CG 15
DEEP EXCAVATIONS

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CONTENTS

- **Introduction**
- **Simplified example**
  - Influence of constitutive model
  - Influence of relative stifffness wall/soil
  - Influence of wall length
- **Comparison of FE-analysis with in situ measurements**
- **Factors of safety for deep excavations**

INTRODUCTION

Analysis of a deep excavation involves modelling of

- various excavation stages
- interaction wall / soil > interface elements
- changes in groundwater level
- struts or anchors (including load transfer to soil)
- adjacent structures (buildings, tunnels, piles, …)

Requires advanced constitutive model because

- stress paths in soil are not monotonic (significant change in stress path direction)
- primary loading and unloading / reloading occurs in different parts of the domain analysed
- some areas will experience large strains with significant plastic deformations, others will be in the very small strain range

  > simple elastic - perfectly plastic models not suffcient

SIMPLIFIED EXAMPLE

Goal of study

- assess influence of relative stiffness between wall and soil on results
- assess influence of wall length
- show influence of constitutive model

> **show trends and qualitative behaviour rather than quantitative comparison**

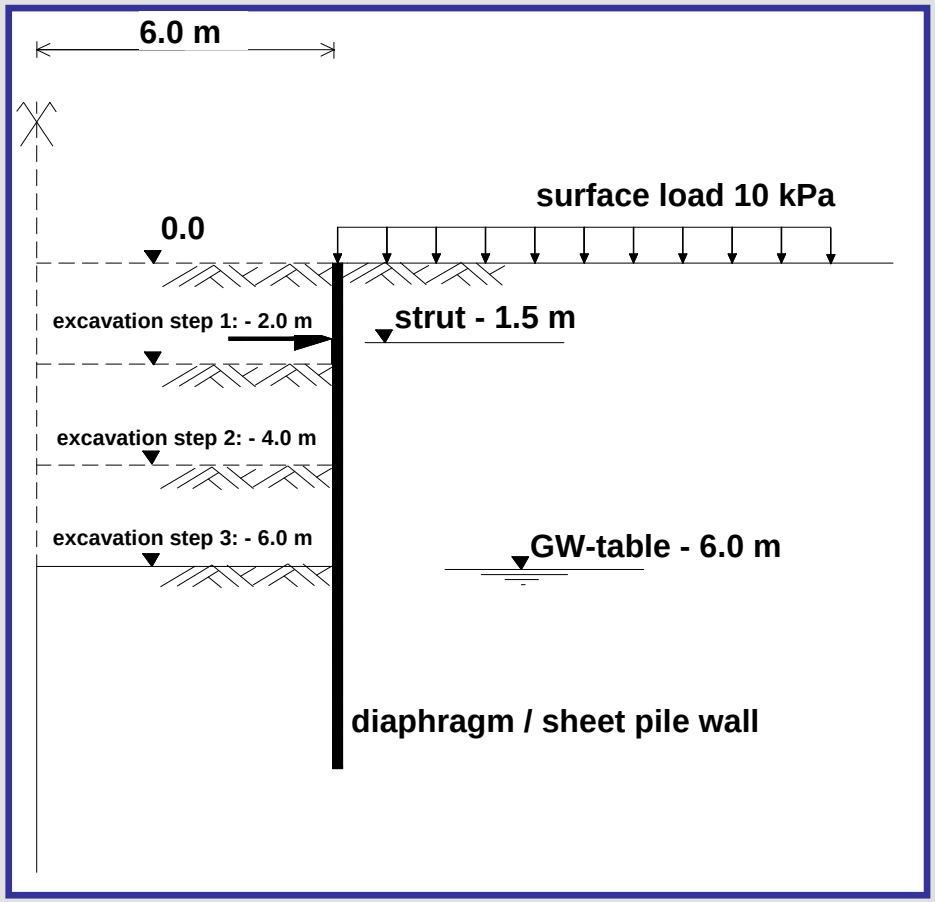
Constitutive models

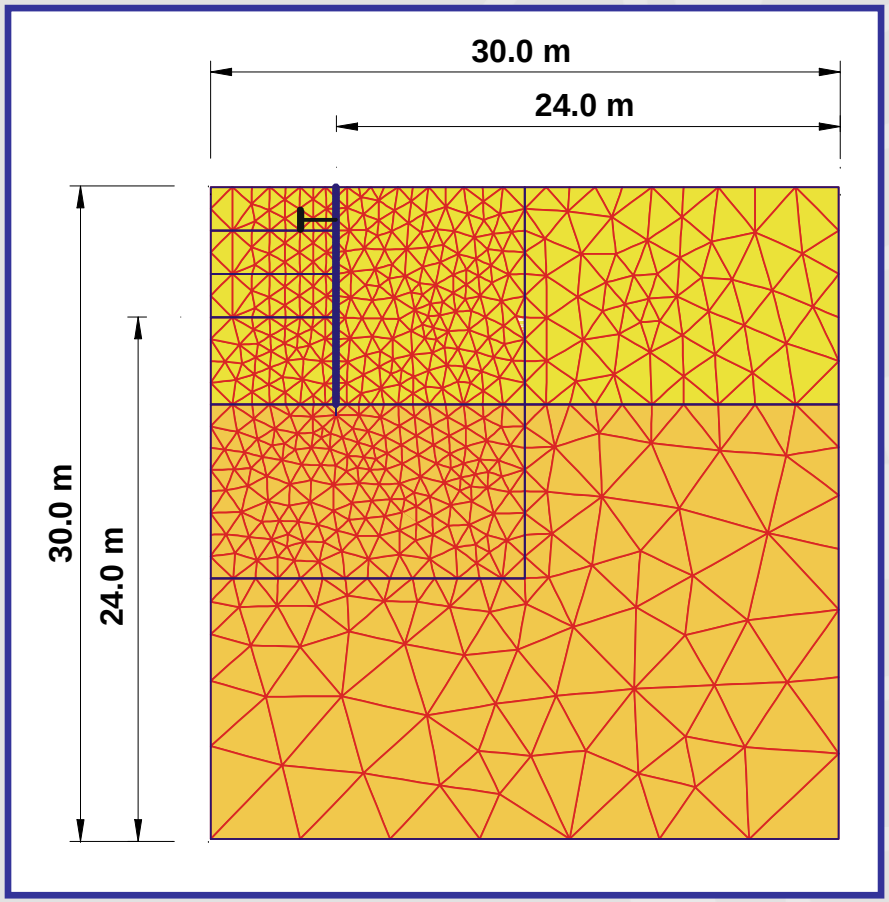
- Mohr-Coulomb
- Hardening Soil
- HS_small
- Soft Soil (excavation in clay only)
- Modified Cam Clay (excavation in clay only)

Results

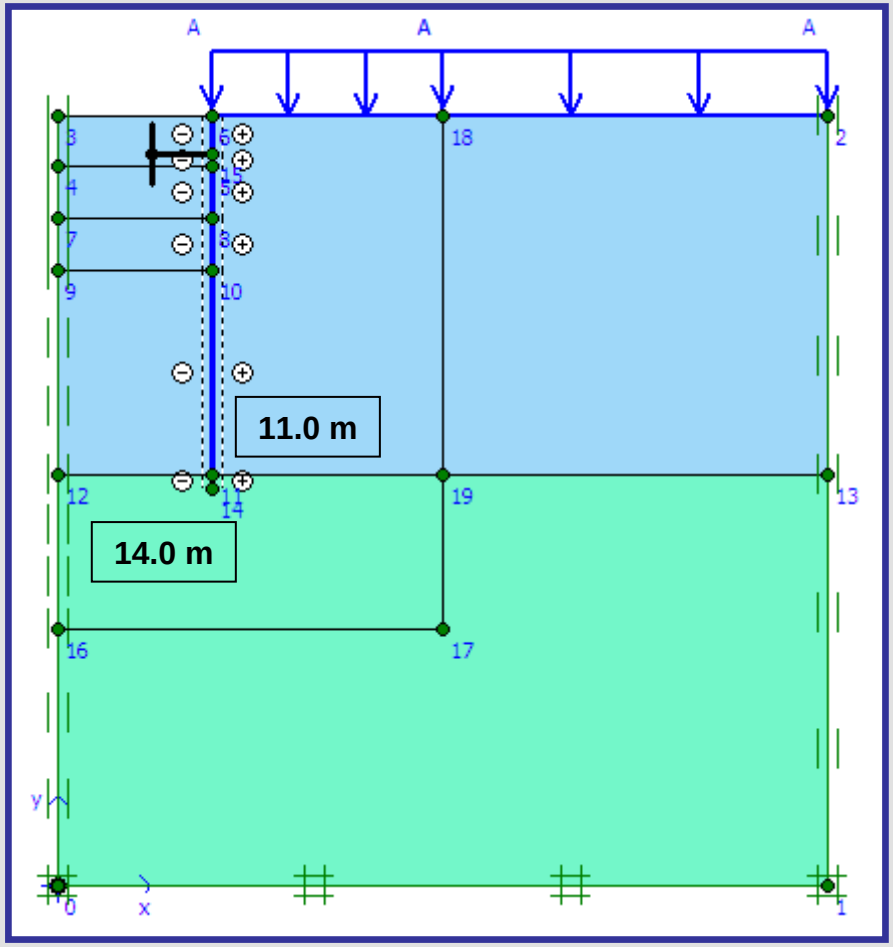
- wall deflection
- bending moments / strut forces
- earth pressure distribution (active - passive)
- vertical displacements behind wall

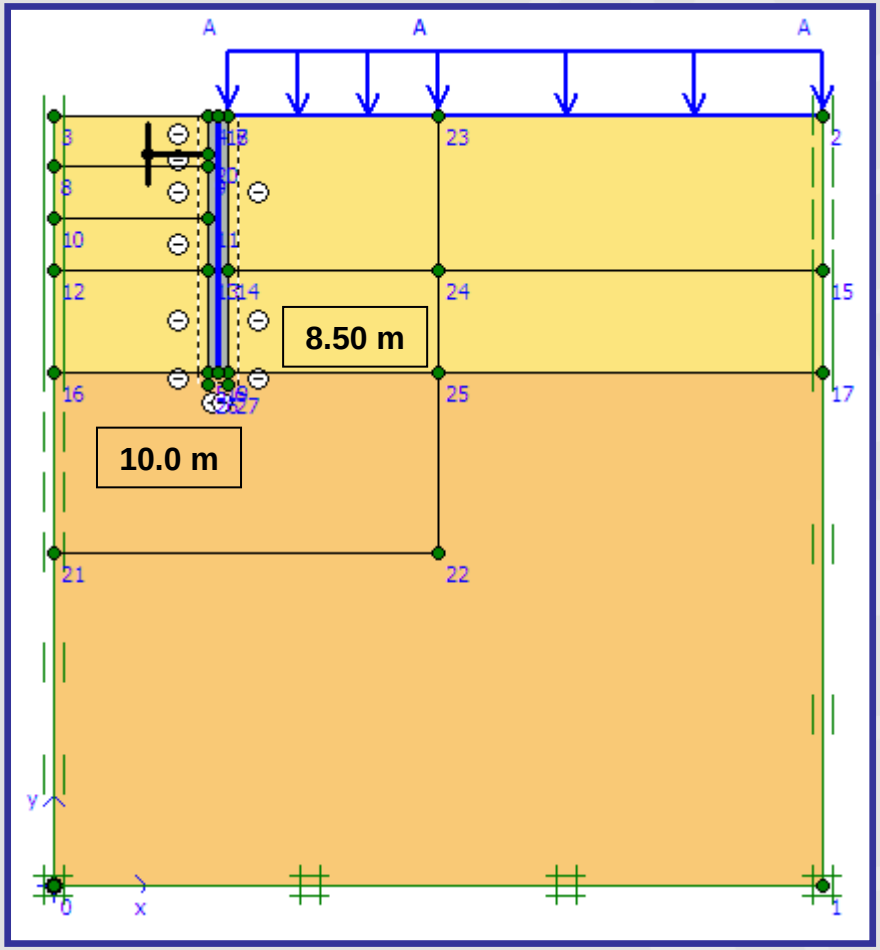
SIMPLIFIED EXAMPLE - GEOMETRY





SIMPLIFIED EXAMPLE - VARIATIONS





Variation of soil stiffness: clay - sand (factor of 10 in difference of stiffness)

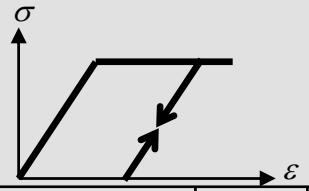
Variation of wall stiffness: sheet pile - diaphragm wall

Variation of wall length: fixed / free earth support (long / short wall)

based on conventional analysis

SIMPLIFIED EXAMPLE - PARAMETERS "CLAY"

Mohr-Coulomb Model

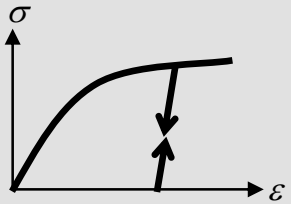


		E [kN/m²]	Tension cut-off [kN/m²]	ν [-]	c´ [kN/m²]	φ´ [°]	ψ [°]	K_0 = 1-sin φ	R_{inter} [-]
Clay	Drained	4 500 18 000	0.0	0.35	5	26	0	0.562	0.7

Soft Soil Model

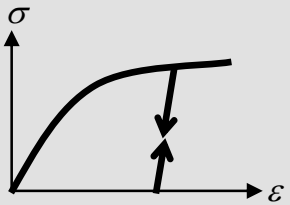
Modified Cam Clay Modell

$\lambda^* > \lambda$, $\kappa^* > \kappa$, $\varphi > M$



		λ* [-]	κ* [-]	ν [-]	c´ [kN/m²]	φ´ [°]	ψ [°]	R_{inter} [-]
Clay	Drained	0.0222	0.01	0.2	5	26	0	0.7

HS (HS-small) Model

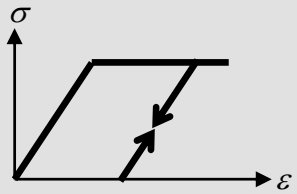


p_{ref} = 100 kPA

		$E_{50,ref}$ [kN/m²]	$E_{oed,ref}$ [kN/m²]	$E_{ur,ref}$ [kN/m²]	$E_{0,ref}$ [kN/m²]	m [-]	ν [-]	c´ [kN/m²]	φ´ [°]	ψ [°]	$\gamma_{0.7}$ [-]	R_{inter} [-]
Clay	Drained	4 500	4 500	18 000	100 000	1.0	0.2	5	26	0	$2x10^{-4}$	0.7

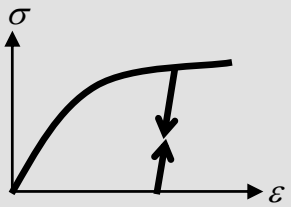
SIMPLIFIED EXAMPLE - PARAMETERS “SAND"

Mohr-Coulomb Model



		E [kN/m²]	Tension cut-off [kN/m²]	ν [-]	c´ [kN/m²]	φ´ [°]	ψ [°]	K_0 = 1-sin φ	R_{inter} [-]
Sand	Drained	45 000 180 000	0.0	0.3	1	35	5	0.426	0.8

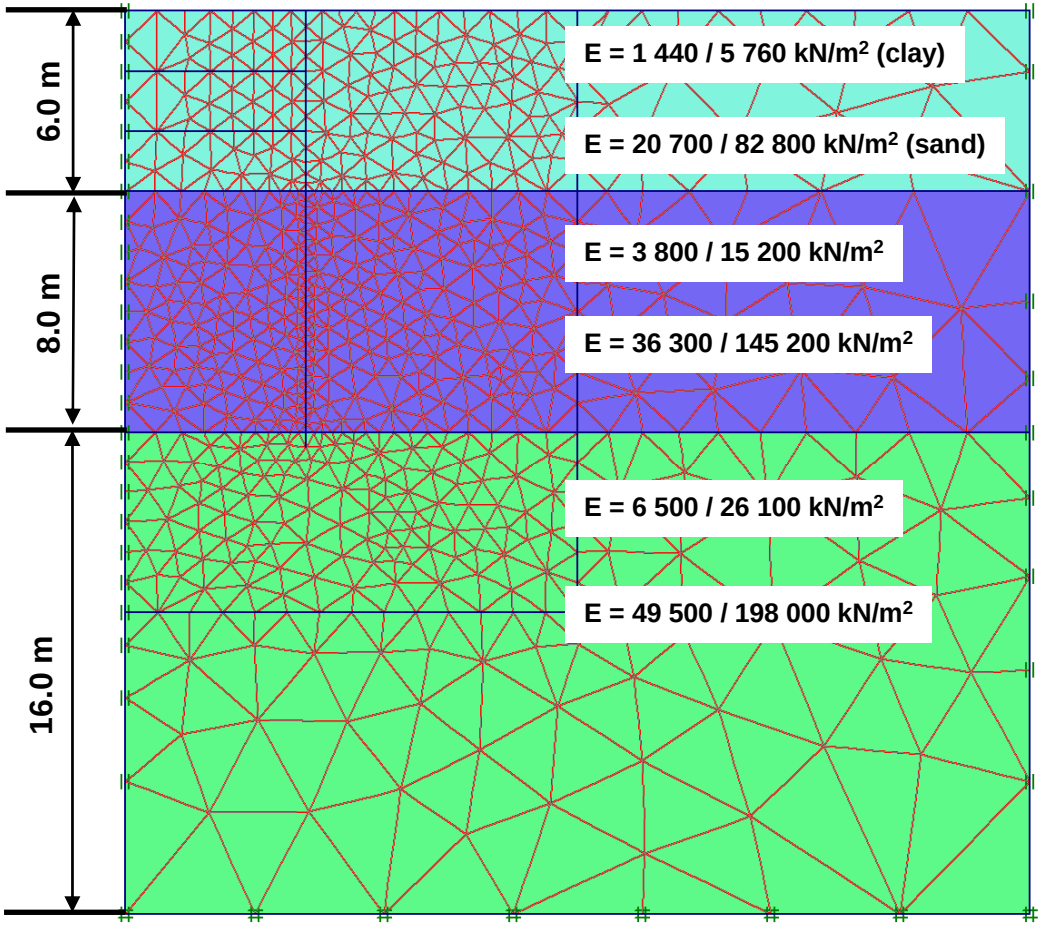
HS (HS-small) Model



p_{ref} = 100 kPA

		$E_{50,ref}$ [kN/m²]	$E_{oed,ref}$ [kN/m²]	$E_{ur,ref}$ [kN/m²]	$E_{0,ref}$ [kN/m²]	m [-]	ν [-]	c´ [kN/m²]	φ´ [°]	ψ [°]	$\gamma_{0.7}$ [-]	R_{inter} [-]
Sand	Drained	45 000	45 000	180 000	400 000	0.55	0,2	1	35	5	2×10^{-4}	0.8

SIMPLIFIED EXAMPLE - VARIATIONS MOHR-COULOMB



Mohr-Coulomb models

MC_1a: constant stiffness $E_{ur,ref}$

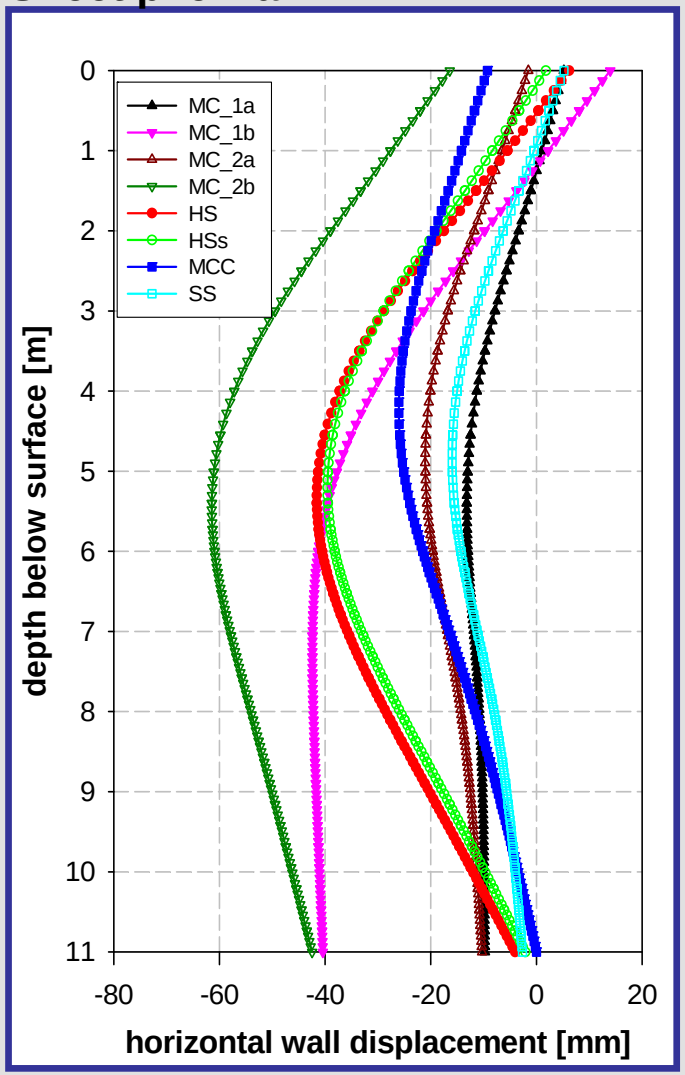
MC_1b: constant stiffness $E_{50,ref}$

MC_2a: 3 layers with average values based on E_{ur}

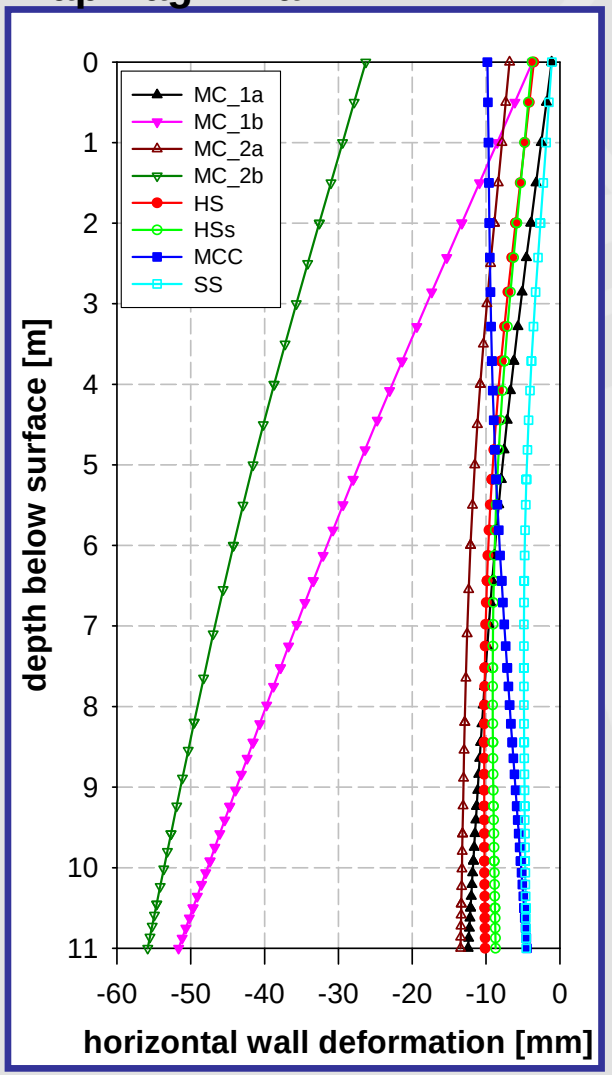
MC_2b: 3 layers with average values based on E_{50}

WALL DISPLACEMENTS - CLAY - SHORT

Sheet pile wall



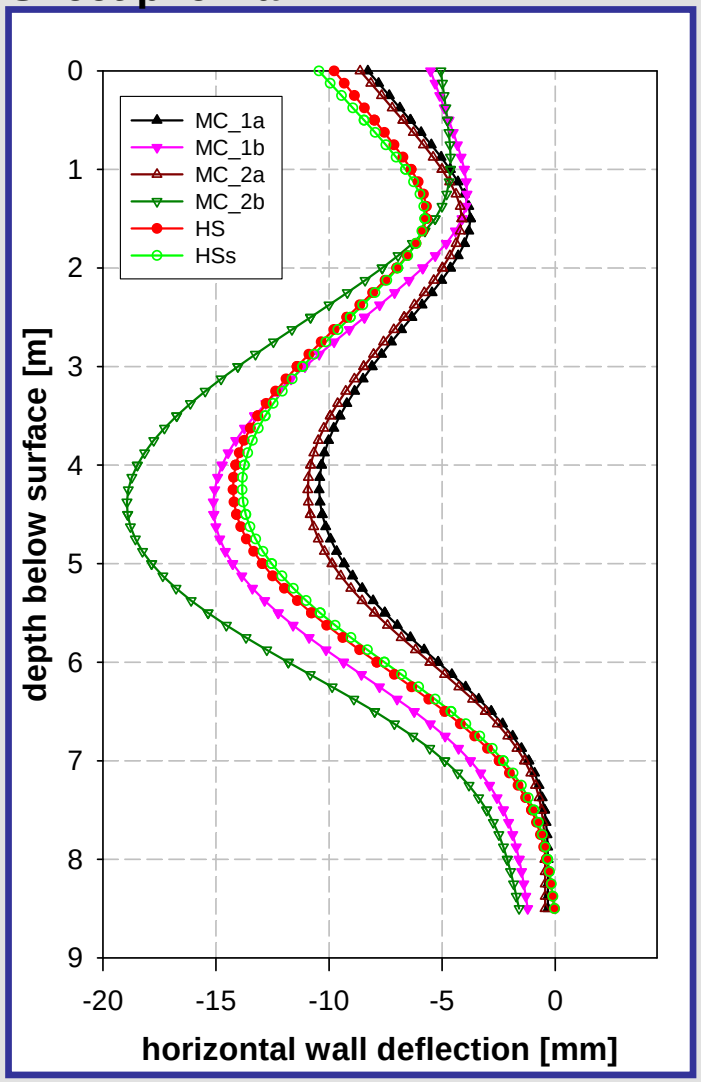
Diaphragm wall



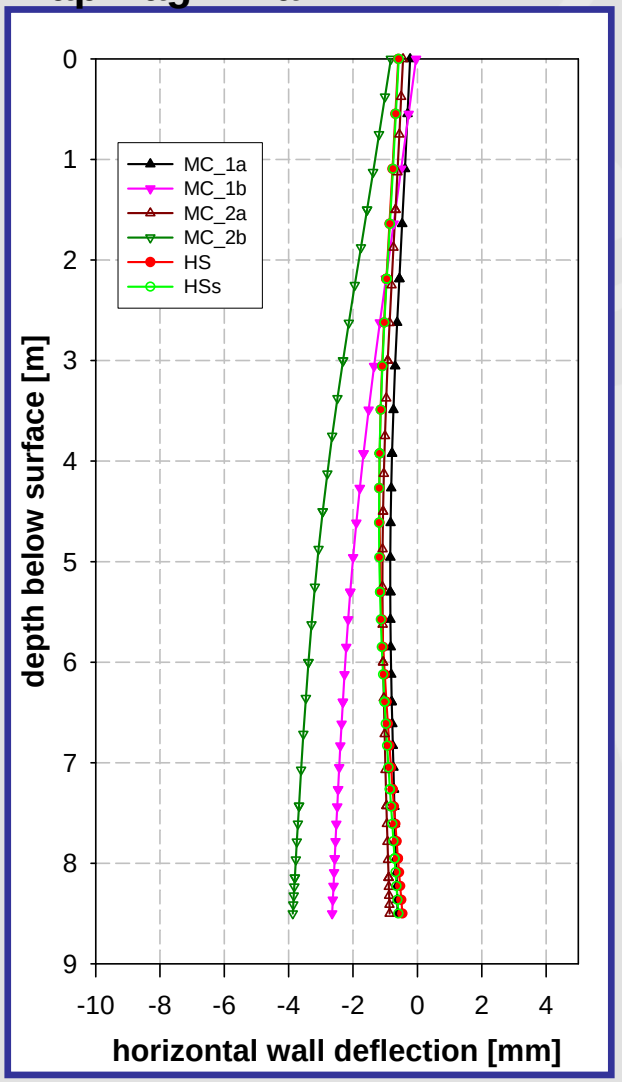
Unrealistic displacements of bottom of wall for MC-models based on E_{50}

WALL DISPLACEMENTS - SAND - SHORT

Sheet pile wall

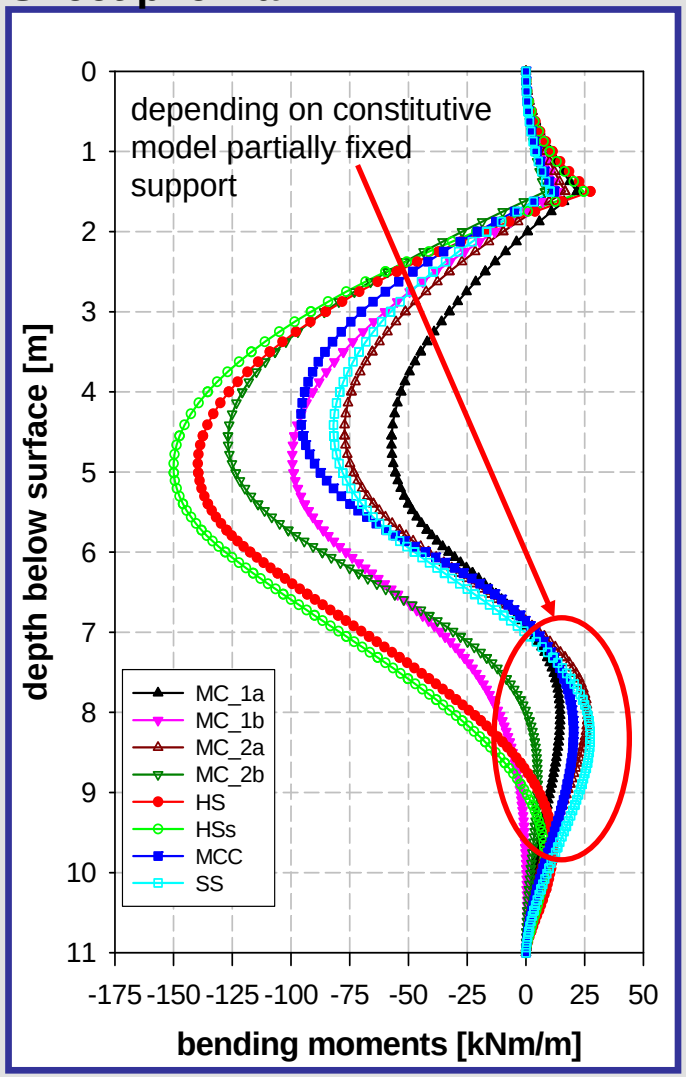


Diaphragm wall

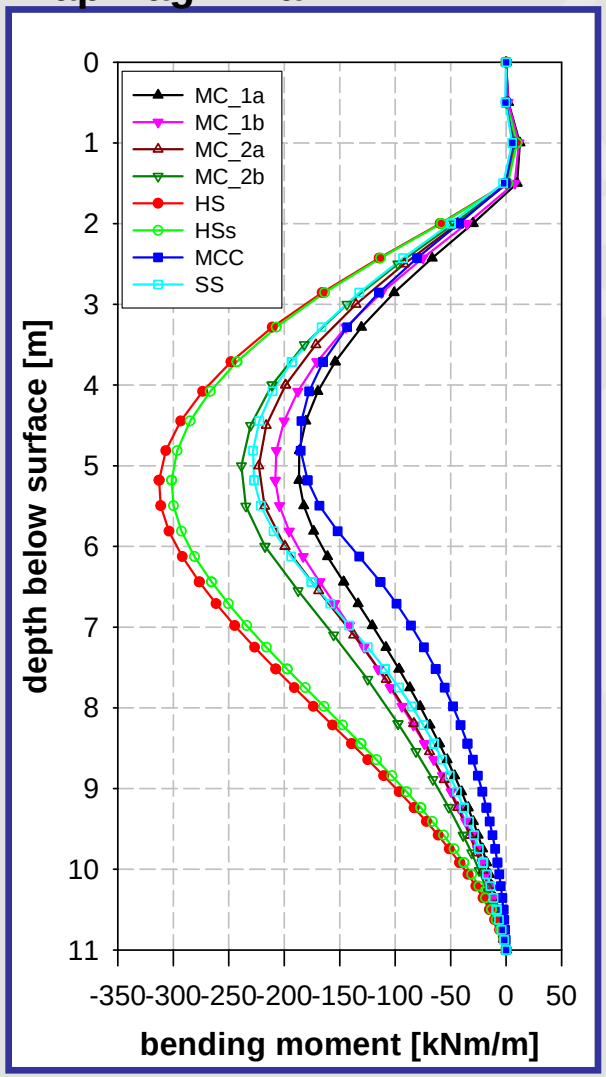


BENDING MOMENTS - CLAY - SHORT

Sheet pile wall



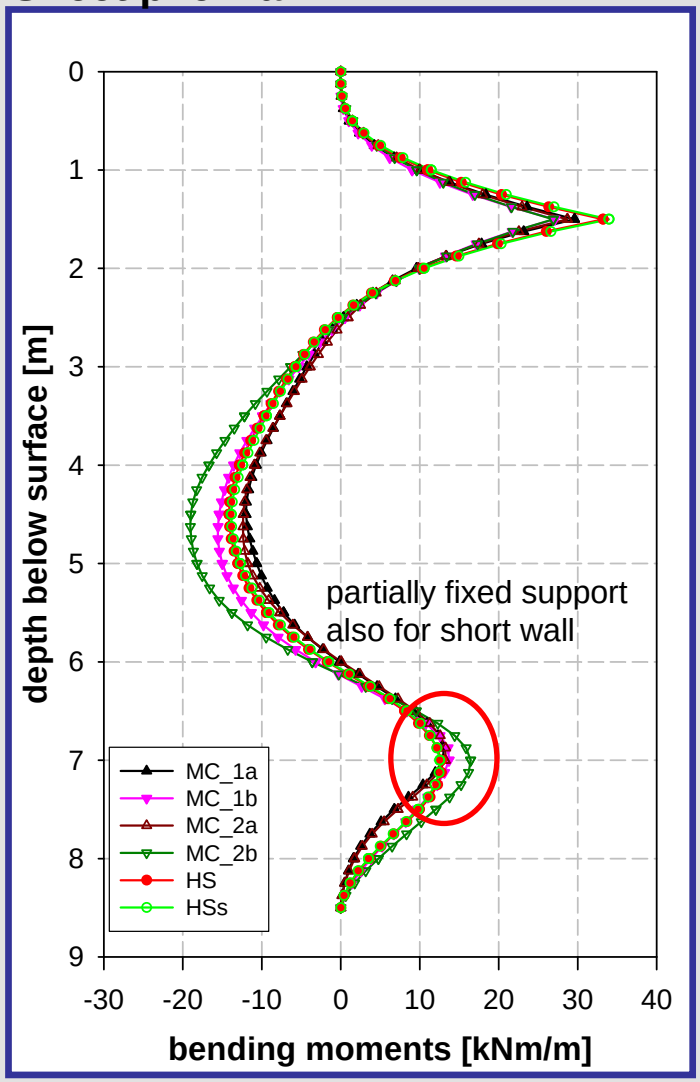
Diaphragm wall



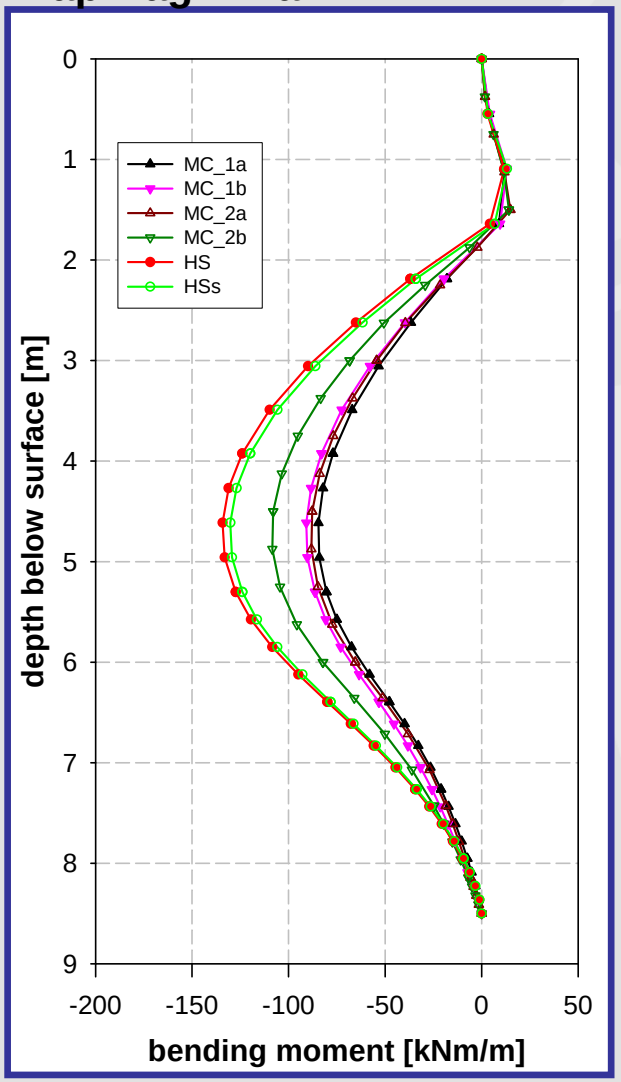
HS-models yield largest bending moments, MC-models with layers sensitive to assumptions

BENDING MOMENTS - SAND - SHORT

Sheet pile wall



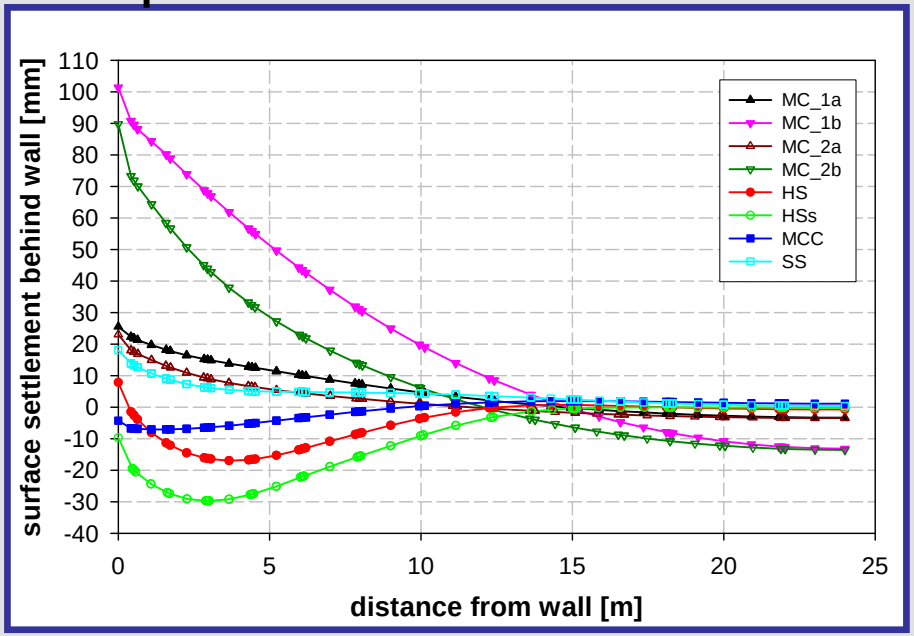
Diaphragm wall



MC-models (E_{50}) yield largest bending moments for sheet pile wall

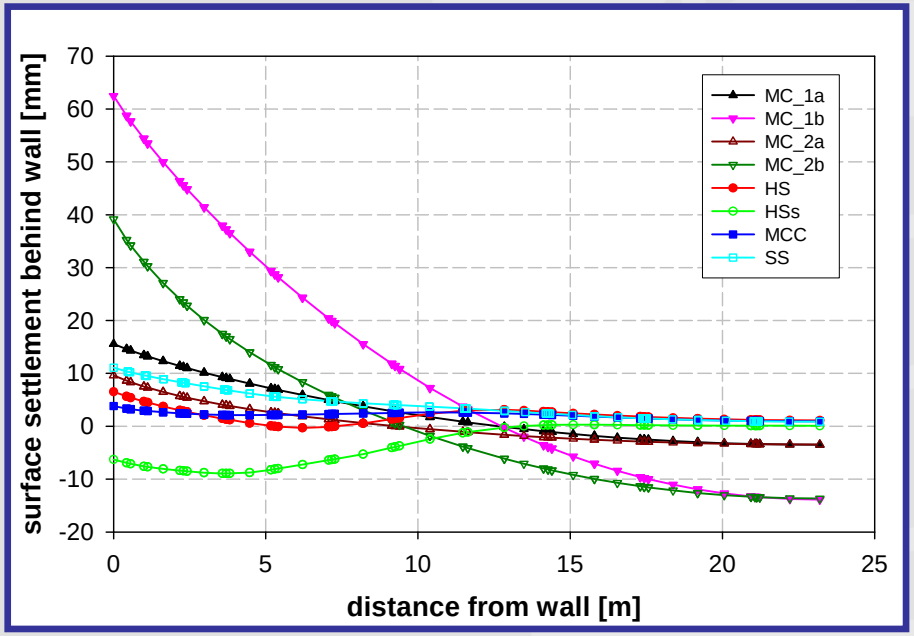
VERTIKAL DISPLACEMENTS BEHIND WALL - CLAY - SHORT

Sheet pile wall



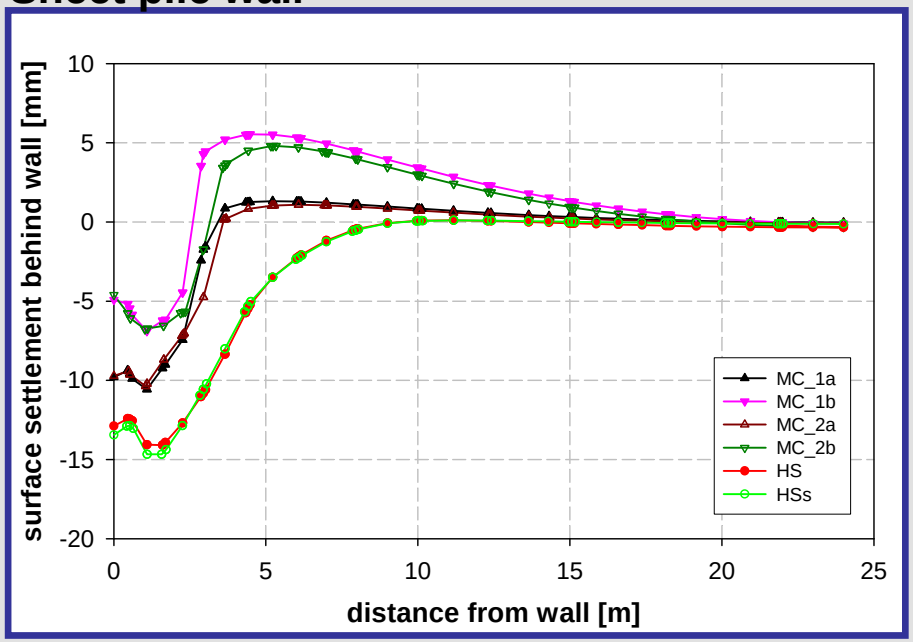
HS-small: largest settlements

Diaphragm wall



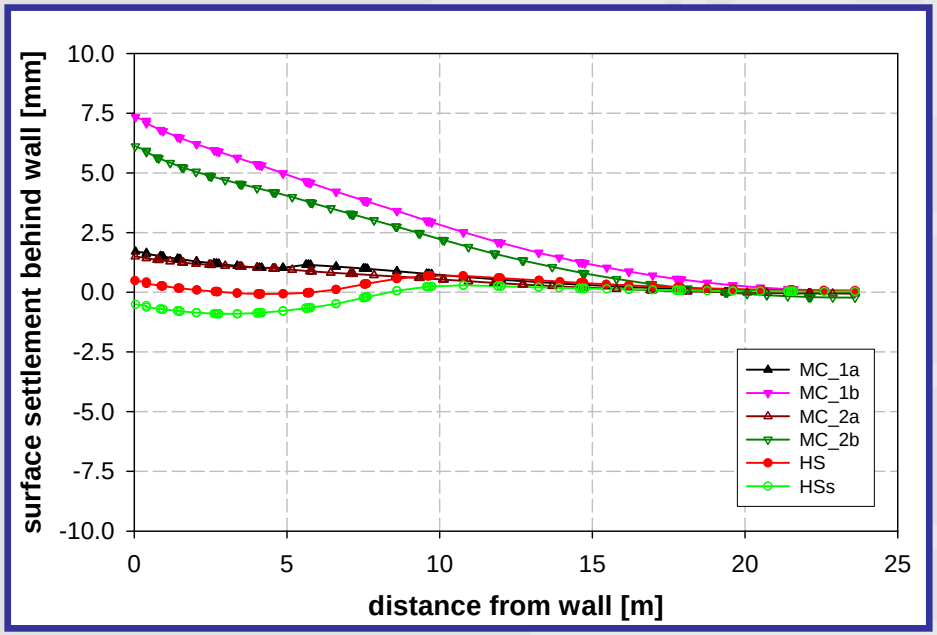
VERTIKAL DISPLACEMENTS BEHIND WALL - SAND - SHORT

Sheet pile wall



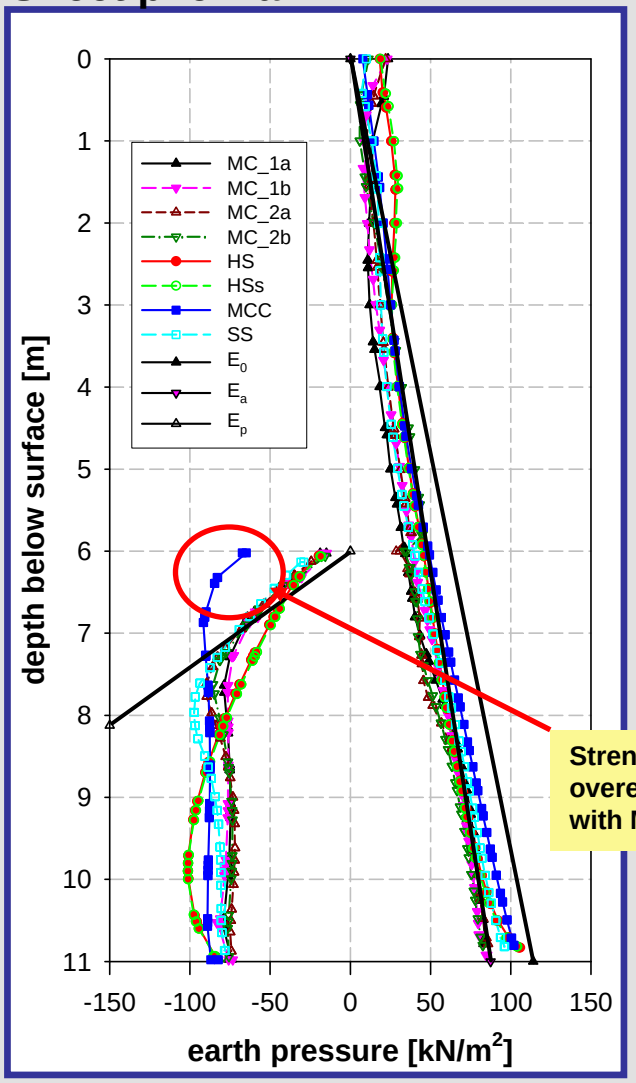
HS-small: largest settlements

Diaphragm wall

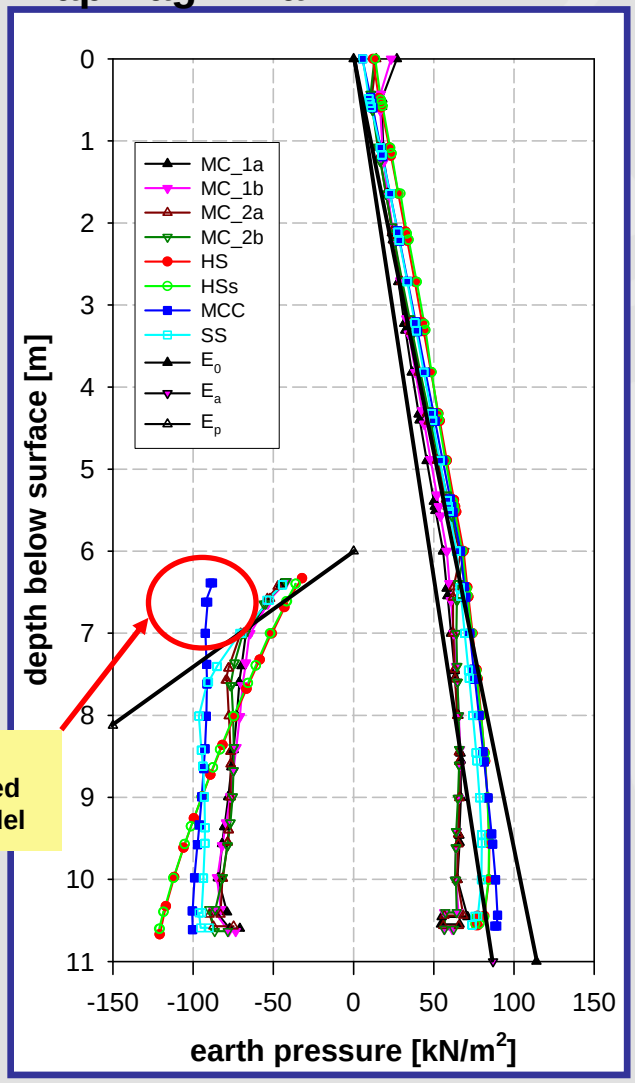


EARTH PRESSURE DISTRIBUTION - CLAY - SHORT

Sheet pile wall



Diaphragm wall

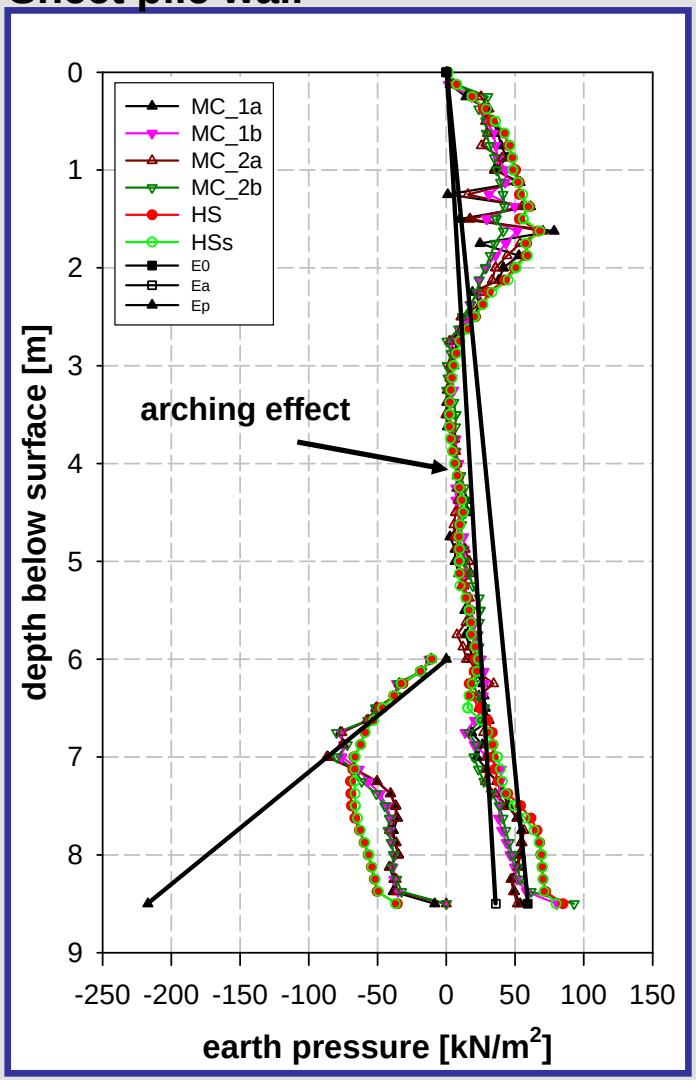


Strength overestimatated with MCC-model

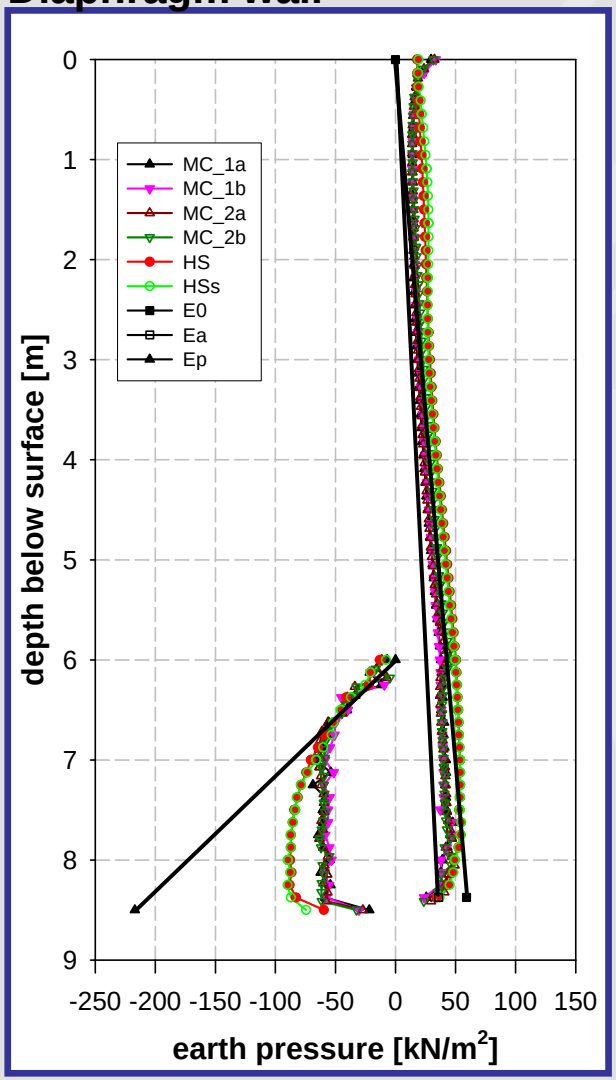
Insignificant earth pressure redistribution at strut level

EARTH PRESSURE DISTRIBUTION - SAND - SHORT

Sheet pile wall

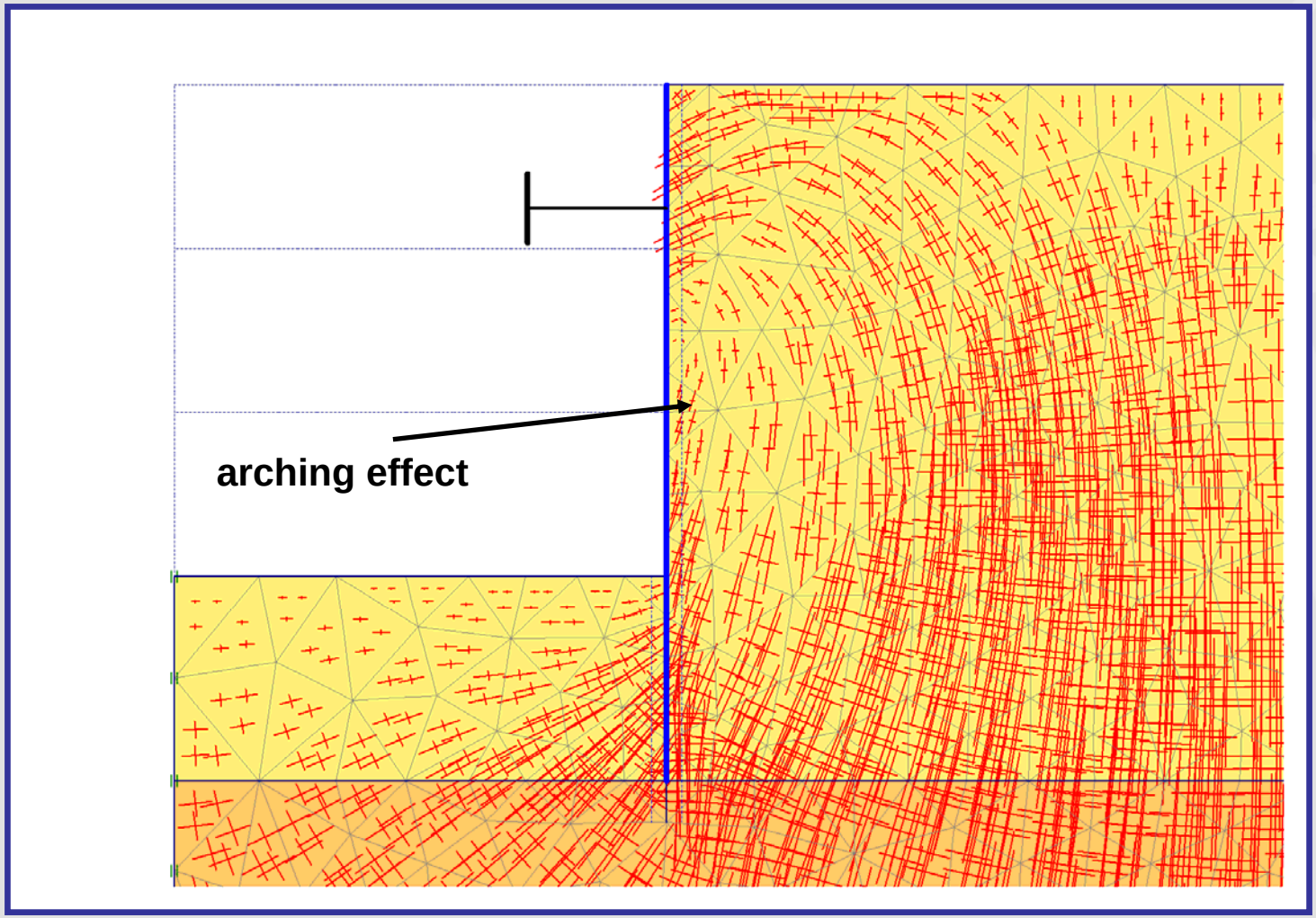


Diaphragm wall



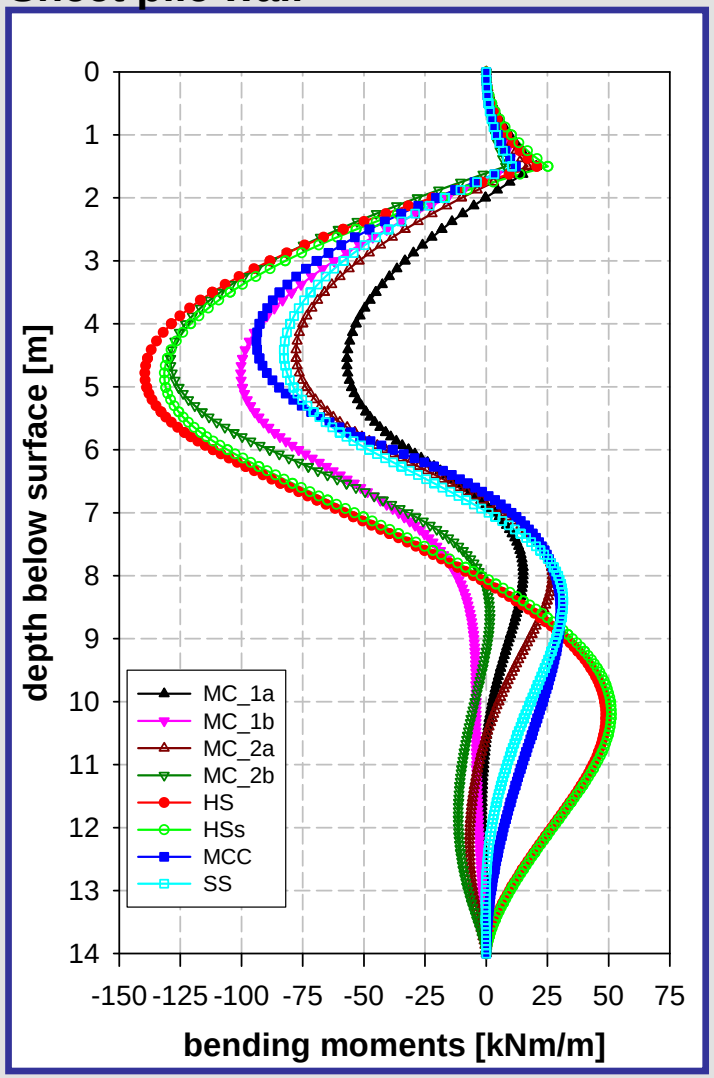
Significant earth pressure redistribution at strut level for sheet pile wall

SHEET PILE WALL - SAND - SHORT

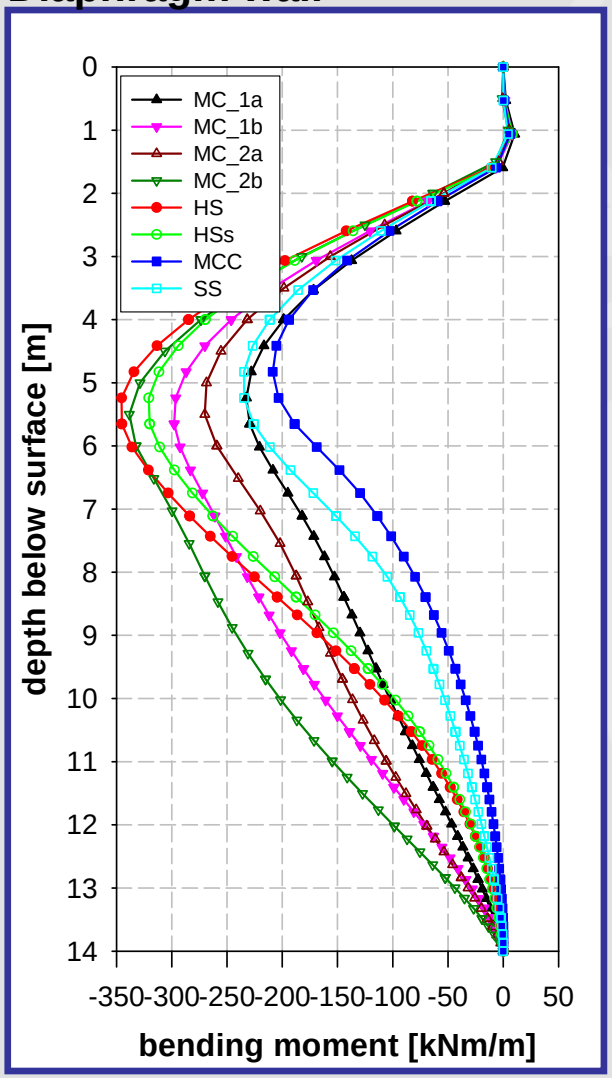


BENDING MOMENTS - CLAY - LONG

Sheet pile wall



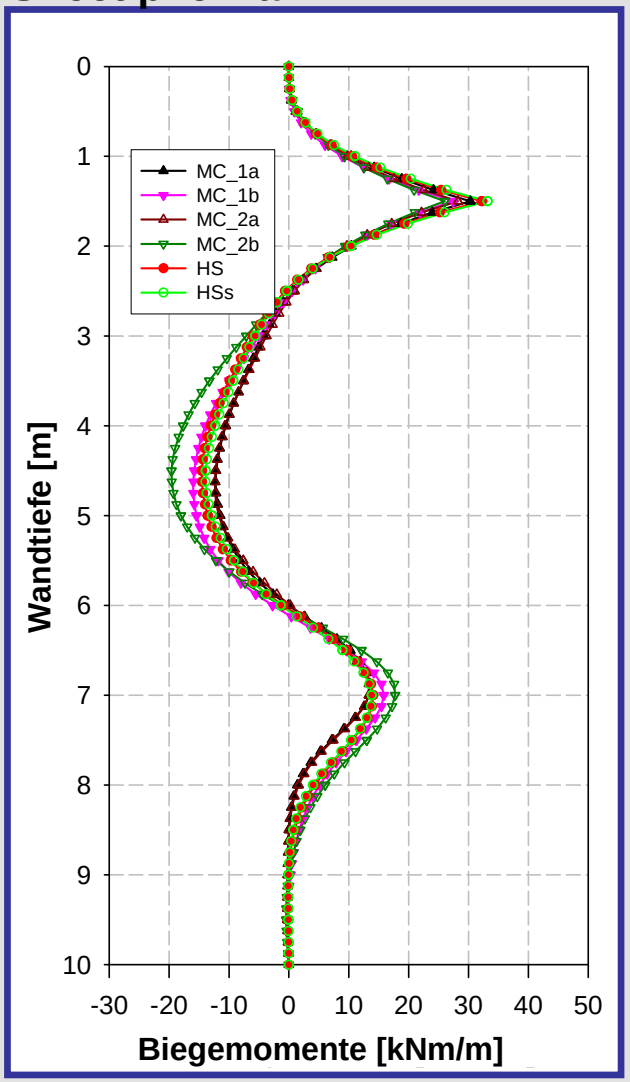
Diaphragm wall



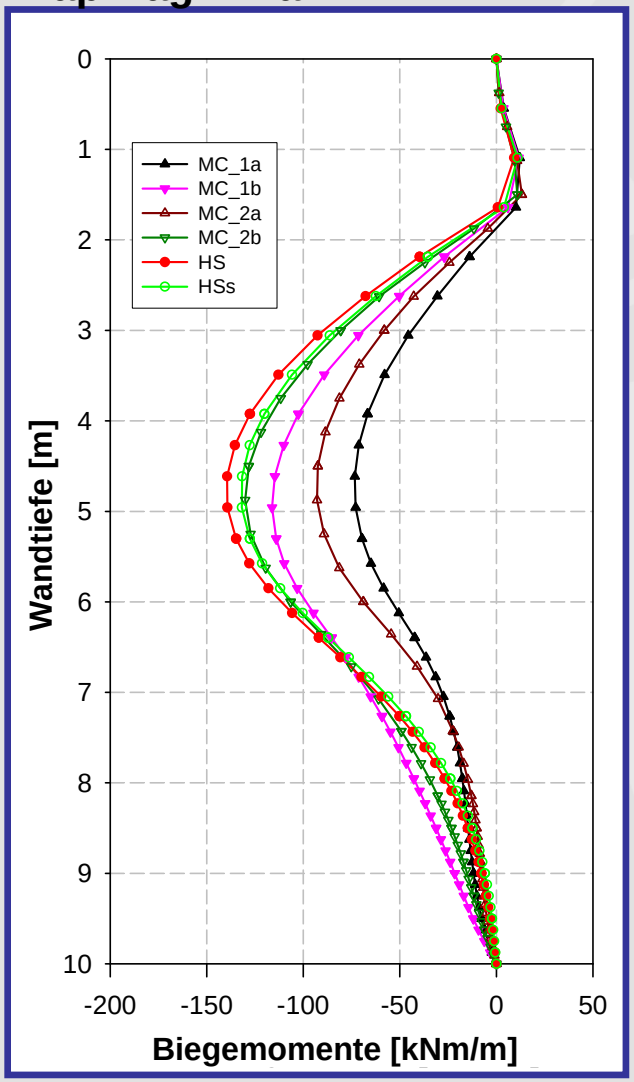
- Also for "long" wall fixed support only for some constitutive models (sheet pile wall)
- No fixed support for diaphragm wall

BENDING MOMENTS - SAND - LONG

Sheet pile wall



Diaphragm wall



STRUT FORCES

General note

- Influence of constitutive model and stiffness of wall is larger in clay than in sand
- Influence of wall length not significant
- Difference for MC-models approx. 10%

Clay

	"short" wall	"long" wall	
Sheet pile wall:	71 (MC_1a) - 138 (HSs)	70 (MC_1a) - 130 (HSs)	kN/m
Diaphragm wall:	140 (MCC) - 203 (HSs)	147 (SS) - 193 (HSs)	kN/m

Sand

	"short" wall	"long" wall	
Sheet pile wall:	88 (MC_2b) - 122 (HSs)	86 (MC_2b) - 120 (HSs)	kN/m
Diaphragm wall:	89 (MC_1a) - 135 (HSs)	82 (MC_1a) - 125 (HSs)	kN/m

SUMMARY FROM SIMPLIFIED EXAMPLE

Bending moments

Dependent on wall stiffness and relative stiffness wall-soil, less on wall length

Strut forces

Large influence of relative stiffness wall-soil

Wall deflection

Magnitude depends on stiffness of soil

Shape depends on relative stiffness wall-soil

Earth pressure distribution

Depends on displacement of wall (stiffness of wall and soil)

Redistribution depends on stiffness of soil and relative stiffness wall-soil

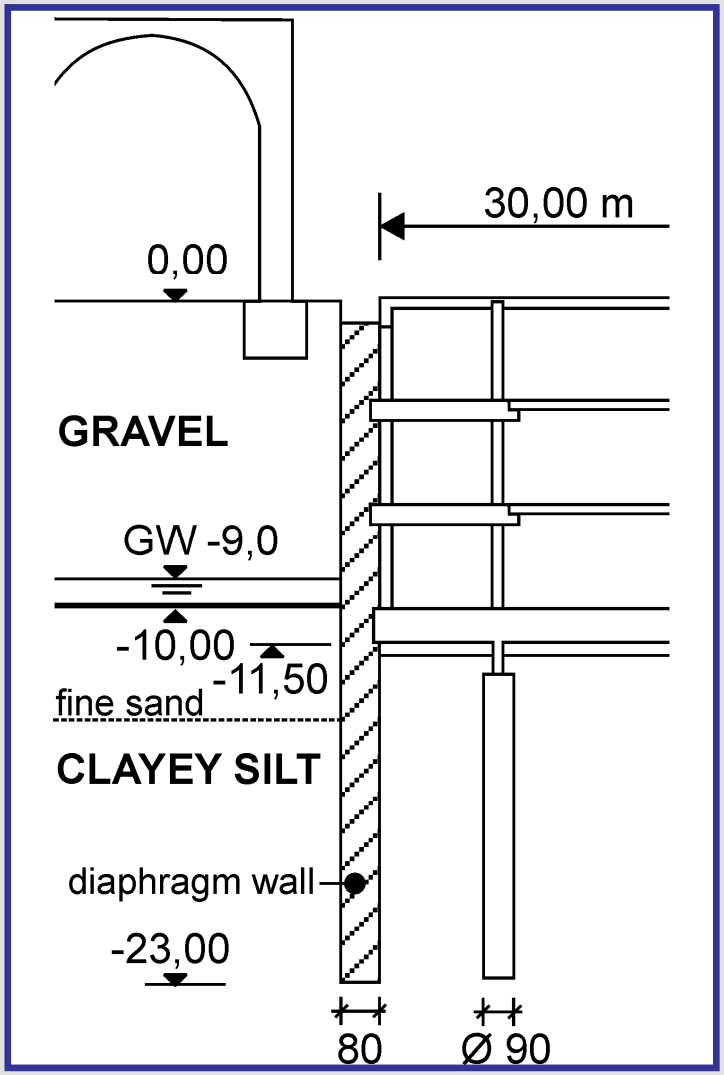
Surface settlements behind wall

MC produces significant heave

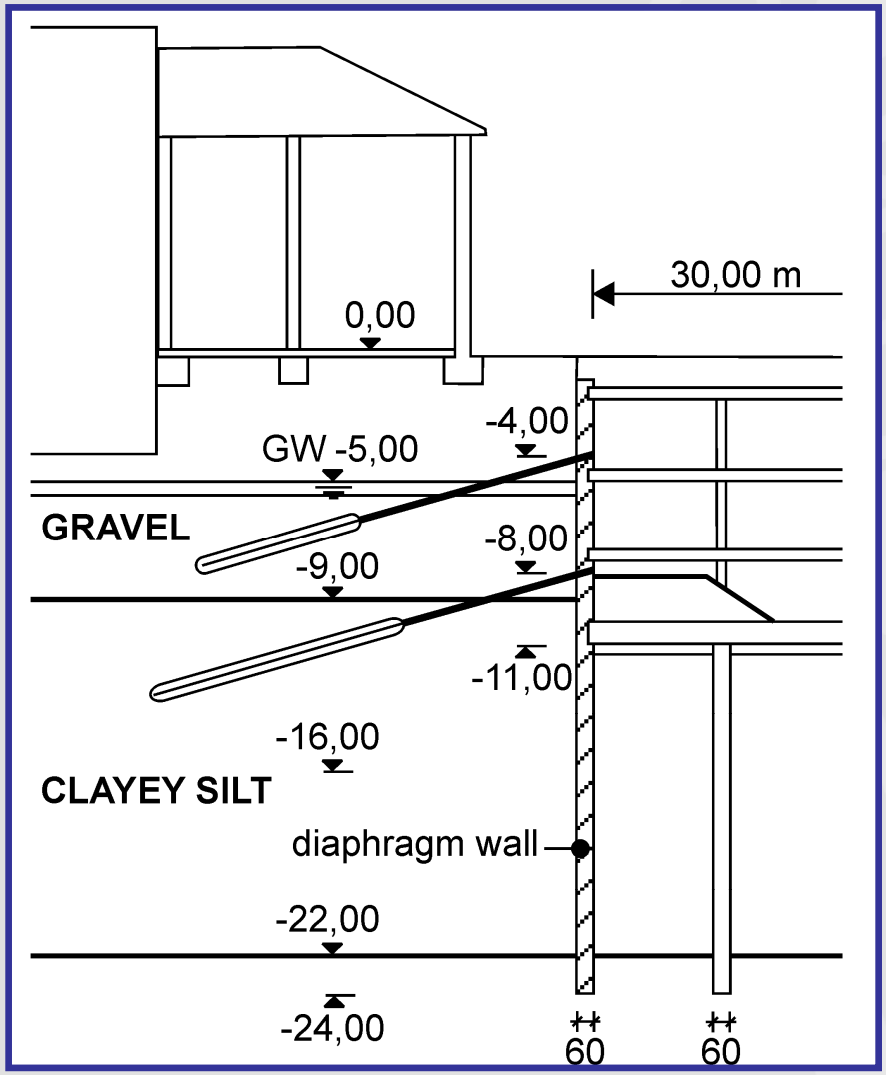
HS and HS-small models produce more realistic settlements

General: Significant influence of constitutive model on results except for earth pressure distribution

BACK ANALYSIS OF DIFFERENT EXCAVATIONS

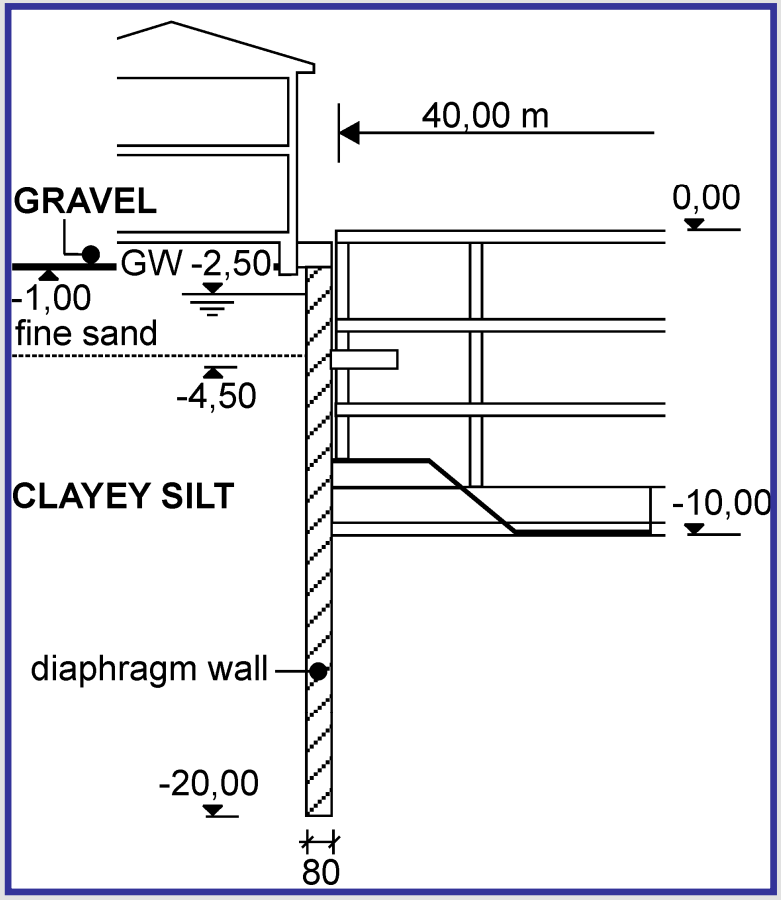


Layout of project "Toskanatrakt"

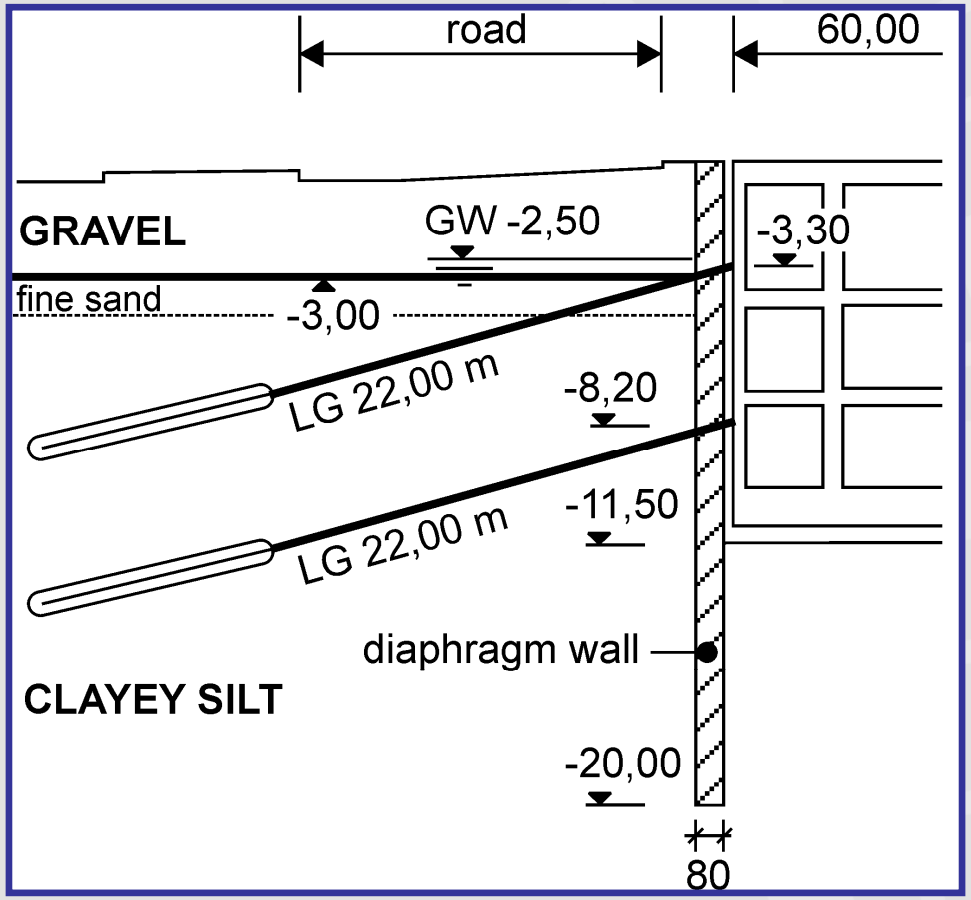


Layout of project "Hypobank"

BACK ANALYSIS OF DIFFERENT EXCAVATIONS

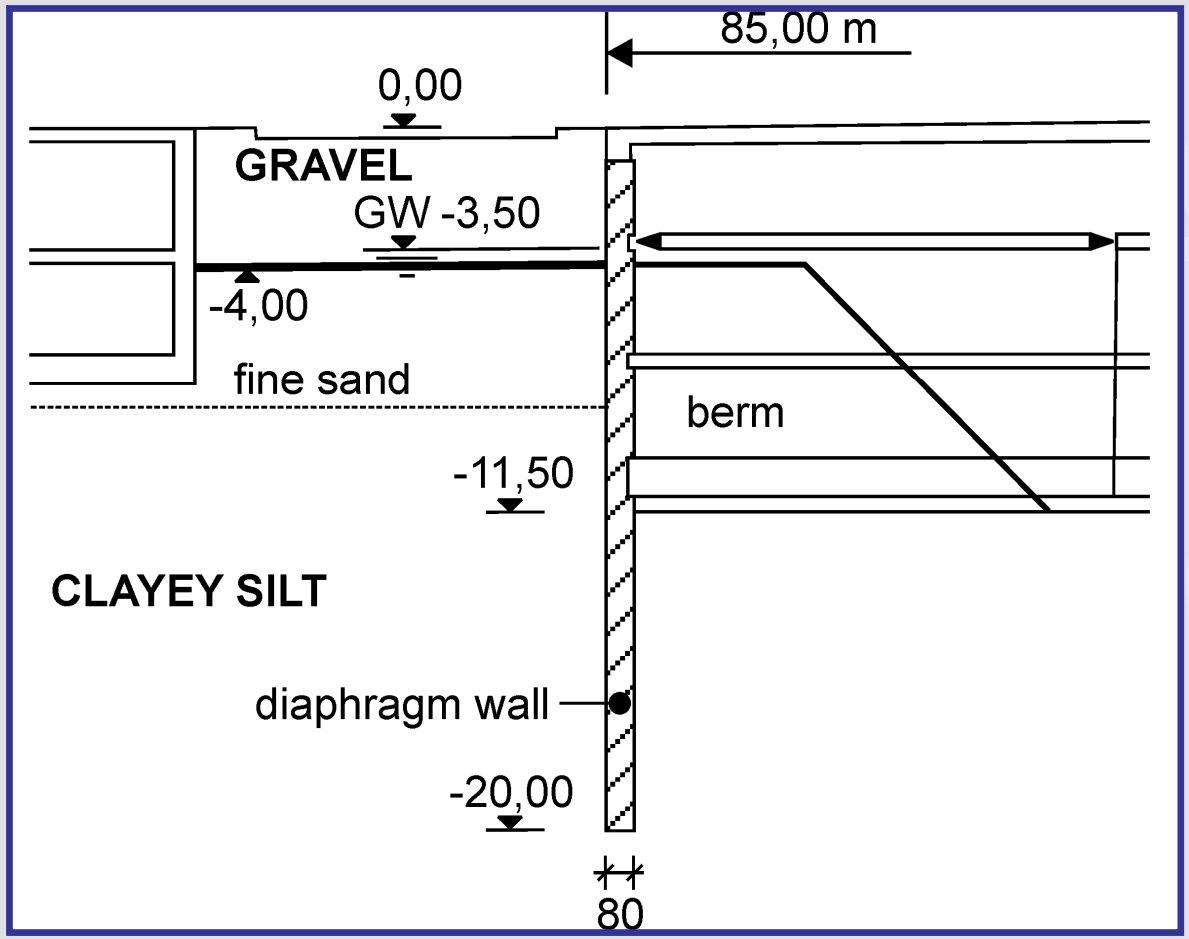


Layout of project "AMV"



Layout of project "Kiesel"

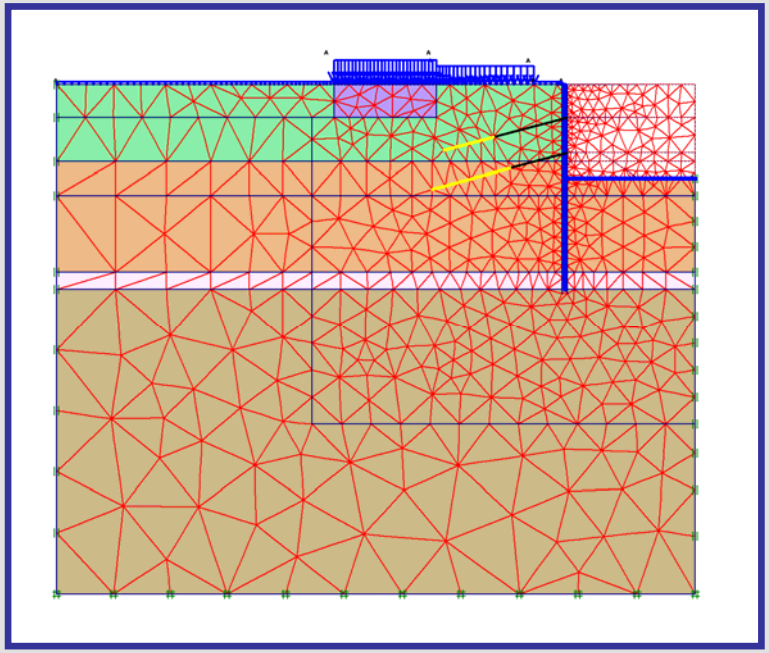
BACK ANALYSIS OF DIFFERENT EXCAVATIONS

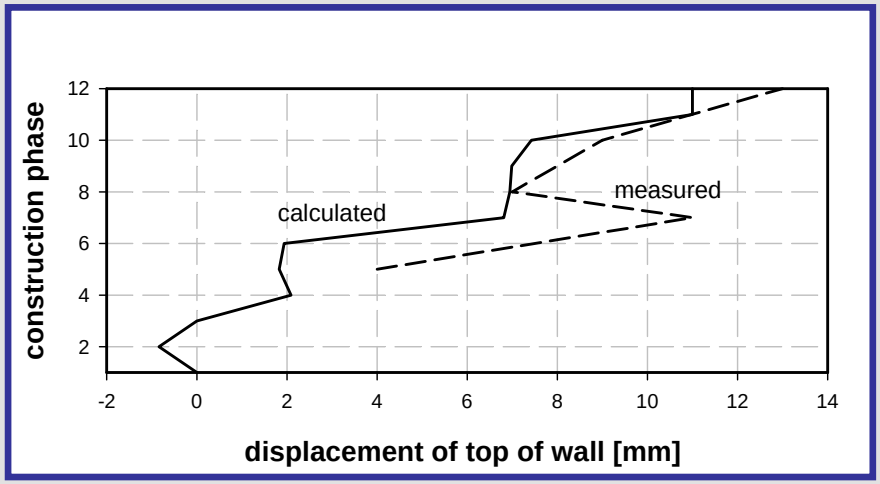


Layout of project "Penta"

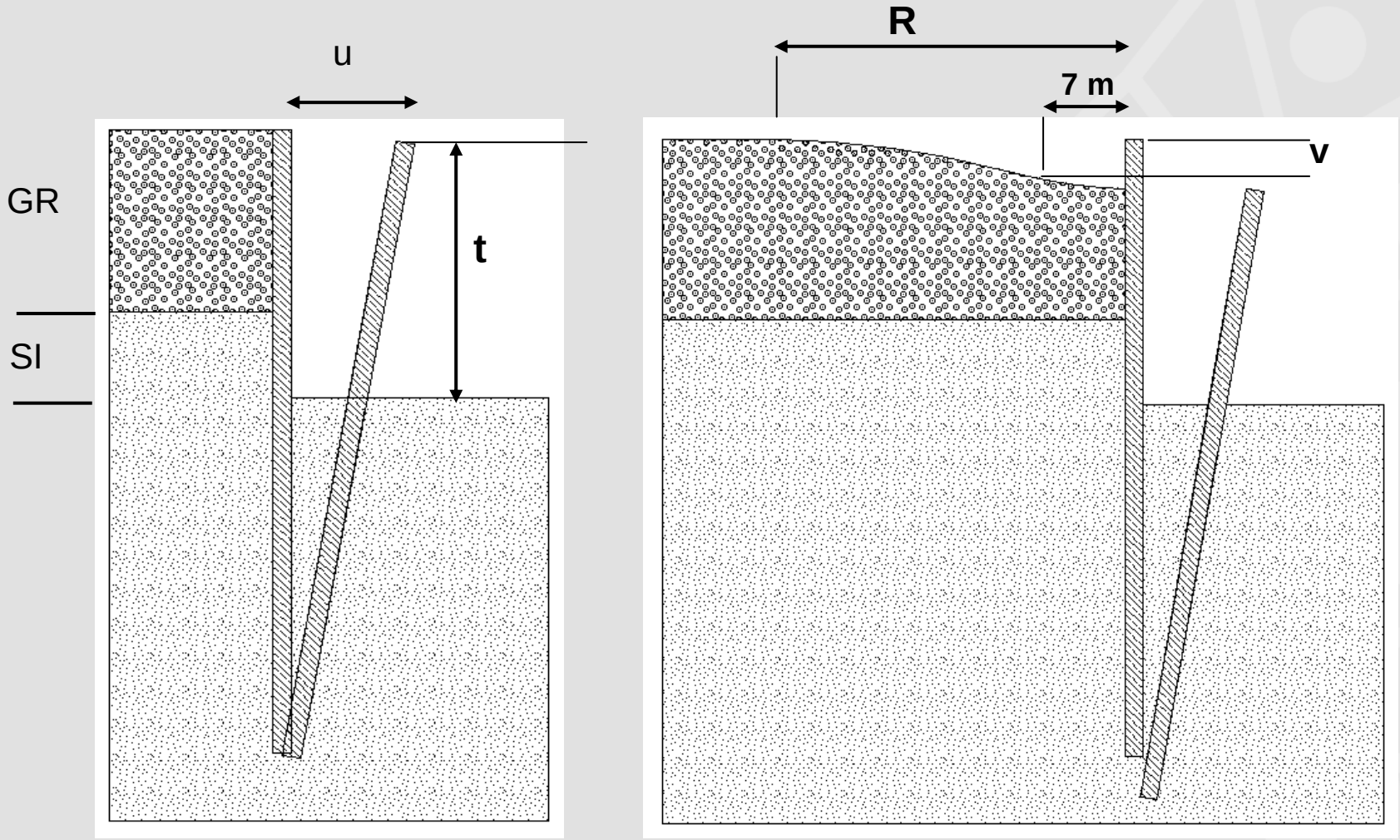
PROJECT HYPOBANK

PROJECT HYPOBANK





BACK ANALYSIS OF DIFFERENT EXCAVATIONS

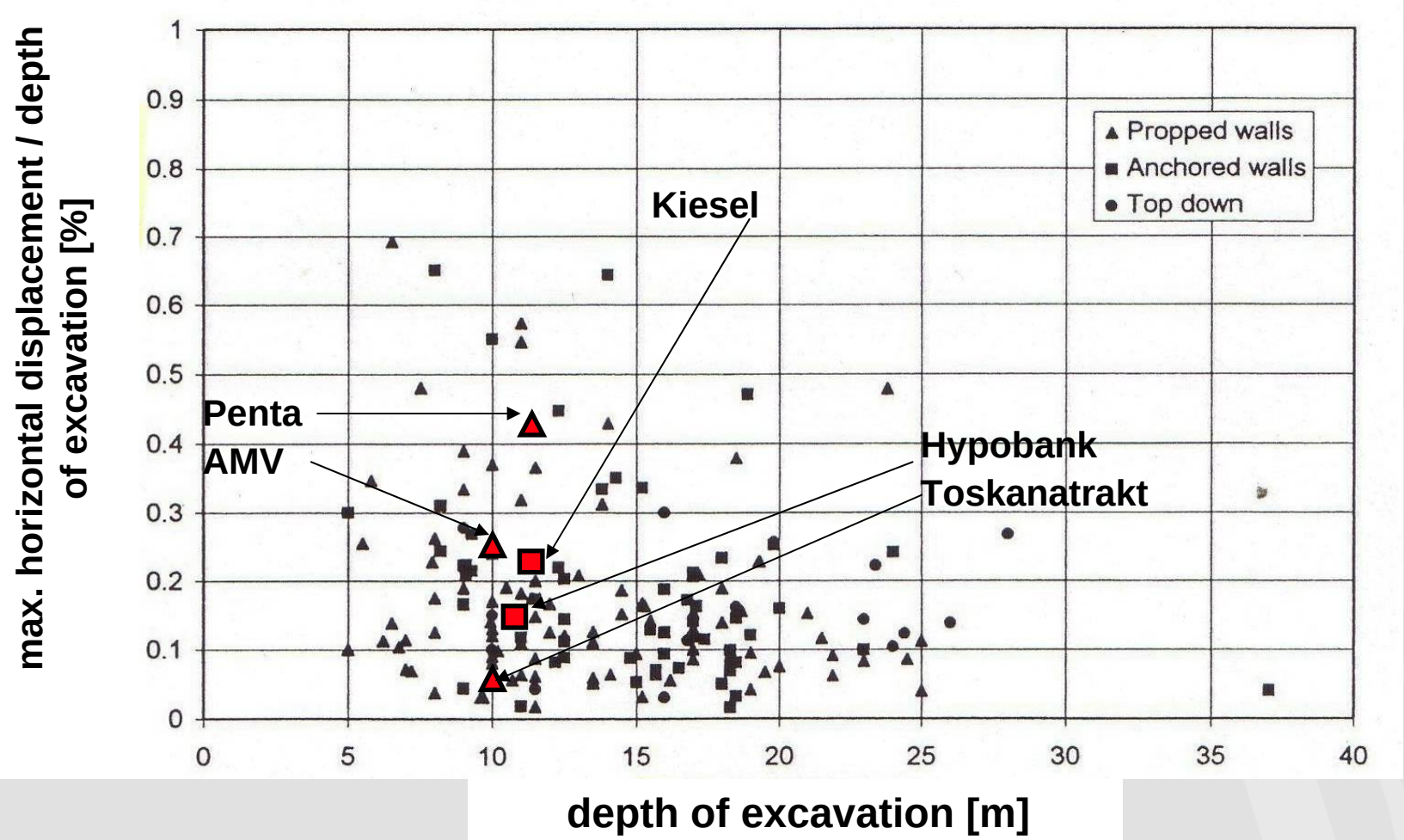


GR / SI ……. ratio of depth of gravel layer to clayey silt layer with reference to excavation level

BACK ANALYSIS OF DIFFERENT EXCAVATIONS

		size		displacements					
				measured	calculated	measured	calculated	measured	calculated
Project	GR/SI	L * B	Vol	u		v		R	
	m/m	m^2	m^3	mm		mm		m	
Toskanatrakt	6.7	850	9800	5	0	8	1	25	40
Hypobank	4.5	1000	11000	13	11	11	9	25	30
AMV	0.1	1800	18000	17	19	26	17	30	35
Kiesel	0.4	2200	25000	20	19	28	13	35	80
Penta	0.5	6500	75000	100	47	30	27	45	100

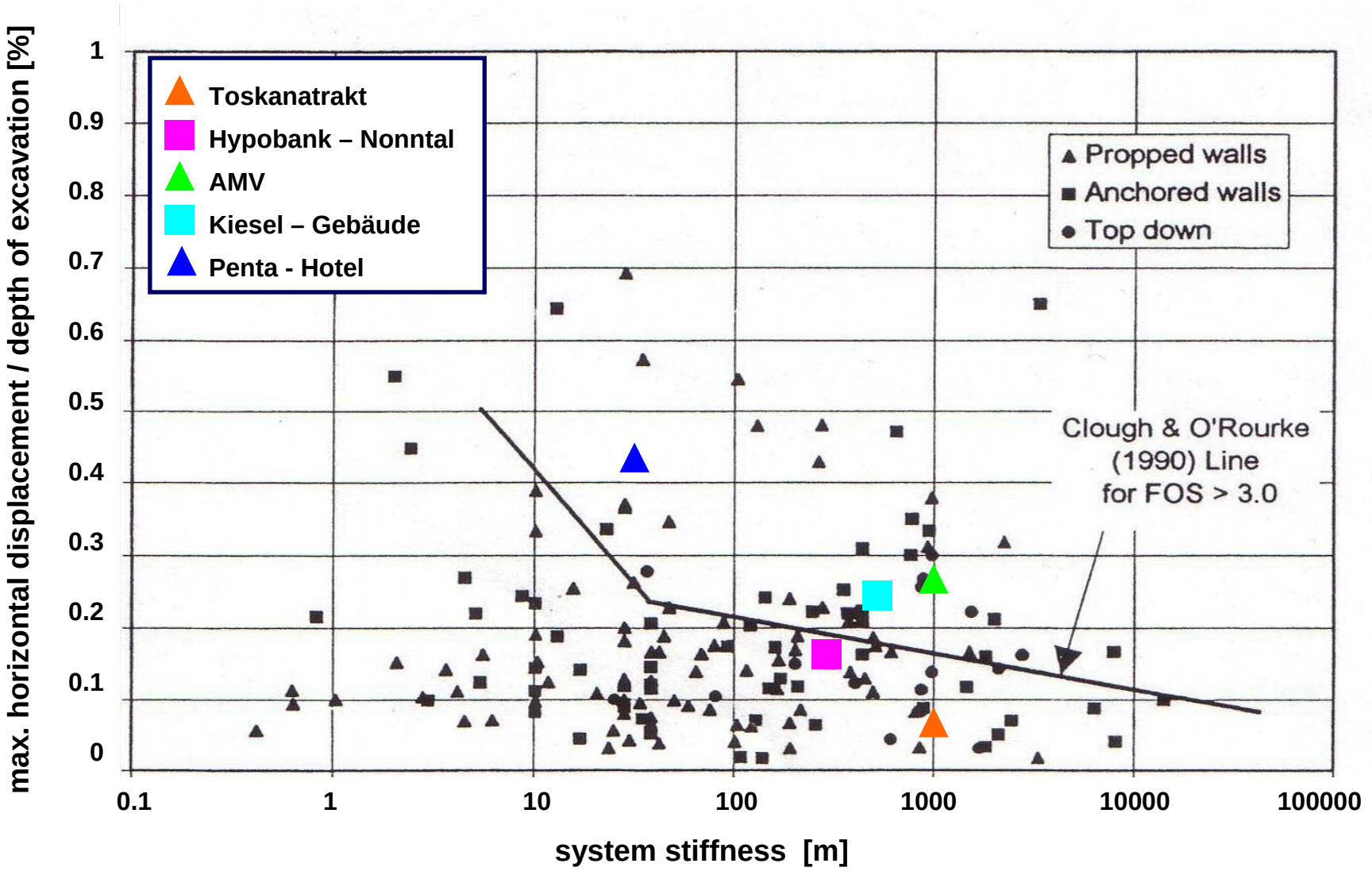
BACK ANALYSIS OF DIFFERENT EXCAVATIONS



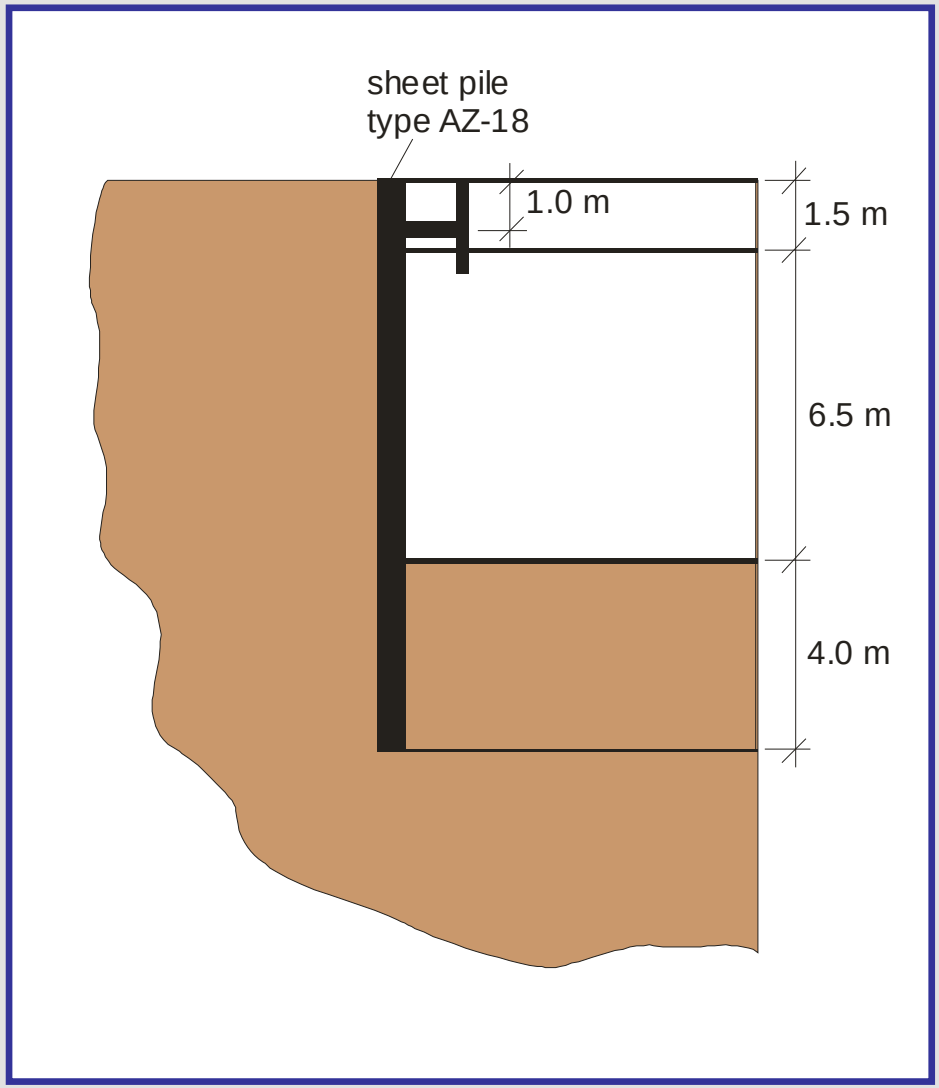
Long, M. (2001). Database for retaining wall and ground movements due to deep excavation, Journal of Geotechnical and Geoenvironmental Engineering, 203-224.

Clough, G.W., Smith, E.M., Sweeney, B.P. (1989). Movement control of excavation support systems by iterative design. Proc. Foundation Engineering-Current Principles and Practices, Vol. 2, ASCE, New York, 869-884.

BACK ANALYSIS OF DIFFERENT EXCAVATIONS



NOTE ON φ / c - REDUCTION



Material parameters soil layer:

$\varphi = 35°$

$c = 0.1\ kN/m^2$

$\gamma = 17\ kN/m^3$

$\psi = 0°$

Properties sheet pile wall:

EA = 3.008E6 kN/m

EI = 6.84E4 kNm^2/m

$M_{pl} = 505\ kNm/m$

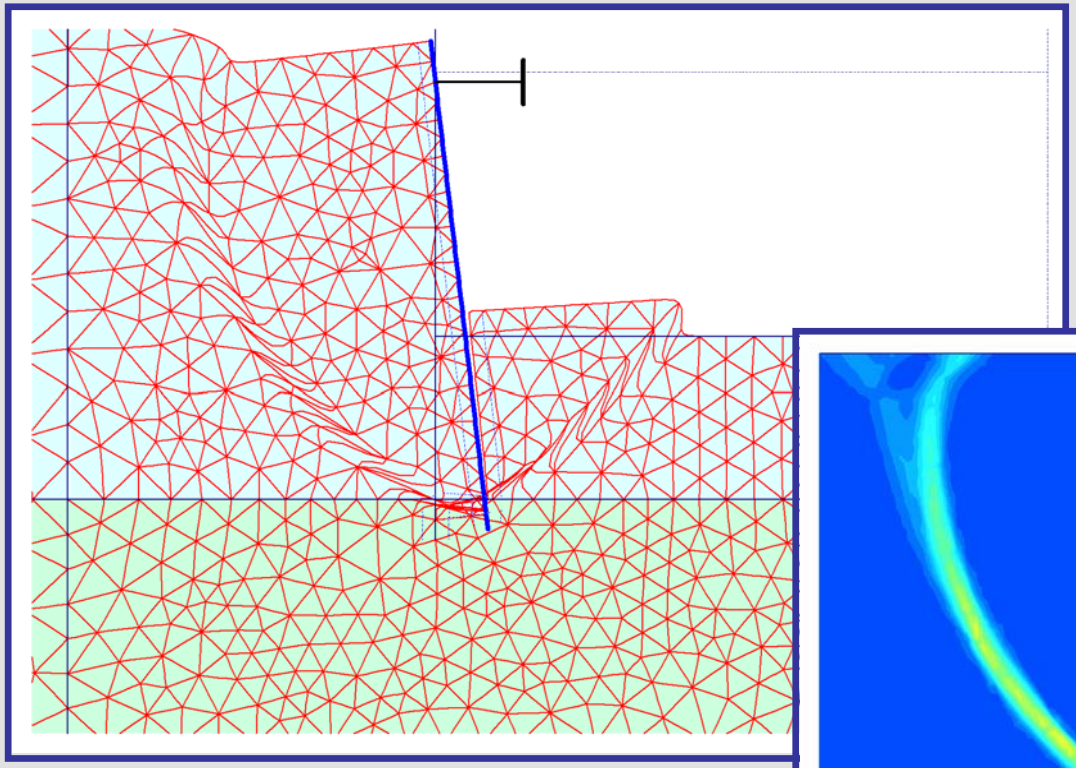
Properties strut:

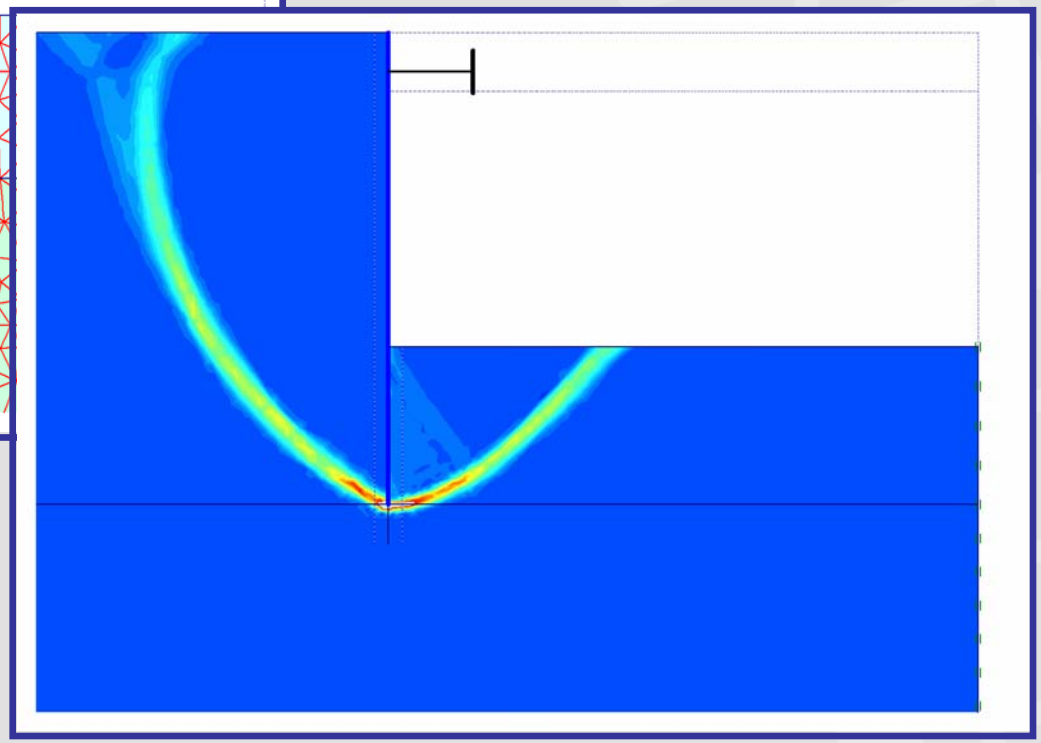
E = 3.0E7 kN/m^2

A = 0.24 m^2

Horizontal strut distance: 1 m

NOTE ON φ / c - REDUCTION

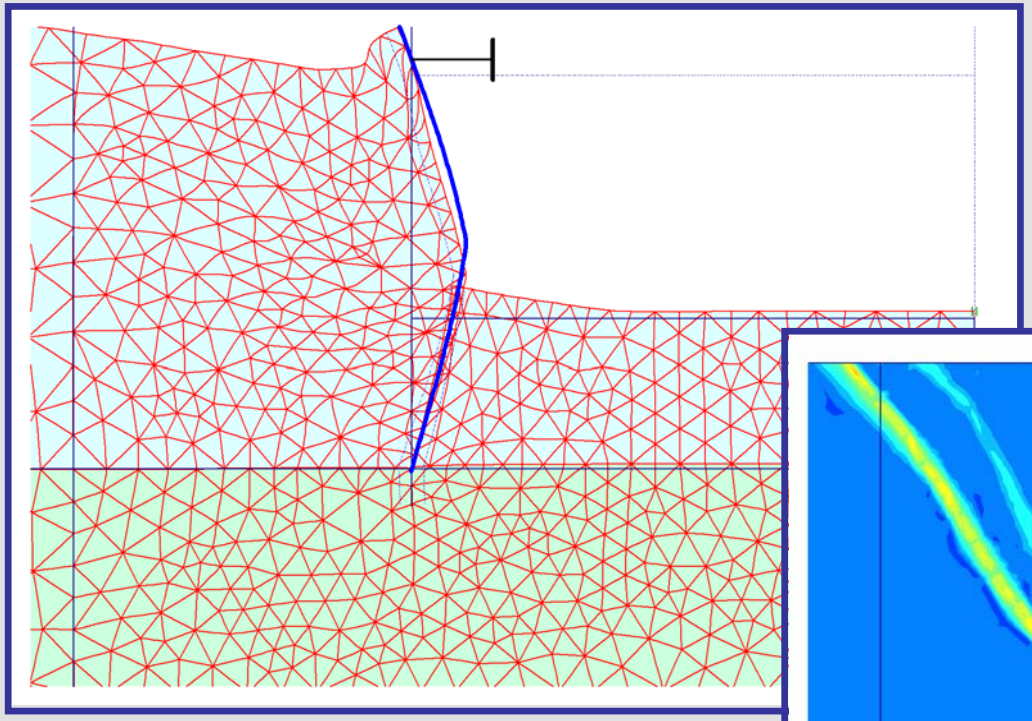


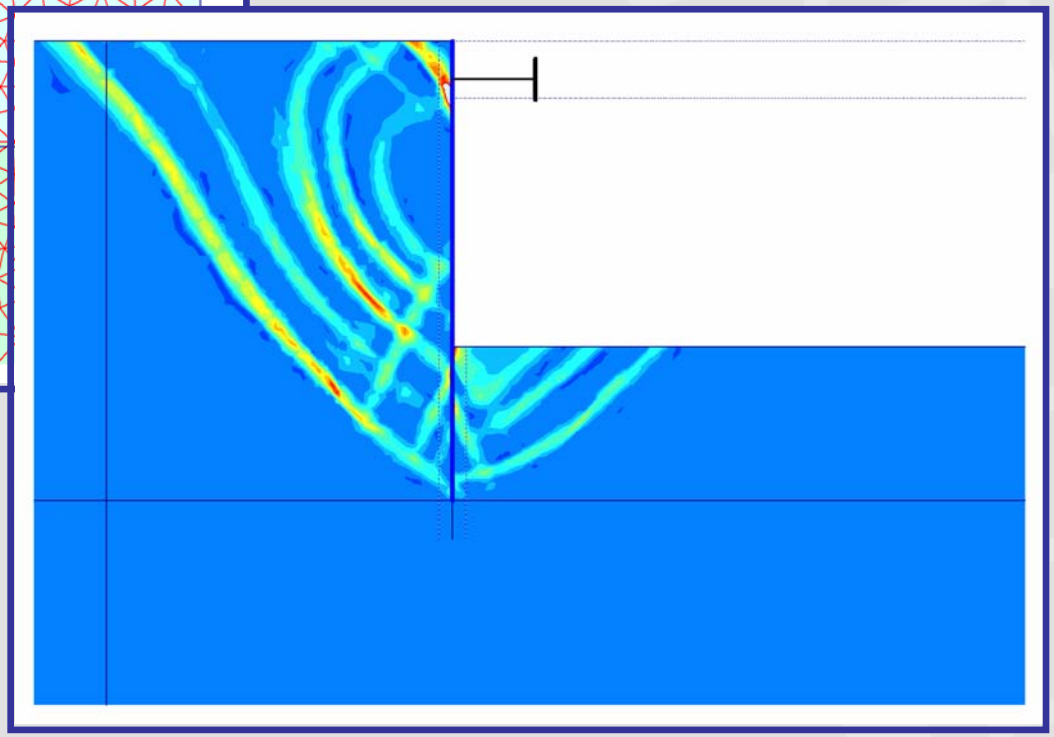


wall elastic

Msf = 1.95

NOTE ON φ / c - REDUCTION





wall elastic - perfectly plastic

Msf = 1.73