Branschsamverkan i Grunden

CHALMERS
UNIVERSITY OF TECHNOLOGY

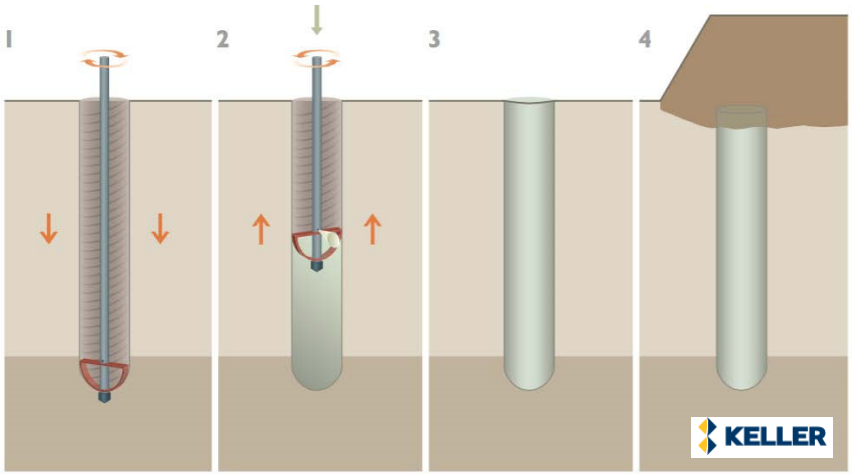
BIG - Branschsamverkan I Grunden Webinar 2023

Deep mixing for urban excavations (A2020-13)

Sinem Bozkurt, Ayman Abed, Minna Karstunen

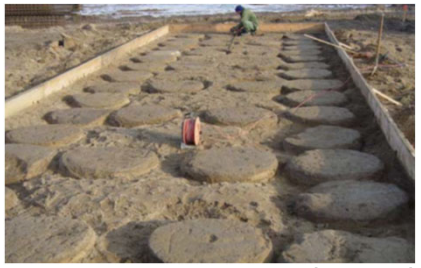
FORMAS
VINNOVA
Sweden's Innovation Agency
TRAFIKVERKET
SWEDISH TRANSPORT ADMINISTRATION

Background

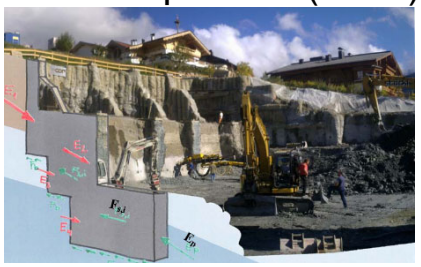


Dry Soil Mixing (DSM)





Topolnicki (2004)

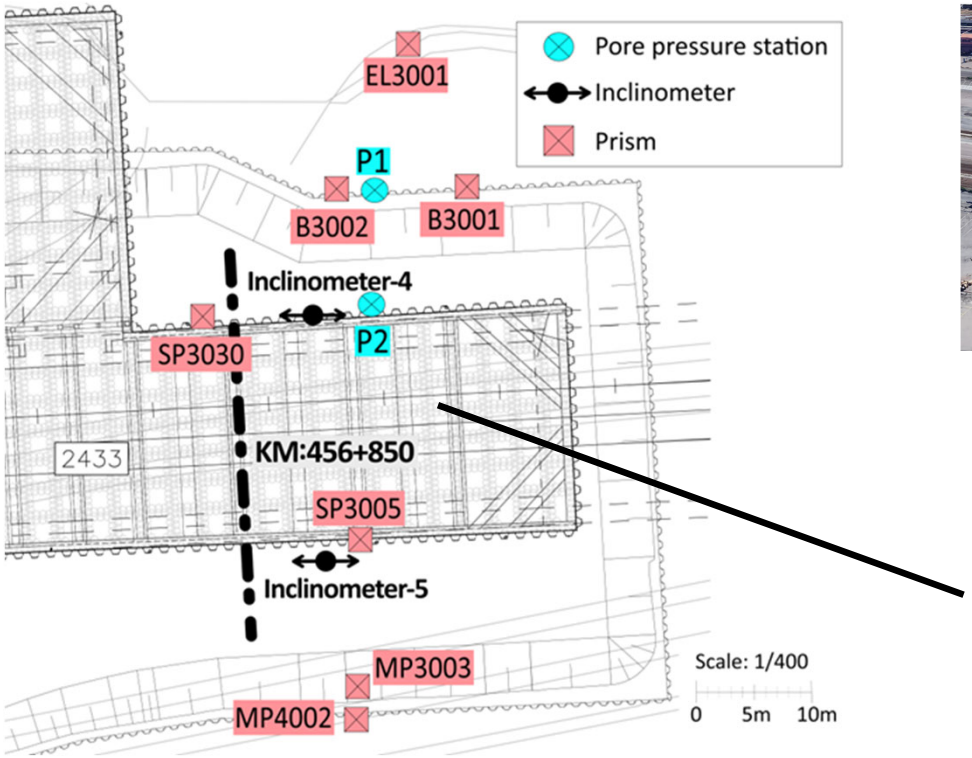


Marte et al. (2017)

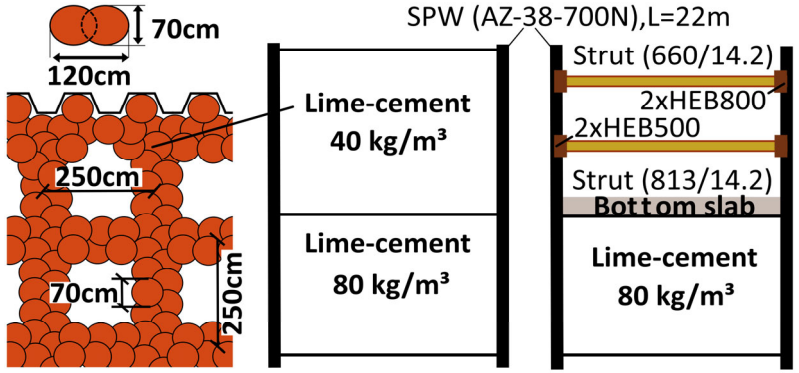
Outline

- Case study of West link deep excavation
  - 2D & 3D analyses of the excavation
- Volume averaging technique (VAT) for deep excavations
- Conclusions
- Future recommendations

Site location

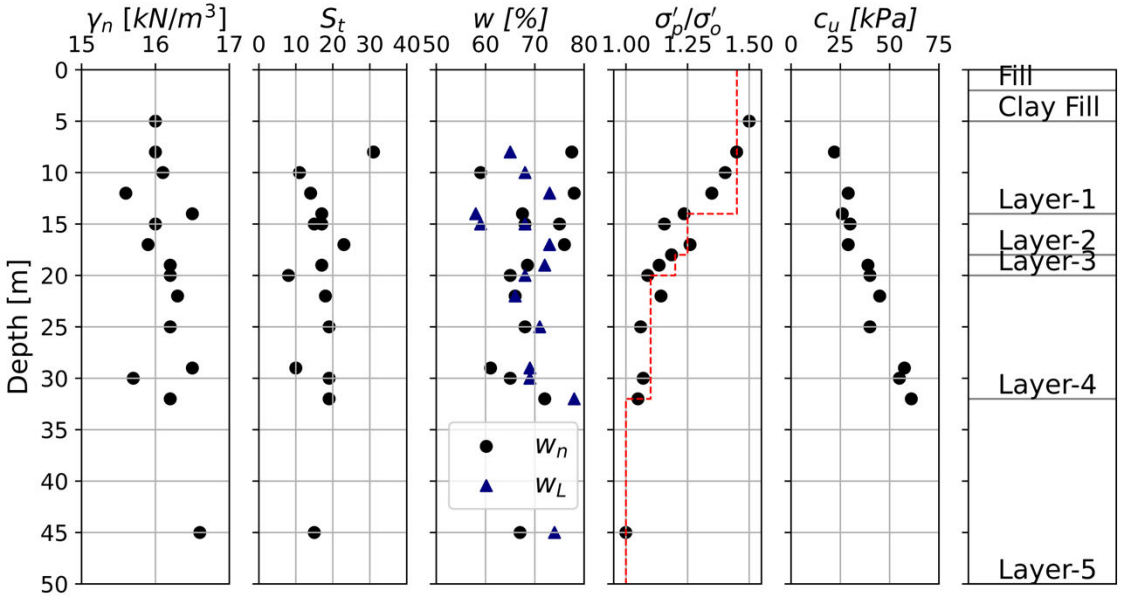






*Data from NCC

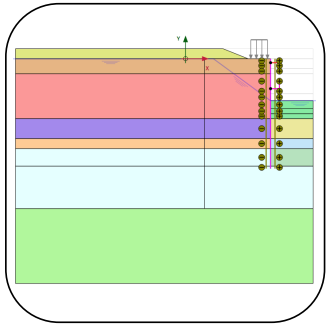
Laboratory tests



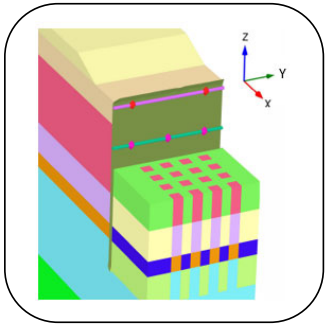
LC column: IL and CAUE/C tests

Clay: IL and CADC/E and CAUC/E

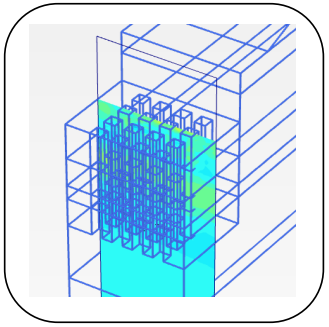
Methodology



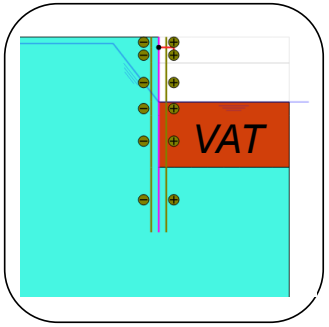
Plane strain analysis (2D)



3D analysis

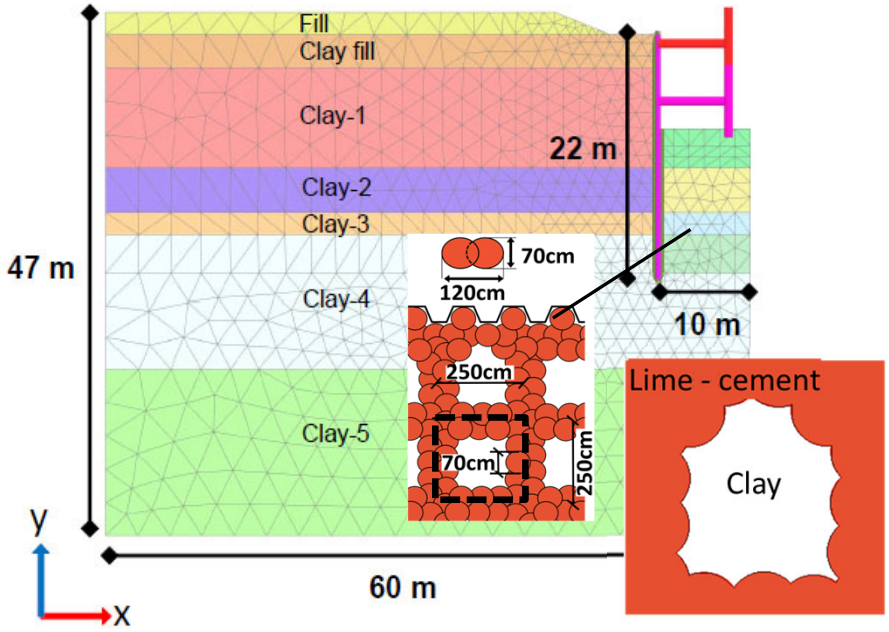


Clay-column interaction



VAT stabilised clay

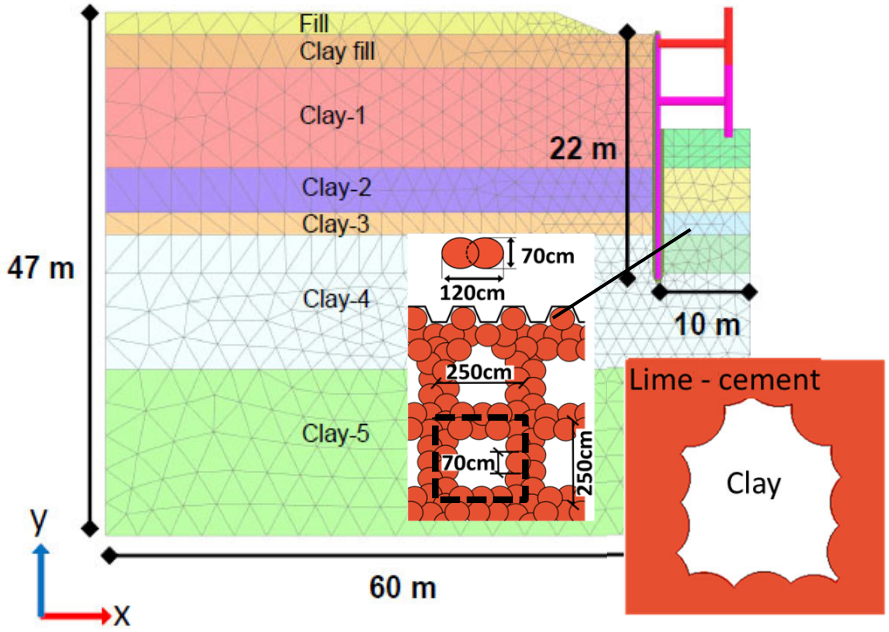
Numerical analyses

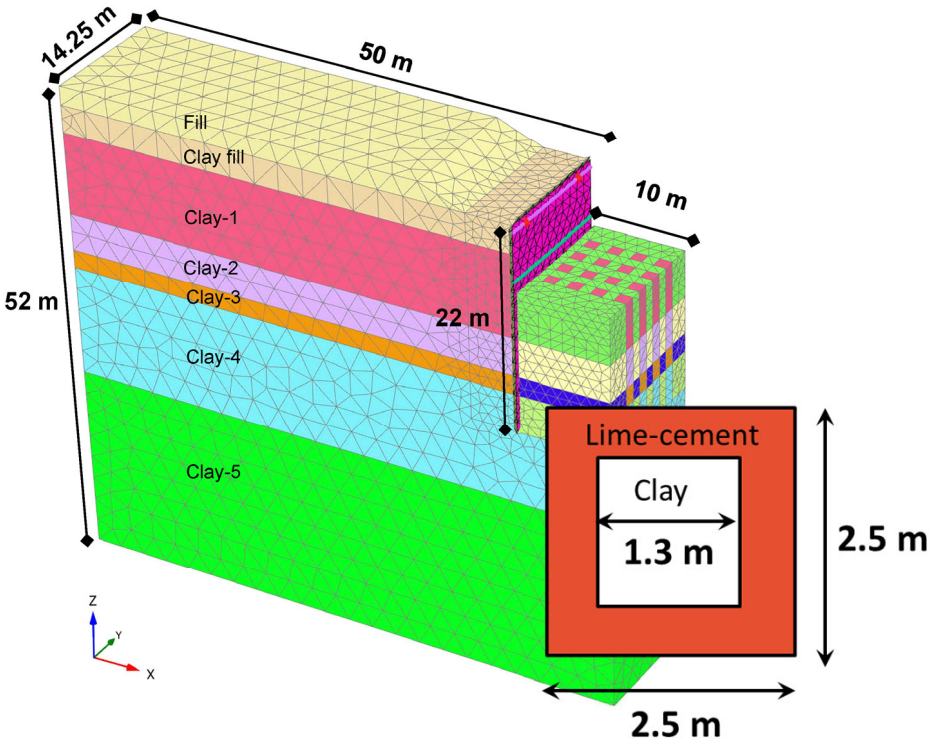


$$A_{column} = 0.66$$

$$E'_{composite} = 0.66 \times E'_{column} + 0.34 \times E'_{clay.avg}$$

Numerical analyses





$$A_{column} = 0.66$$

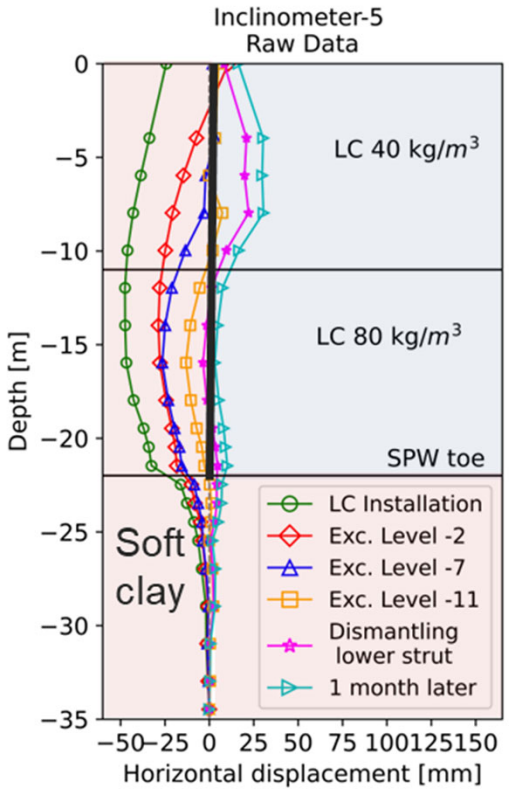
$$E'_{composite} = 0.66 \times E'_{column} + 0.34 \times E'_{clay.avg}$$

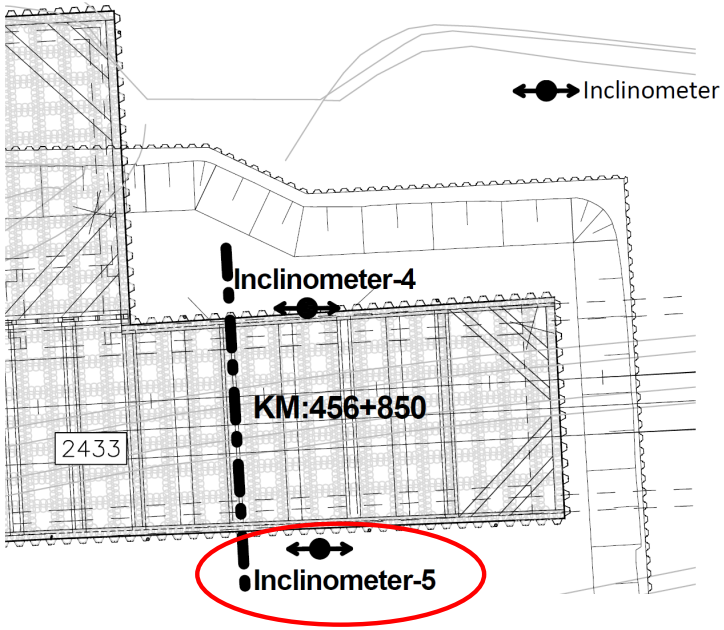
Numerical analyses

Phase Number	Phase	Time interval (days)	Date
0	Initial inclinometer readings		2019-06-17
1	Excavation of fill layer	67	2019-04-09
2	Installation of SPW	69	2019-06-17
3	LC column installation	51	2019-08-07
4	Excavation to -2 level	49	2019-09-25
5	Excavation to -7 level	12	2019-10-17
6	Installation of lower strut	10	2019-11-21
7	Excavation to -11 level	35	2019-12-12
8	Dismantling lower strut	21	2020-01-15
9	Last inclinometer readings	34	2020-02-17



Modelling installation effects



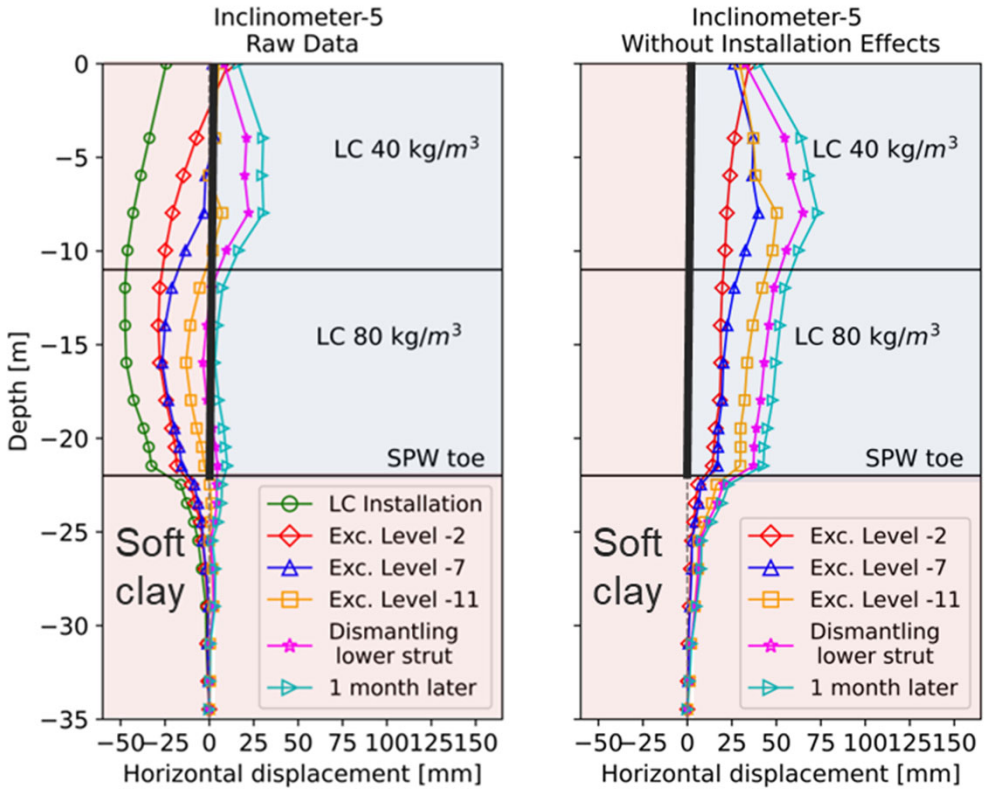


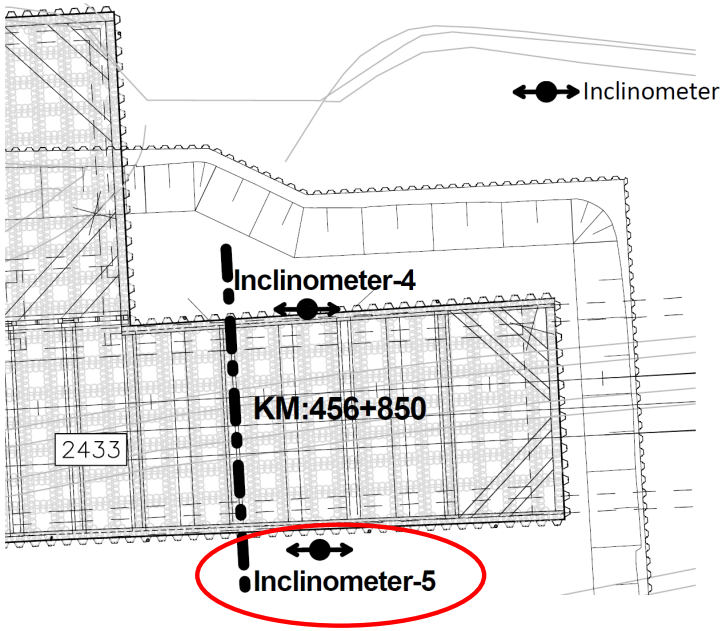
Sign convention

(+) towards excavation

(-) away from excavation

Modelling installation effects



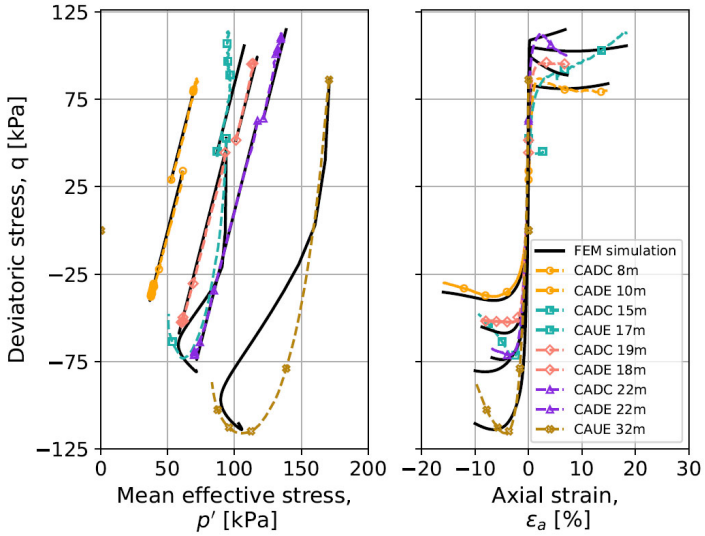


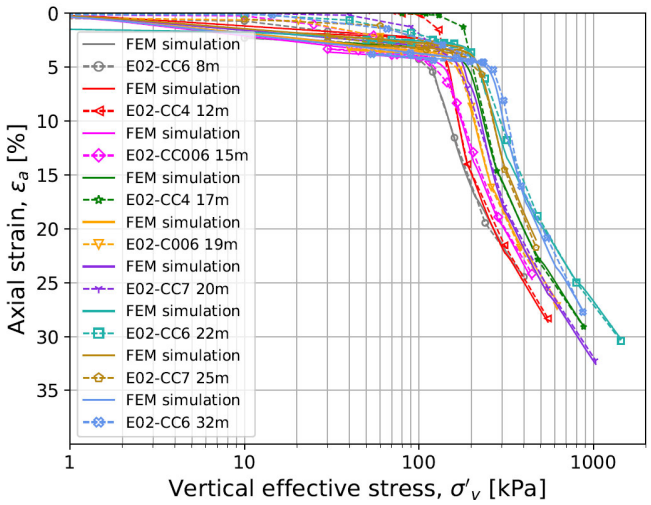
Sign convention

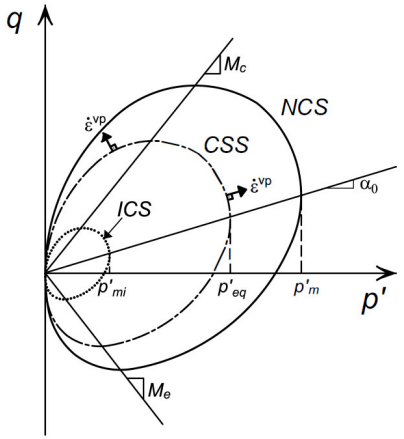
(+) towards excavation

(-) away from excavation

Modelling soft clay: Creep-SCLAY1S

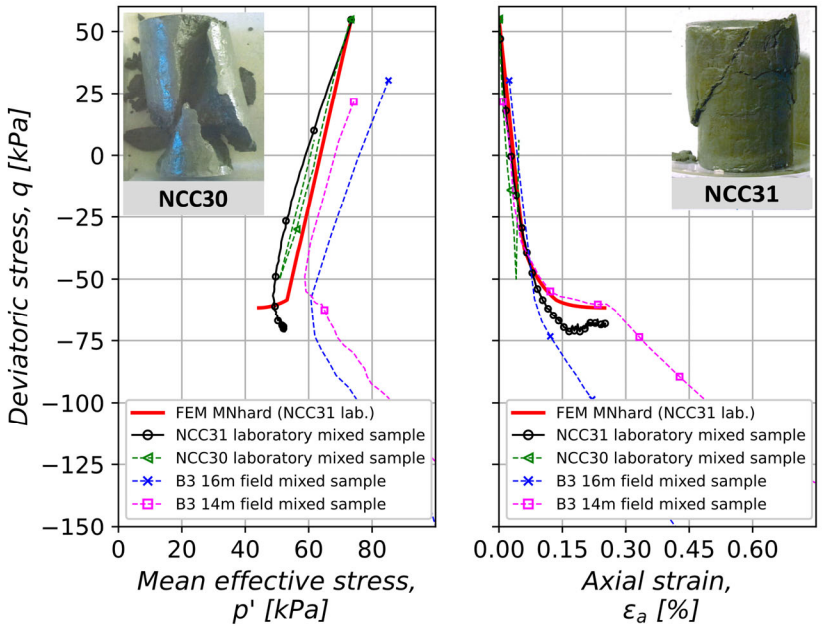




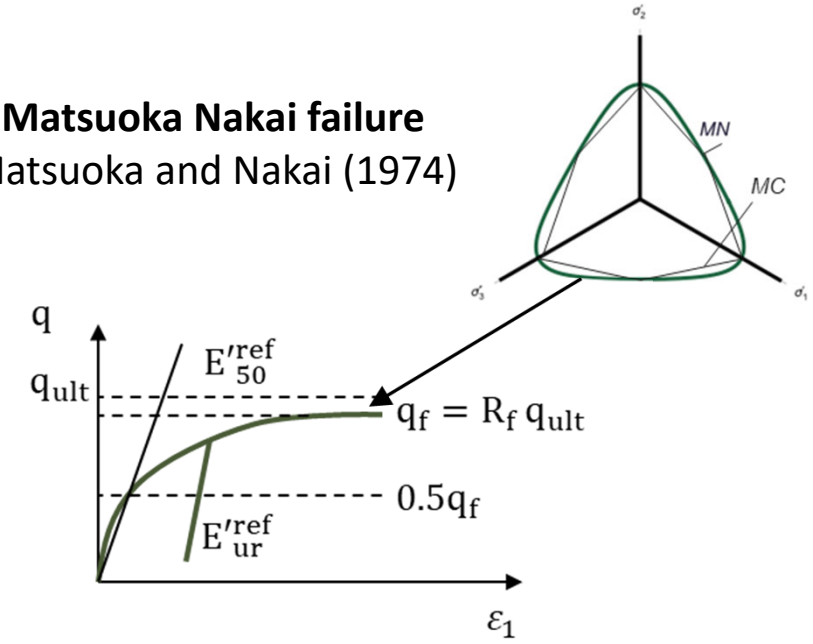


Sivasithamparam et al. (2015)
Gras et al. (2018)

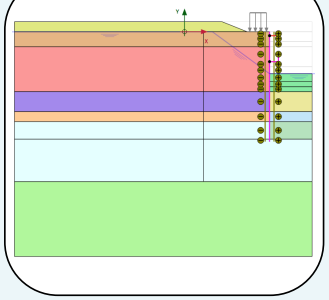
Modelling lime-cement columns: Matsuoka-Nakai Hardening (MNhard) model



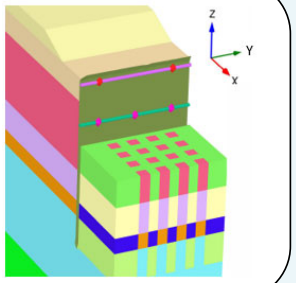
Matsuoka Nakai failure
Matsuoka and Nakai (1974)



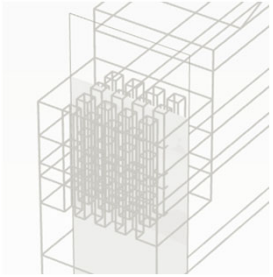
Benz (2007)



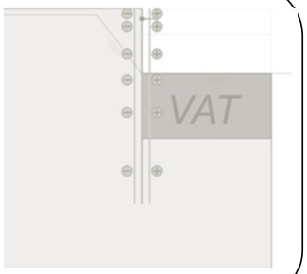
Plane strain analysis (2D)



3D analysis

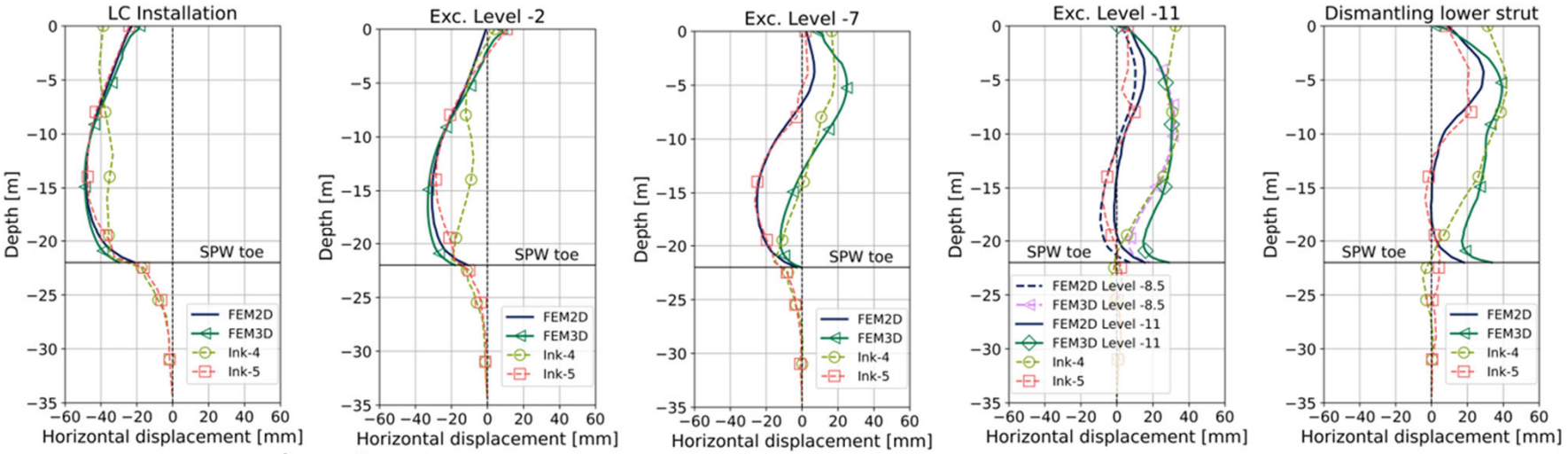


Clay-column interaction

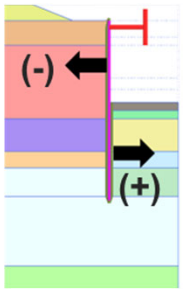


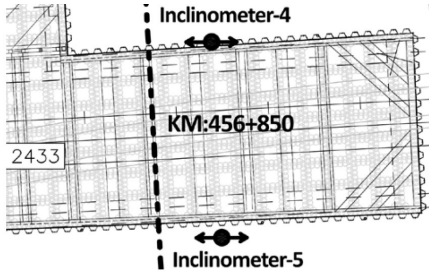
VAT stabilised clay

Comparison of 2D and 3D analyses

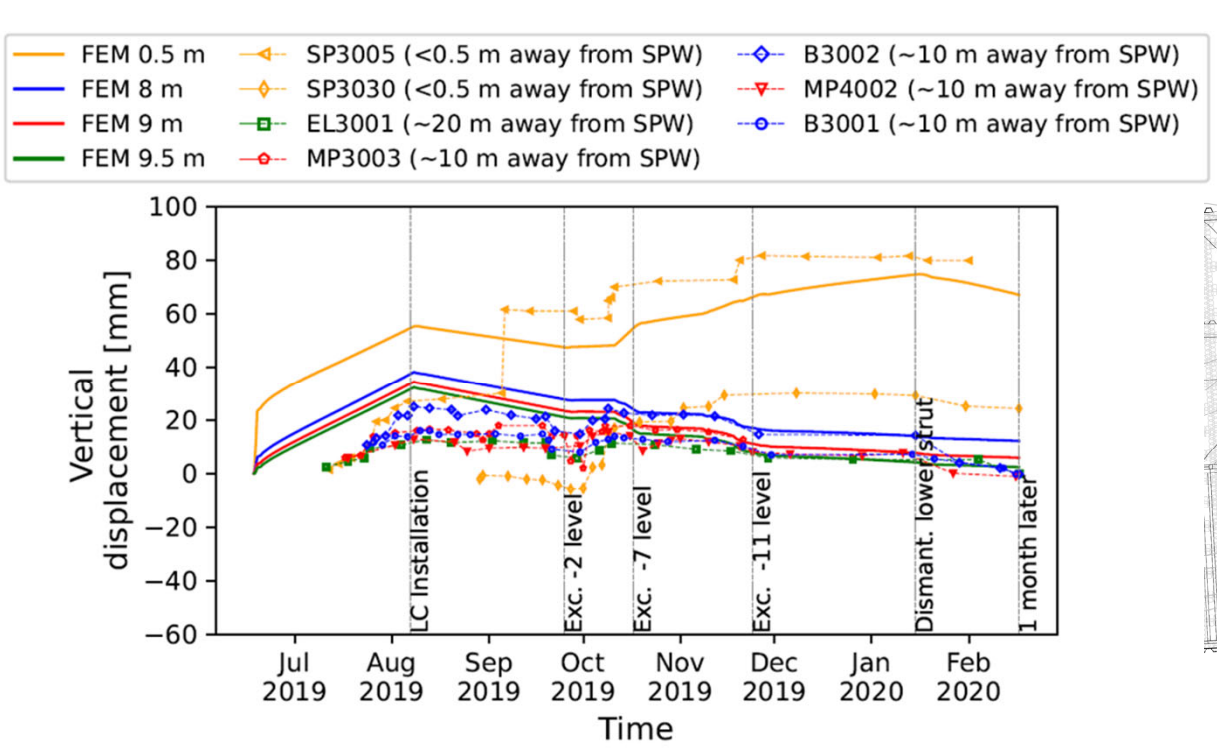


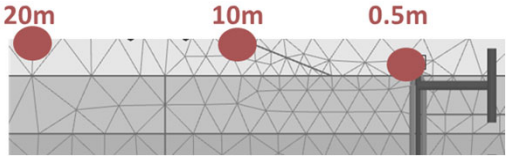
External strain application

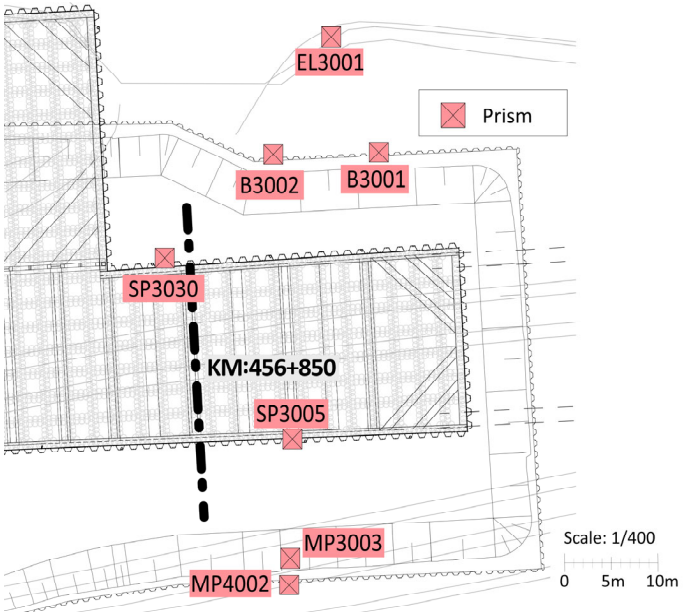


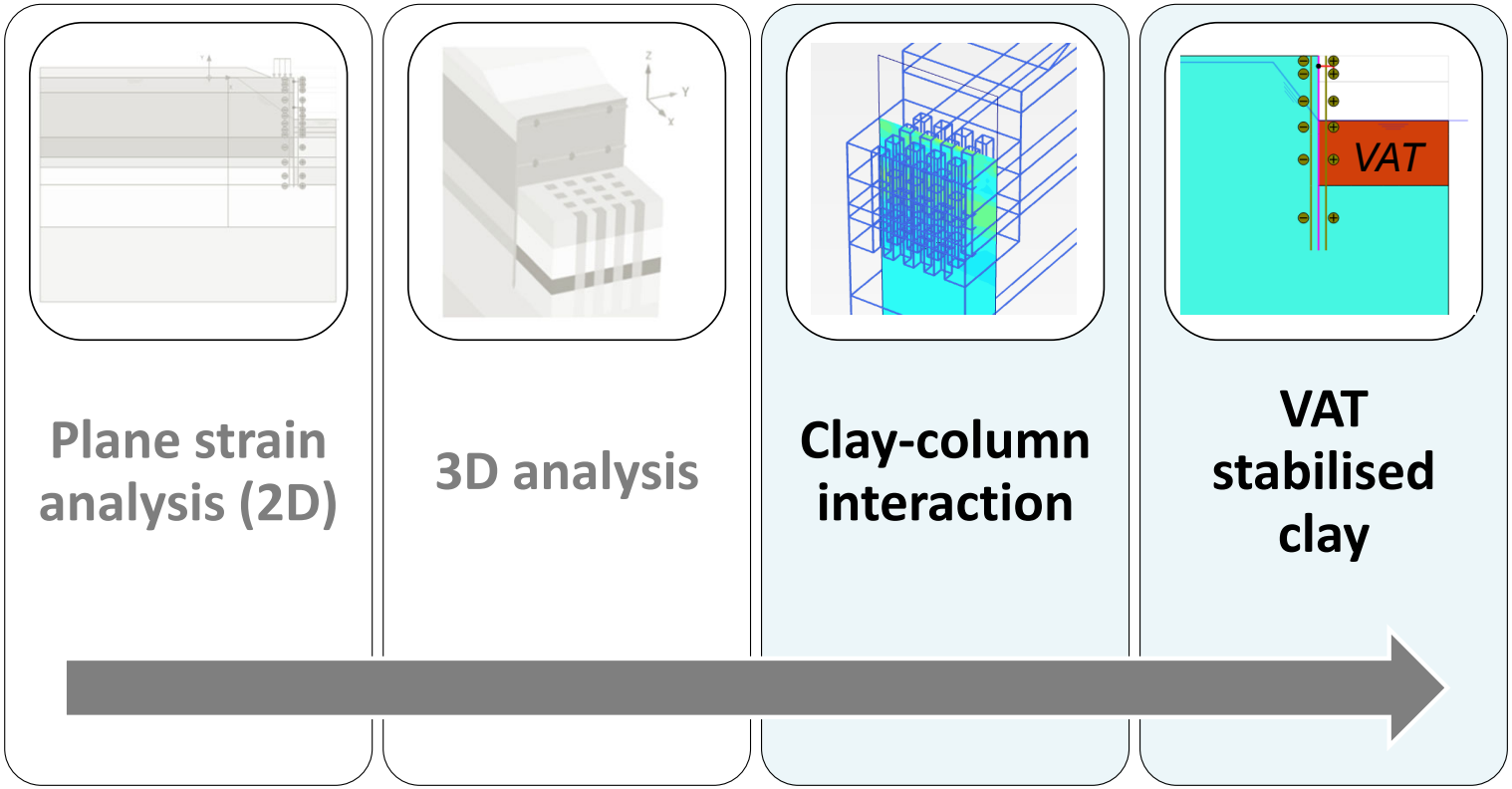


Plane strain analysis

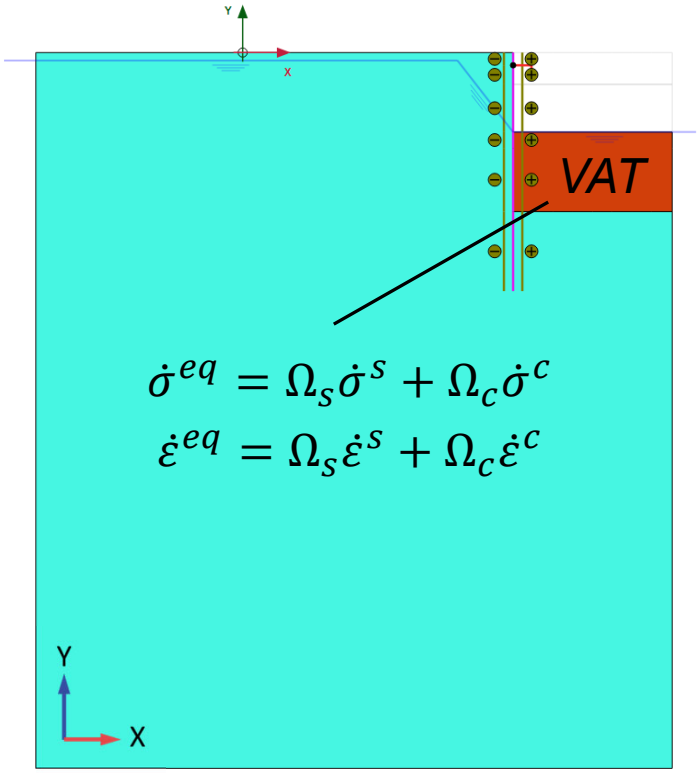




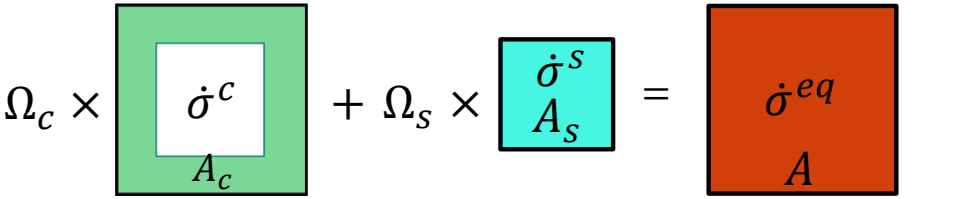



VAT
Plane strain analysis (2D)
3D analysis
Clay-column interaction
VAT stabilised clay

Volume averaging technique (VAT)



$$\dot{\sigma}^{eq} = \Omega_s \dot{\sigma}^s + \Omega_c \dot{\sigma}^c$$
$$\dot{\varepsilon}^{eq} = \Omega_s \dot{\varepsilon}^s + \Omega_c \dot{\varepsilon}^c$$

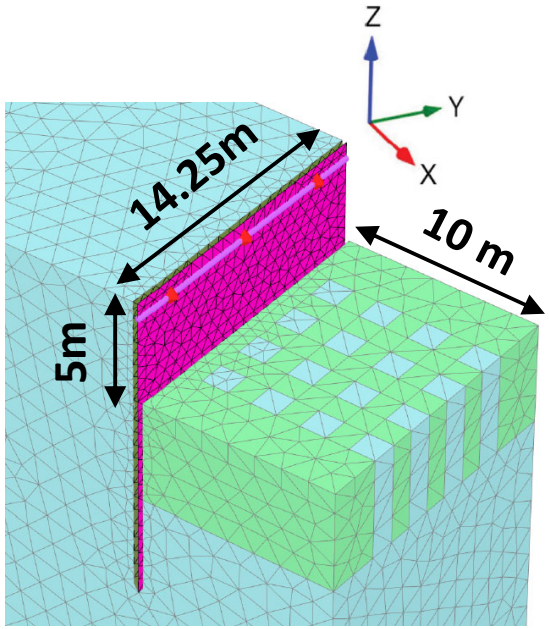


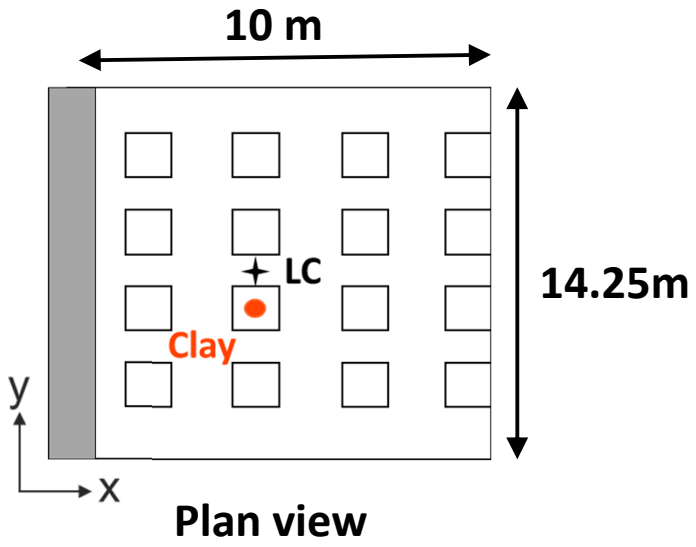
Column Clay Stabilised clay

Column fraction : $\Omega_c = \frac{A_c}{A}$

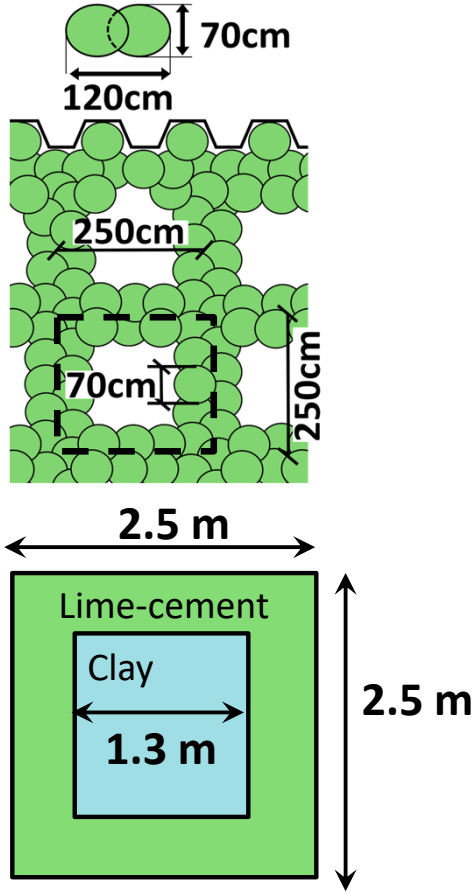
Soil fraction : $\Omega_s = 1 - \Omega_c$

Clay/column interaction



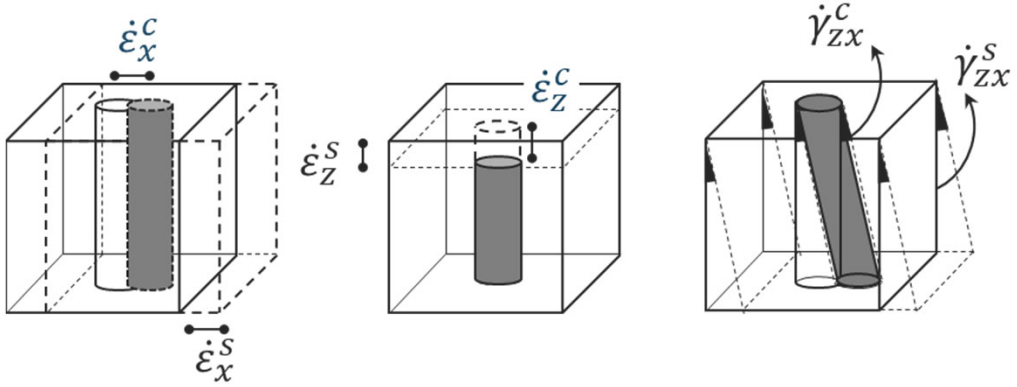


Plan view



Column : MNhard
Soil : SCLAY1S

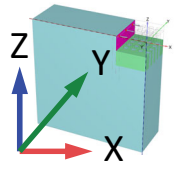
Clay/column interaction (3D)



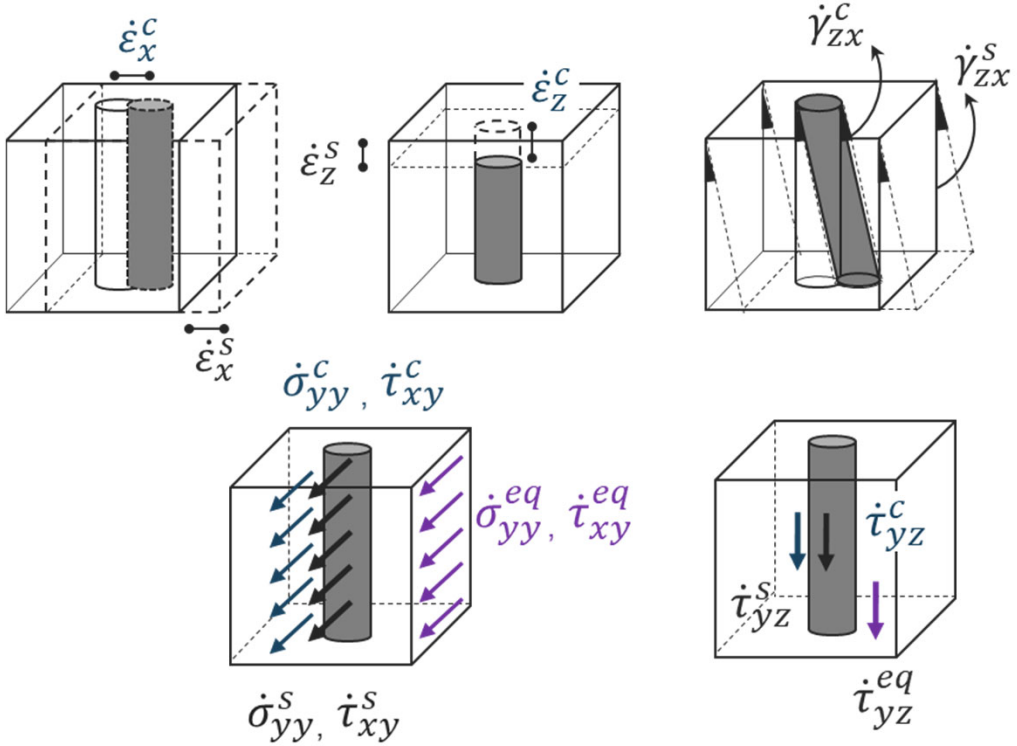
Kinematic conditions

$$\dot{\varepsilon}_{xx}^{eq} = \dot{\varepsilon}_{xx}^{col} = \dot{\varepsilon}_{xx}^{soil}$$
$$\dot{\varepsilon}_{zz}^{eq} = \dot{\varepsilon}_{zz}^{col} = \dot{\varepsilon}_{zz}^{soil}$$
$$\dot{\gamma}_{zx}^{eq} = \dot{\gamma}_{zx}^{col} = \dot{\gamma}_{zx}^{soil}$$

3D



Clay/column interaction (3D)



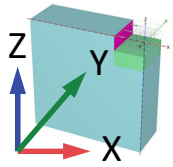
Kinematic conditions

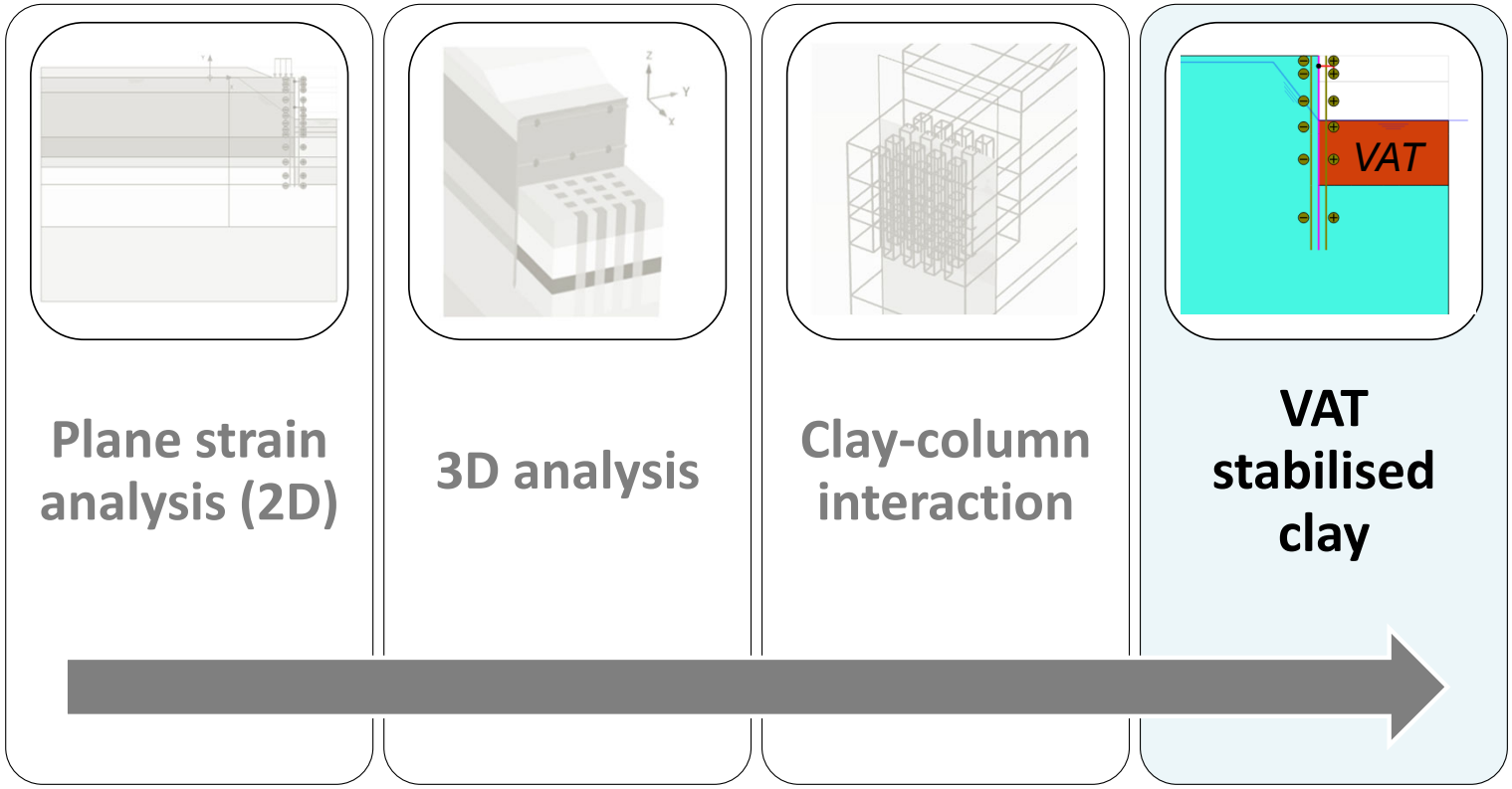
$$\dot{\varepsilon}_{xx}^{eq} = \dot{\varepsilon}_{xx}^{col} = \dot{\varepsilon}_{xx}^{soil}$$
$$\dot{\varepsilon}_{zz}^{eq} = \dot{\varepsilon}_{zz}^{col} = \dot{\varepsilon}_{zz}^{soil}$$
$$\dot{\gamma}_{zx}^{eq} = \dot{\gamma}_{zx}^{col} = \dot{\gamma}_{zx}^{soil}$$

Local equilibrium

$$\dot{\sigma}'^{eq}_{yy} = \dot{\sigma}'^{col}_{yy} = \dot{\sigma}'^{soil}_{yy}$$
$$\dot{\tau}_{xy}^{eq} = \dot{\tau}_{xy}^{col} = \dot{\tau}_{xy}^{soil}$$
$$\dot{\tau}_{yz}^{eq} = \dot{\tau}_{yz}^{col} = \dot{\tau}_{yz}^{soil}$$

3D




VAT
Plane strain analysis (2D)
3D analysis
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VAT stabilised clay

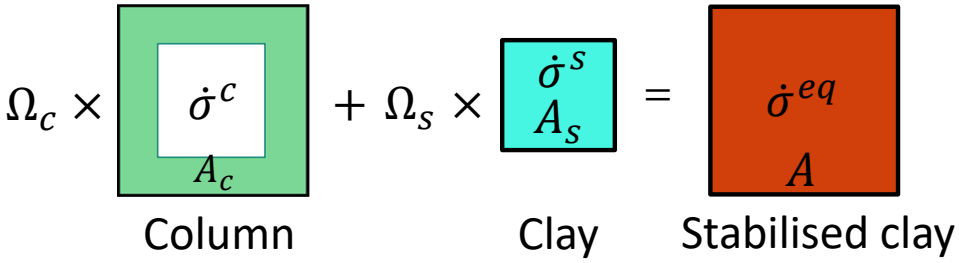
Equivalent stiffness matrix

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \tau_{xy}\\ \tau_{yz}\\ \tau_{zx}\end{bmatrix}_{c,s} = \begin{bmatrix}D_{11} & D_{12} & D_{13} & D_{14} & D_{15} & D_{16}\\ D_{21} & D_{22} & D_{23} & D_{24} & D_{25} & D_{26}\\ D_{31} & D_{32} & D_{33} & D_{34} & D_{35} & D_{36}\\ D_{41} & D_{42} & D_{43} & D_{44} & D_{36} & D_{46}\\ D_{51} & D_{52} & D_{53} & D_{45} & D_{37} & D_{56}\\ D_{61} & D_{62} & D_{63} & D_{46} & D_{38} & D_{66}\end{bmatrix}_{c,s} \begin{bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_z\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{zx}\end{bmatrix}_{c,s}$$

$$(\dot{\sigma}^{eq})' = \Omega_s(\dot{\sigma}^s)' + \Omega_c(\dot{\sigma}^c)'$$

$$\boldsymbol{D^{eq} = \Omega_s D^s S_1^s + \Omega_c D^c S_1^c}$$

$$S_1^{s,c} = f\,(\Omega_s/\Omega_c, D^s, D^c)$$



$$\Omega_c = \frac{A_c}{A}$$

$$\Omega_s = 1 - \Omega_c$$

Implementation for 2D

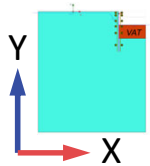
Kinematic conditions

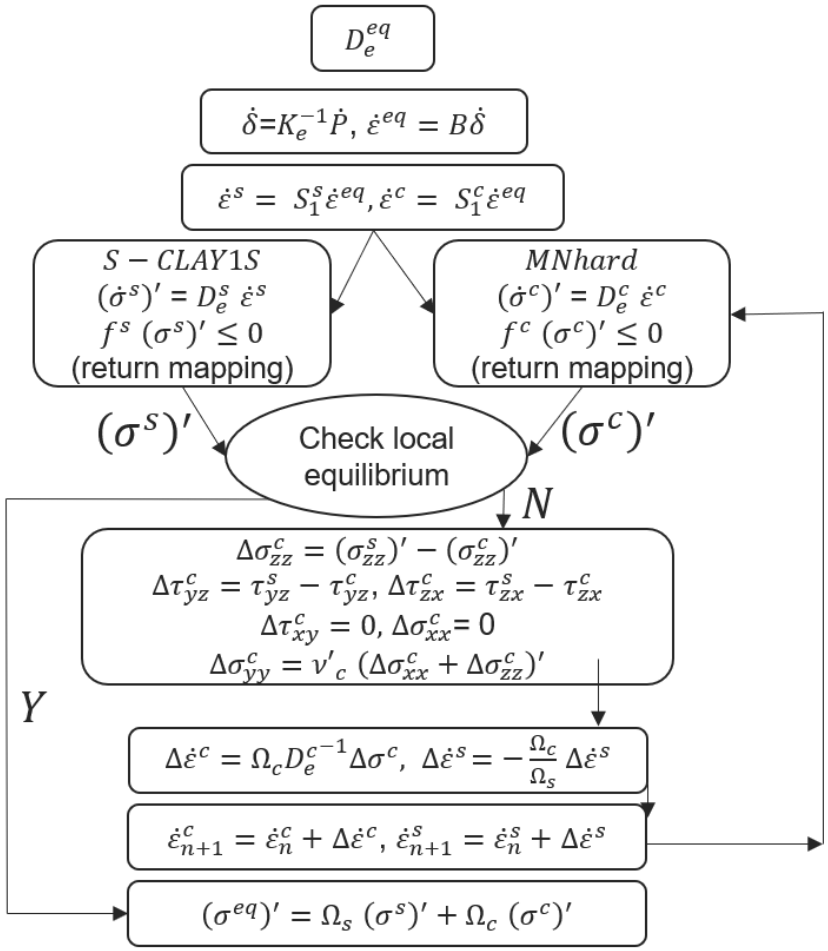
$$\dot{\varepsilon}_{xx}^{eq} = \dot{\varepsilon}_{xx}^{col} = \dot{\varepsilon}_{xx}^{soil}$$
$$\dot{\varepsilon}_{yy}^{eq} = \dot{\varepsilon}_{yy}^{col} = \dot{\varepsilon}_{yy}^{soil}$$
$$\dot{\gamma}_{xy}^{eq} = \dot{\gamma}_{xy}^{col} = \dot{\gamma}_{xy}^{soil}$$

Local equilibrium

$$\dot{\sigma}'^{eq}_{zz} = \dot{\sigma}'^{col}_{zz} = \dot{\sigma}'^{soil}_{zz}$$
$$\dot{\tau}_{yz}^{eq} = \dot{\tau}_{yz}^{col} = \dot{\tau}_{yz}^{soil}$$
$$\dot{\tau}_{zx}^{eq} = \dot{\tau}_{zx}^{col} = \dot{\tau}_{zx}^{soil}$$

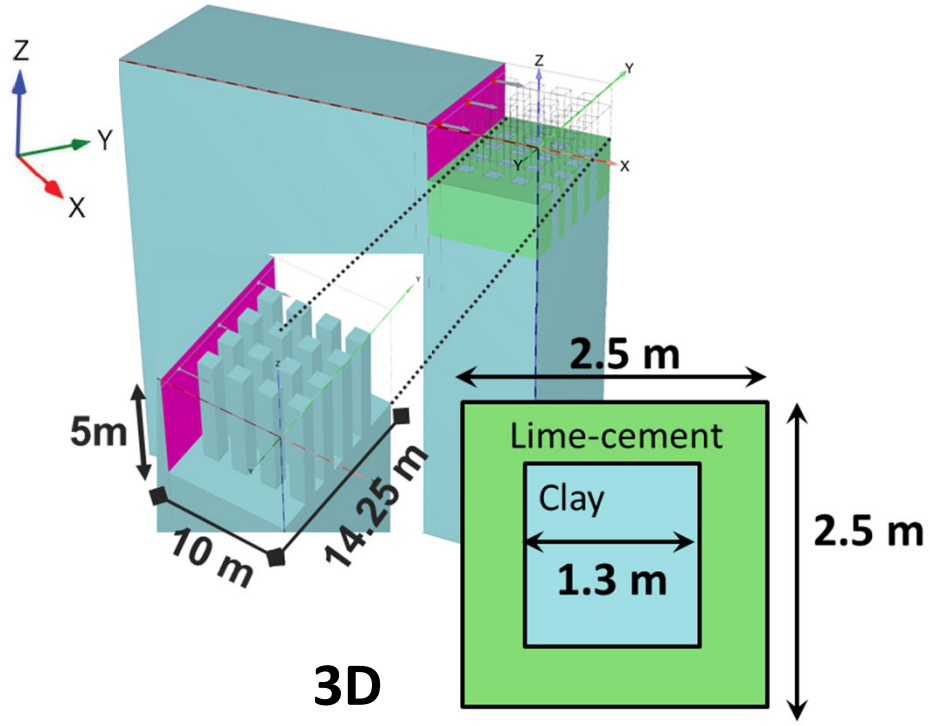
$$\boldsymbol{D^{eq}} = \Omega_s D^s \boldsymbol{S_1^s} + \Omega_c D^c \boldsymbol{S_1^c}$$

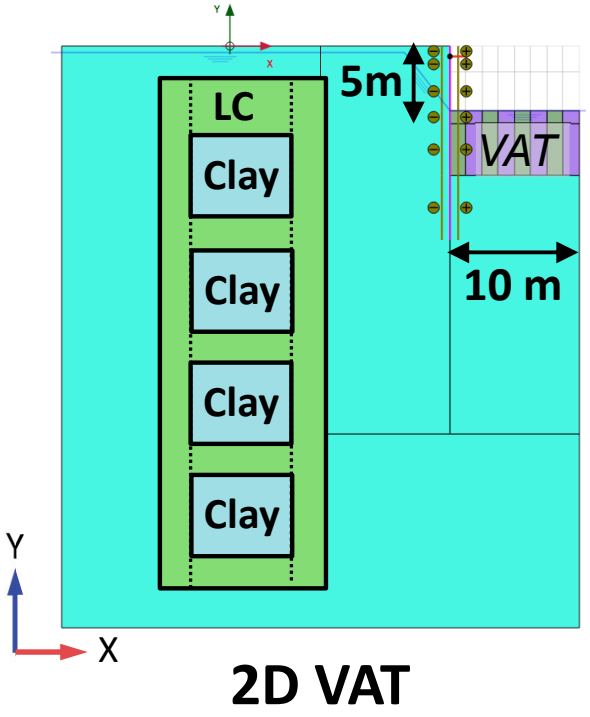




VAT Verification

Column : MNhard
Clay : SCLAY1S
Column fraction : Ω_c

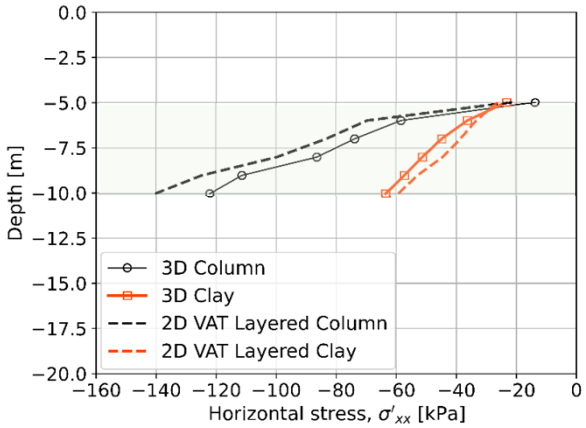


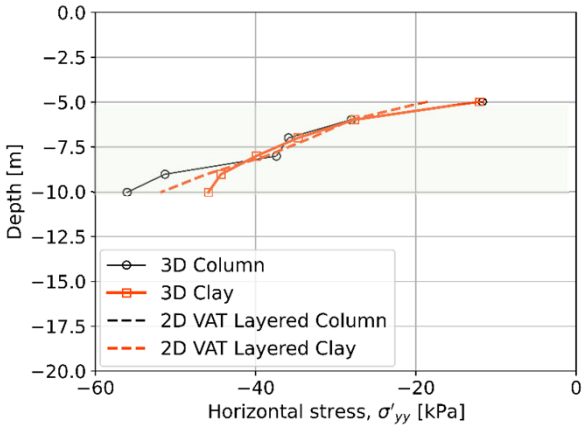


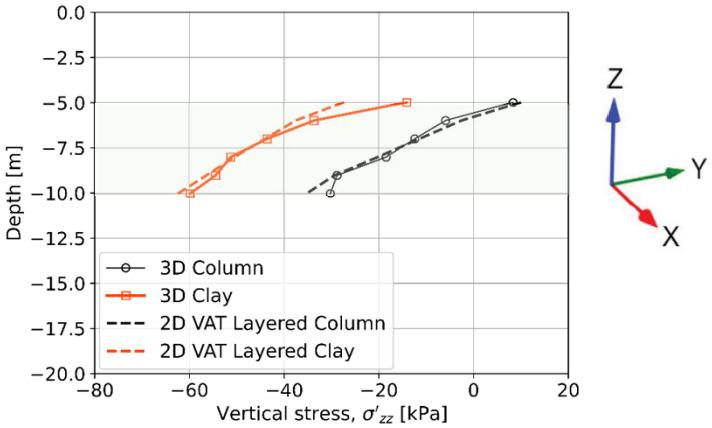
Ω_c = 0.64-1.00

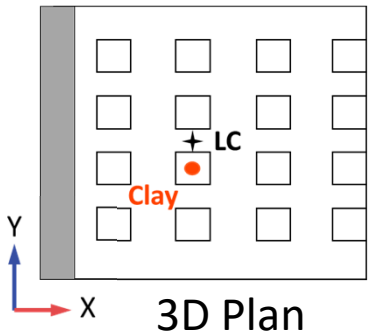
(Layer dependent)

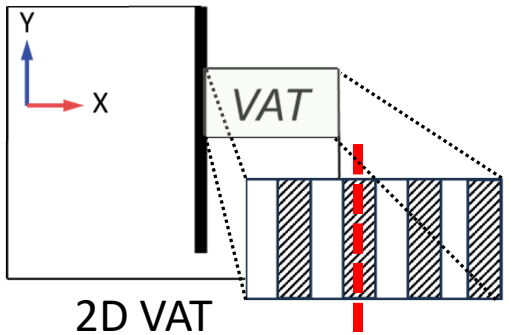
VAT Verification







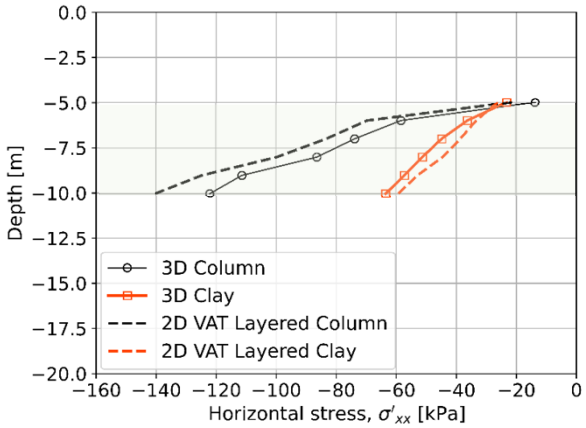


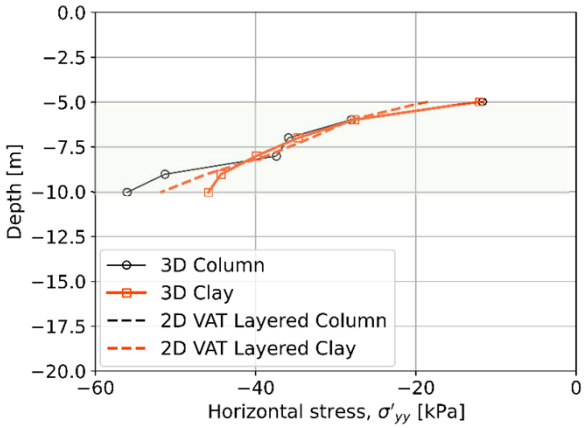


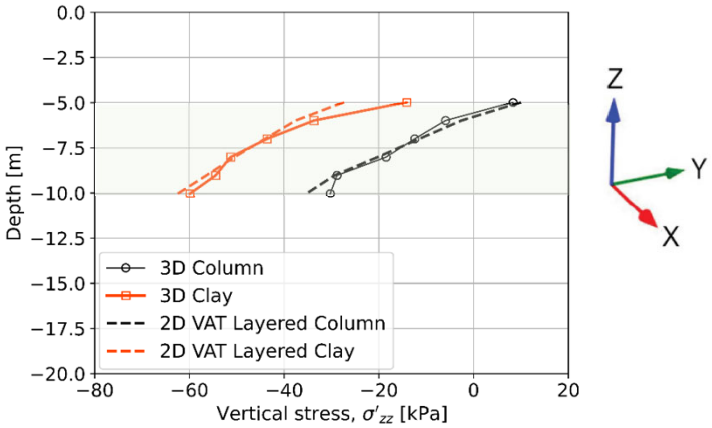
Ω_c = 0.64-1.00

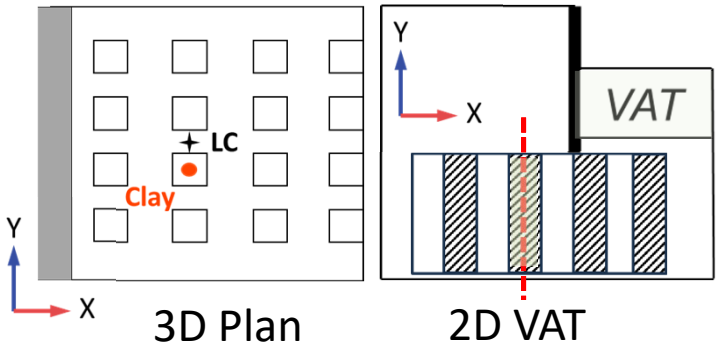
(Layer dependent)

VAT Verification









3D Analysis

$$\dot{\sigma}'^{eq}_{yy} = \dot{\sigma}'^{col}_{yy} = \dot{\sigma}'^{soil}_{yy}$$

$$\dot{\tau}^{eq}_{xy} = \dot{\tau}^{col}_{xy} = \dot{\tau}^{soil}_{xy}$$

$$\dot{\tau}^{eq}_{yz} = \dot{\tau}^{col}_{yz} = \dot{\tau}^{soil}_{yz}$$

2D Analysis

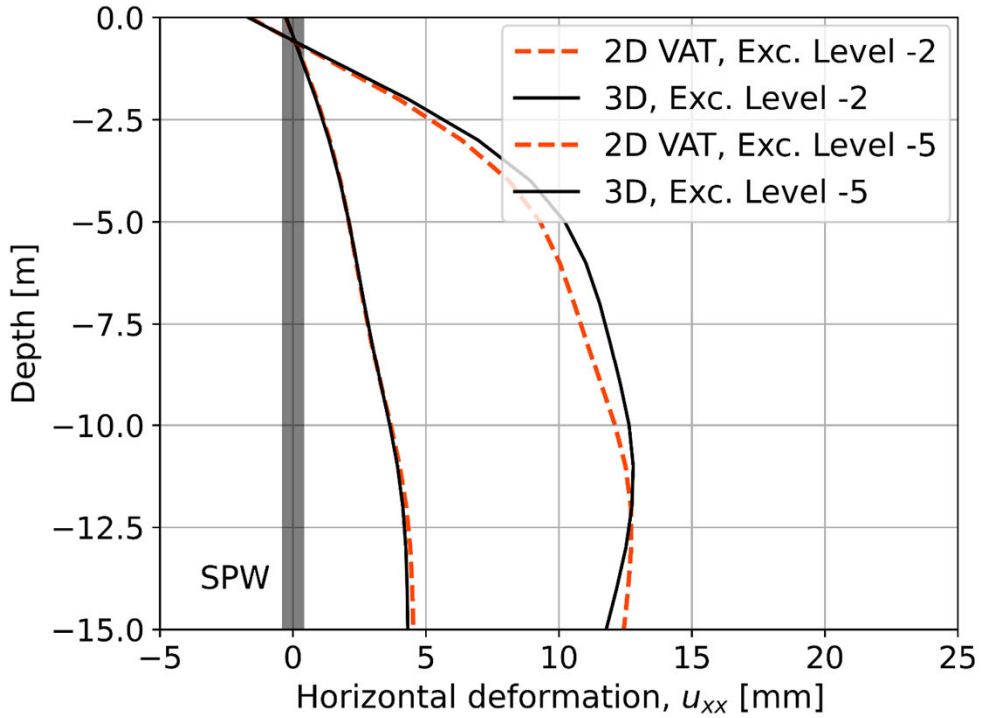
$$\dot{\sigma}'^{eq}_{zz} = \dot{\sigma}'^{col}_{zz} = \dot{\sigma}'^{soil}_{zz}$$

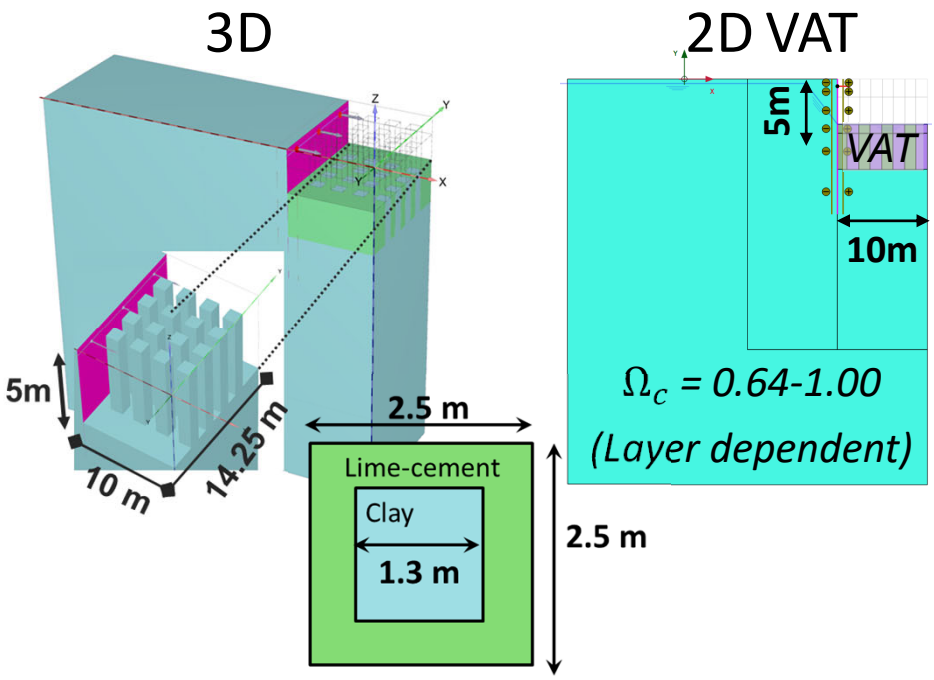
$$\dot{\tau}^{eq}_{zx} = \dot{\tau}^{col}_{zx} = \dot{\tau}^{soil}_{zx}$$

$$\dot{\tau}^{eq}_{yz} = \dot{\tau}^{col}_{yz} = \dot{\tau}^{soil}_{yz}$$

→ Zero for plane strain conditions

Comparison of 3D & 2D-VAT





Conclusions

- Accurate predictions of the deformations necessitate taking into account *the installation effects* and *the three-dimensional effects*.
- Using a nonlinear elasto-plastic models ensured a realistic representation of stabilised clay behaviour.
- The analytically established VAT for the unloading state was implemented into a FEM code and successfully applied to a 2D boundary value problem.
- The 2D VAT enables time-saving results comparable to 3D analysis and simplifies sensitivity analyses.

Future recommendations

- Installation effects should be considered as a part of the Observational Method.
- Probabilistic methods can be used to account for the spatial variability of the properties of both natural and stabilised clay.

Tack!



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CHAT
Webbinarium 2023-11-17: Djupstabilisering

[12:20] Jonsson, Carl

What would your recommendation be for modeling stabilized soil in case where simpler models than S-CLAY1S have to be used. Given Triaxial both in ext/comp are quite rare?

[12:21] Naseer Baho (Gäst)

Where did you use elasto-plastic parameters? I can see elastic parameter matrix

[12:25] Tan Manh Do

Why did you simplify piles? Plaxis 3d can simulate volume pile (round shape) and Plaxis 2d can embedded piles. Then if the piles are simplified? Any interface elements are considered or simulated in your models?

like 3
[12:28] Per Gunnvard

In Plaxis 3D a swept mesh can be used to reduce the number of extra elements due to the rounded shape, which might save enough time

like 1
[12:30] Tara Wood
Embedded pile is wished in place
[12:30] Tara Wood
No installation effect
[12:31] Edstam, Torbjörn

I have two questions

[12:34] MATTI KIVELÖ (Gäst)

Can we miss any failuremodes, behavior, when using this model/simplifications?

[12:34] Stefan Larsson

There is an inherent variability regarding the strength and stiffness parameters. Also, The strength and stiffness also increase in time and the variability may also differs with time. Furtheremore, results from labb test normally differs from what can be achieved in the field. How do you determine the strength and stiffness parameters for the simulations? part2 of the project

[12:45] viking TRV (Gäst)

TKgeo (TRVInfra 230 numera) är ett regelverk baserat på tidigare erfarenhet. Det vi har gjort i Västlänken är INTE baserat på "tidigare" erfarenhet. Därför utförs sådana övningar som "särskild utredning". En skriftlig version av vad Per utvecklade muntligen.