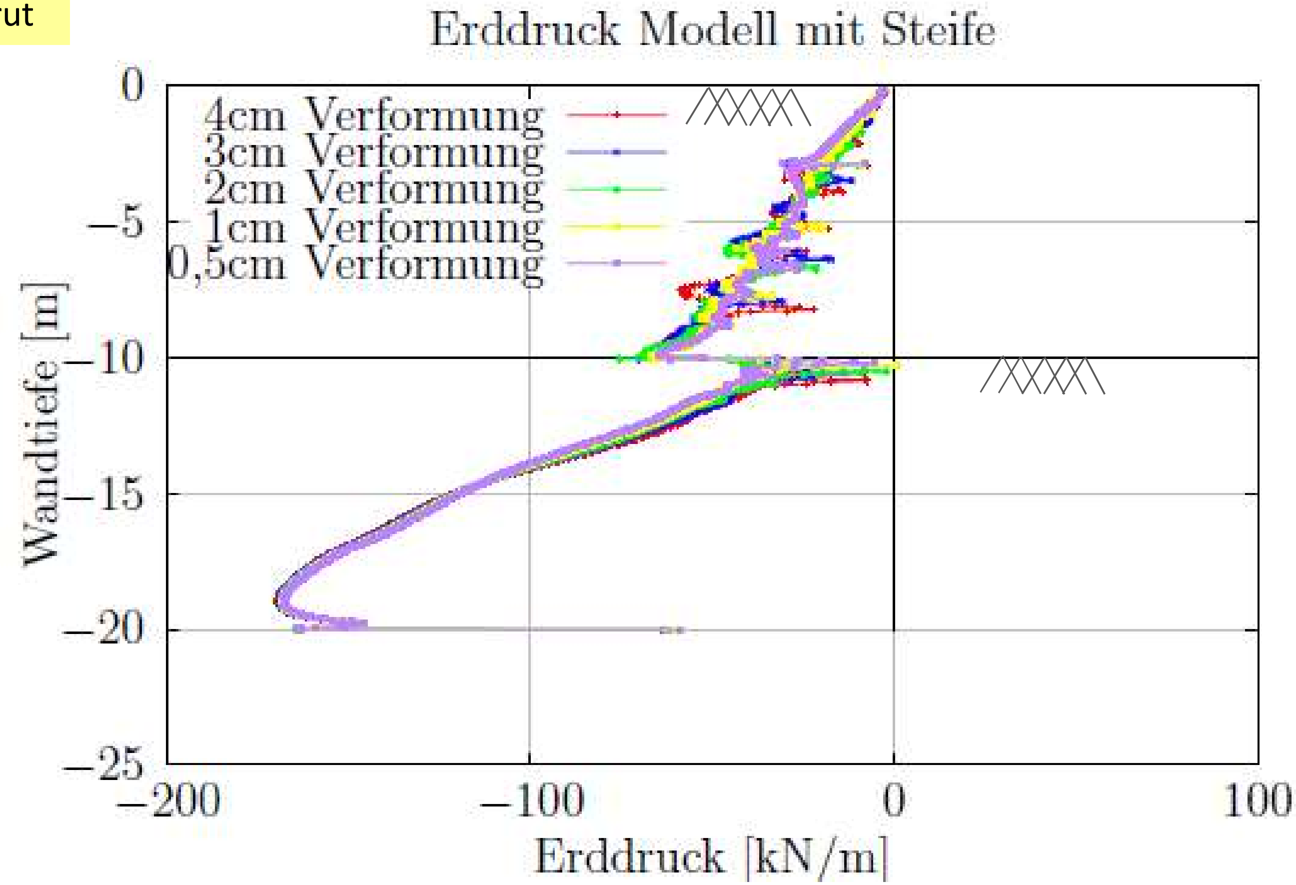
Earth pressures on the left side of the wall by prescribed displacement in depth of the strut (phase 6)

Numerical studies on a simplified real system

Prescribed deformation at level of the strut



Wall deformations by prescribed displacement in depth of the strut (phase 6)



Earth pressures on the left side of the wall by prescribed displacement in depth of the strut (phase 6)

Numerical studies on a simplified real system

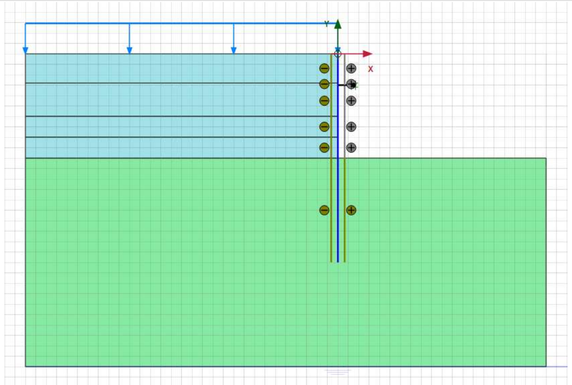
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay and **activated strut** (phase 2)

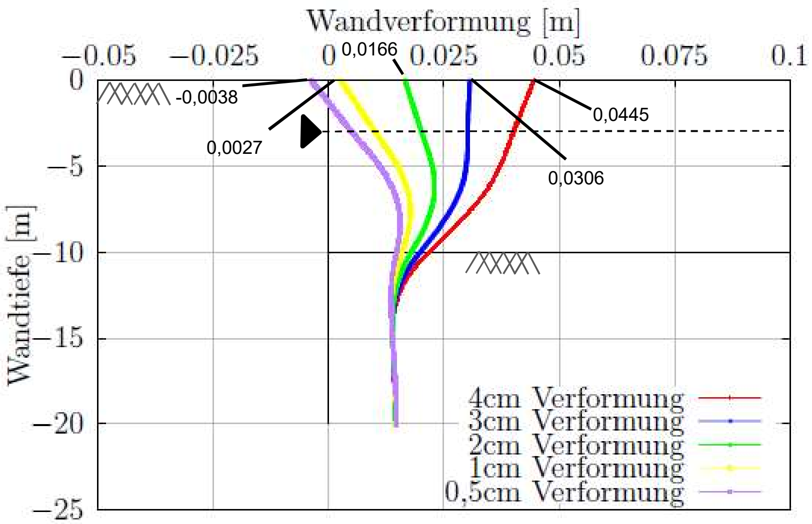
Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m (phase 4)
- third layer 2.8 m (phase 5)

Total backfill 10 m

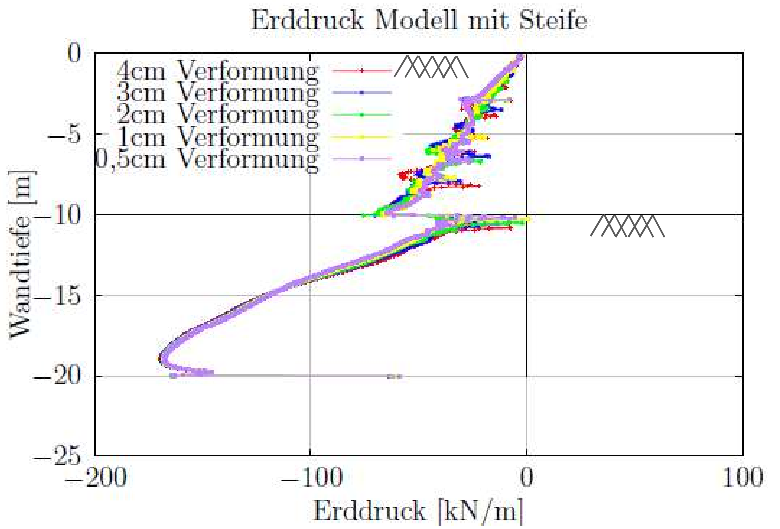
Surface load of 10 kPa (phase 6)



Prescribed deformation at level of the strut



Wall deformations by prescribed displacement in depth of the strut (phase 6)



Earth pressures on the left side of the wall by prescribed displacement in depth of the strut (phase 6)

Numerical studies on a simplified real system

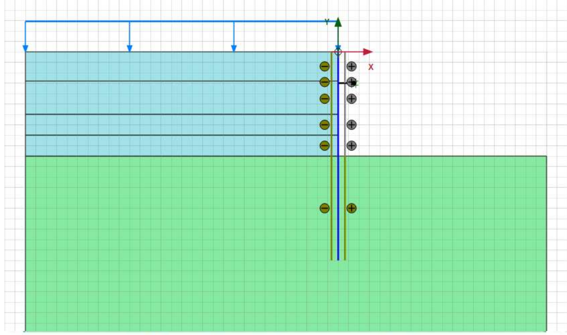
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay and **activated strut** (phase 2)

Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m (phase 4)
- third layer 2.8 m (phase 5)

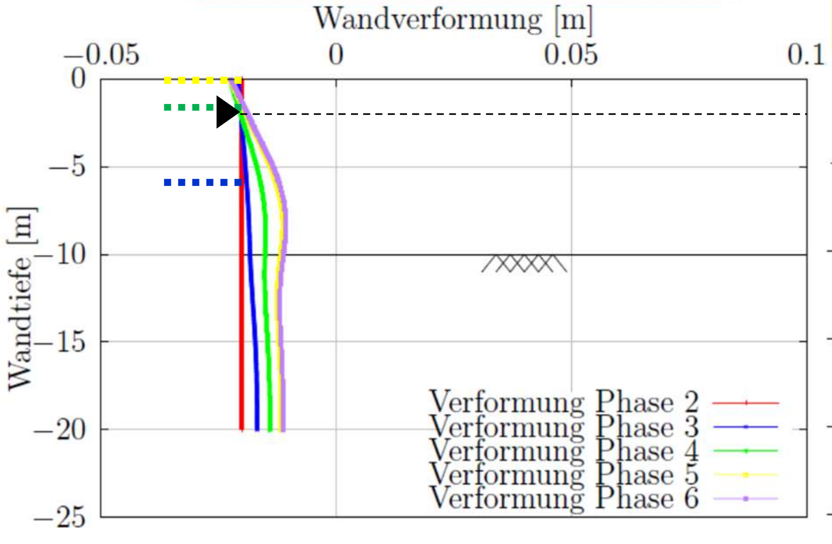
Total backfill 10 m

Surface load of 10 kPa (phase 6)

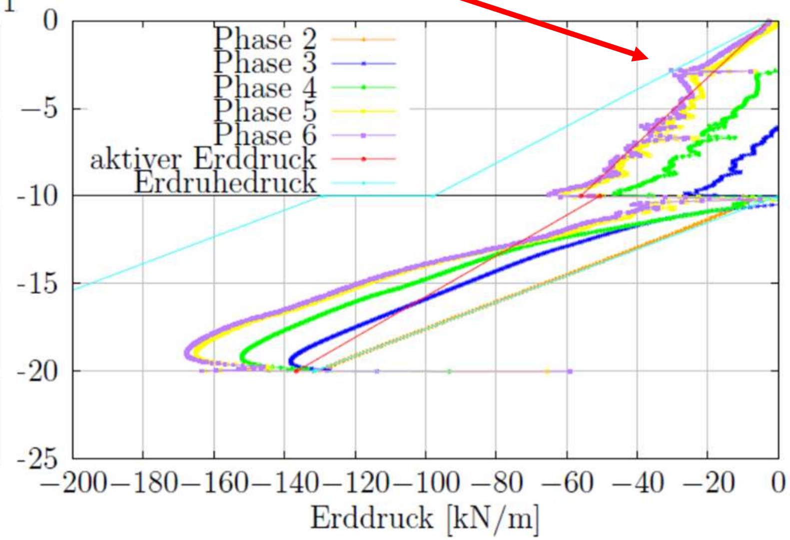


Prescribed deformation at level of the strut: 0.5 cm

Earth pressure concentration on the connection point is visible for phases 5 and 6 due to limited deformation at the level of the strut and existing soil up to soil surface.



Wall deformations by prescribed displacement of 0.5 cm in depth of the strut (phases 2 to 6)



Earth pressures on the left side of the wall by prescribed displacement of 0.5 cm in depth of the strut (phases 3 to 6)

Numerical studies on a simplified real system

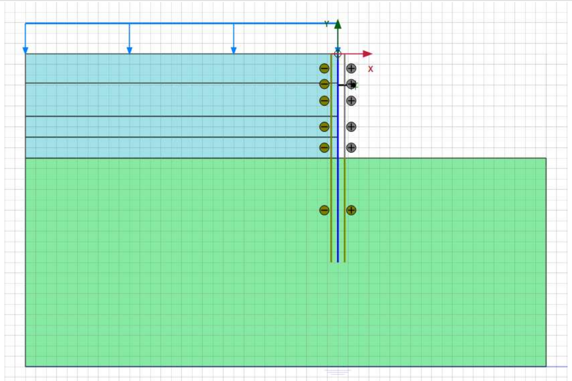
20 m clay layer (phase 1)

20 m sheet pile wall with 10 m embedded length in the clay and **activated strut** (phase 2)

Backfilling of sand
- first layer 4 m (phase 3)
- second layer 3.2 m (phase 4)
- third layer 2.8 m (phase 5)

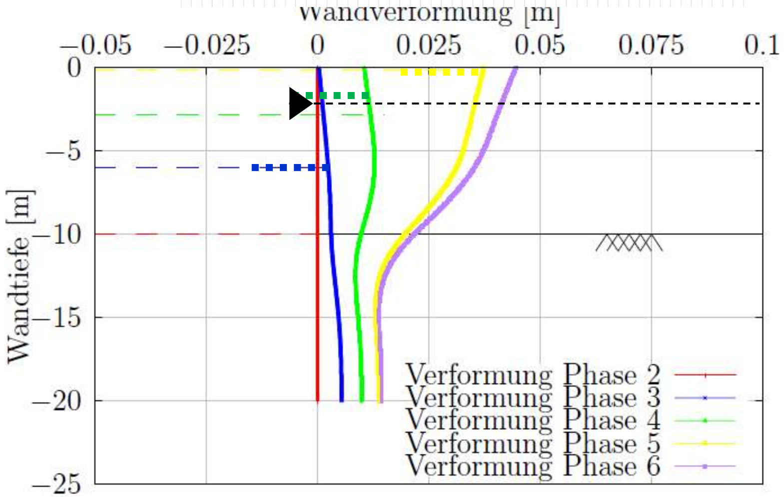
Total backfill 10 m

Surface load of 10 kPa (phase 6)

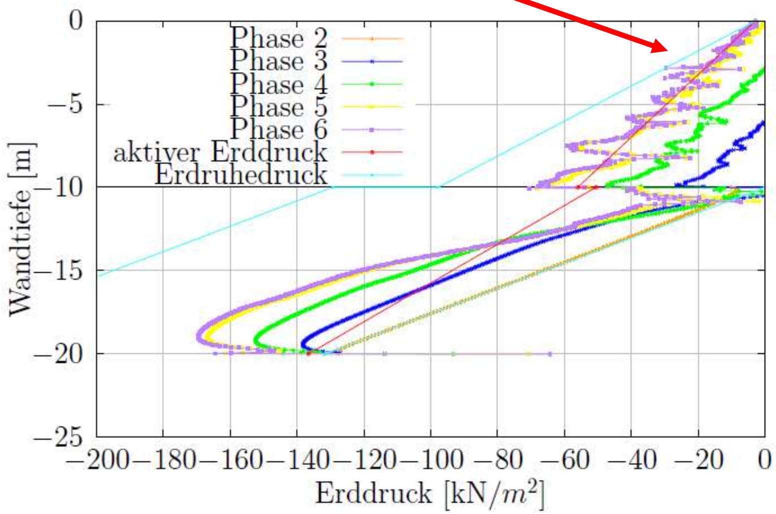


Prescribed deformation at level of the strut: 4.0 cm

Earth pressure concentration on the connection point is not visible for phases 5 and 6 due to large deformations at the level of the strut.



Wall deformations by prescribed displacement of 4.0 cm in depth of the strut (phases 2 to 6)



Earth pressures on the left side of the wall by prescribed displacement of 4.0 cm in depth of the strut (phases 3 to 6)

Numerical studies on a simplified real system

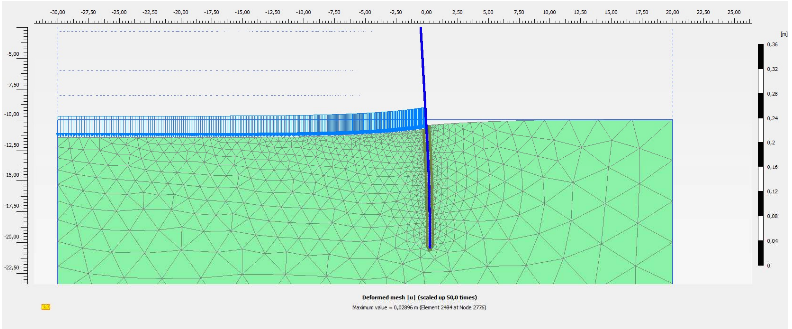
20 m clay layer (phase 1)

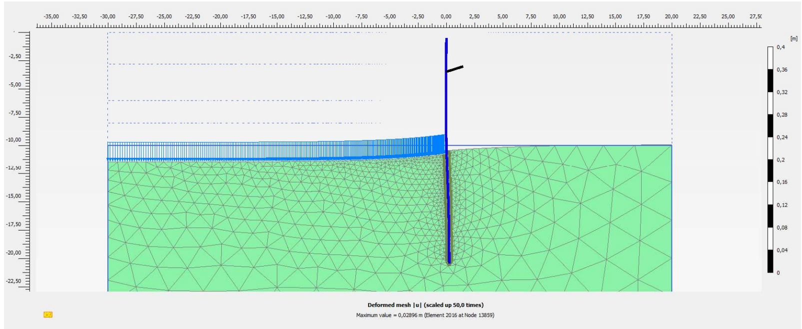
20 m sheet pile wall with 10 m embedded length in the clay (phase 2) and either without or with activated strut

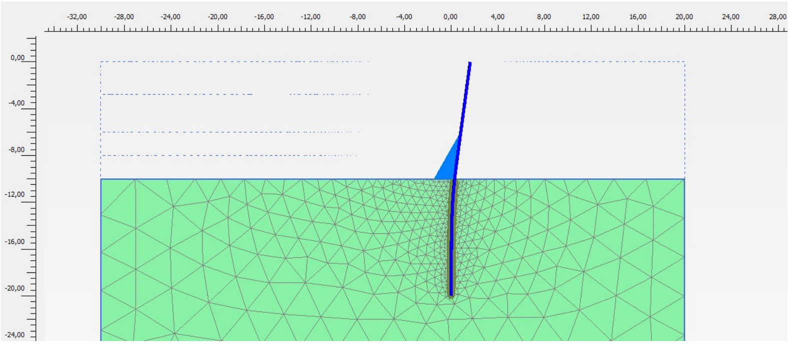
Surface load equivalent to 4 m fill at the left side of the wall (phase 3)

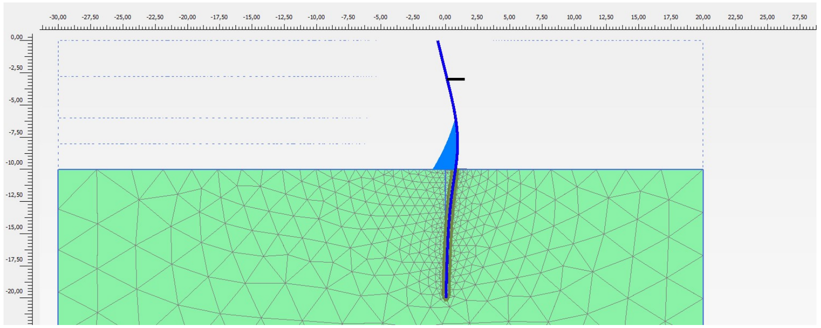
or

horizontal load equivalent to horizontal earth pressure of 4 m fill (phase 3)







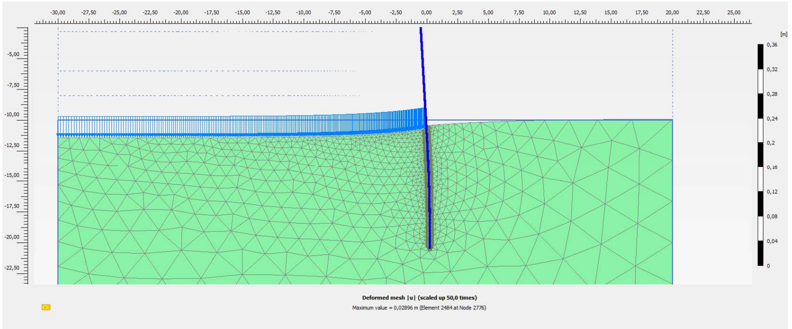


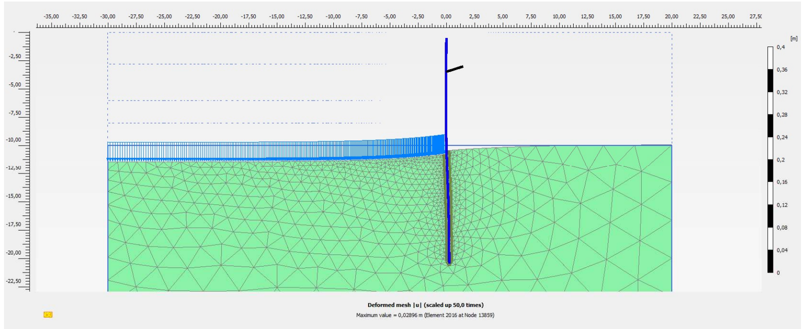
Numerical studies on a simplified real system

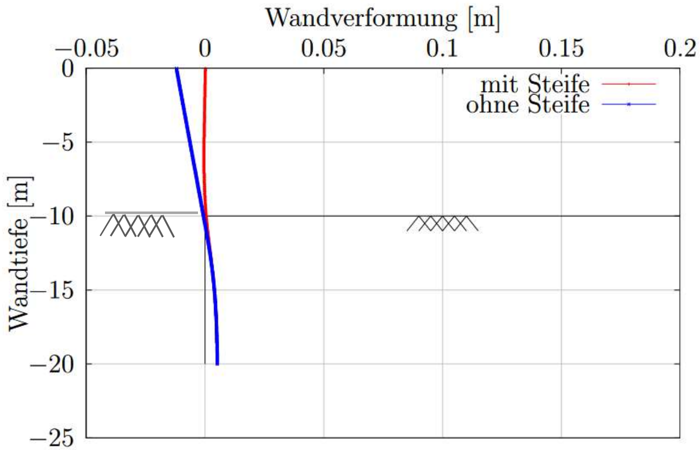
20 m clay layer (phase 1)

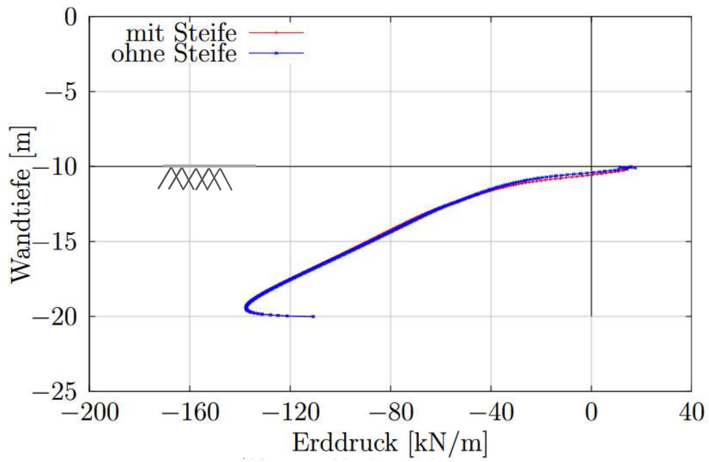
20 m sheet pile wall with 10 m embedded length in the clay (phase 2) and either without or with activated strut

Surface load equivalent to 4 m fill at the left side of the wall (phase 3)







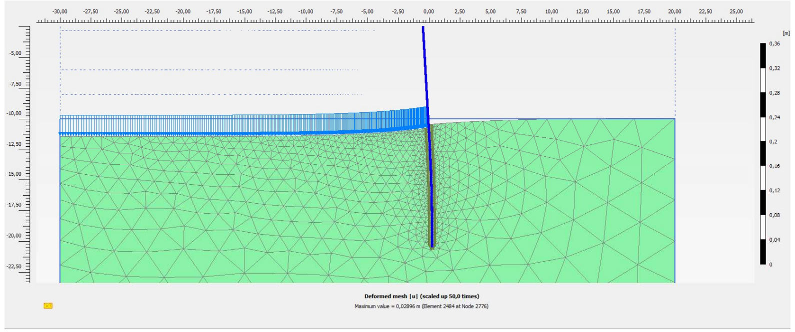


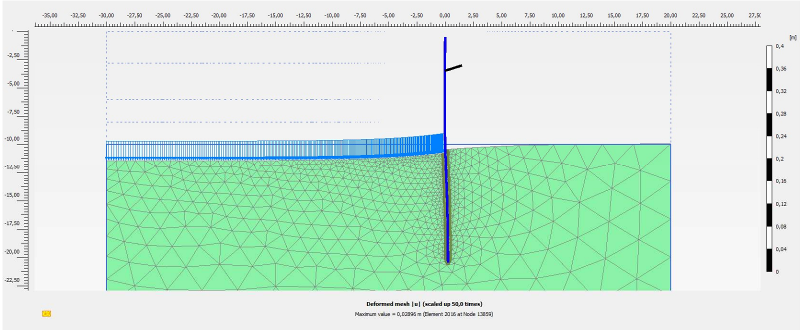
Numerical studies on a simplified real system

20 m clay layer (phase 1)

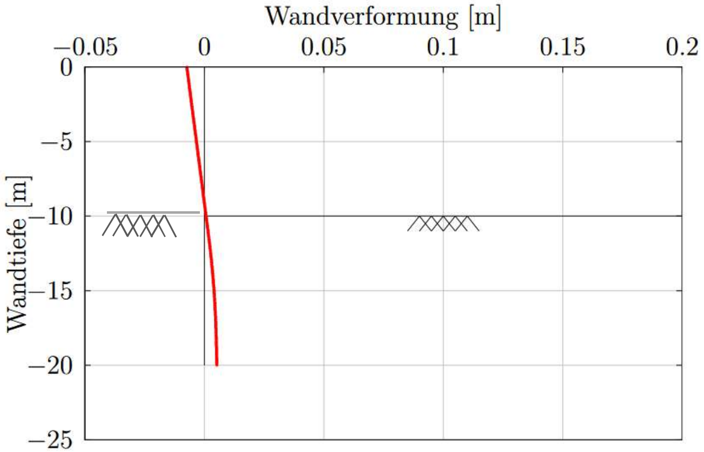
20 m sheet pile wall with 10 m embedded length in the clay (phase 2) and either without or with activated strut

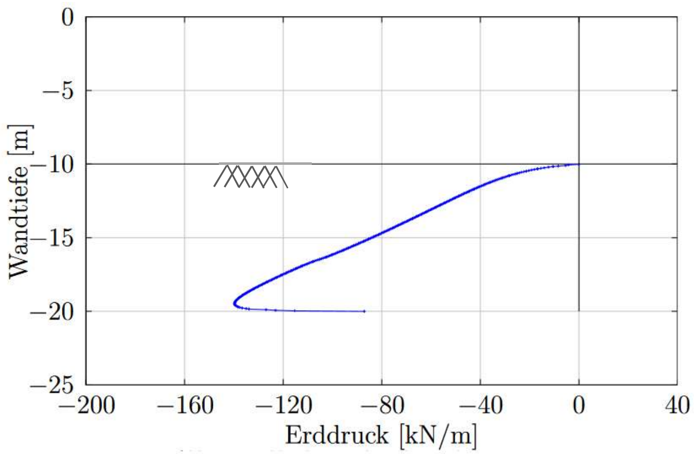
Surface load equivalent to 4 m fill at the left side of the wall (phase 3)





Without cohesion in the interface between wall and clay (clay still with cohesion)



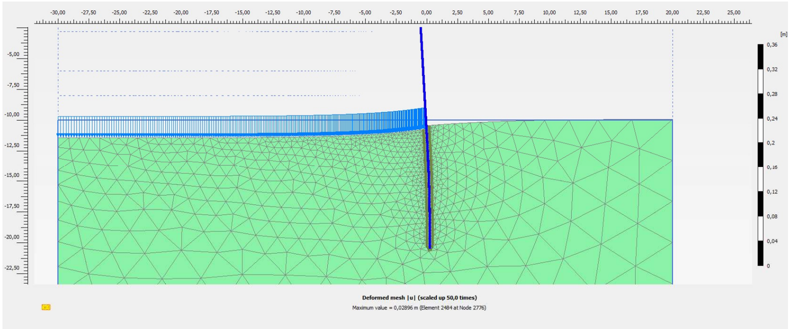


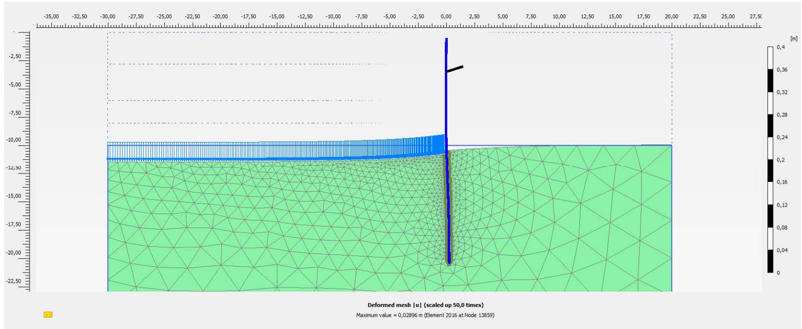
Numerical studies on a simplified real system

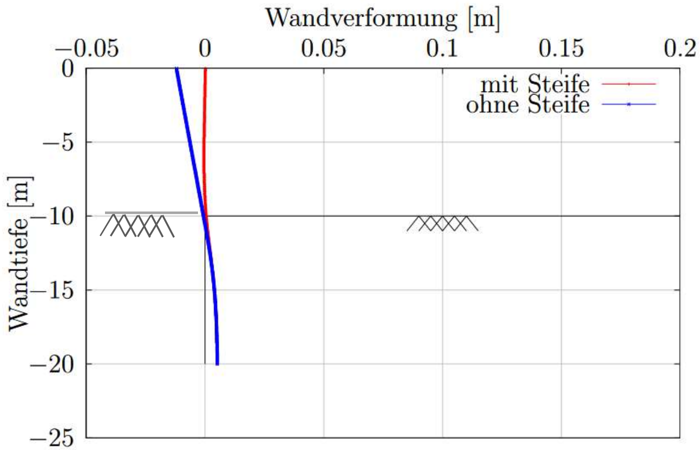
20 m clay layer (phase 1)

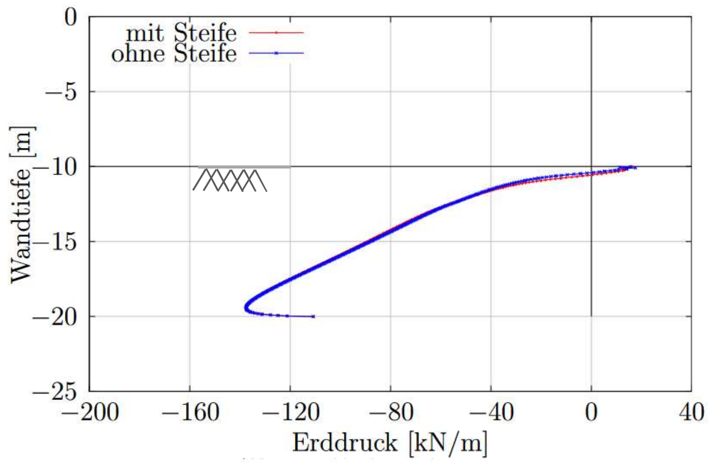
20 m sheet pile wall with 10 m embedded length in the clay (phase 2) and either without or with activated strut

Surface load equivalent to 4 m fill at the left side of the wall (phase 3)







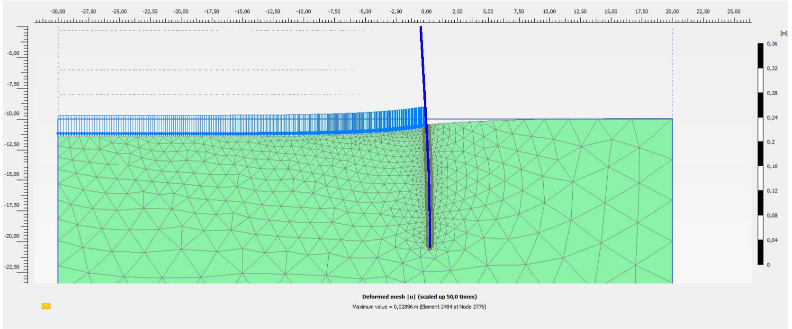


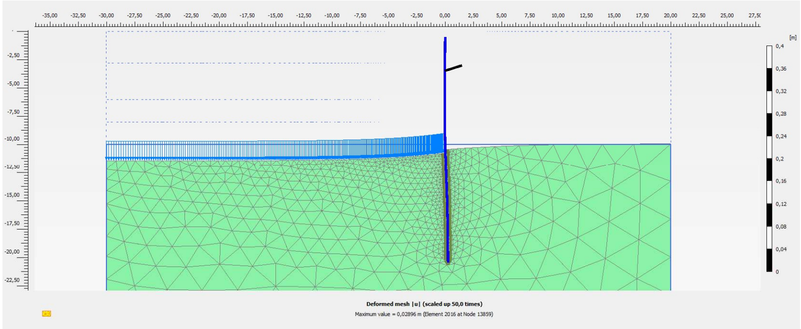
Numerical studies on a simplified real system

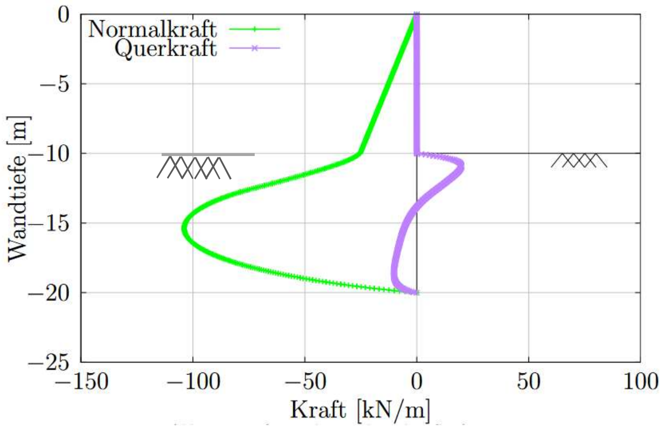
20 m clay layer (phase 1)

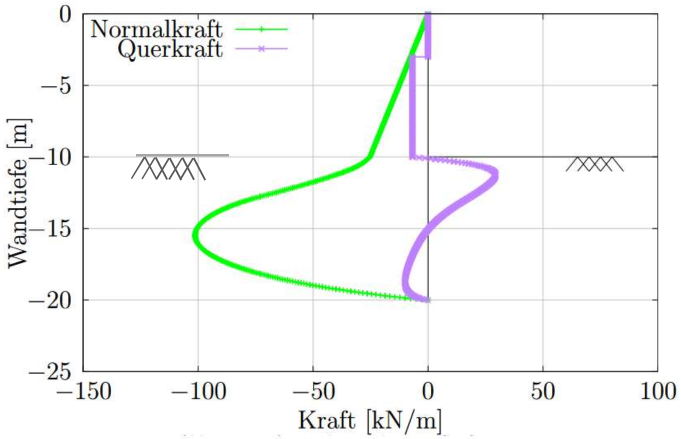
20 m sheet pile wall with 10 m embedded length in the clay (phase 2) and either without or with activated strut

Surface load equivalent to 4 m fill at the left side of the wall (phase 3)







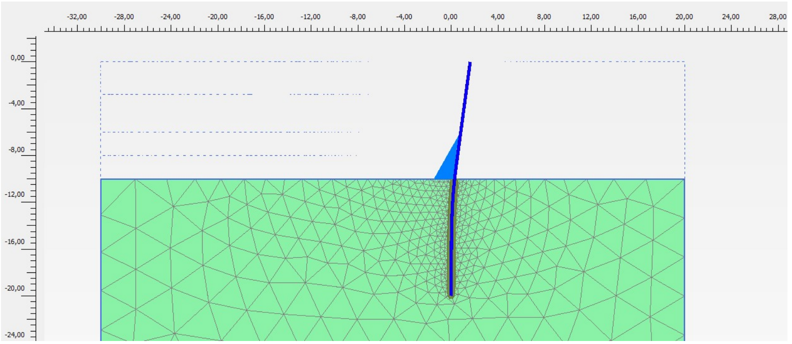


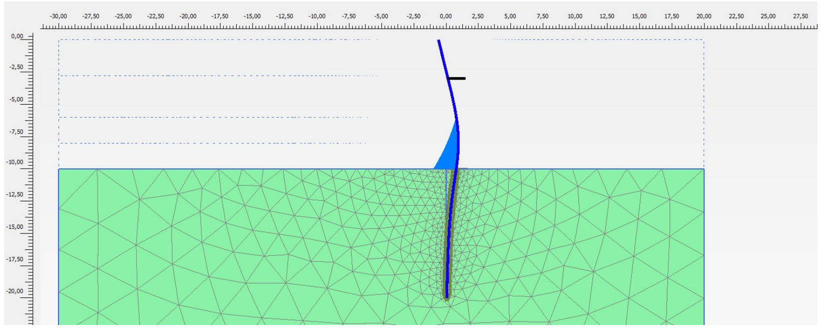
Numerical studies on a simplified real system

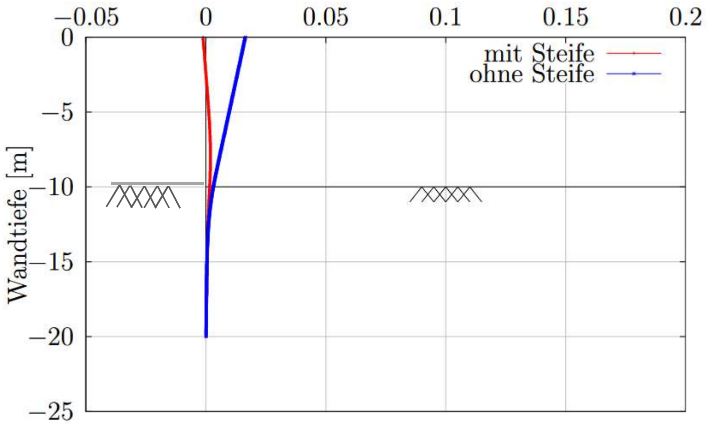
20 m clay layer (phase 1)

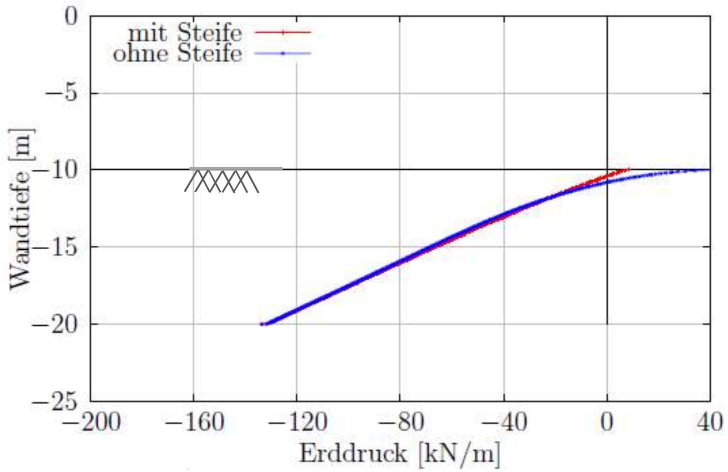
20 m sheet pile wall with 10 m embedded length in the clay (phase 2) and either without or with activated strut

Horizontal load equivalent to horizontal earth pressure of 4 m fill (phase 3)







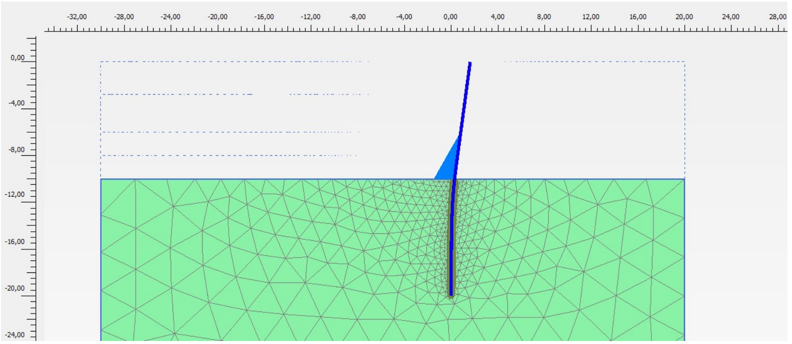


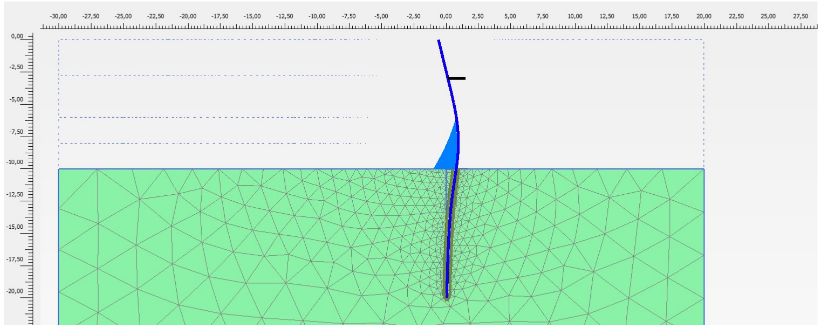
Numerical studies on a simplified real system

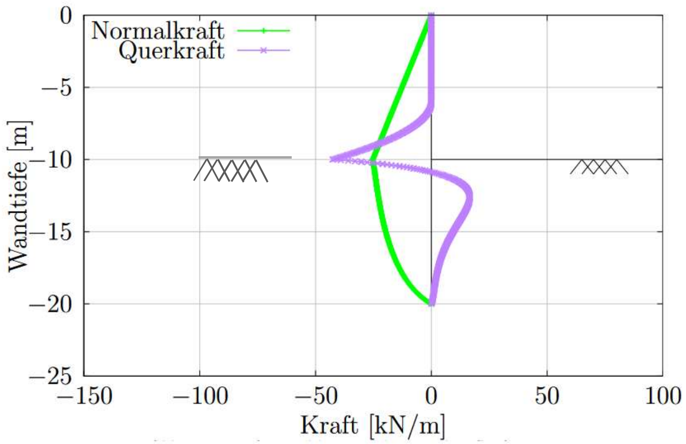
20 m clay layer (phase 1)

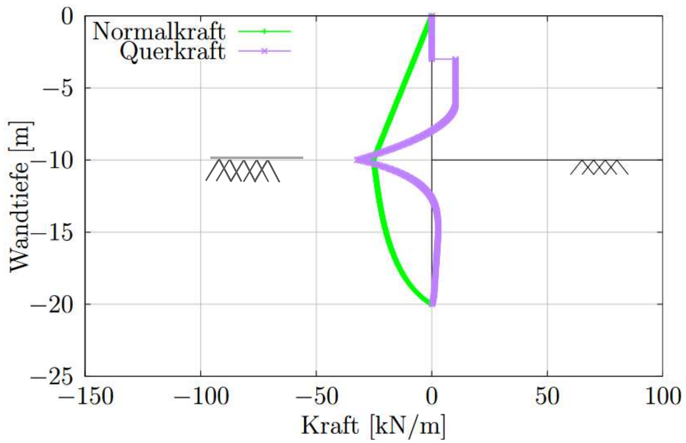
20 m sheet pile wall with 10 m embedded length in the clay (phase 2) and either without or with activated strut

Horizontal load equivalent to horizontal earth pressure of 4 m fill (phase 3)









Numerical studies on a simplified real system

- FE-simulations in real scale; base simplified realistic system- Summary

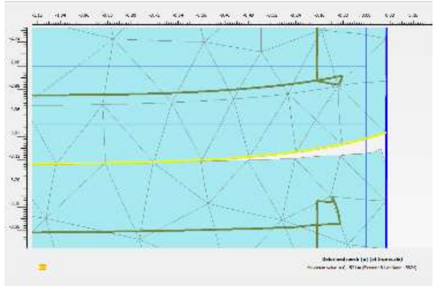
Earth pressure distribution is influenced by the geogrid: mainly reduction of earth pressure directly below the geogrid.

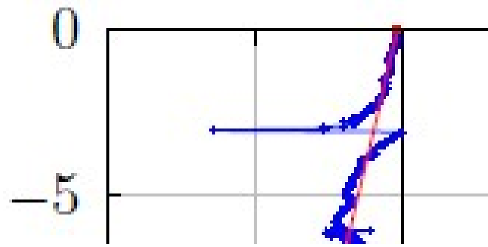
Reason for that is the membrane effect of the geogrid. The effect is limited to a very small area below the grid.

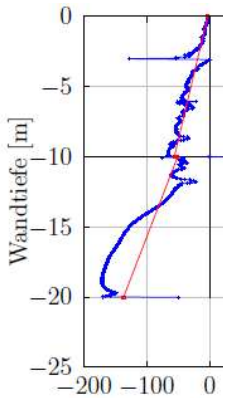
Earth pressure distribution follows the theoretical active earth pressure.

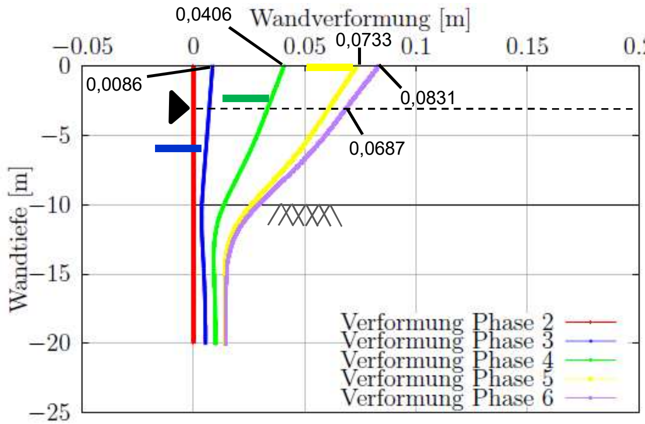
Most of the deformation of the wall happened during the first filling steps before the geogrid is active.

Increase of earth pressure force due to geogrid is not confirmed.









Summary

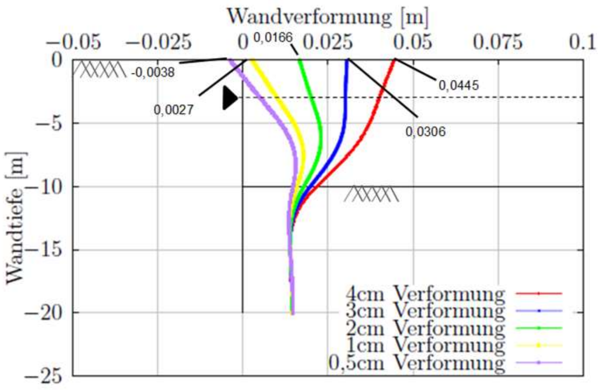
Soil – wall – geogrid interaction is still exiting and challenging – by both physical and numerical modelling.

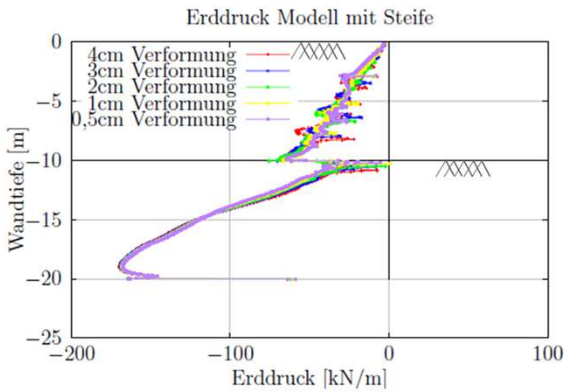
Process of backfilling has to be kept in mind. Additional earth pressure due to compaction work is not included in this study.

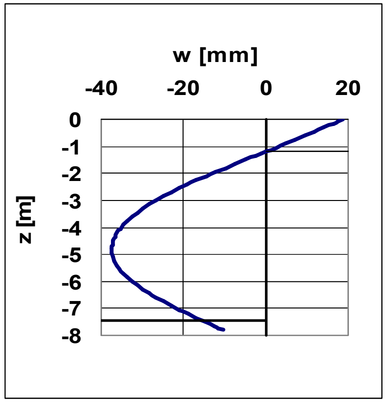
Influence of geogrid on earth pressure distribution seems to be small.

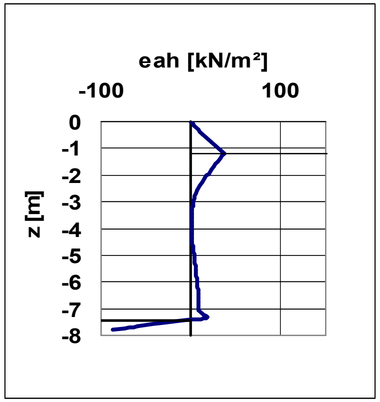
Influence of prestressing and inclined position of geogrid has to be investigated.

We should show, that we are able to simulate earth pressure distributions depending on type of wall movement for excavated walls.









Summary

Thank you for your attention!

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