Practice course - braced excavation modeling with

DeepXcav 2010

Deep Excavation LLC

INTRODUCTION

DeepXcav 2010 is a software program for braced excavations in soils with 2D limit-equilibrium and non-linear analysis methods, and structural verification of all elements (with AISC, ASD, Eurocodes).

It offers the ability to analyze walls with multiple braces (tiebacks) in multilayered soils.

The non-linear analysis considers elastoplastic behavior for the whole soil-wall-support system.

The program also offers the ability to perform traditional limit-equilibrium analyses.

The graphical interface is completely interactive and the input is simplified to a great extend.

The program utilizes archives of wall types, structural and soil materials, ground anchors etc.

The analysis can be performed in either an utlimate state or at a service state (allowable design or LRFD).

The program offers the ability to automatically set all critical settings according to the desired design methodology.

INTRODUCTION

It is strongly recommended to model all the necessary construction stages as the real construction sequence affects the obtained results. It is therefore advised to subdivide the construction of the model in more than one stages as required.

Stage 0

- Define basic project information (name, coordinates etc).
- Reset global elevations to match the general site elevations.
- Material selection

  - Definition of soil types and soil stratigraphy (borings).

  - Definition of structural material archives for concrete, steel, and rebar steel used in walls and supports (tiebacks, struts, slabs, etc.).

INTRODUCTION

- Define the initial surface elevations and coordinates (horizontal, inclined, berms etc)..
- Apply surface loads: strip loads (uniform or trapezoid), linear loads, 3D.
- Apply loads directly on the wall: Distributed loads, linear loads, moments, imposed displacements or rotations.
- Define basic wall type: Soldier pile walls, sheet pile, secant pile, diaphragm walls etc.

INTRODUCTION

- **STAGE 1**

  - Excavation

  - Lowering the excavation to the first level (left or right, typically up to 10ft or 3.5m)

- **STAGE 2**

  - Insert ground anchor, strut, or slab support above the excavation level. It is recommended to create a separate stage where the support is activated and the excavation levels are kept the same as in the previous stage.

  - Define the newly inserted support type, basic dimensions, and prestress for ground anchors.

INTRODUCTION

- **STAGE 3**

  - Final retained ground level;

  - Final excavation to subgrade level.

- **STAGE 4**

  - Application of seismic loads if required. The seismic load can be applied at anytime during the construction of the model, not only at the end. Like for the insertion of the supports, it is better to create an appropriate phase in which only the seismic load is applied.

  - Select the applicable structural design code (USA, Europe, etc).

  - Automatic generation of the Design Approached (Europe).

  - Calculate and verify the design.

INTRODUCTION

- **4 levels of results**

  - Summary tables showing principal results.

  - On screen diagrams.

  - Detailed diagrams.

  - Detailed tables showing wall results for every node and every stage along the wall.

- **Report**

  It is possible to construct a report with simple drag & drop of prototype report sections. The reports can include any stage and any design section of the calculation. Reports can be exported in PDF and Word formats.

  Do not forget to Press "Select all" to include all the stages and design sections for the report.

Soil properties

ϕ' = friction angle used in calculations for non-clay soils and limit-equilibrium analysis.

Serves for the calculation of the lateral earth pressure coefficients K_0, Ka and Kp .

E' elasticity of the soil (in non-linear analysis).

ϕ_{cv} = Constant volume shearing angle (used for clays in NL analysis).

ϕ_{cv} is NOT used for sand, silt and rock soil types.

The program offers a number of correlations to help the user estimate ϕ_{cv} and the calculation friction angle ϕ'.

ϕ_{cv} is required for clay soil types when a non-linear analysis is performed.

SOIL PROPERTIES

ϕ_{PEAK} = Peak angle of shearing (used for clays in NL analysis).

NOT required for sands, silts and rocks.

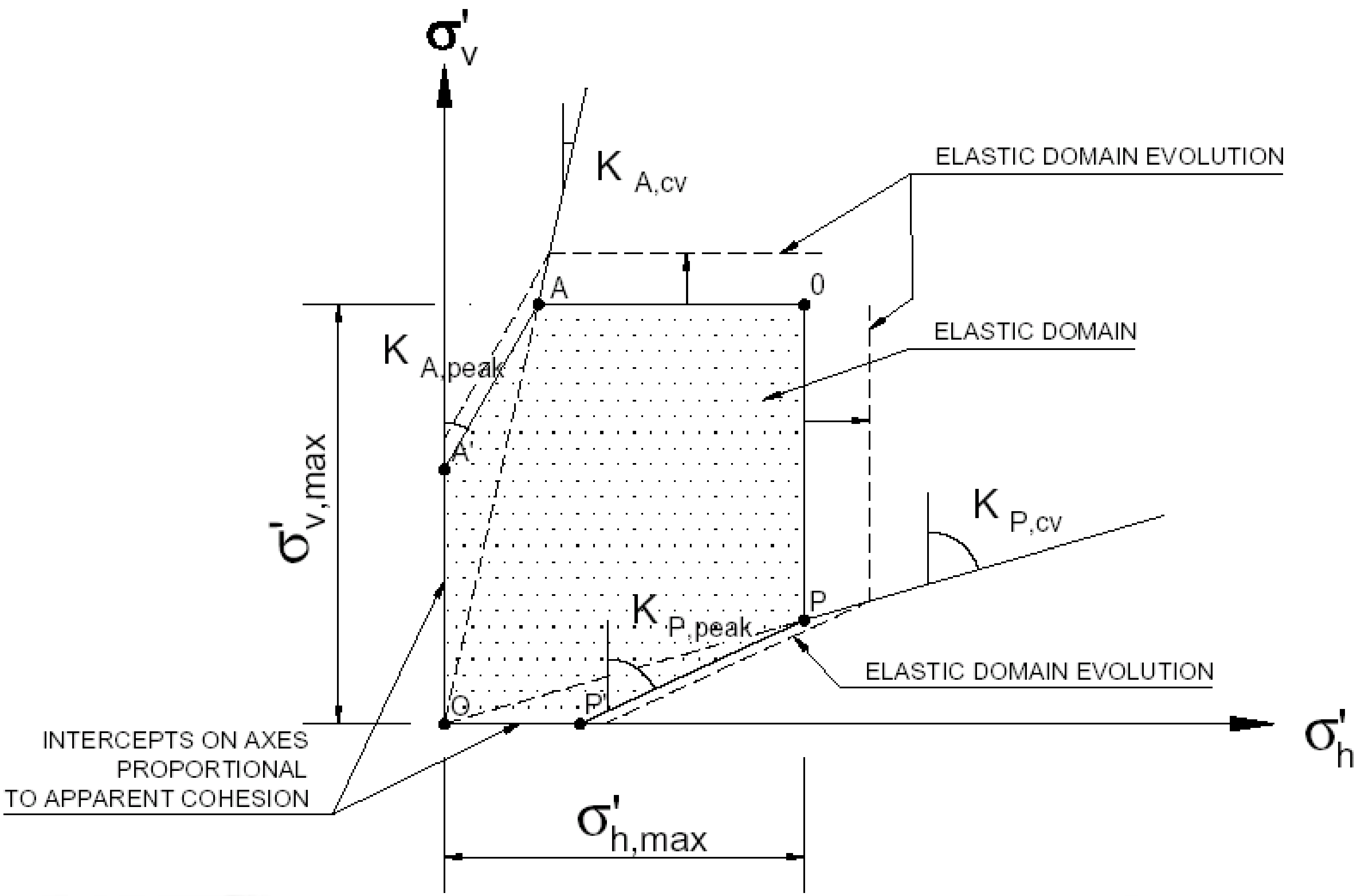
Correlations are available to relate ϕ_{cv} with ϕ_{PEAK} and ϕ'.

ϕ_{PEAK} is required for clays in non-linear analysis and is used in determining the soil elasticity domain.

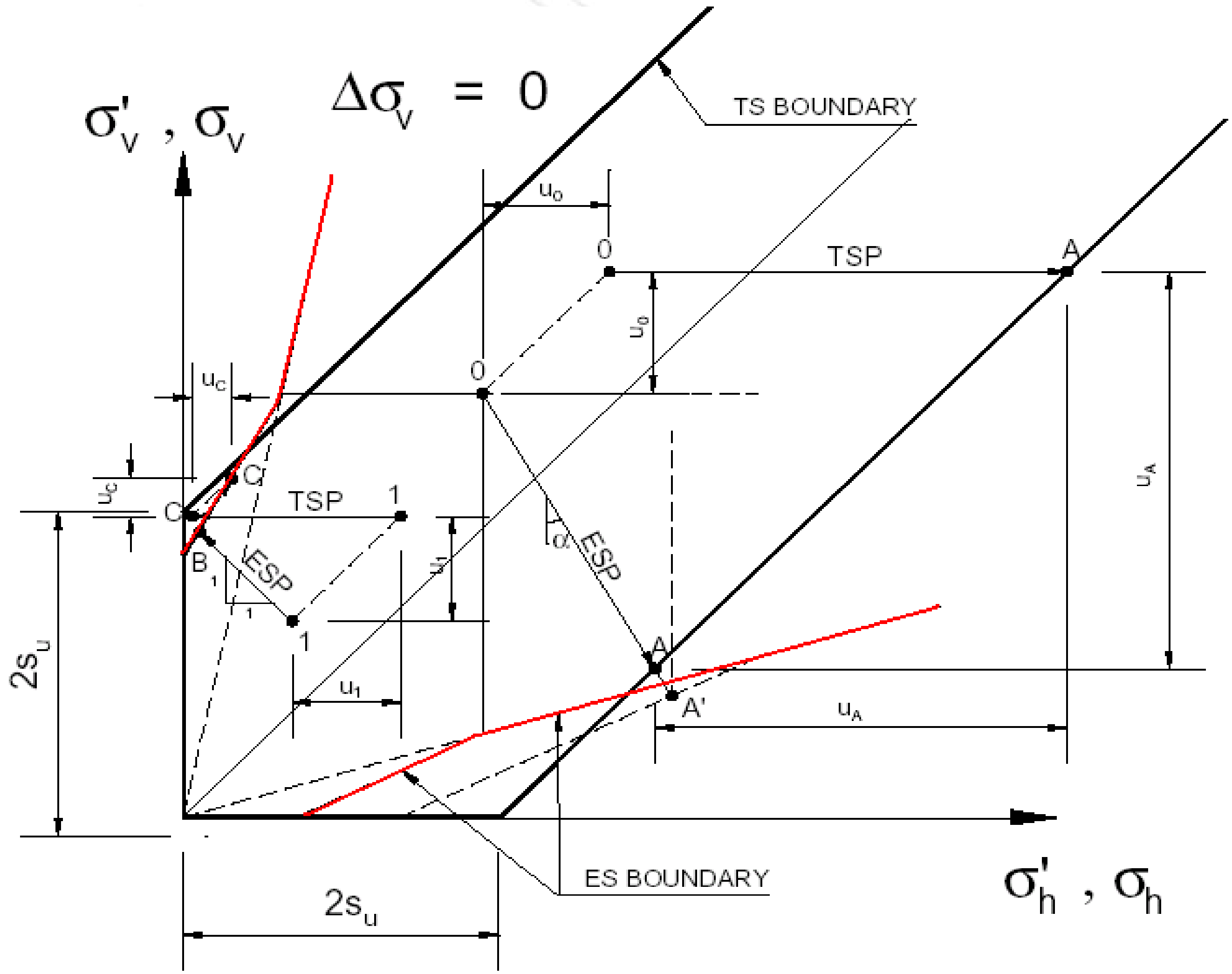
S_u (undrained shear strength) is not enabled with sands, silts and rocks. E' and S_u are required with clays as it defines the elastic domain frontier. When the simplified clay modeling is used, Su is the only parameter used together with the undrained elastic modulus E_u.

c' (effective cohesion) is an optional parameter for sands, silts, and rocks. For clays it is only used in limit equilibrium analysis during drained conditions.

SOIL PROPERTIES –ELASTICITY SOIL DOMAIN



SOIL PROPERTIES



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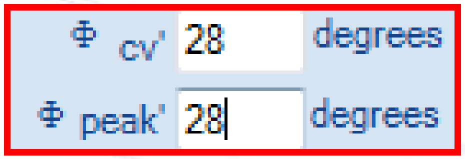
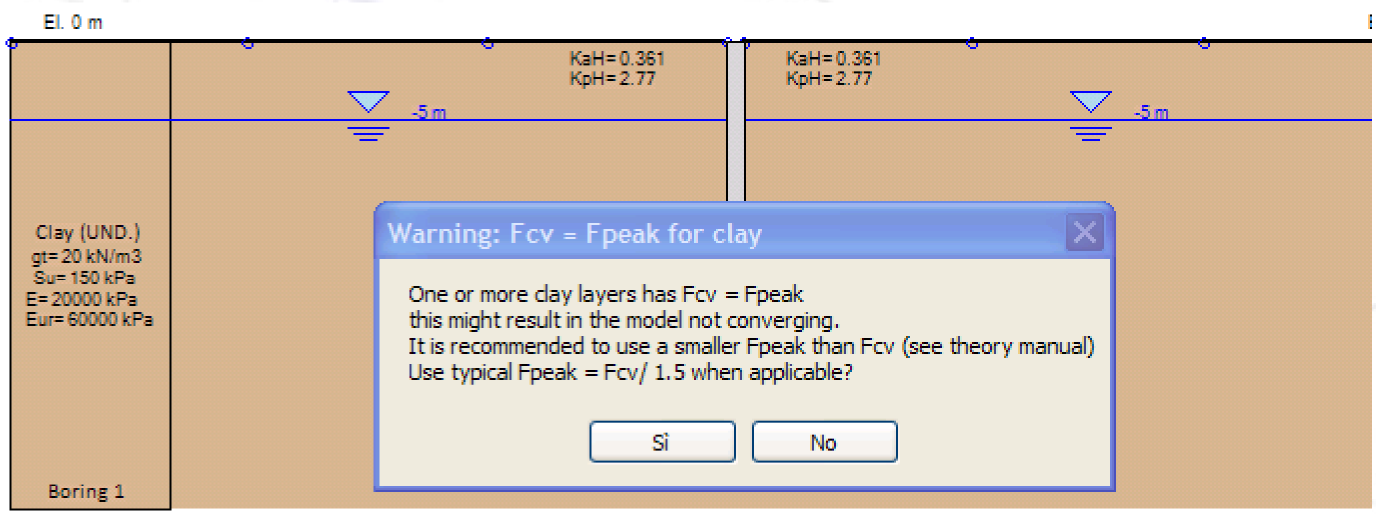




Analysis warning: For clays when $\phi_{PEAK} = \phi_{CV}$

Analysis NL: it gives a warning since the apparent cohesion c' cannot be determined

SOIL PROPERTIES

k_x = horizontal permeability coefficient.

k_z = vertical permeability coefficient.

k_x & k_z used to determine water pressures in ground water flow analysis (1D-2D) and hydrodynamic effects during earthquakes.

Ka = active earth pressure coeffient. Calculated with Rankine method (default).

Kp = passive earth pressure coeffient. Calculated with Rankine method (default).

Note: Ka and Kp within the soil type dialog are calculated with the corresponding friction angle. It is strongly recommended to only use the default rankine values within this dialog.

SOIL PROPERTIES

- [x] Autoestimate Ka-Kp when Soil friction values are changed
- [ ] Use default engine Ka and Kp (Rankine, soil friction only)

8. Include soil in parameter variation

- [x] Include in parameter variation (i.e. Eurocode, Statistical analysis). It is strongly recommended to keep this option checked.

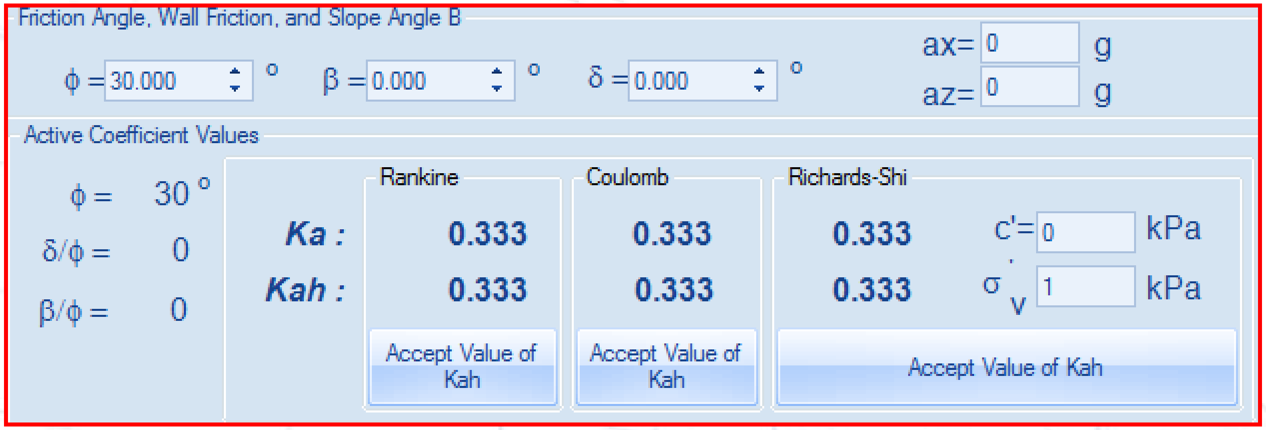
- It is recommended to maintain the option Autoestimate Ka and Kp for friction angle checked. This allows the automatic calculation of Ka and Kp when the friction angle is changed.

- *The option Use default engine Rankine Ka – Kp is used in the NL analysis.*

- *Option include soil in parameter variation:* Includes the soil type in soil strength reduction design approaches (similar to Eurocode 7, etc)

A tool is available that allows the manual calculation of Ka and Kp based on various theories.

SOIL PROPERTIES



Ka estimation dialog and data:

– ϕ': soil friction angle

- β = surface slope angle

- δ = wall-soil interface friction angle.

Note: For clays the angle d must necessarily be inserted in this window and it cannot change during all the course of the analysis. For sands d can be changed from the main menu and can have various values in any stage.

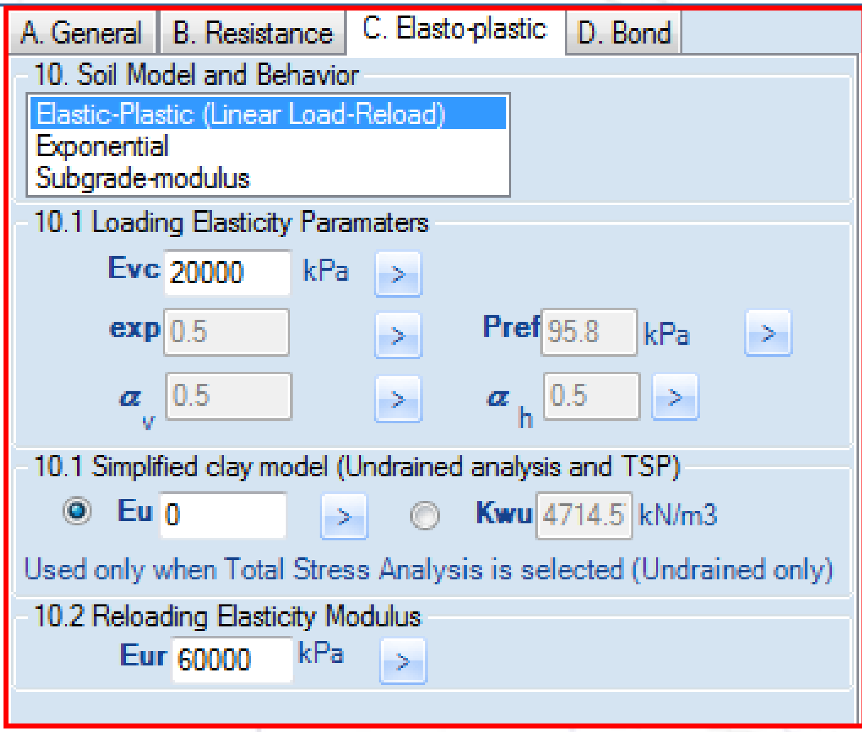
Note: When the window is closed the values of b and d are reset, however the Ka values are preserved.

SOIL PROPERTIES

Method	Active Coefficient				Passive Coefficient			
	Available	Surface angle	Wall Friction	EQ.[2]	Available	Surface angle	Wall Friction	EQ.
Rankine	Yes	No[1]	No[1]	No	Yes	No[1]	No[1]	No
Coulomb	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Caquot-Kerisel Tabulated	No	-	-	-	Yes	Yes	Yes	No
Lancellota	No	-	-	-	Yes	Yes	Yes	Yes

[1] The Rankine values are converted automatically to Coulomb if the program detects soil-wall friction or an inclined surface with a single slope angle.

[2] Seismic effects are considered separately.



SOIL PROPERTIES

The *Elasto – Plastic tab* is used to define the elastoplastic behavior of the soil (and therefore the soil reactions) in each calculation stage, depending on the drainage conditions and the stress history.

For clays an option to use a Simplified clay model is also available (Total Stress Analysis).

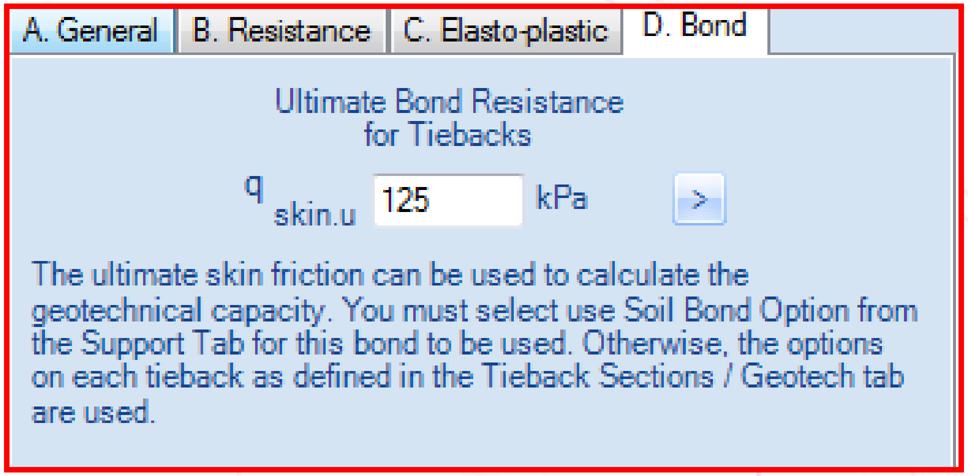
For all soil types:

-Evc = Elastic compression modulus during primary loading. The oedometer modulus can be used as a rough approximation.

- Eur = Elastic modulus during reloading (on excavation side)

For the clays and the Simplified Clay Model:

- Eu = Elastic modulus during undrained conditions.



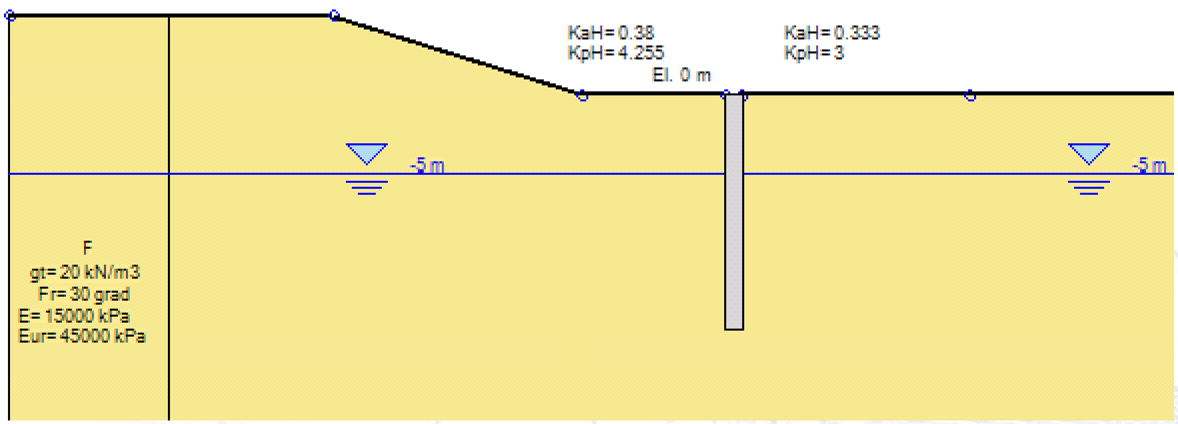
SOIL PROPERTIES

In the Tab D. Bond it is possible to select the ultimate adhesion value between the soil type and the fixed length of ground anchors.

Note: The software considers initially an arbitrary default value. This value is used for all anchors whose grouted length is within this type of soil layer. The possibility exists to define a custom value of skin friction for each tieback type irrespective of the soil type. In order to activate this option go to the Load/Support tab in the main program and uncheck the "Use soil bond values to calculate geotech capacity of tiebacks). In this way the software uses the defined value of q in the window of the pulling properties of each tieback section (archive).

A tool is available to correlate q with pressiometer test data according to correlations by Bustamante and FHWA. Note that q is dependent both on the soil type and on the drilling technique.

Surface profile definition



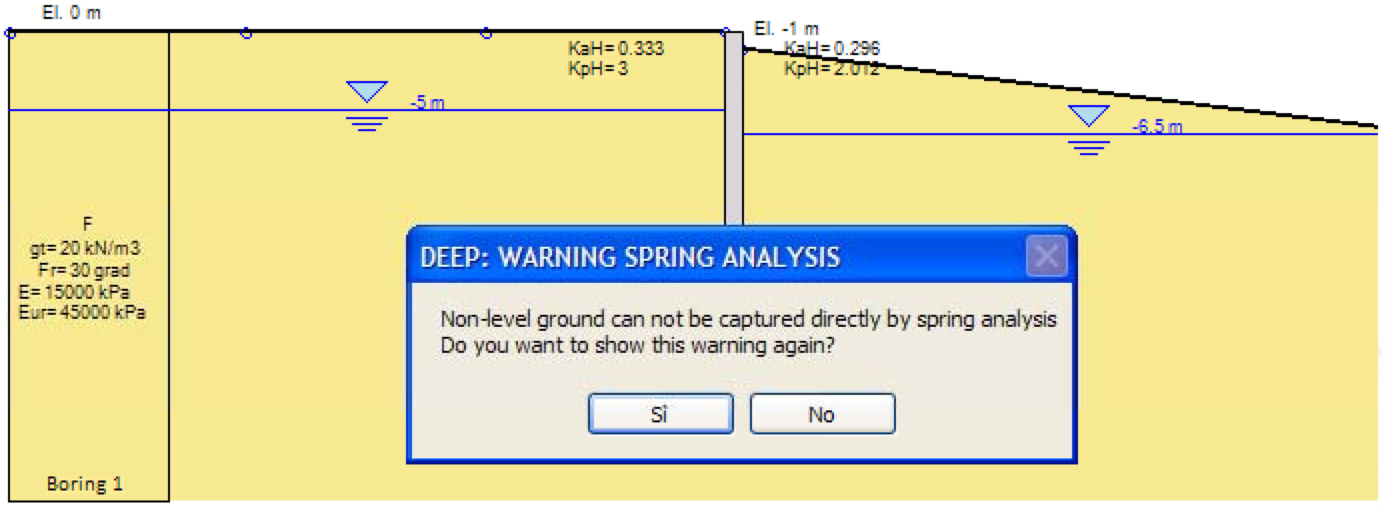
Conventional analysis: no warning.

NL Analysis: no warning.

Note: Remember to extend the model coordinates so that the surface profile fits.

Surface profle definition (inclined surface)

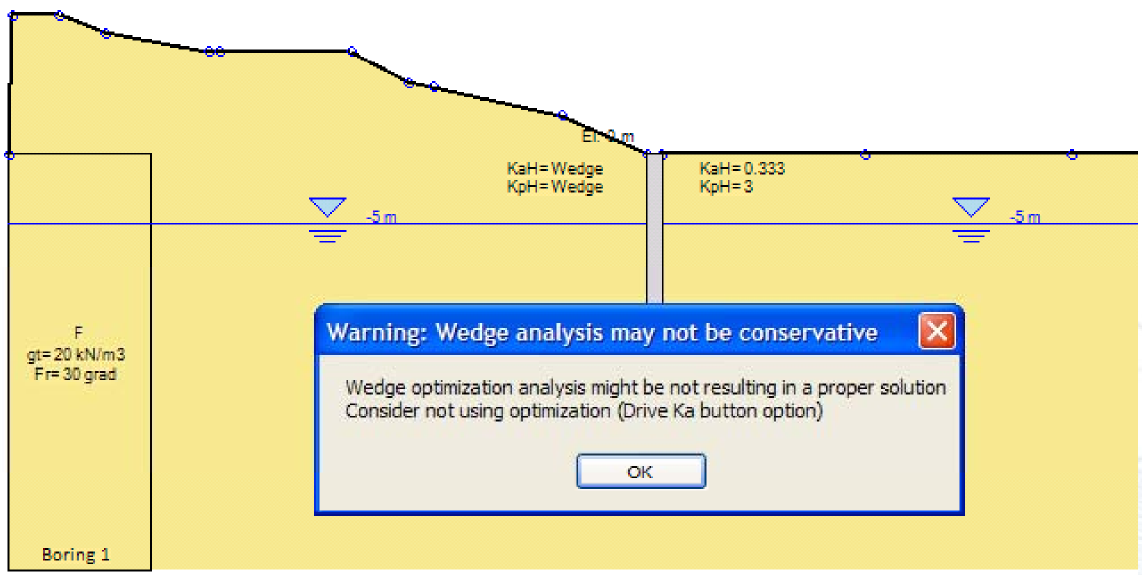
:



Conventional analysis: no warning

NL Analysis: Warning for approximations during analysis with inclined surface.

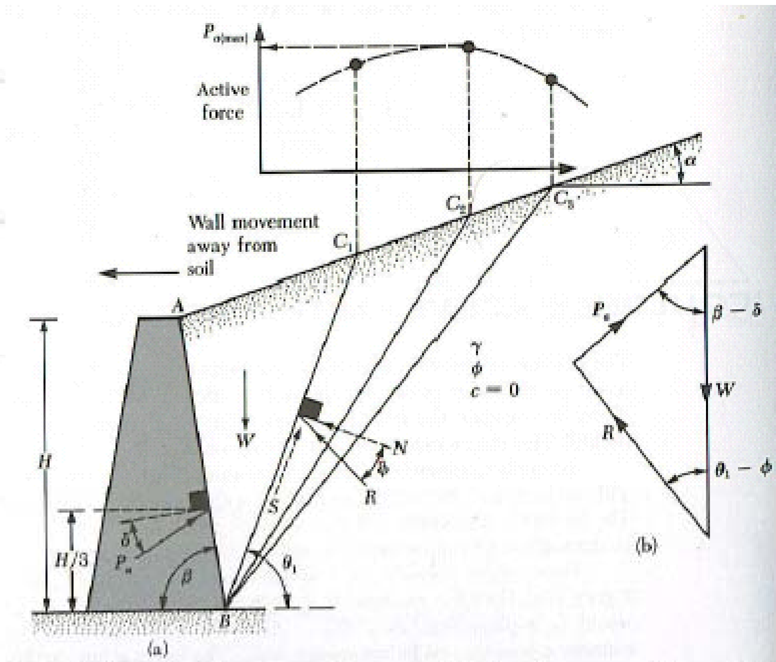
Surface profile definition

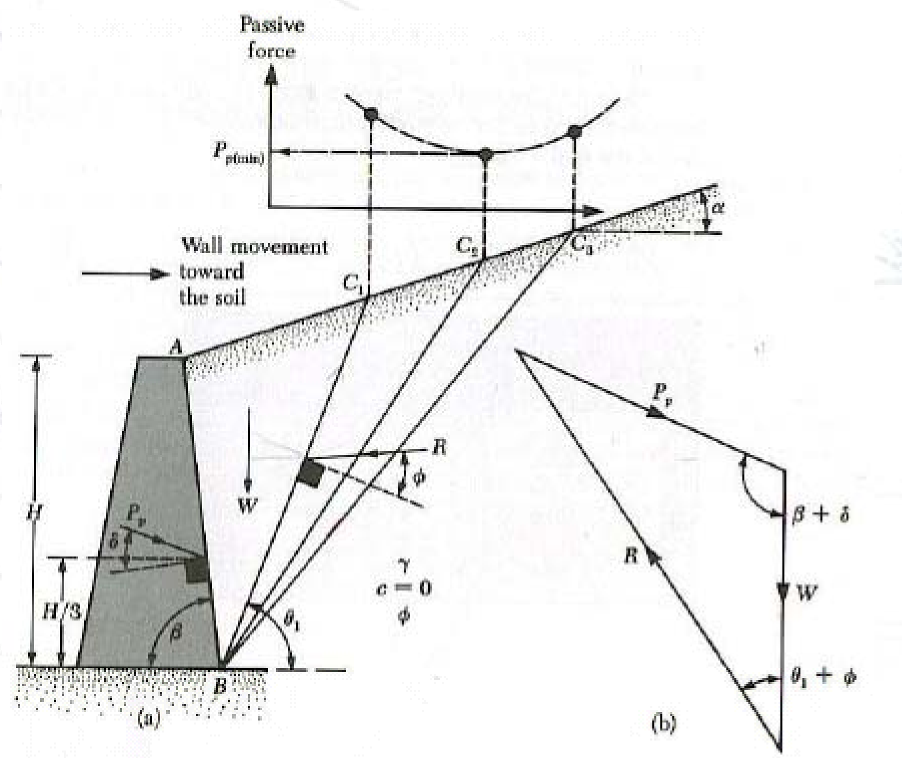


Conventional analysis: Warning that wedge analysis optimization might not be resulting in a proper solution.
Recommendation -> deactivate wedge analysis optimization from ka button.

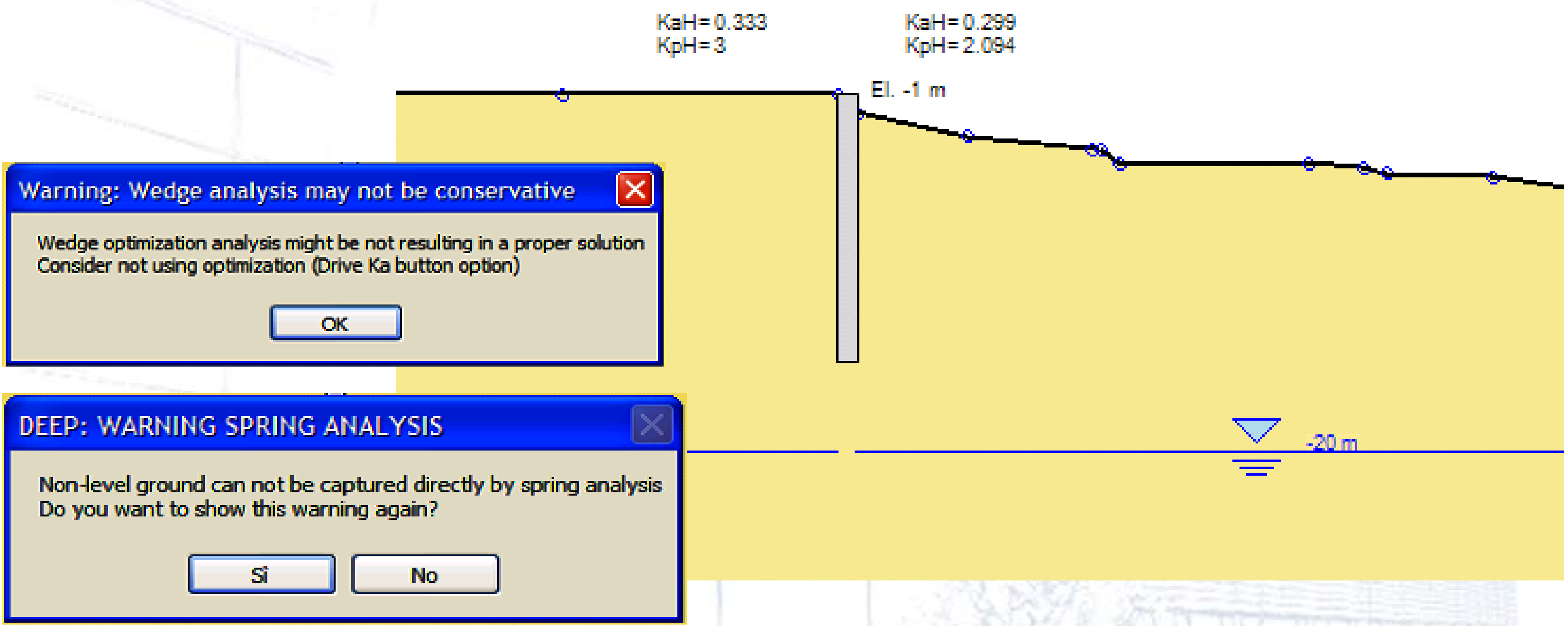
NL Analysis: no warning (left side modelled with a series of strip loads).

Surface profile definition
(Wedge analysis with Culmann's method)





Surface profile definition



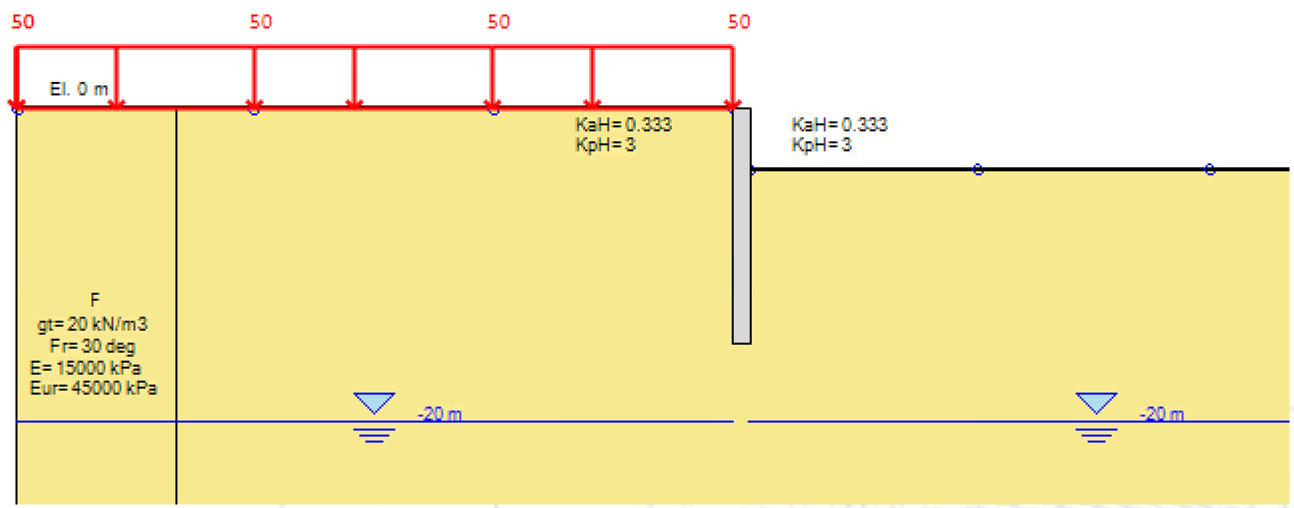
Conventional analysis: Wedge analysis optimization routine warning.

NL Analysis: Warning that certain aproximations are made.

Available load types

Surcharge Type	Permanent/ Temporary (P/T)	Exists in Paratie Engine	Exists in Conventional Analysis	Conventional Analysis Comments
Surface Line load	P & T	No	Yes	Theory of elasticity. Can include both Horizontal and Vertical components.
Line load	P & T	No	Yes	Same as above
Wall Line Load	P & T	No	Yes	Same as above
Surface Strip Surcharge	P & T	Yes	Yes	Same as above
Wall strip Surcharge	P & T	Yes	Yes	Same as above
Arbitrary Strip Surcharge	P & T	No	Yes	Theory of elasticity. Vertical Direction only.
Footing (3D)	P	No	Yes	
Building (3D)	P	No	Yes	
3D Point Load	P & T	No	Yes	
Vehicle (3D)	T	No	Yes	
Area Load (3D)	P & T	No	Yes	
Moment/Rotation	-	Yes	No	-

Surface loads

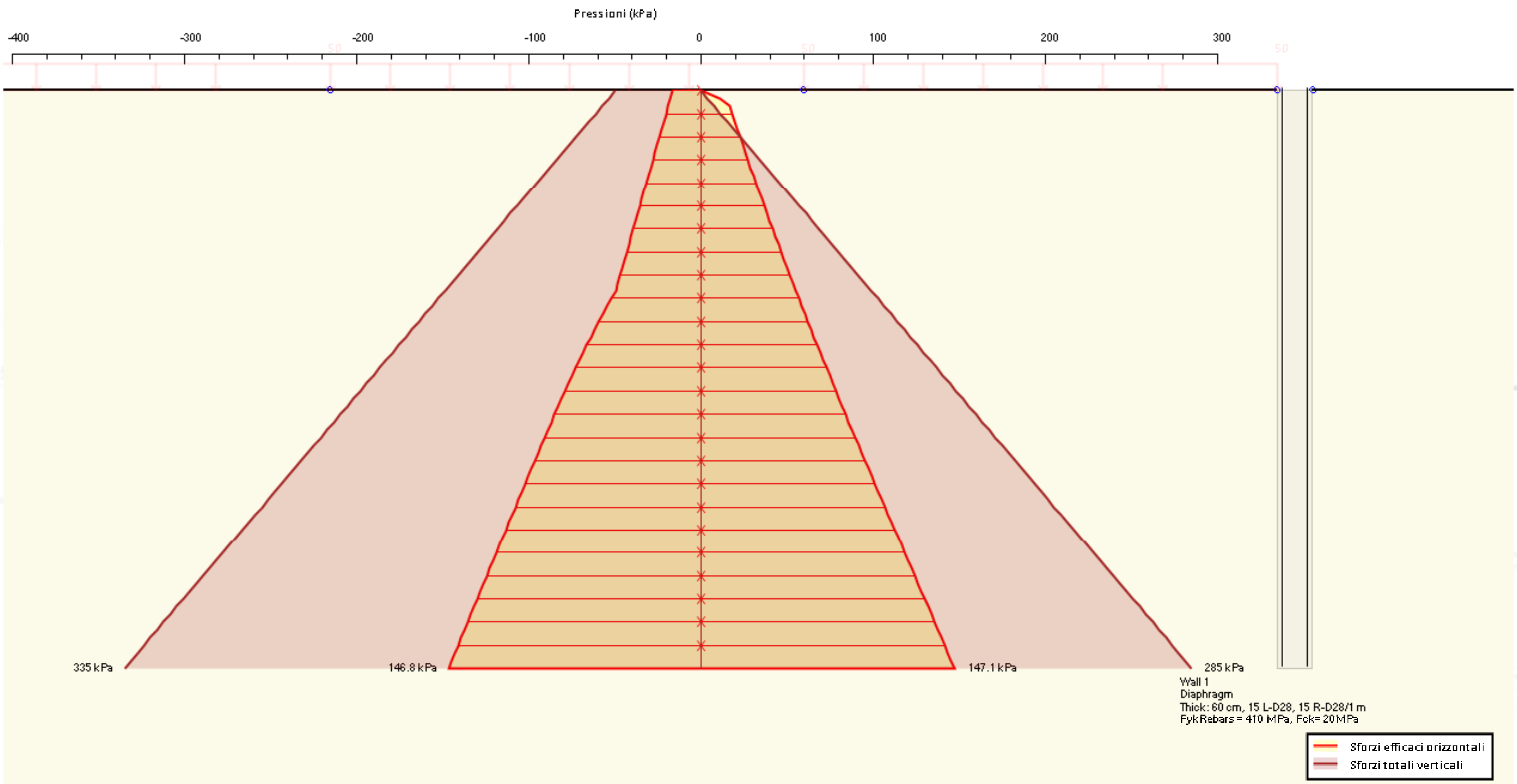


Surface loads or strip loads (infinite length) are available with different options:
- Uniform field surcharge applied on the whole side (directly on the vertical stress)
- Strip load with theory of elasticity or distribution angle.
- Strip load not applied on the surface or with trapezoidal distribution.

Note: a load of equal length to the halfspace, is automatically used as a field surcharge surcharge even if the option is explicitly selected.

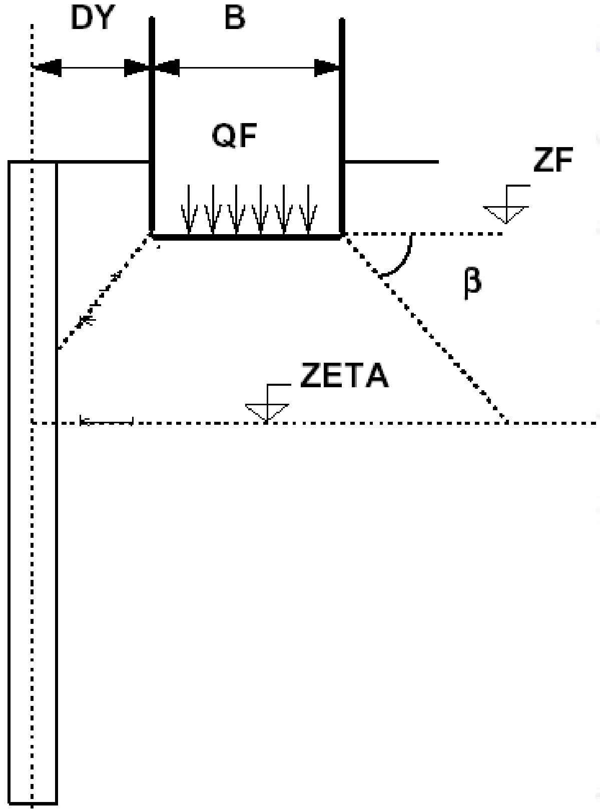
Surface loads

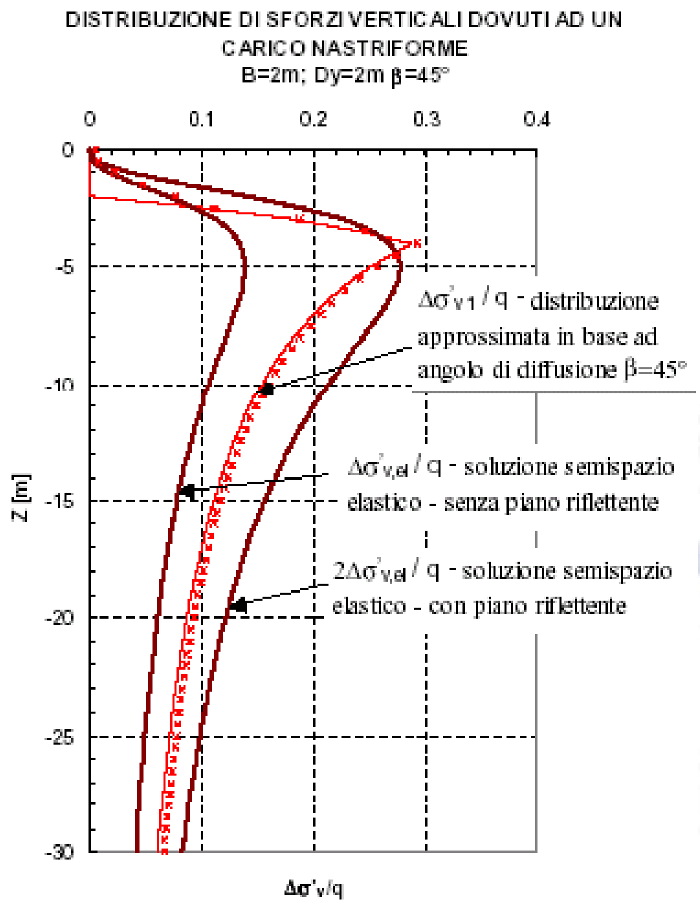
Field surcharge applied on model half space (vertical stress increase on left)



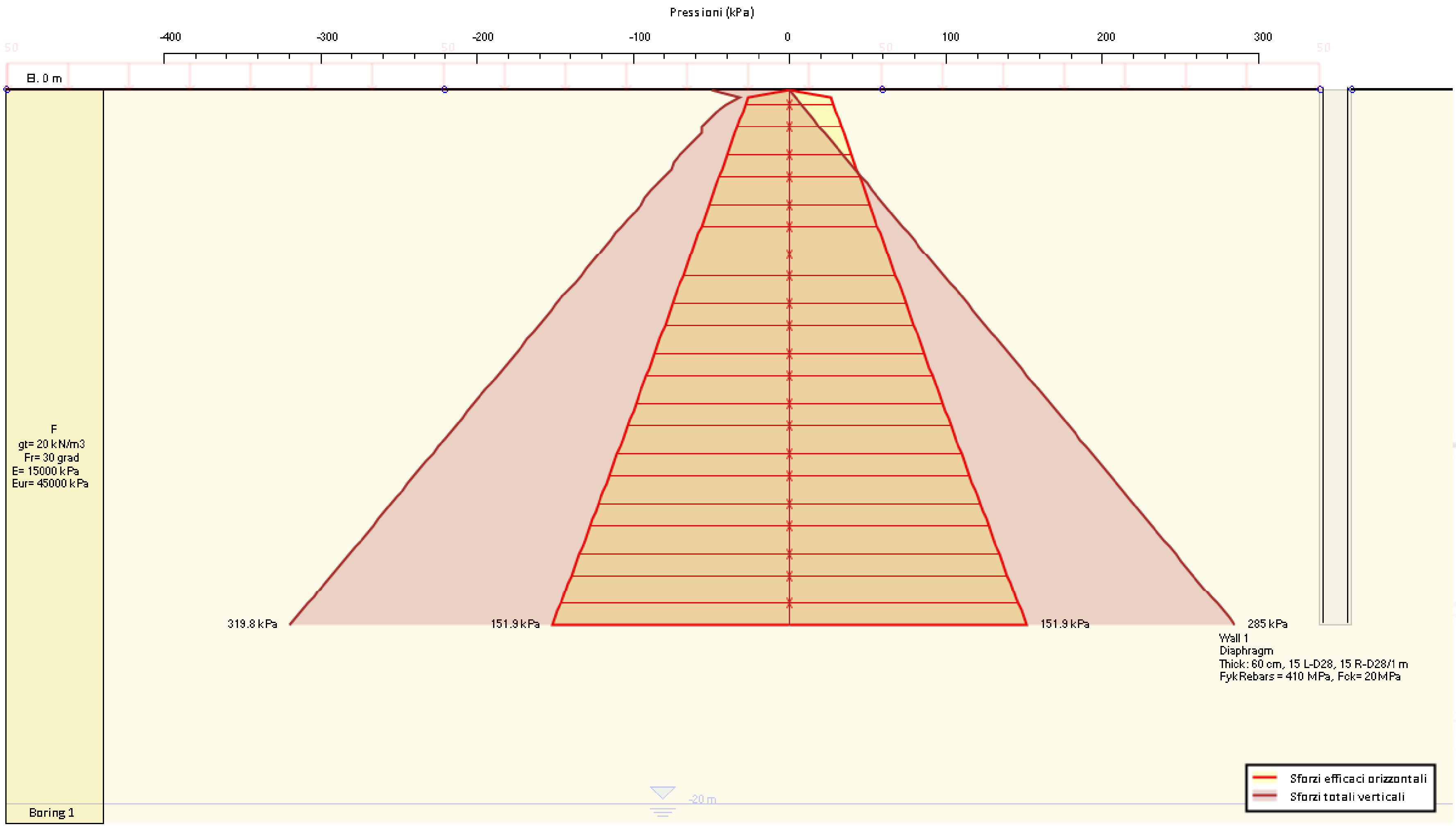
Strip load with distribution angle (NL Analysis)

Uniform load of finite length



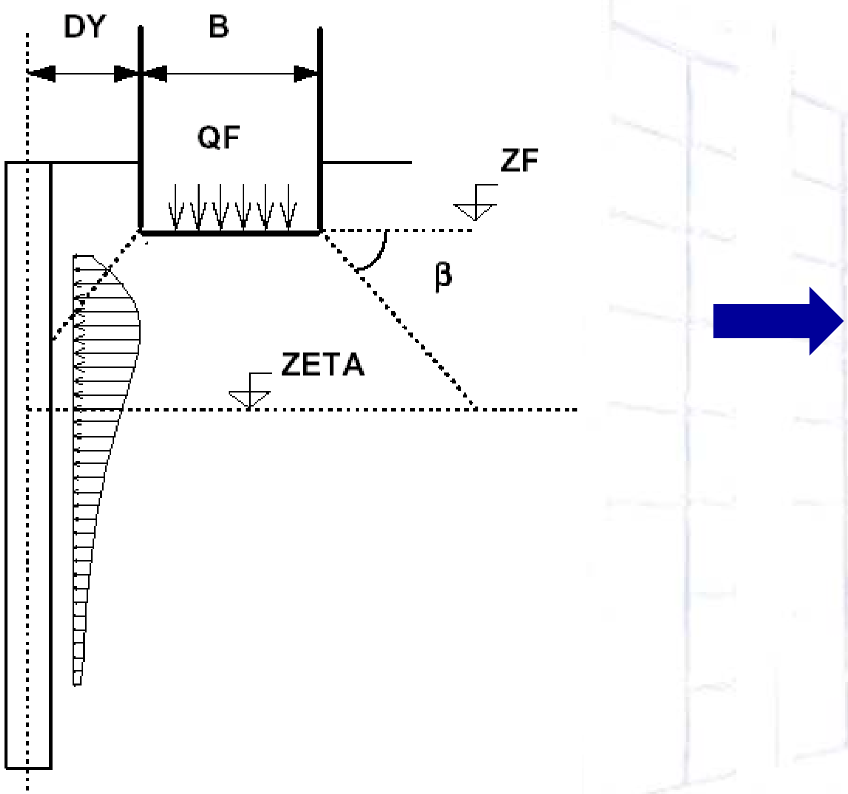


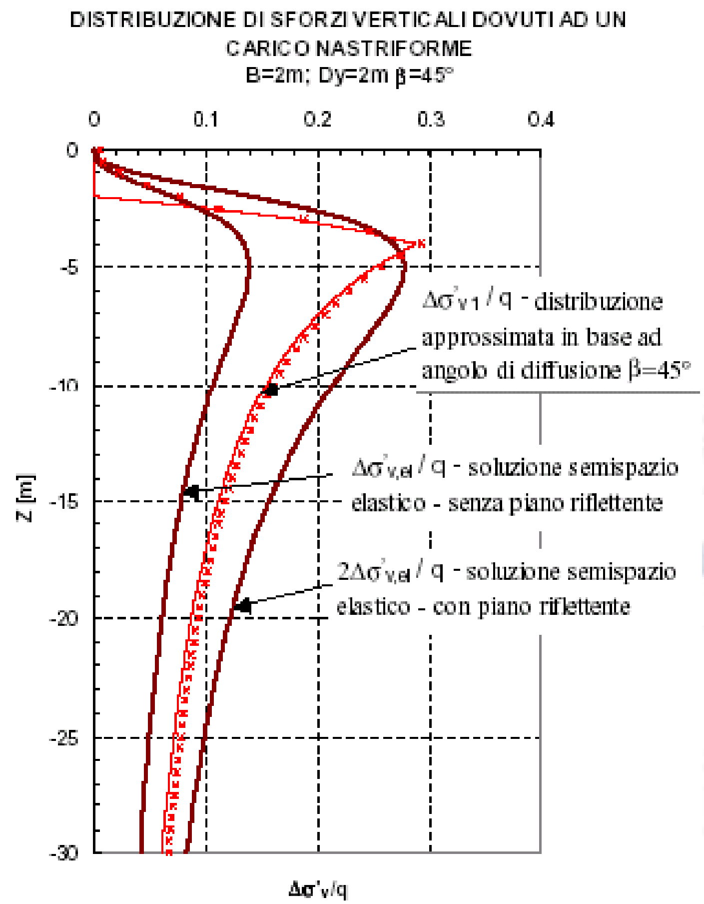
Surface loads



Surface loads

Strip modificato per mezzo del fattore m





Surface loads from elasticity applied on the wall

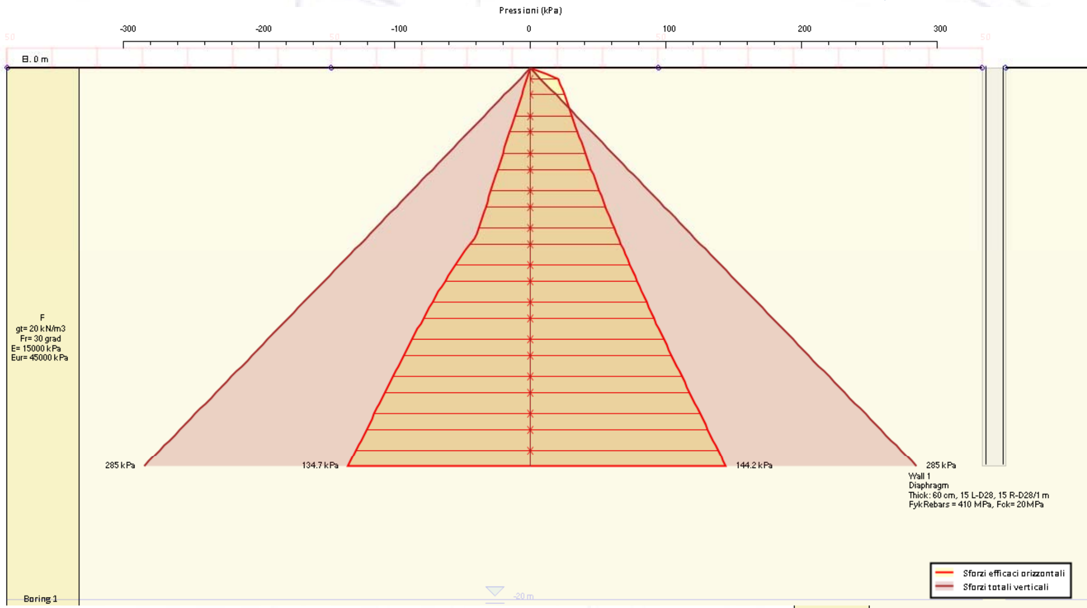
Input file NL analysis.

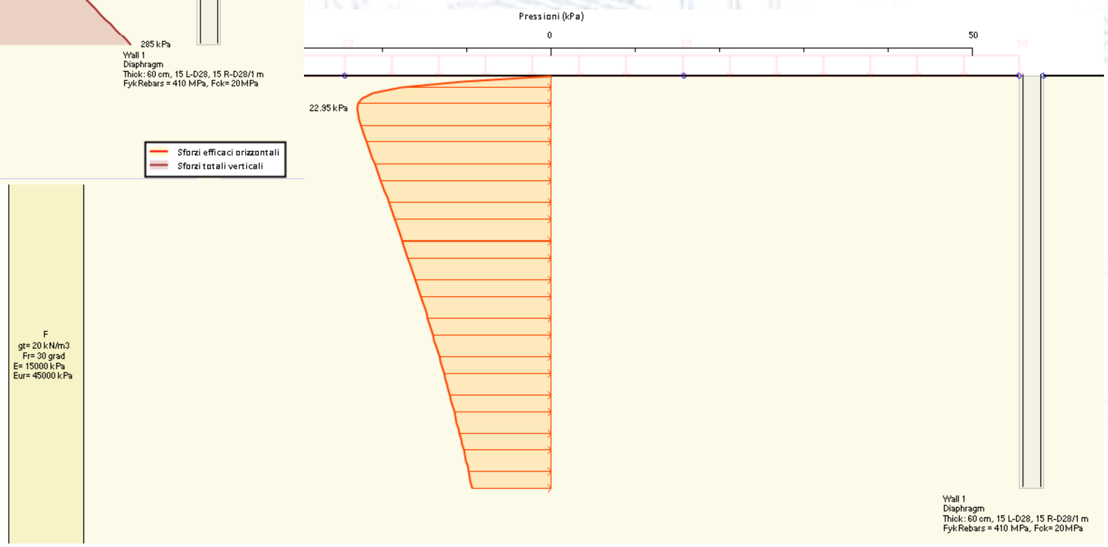
```
step 0 : Stage 0
setwall Leftwall
    geom 0 0
    water -20 0 -15 0 0

        dload step Leftwall -0.2 10.7774 0 0
        dload step Leftwall -0.4 17.7593 -0.2 10.7774
        dload step Leftwall -0.6 21.069 -0.4 17.7593
        dload step Leftwall -0.8 22.3904 -0.6 21.069
        dload step Leftwall -1 22.8495 -0.8 22.3904
        dload step Leftwall -1.2 22.9459 -1 22.8495
        dload step Leftwall -1.4 22.8805 -1.2 22.9459
        dload step Leftwall -1.6 22.7365 -1.4 22.8805
        dload step Leftwall -1.8 22.5512 -1.6 22.7365
        dload step Leftwall -2 22.343 -1.8 22.5512
        dload step Leftwall -2.2 22.1213 -2 22.343
        dload step Leftwall -2.4 21.8914 -2.2 22.1213
        dload step Leftwall -2.6 21.6565 -2.4 21.8914
        dload step Leftwall -2.8 21.4186 -2.6 21.6565
        ……………………………………………………………………………..
```

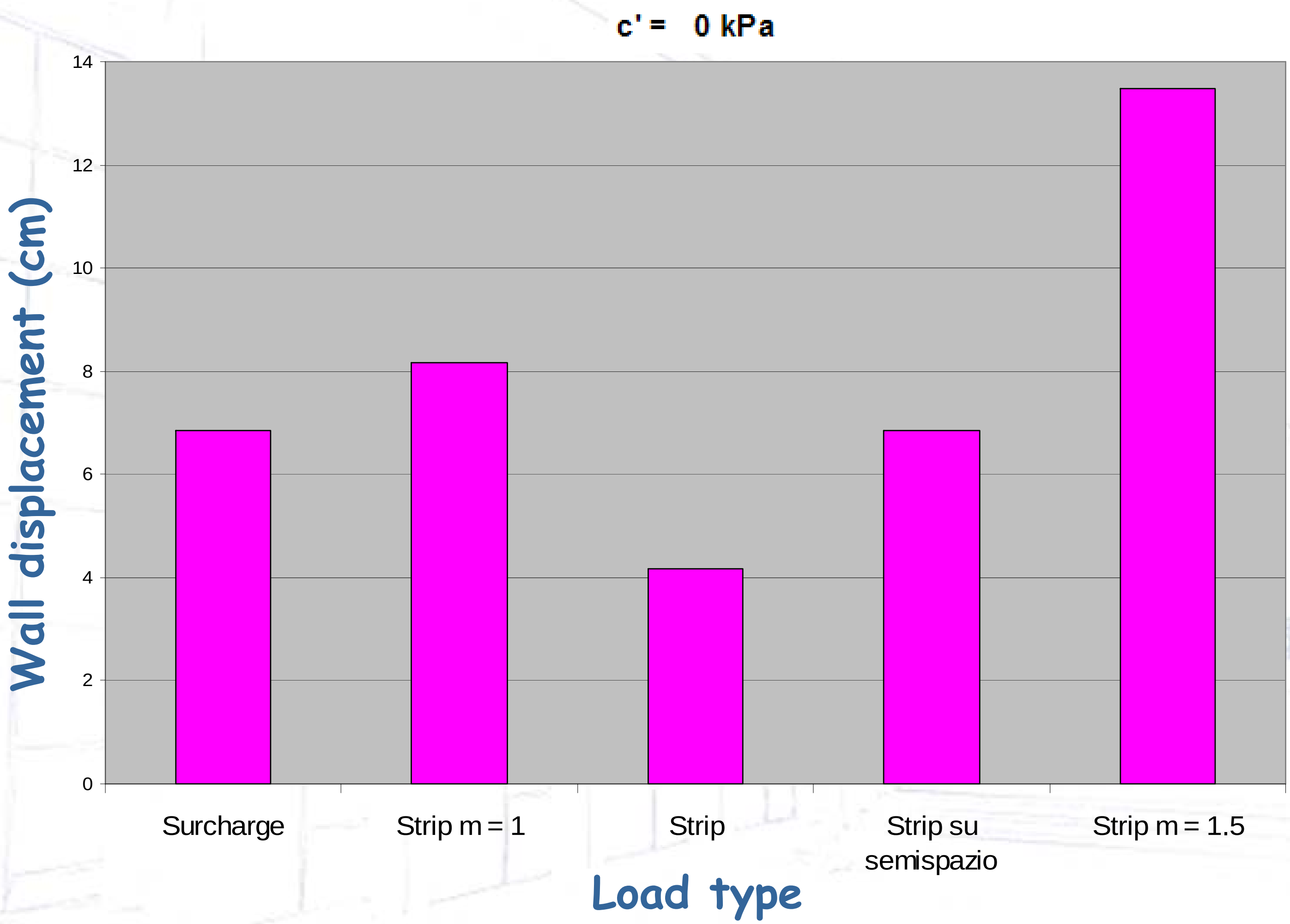
Surface loads

When the theory of elasticity is used.

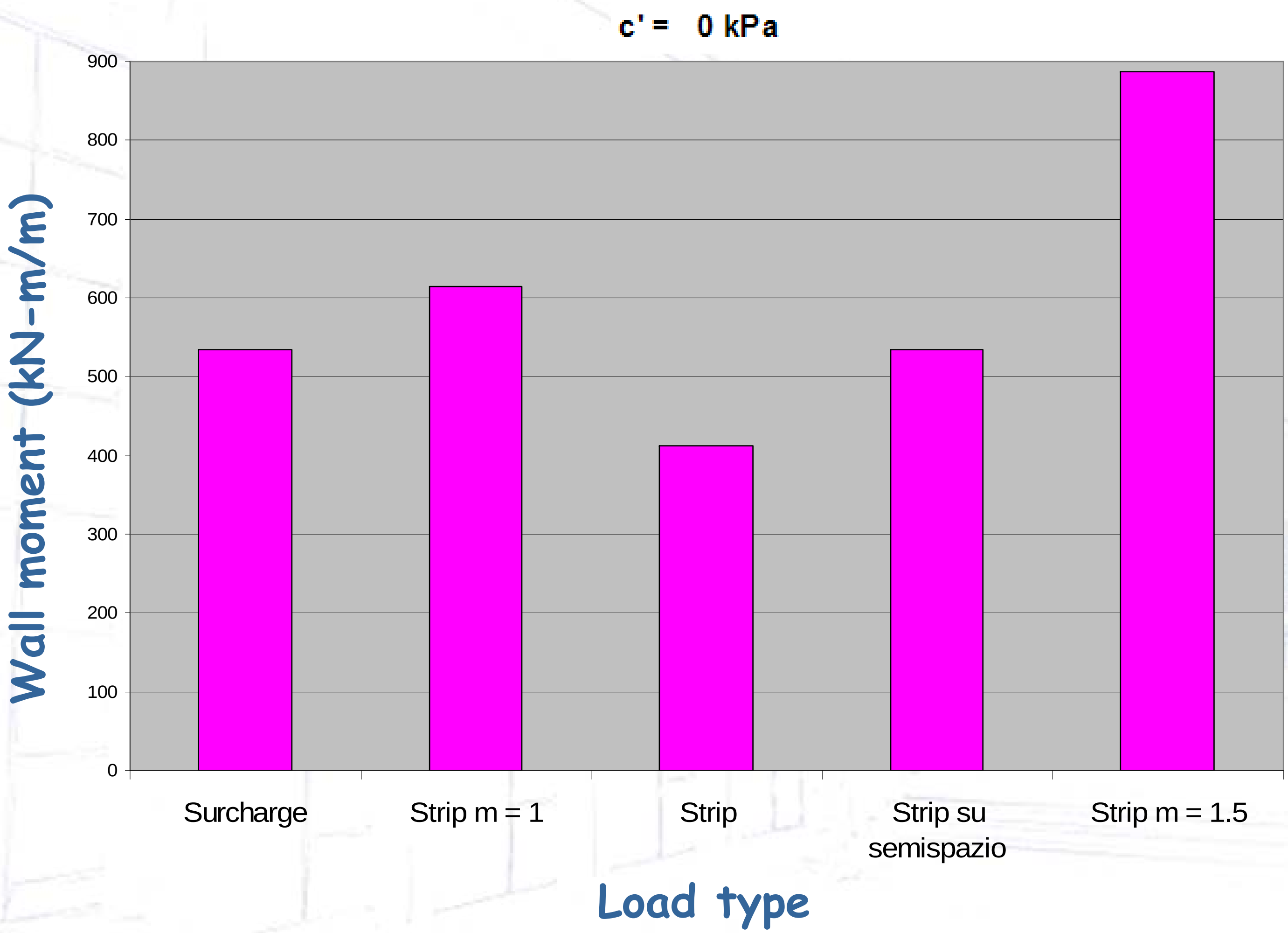




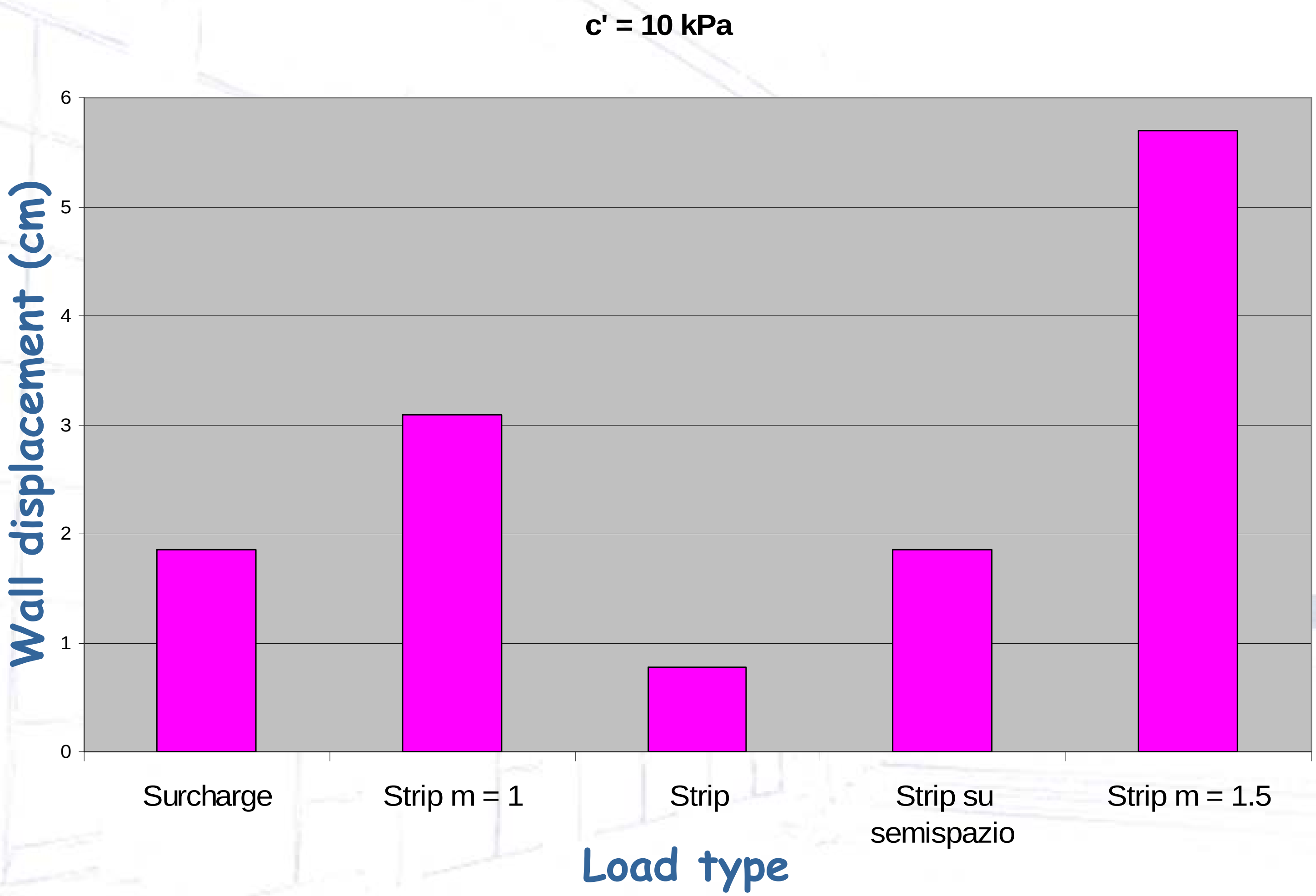
Surface loads



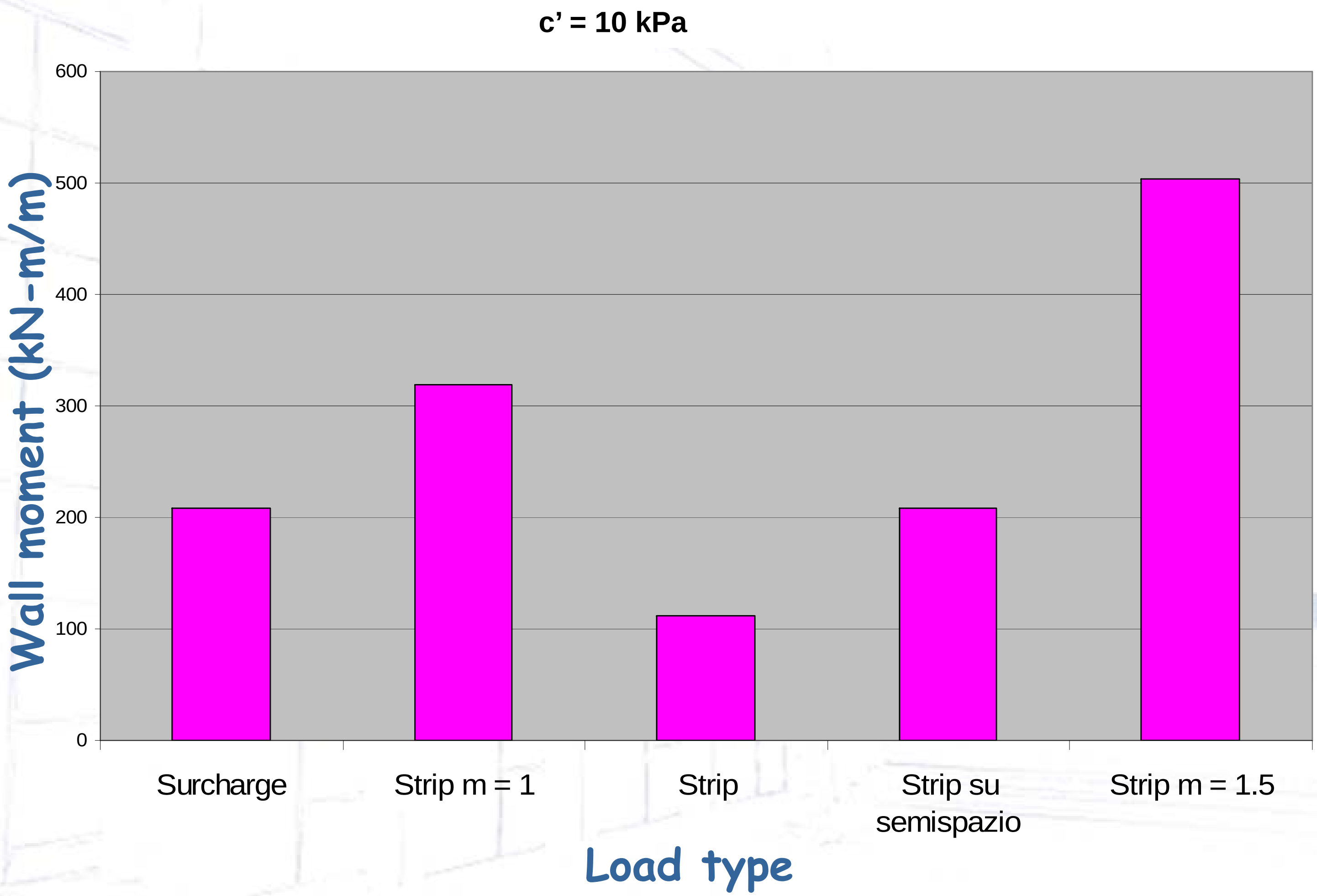
Surface loads



Surface loads

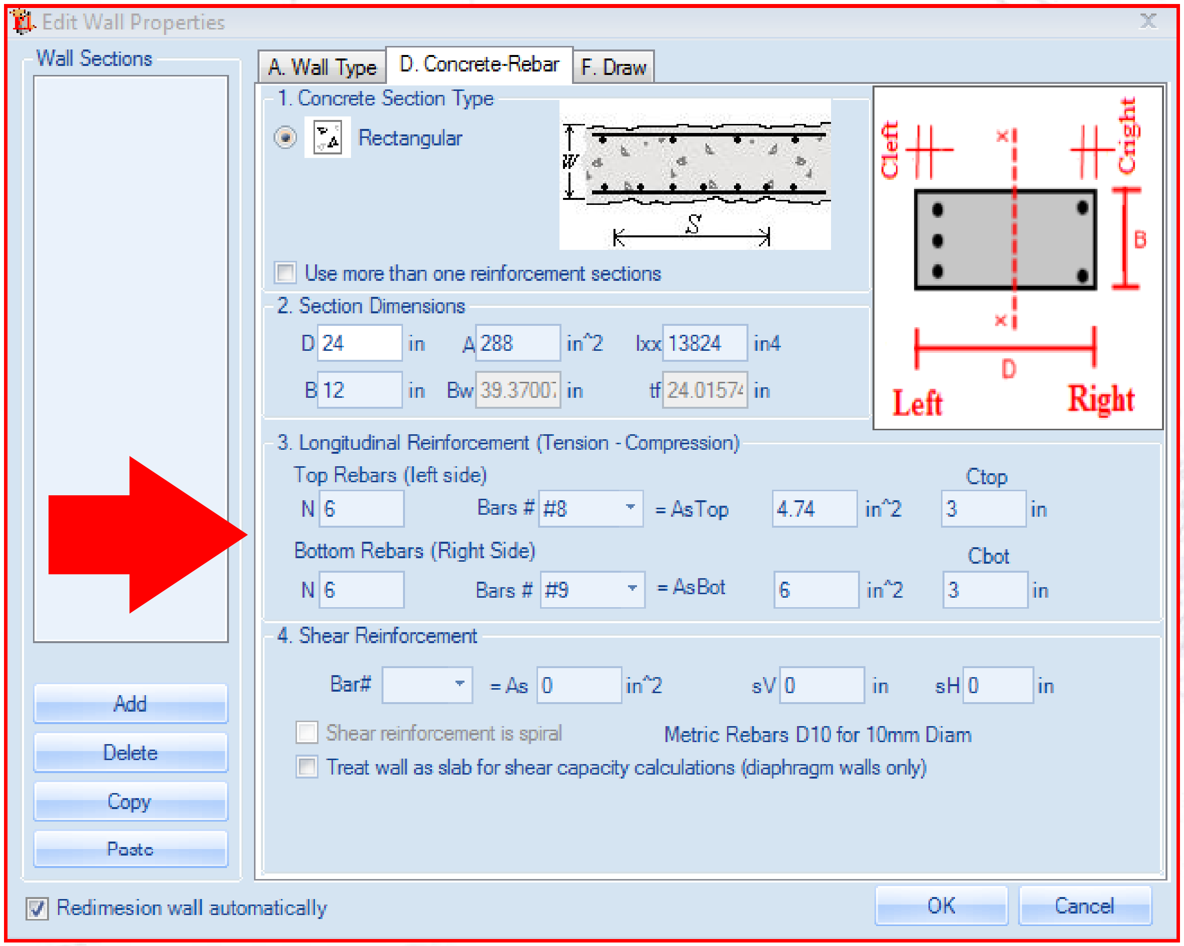


Surface loads



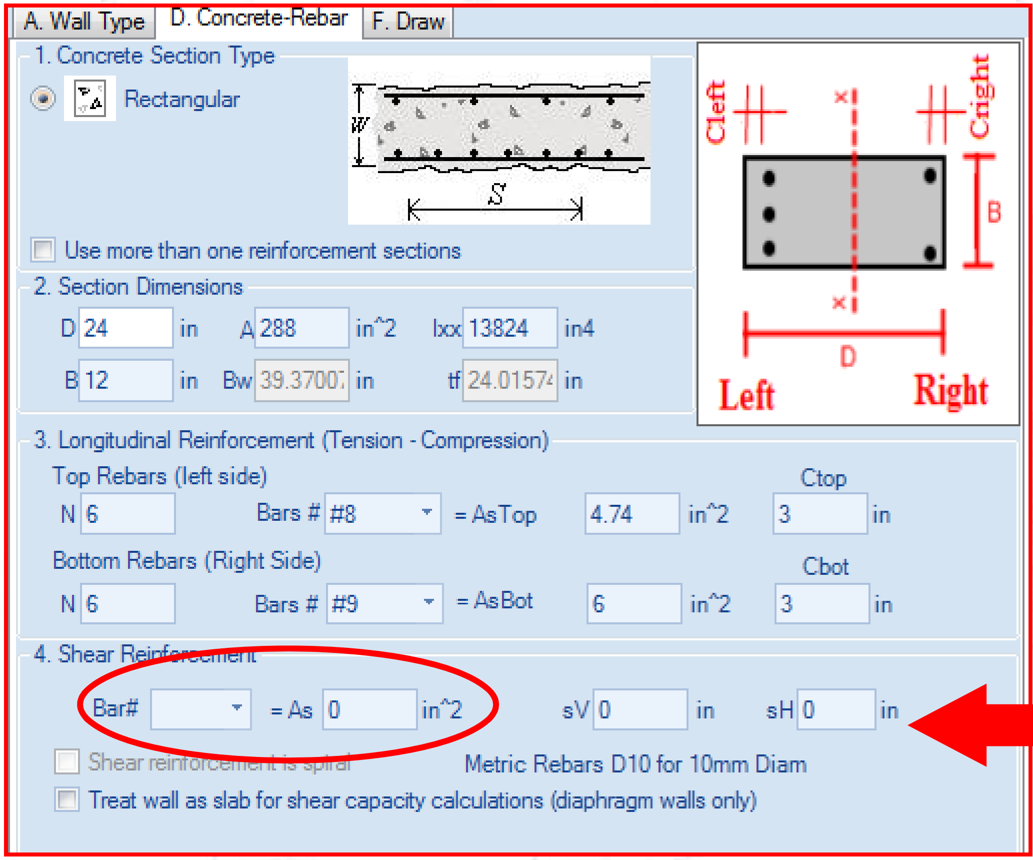
WALL PARAMETERS

Diaphragm wall reinforcement options (left side and right side)



WALL PARAMETERS

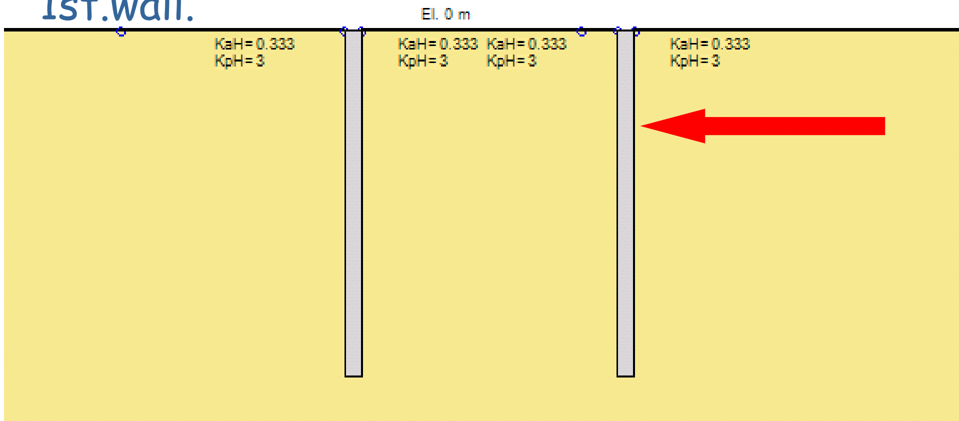
Diaghragm walls shear reinforcement.

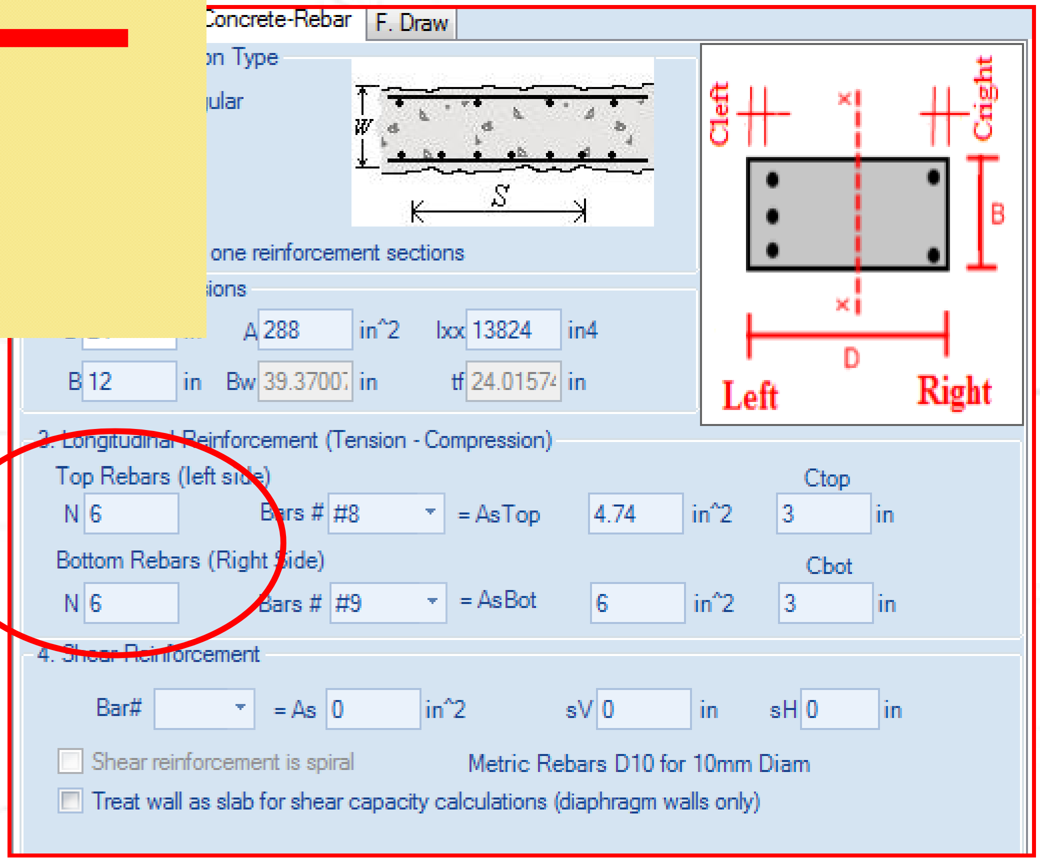


Note: In the default option there is no shear reinforcement.
sV = Vertical spacing.
sH = Horizontal spacing.

WALL PARAMETERS

Warning: The reinforcement on the 2nd wall has the same layout (left & right) as the 1st.wall.

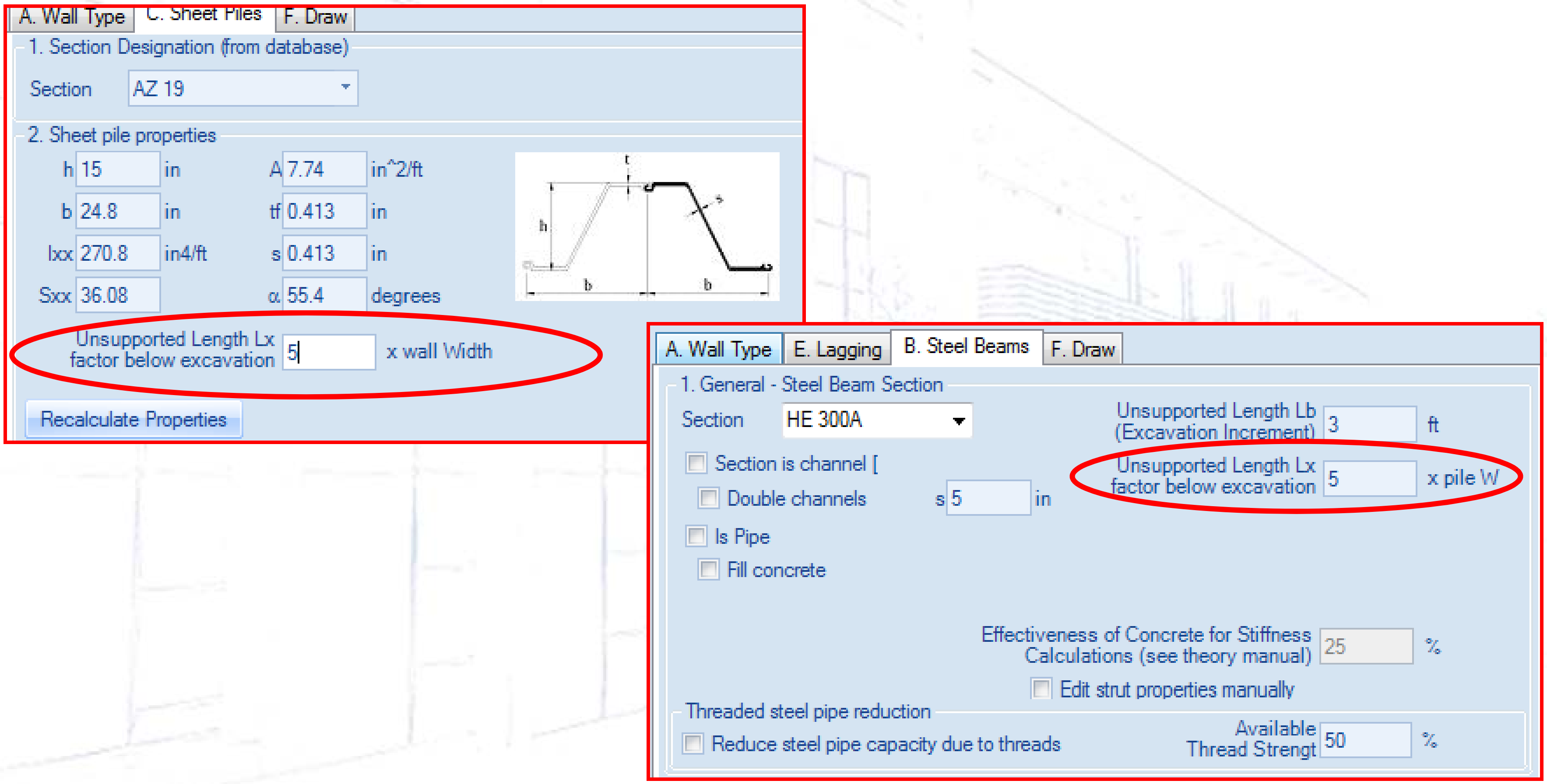




WALL PARAMETERS

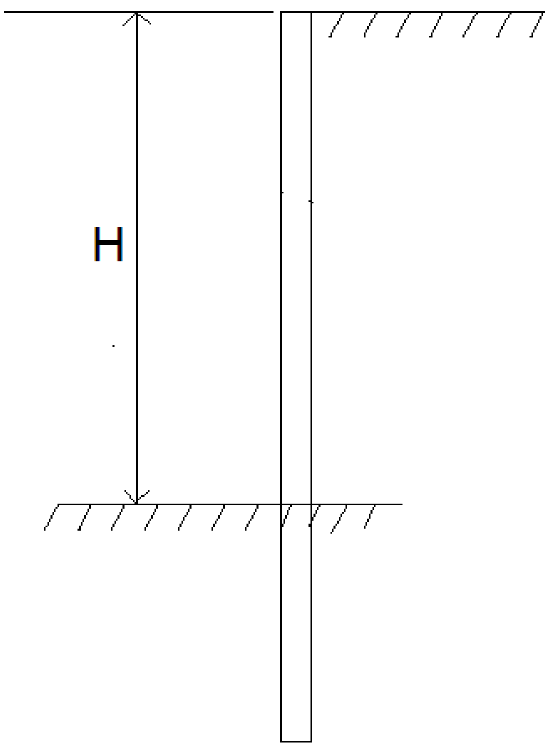
For pile walls and sheet pile walls:

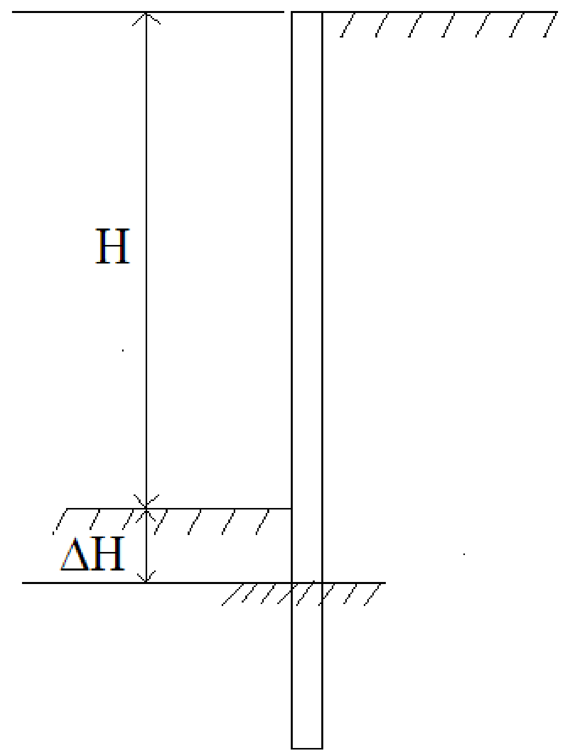
The parameter unsupported length factor below the excavation is important.



WALL PARAMETERS

Unbraced length for structural design of soldier piles and sheet piles





With factor = 0

With unbraced length increased by ΔH
ΔH = x/100 spessore paratia or
ΔH = LF x Wall width

WALL PARAMETERS

Soldier piles and sheet piles: equivalent thickness calculation

Sheet piles: $$T_{eq} = \sqrt[3]{\frac{12 J_{xx}}{S}}$$

S = 1 for sheet pile walls

Piles:

$$J_{eq} = \frac{\left(E_s J_{tubo} + E_{cls} J_{cls}\right)}{E_{om} N}$$

N = 1/S, S = pile spacing

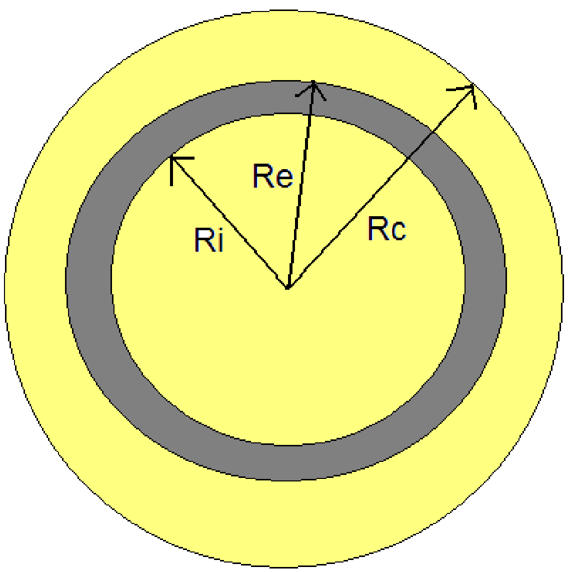
E_{om} = E mat. Selected normalization material.

WALL PARAMETERS

Soldier piles: equivalent thickness in DeepXcav

$$J_{eq} = \frac{\left(E_s J_{tubo} + E_{cls} J_{riempimento+crosta}\right)}{E_s N}$$

E steel



$$J_{tubo} = \frac{\pi (R_e - R_i)^4}{4}$$

$$J_{riempimento+crosta} = \frac{\pi R_i^{\ 4}}{4}\frac{x}{100} + \frac{\pi (R_c - R_e)^4}{4}$$

$$T_{eq} = \sqrt[3]{\frac{12 J_{xx}}{S}}$$

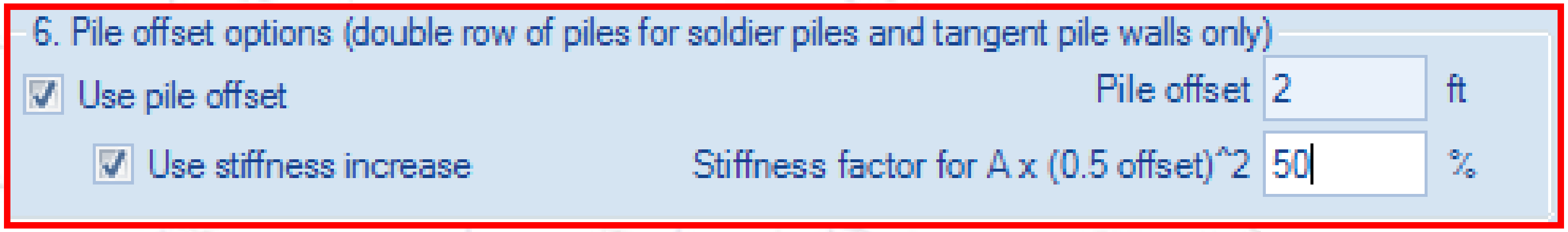
WALL PARAMETERS

TABELLA DI CONFRONTO SPESSORI EQUIVALENTI

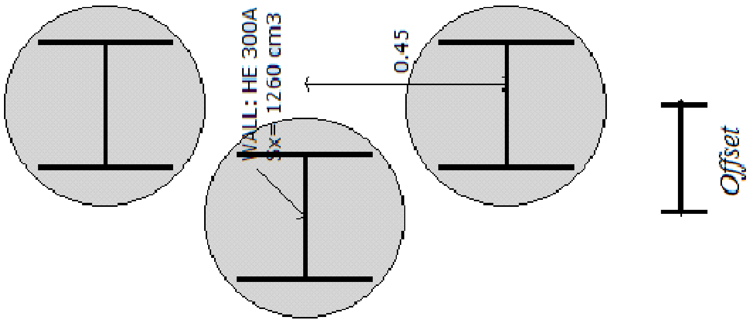
	PARATIE 7.0	PARATIE PLUS (senza camicia)	PARATIE PLUS (camicia esterna)
$t_{tubo\ (cm)}$	1,2	1,2	1,2
$r_{est,tubo}$ (cm)	9	9	9
I_{tubo} (cm4)	2246	2246	2246
r_{est} (cm)	11	11	11
r_{int} (cm)	7,8	7,8	7,8
$I_{cls\ -\ interno}$ (cm4)		2907	2907
$I_{cls\ -\ cover}$ (cm4)		0	6346
% area cls	/	100	100
$I_{cls\ -\ tot}$ (cm4)	11499	2907	9253
E_{cls} (Mpa)	31000	31000	31000
E_{steel} (Mpa)	210000	210000	210000
s (passo in cm)	40	40	40
N (=1/s)	0,025	0,025	0,025
Jeq (cm4)	98,58	66,87	90,29
t (cm)	**10,6**	**9,3**	**10,27**

WALL PARAMETERS

Soldier piles with offset



$$\frac{\Delta J}{palo} = \frac{x}{100} A \left(\frac{offset}{2}\right)^2$$



A = Steel or concrete element area.
x = Factor for increase in stiffness by user.

Note: the increased moment of inertia DJ is only used in the equivalent thickness of the wall during analysis and not for the structural capacity calculations.

WALL PARAMETERS

Custom wall

3. Dati genera...

User mat.

Release bottom and top.

	Top (m)	Mat.	Ixx (cm4)	Svincolo base paratia	...icolo ...ommità paratia	t (m)
	10	0: Use...	3750000	All	None	1
▶	5	0: Use...	3750000	None	All	1

Top elevation

Inertia

Equiv. thickness

$$T_{eq} = \sqrt[3]{\frac{12 J_{eq}}{S}}$$

Warning:

DEEP: WARNING

For conventional analysis only first user beam is used.
For Spring Analysis, ALL beams are used.

OK

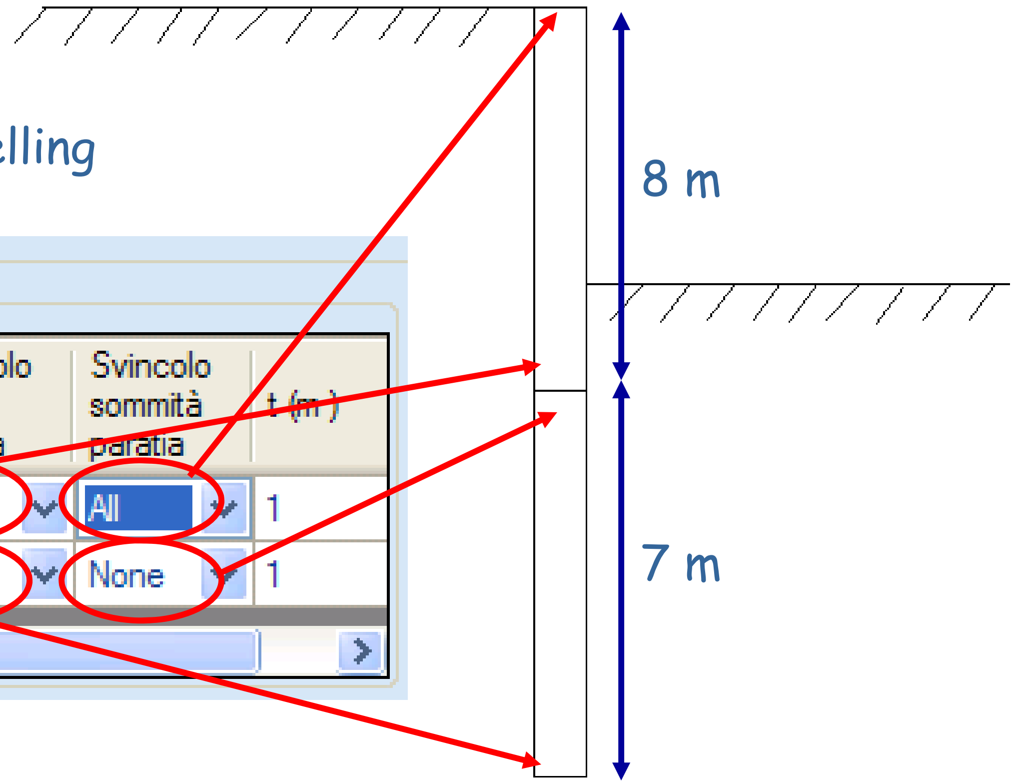
WALL PARAMETERS

Custom wall

Correct modelling

3. Dati generali sezione

	Top (m)	Mat.	Ixx (cm4)	Svincolo base paratia	Svincolo sommità paratia	t (m)
	8	0: Use...	83333...	None	All	1
	7	0: Use...	83333...	All	None	1



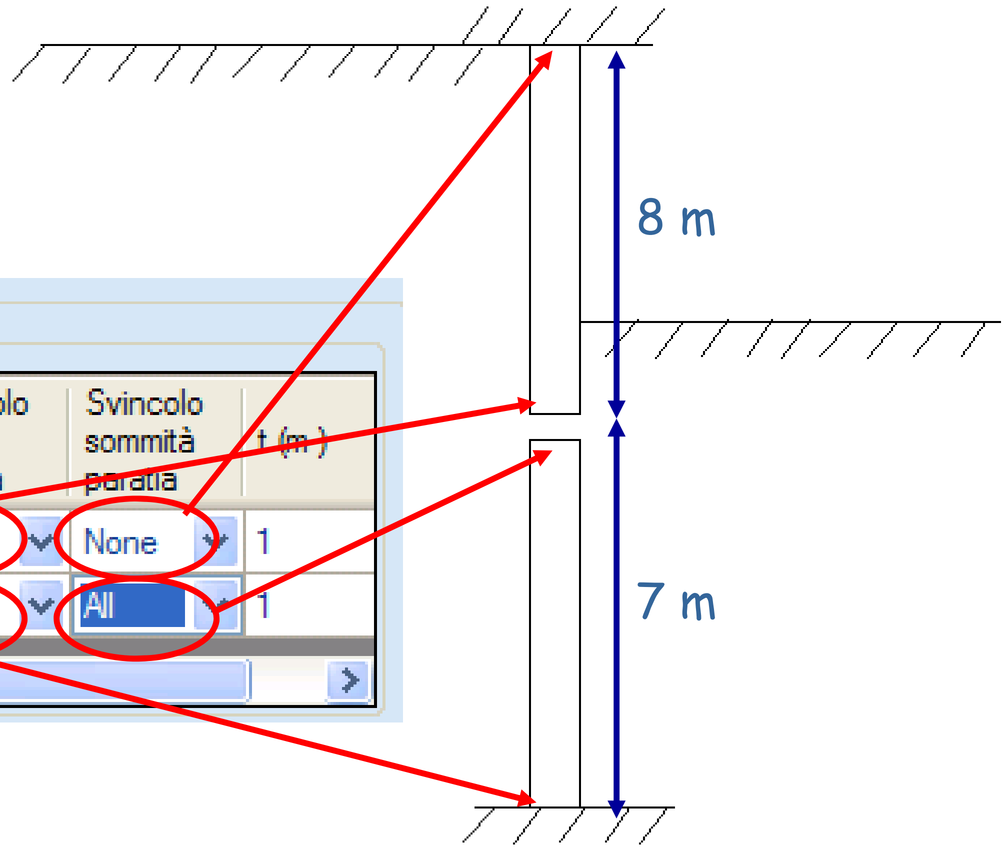
WALL PARAMETERS

Sezioni personalizzate

Assurdo!

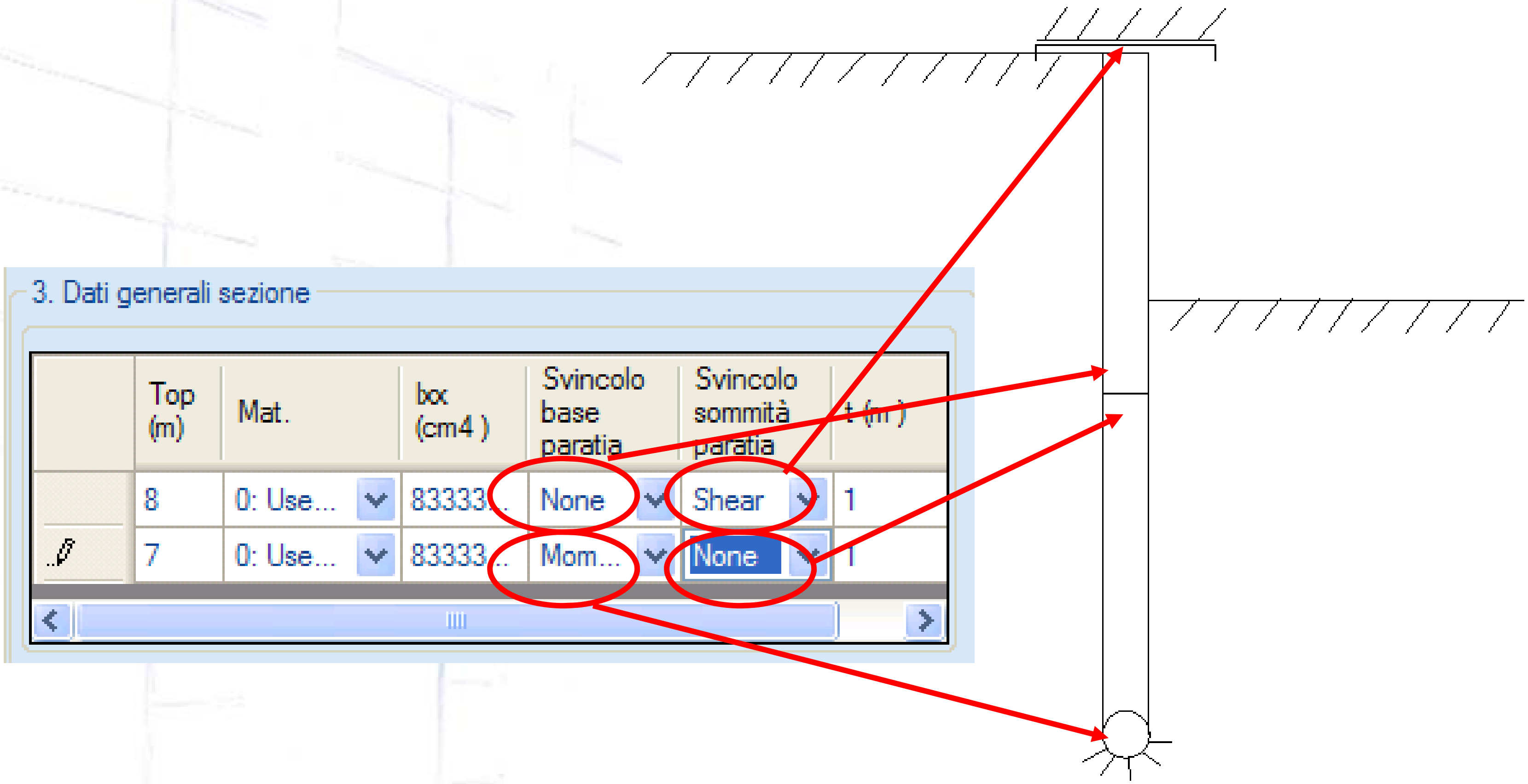
3. Dati generali sezione

	Top (m)	Mat.	Ixx (cm4)	Svincolo base paratia	Svincolo sommità paratia	t (m)
	8	0: Use...	83333...	All	None	1
	7	0: Use...	83333...	None	All	1



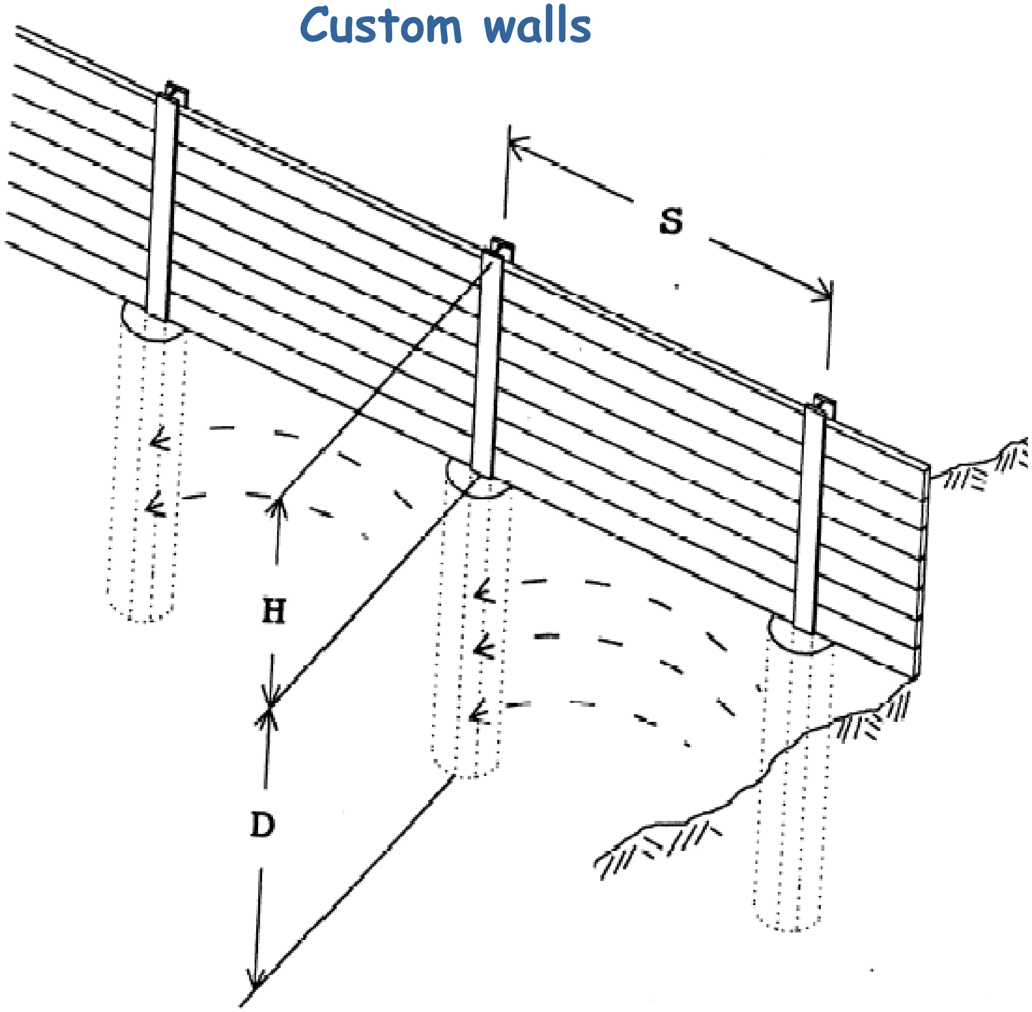
WALL PARAMETERS

Release options



WALL PARAMETERS

Custom walls



Currently a wall of this type can be modeled with the custom wall or with multiple wall elements.

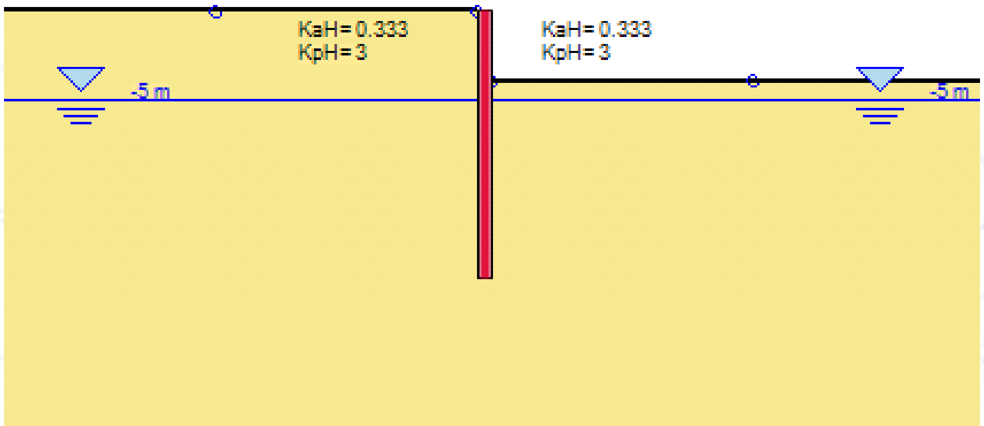
With custom walls it is not possible to perform a structural analysis.

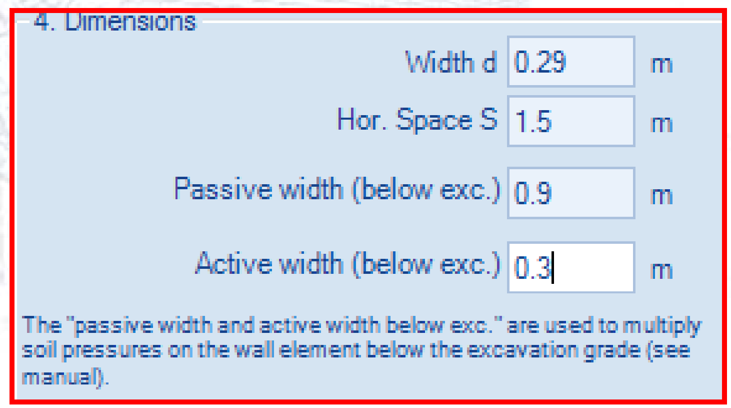
With additional wall elements it is now possible to use different wall sections (Version 8.1)

WALL PARAMETERS

Wall width (conventional analysis)

4m excavation 4 m in sand





WALL PARAMETERS

Safety factors for conventional analysis

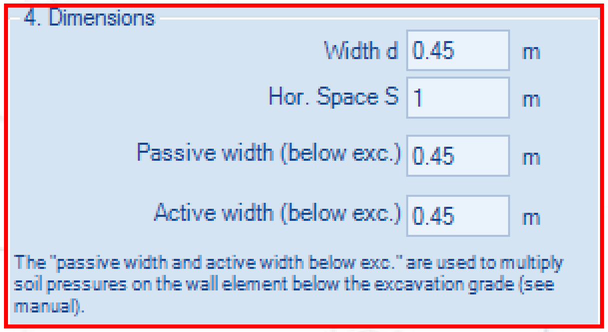
$$FS_{passive} = \frac{F_H \text{ resisting side}}{F_H \text{ driving side}}$$

$$FS_{rotational} = \frac{\text{M resisting}}{\text{M driving}}$$

$$FS_{embedment\ length} = \frac{\text{Provided wall embedment length (below excavation)}}{\text{Embedment length required for FS} = 1 \text{ from preceding safety factors}}$$

WALL PARAMETERS

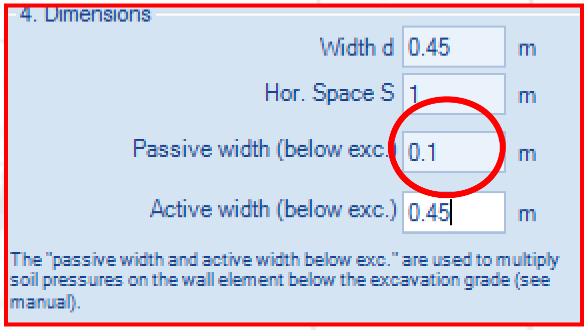
Active and passive widths (conventional analysis)



$FS_H = 1.597$

$FS_{rot} = 1.053$

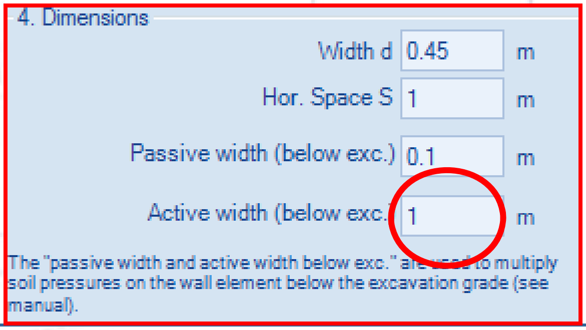
$FS_{inf} = 2.001$



$FS_H = 0.356$

$FS_{rot} = 0.234$

$FS_{inf} = 0.234$

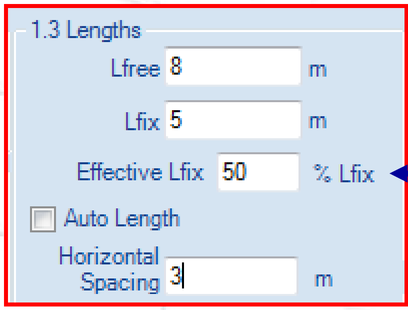


$FS_H = 1.459$

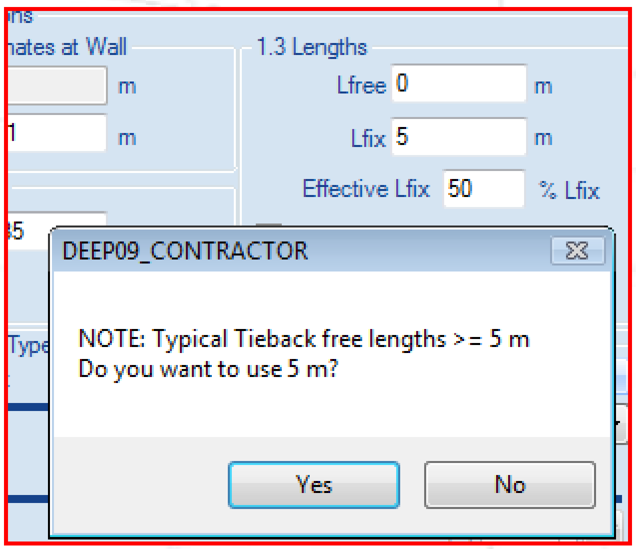
$FS_{rot} = 1.284$

$FS_{inf} = 1.333$

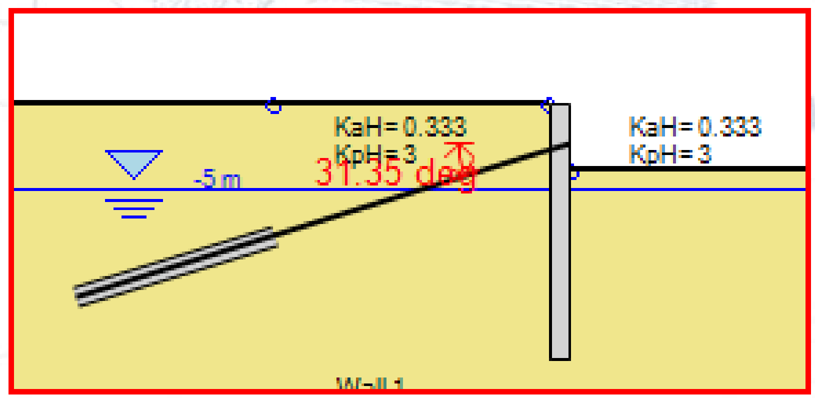
Ground anchors (Tiebacks)



Percentage of the fixed length included in the stiffness calculation.

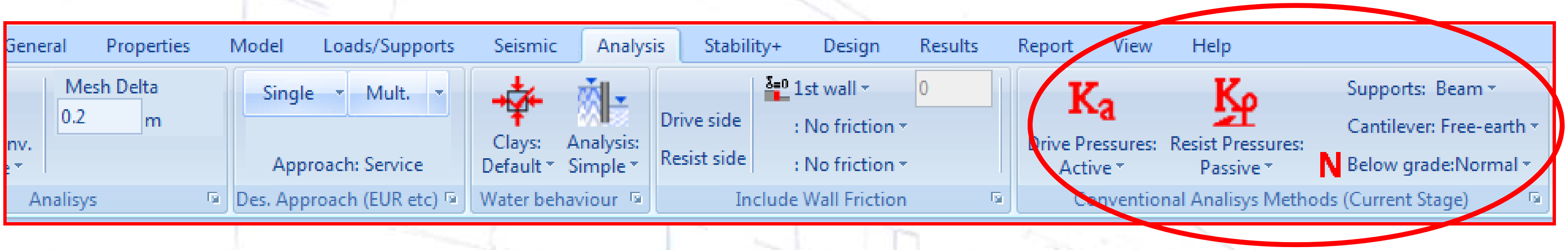


Modellazione micropali di ancoraggio

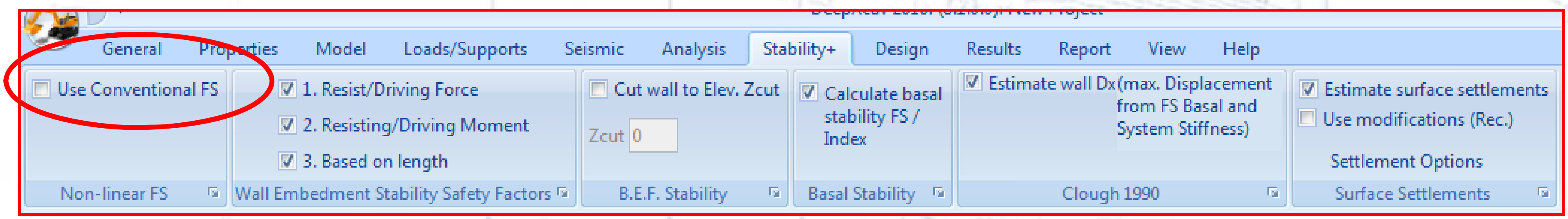


Conventional analysis options

Analysis menu:



Stability + Menu:



Classical

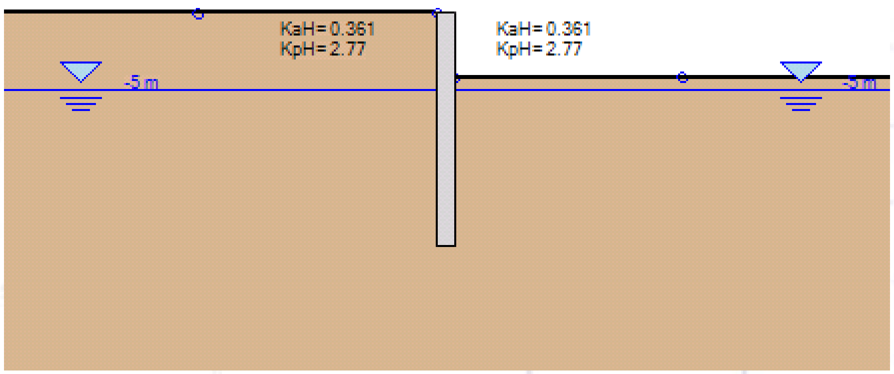
NL

Classical

Classical /NL

Example 1: ϕ_{cv} = ϕ_{peak} with clay model

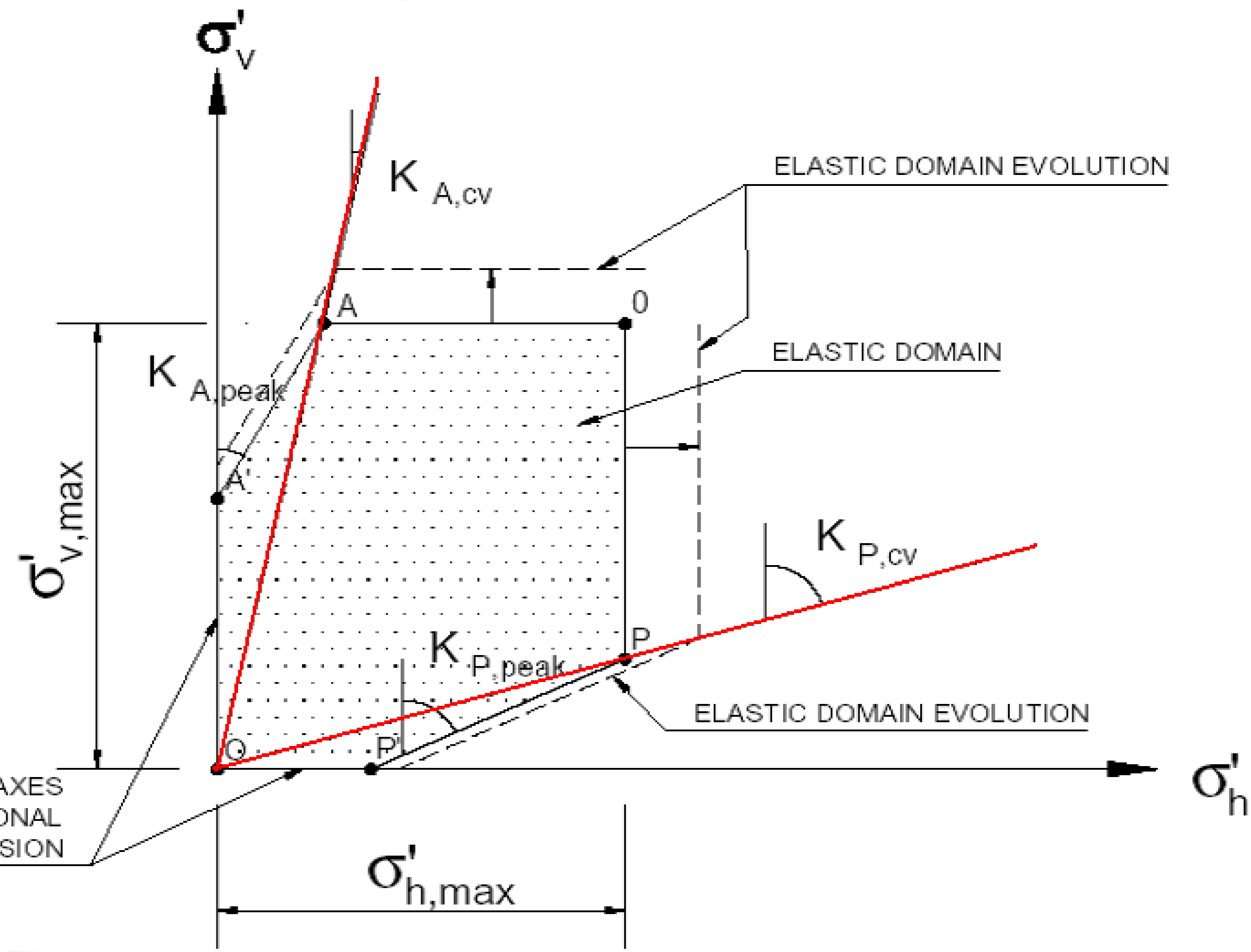
Excavation 4.5 m in clay. Wall = default diaphragm wall



$\phi_{cv} = 21°$, $\phi_{peak} = 15.1°$ ➡ Max displacement = 2.09 cm

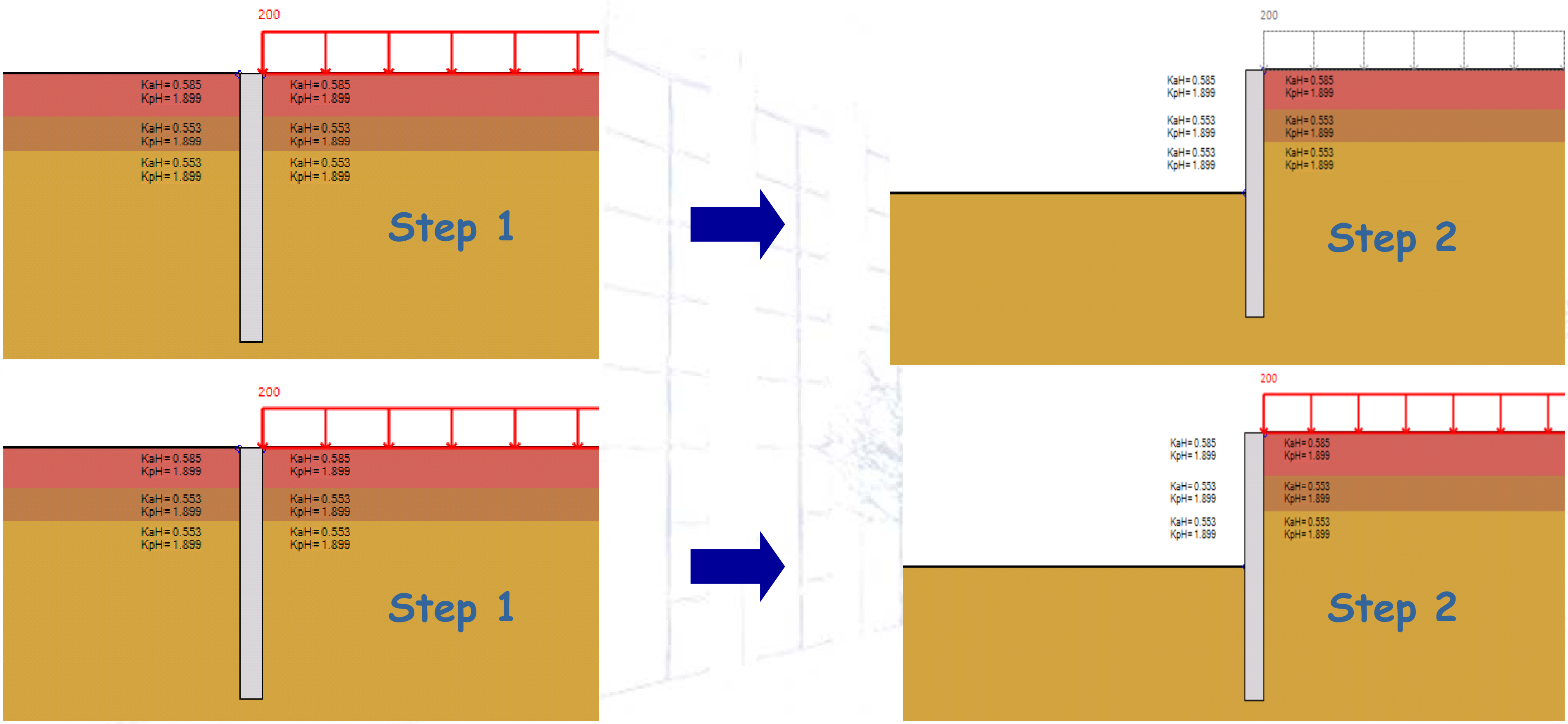
$\phi_{cv} = 21°$, $\phi_{peak} = 21°$ ➡ Max displacement = 2.32 cm

Example 1: ϕ_{cv} = ϕ_{peak} with clay model

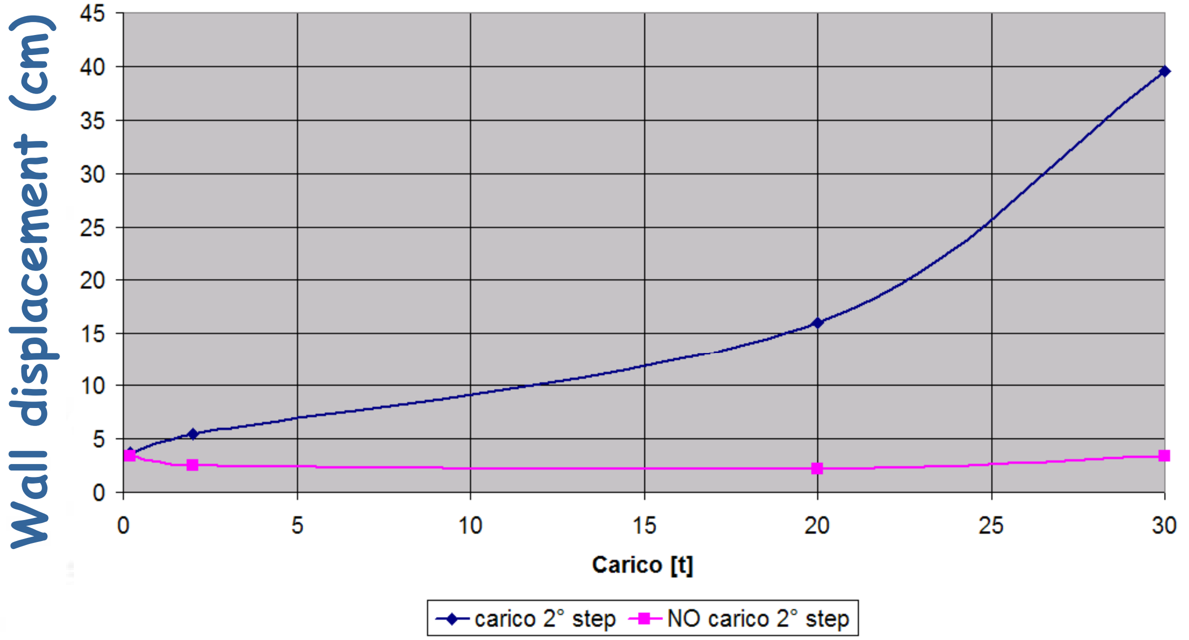


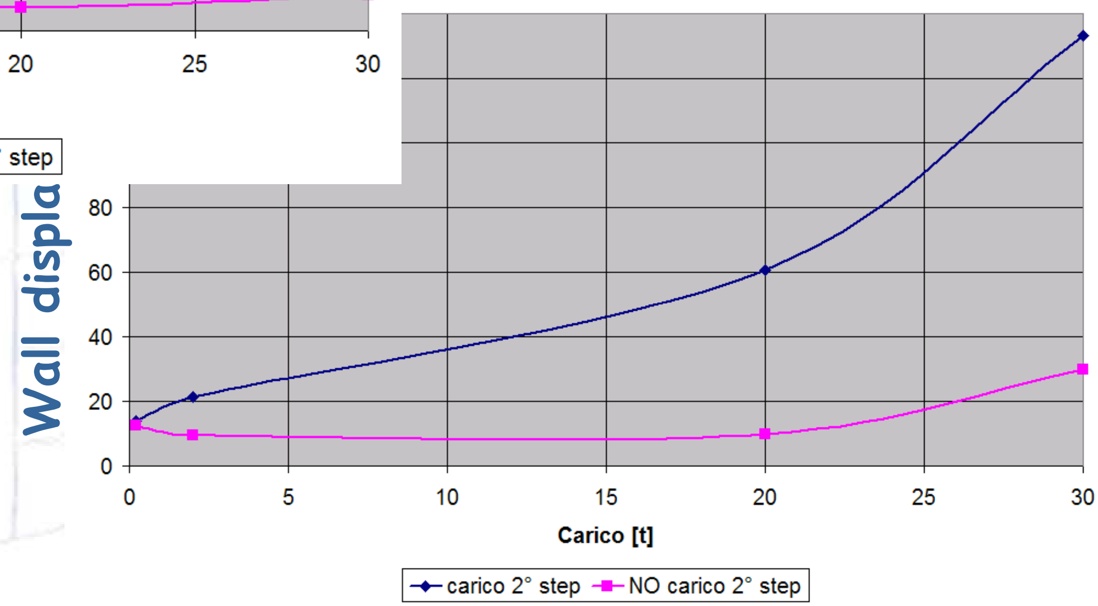
Example 2: Clays with overconsolidation

Excavation 6. 5 m in clay. Wall = diaphragm, 40 cm, 6ϕ16mm reinforcement

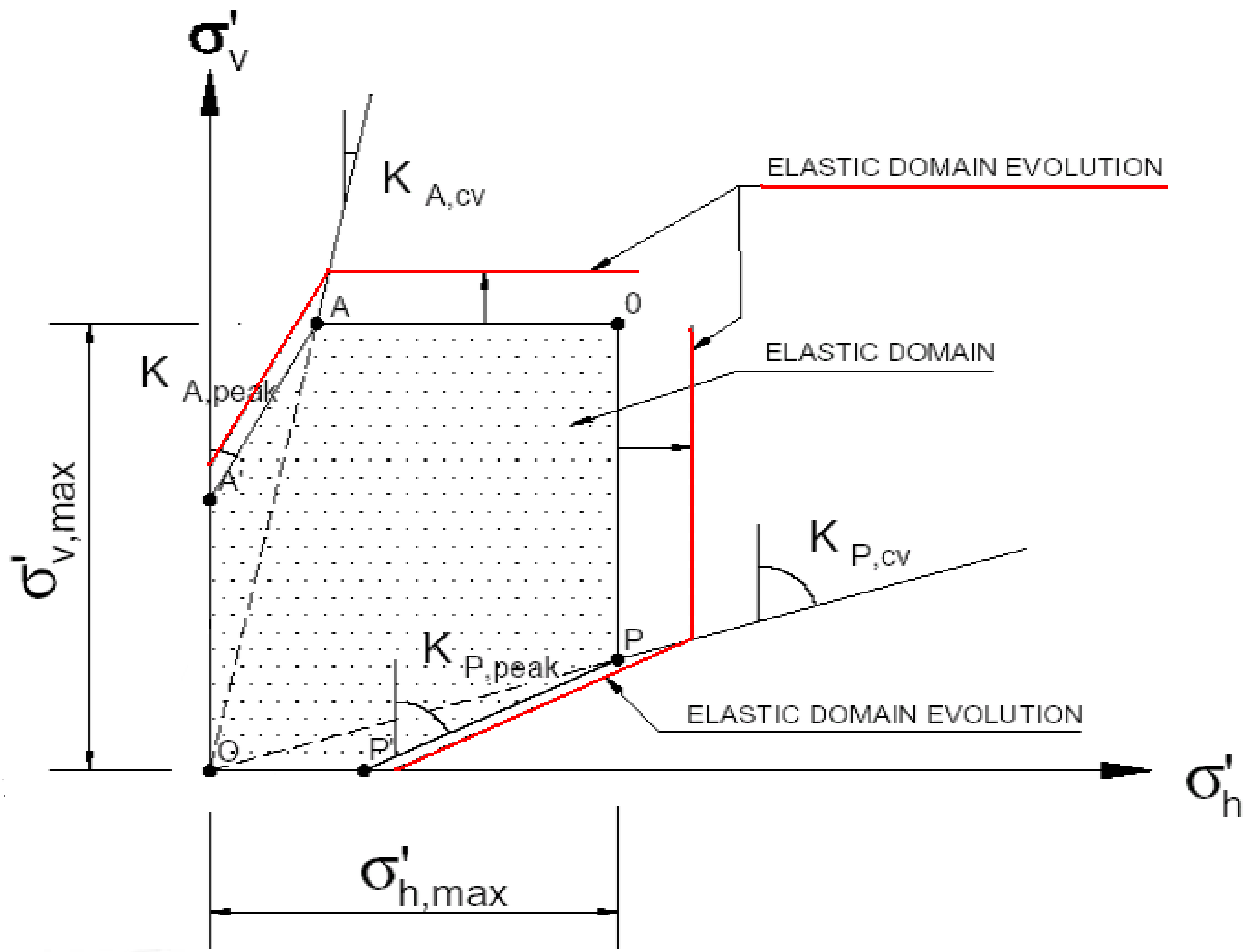


Example 2: Overconsolidation and clays



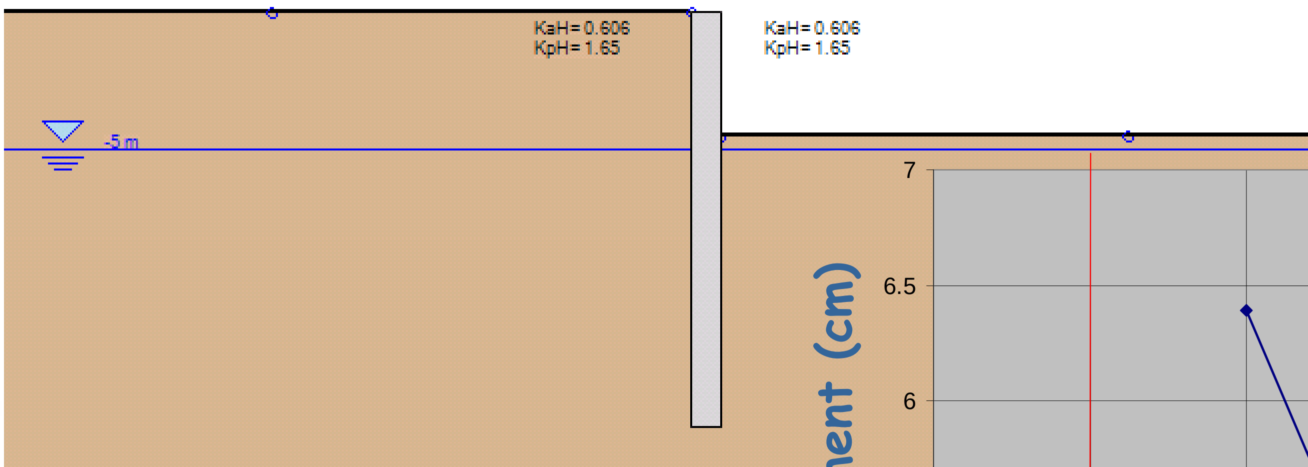


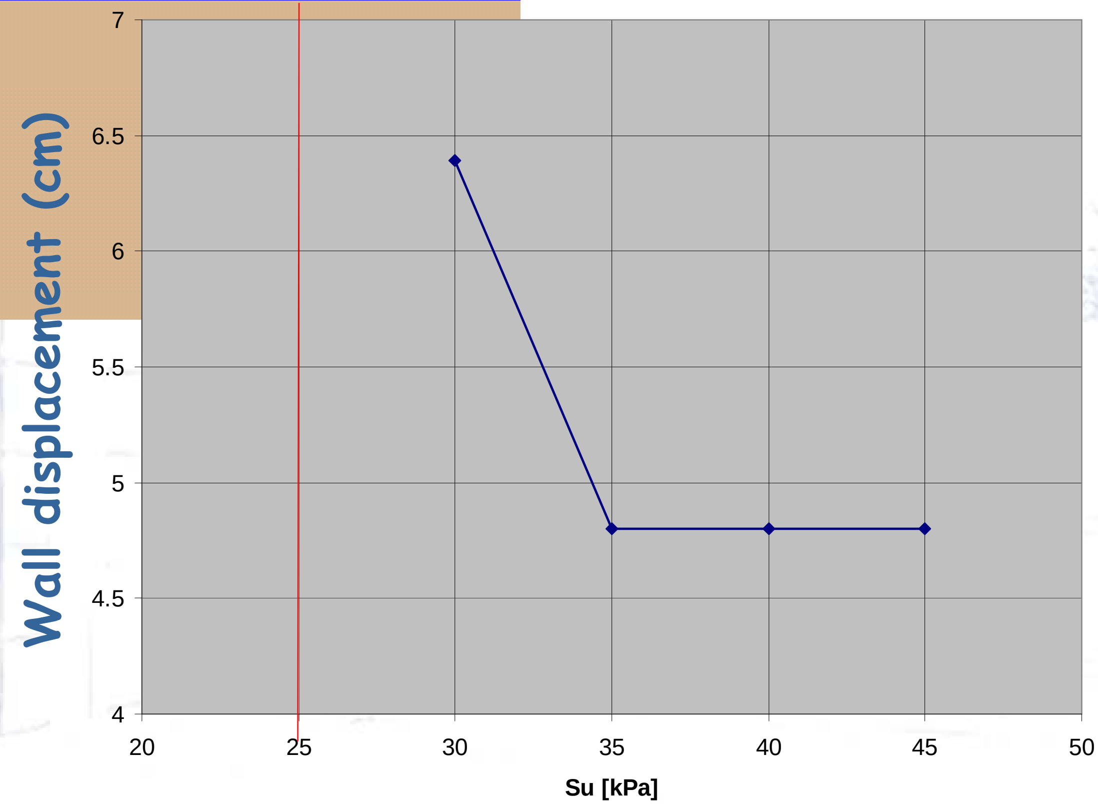
Example 2: Sovraconsolidazione nelle argille



Example 3: Effect of undrained shear strength Su

Excavation di 4.5 m in clay. Wall = diaphragm (default)





Su = 25 kPa: NOT CONVERGED

Su = 30 kPa: 6.39 cm

Su = 35 kPa: 4.8 cm

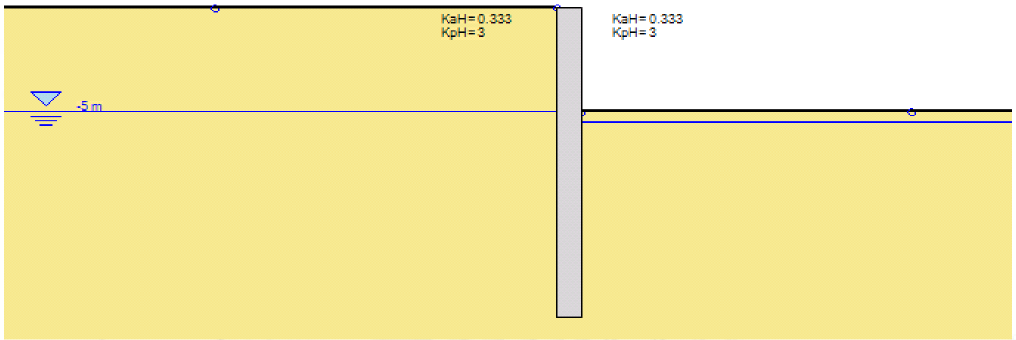
Su = 40 kPa: 4.8 cm

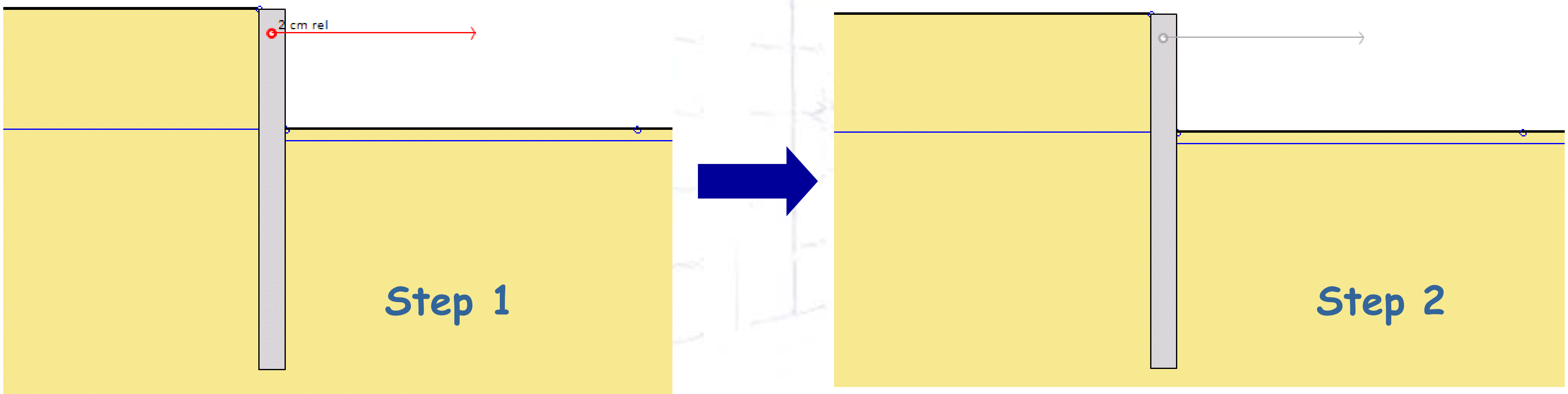
Example 4: Imposed displacement

Excavation 5.0 m in sand. Wall = diaphragm (default)

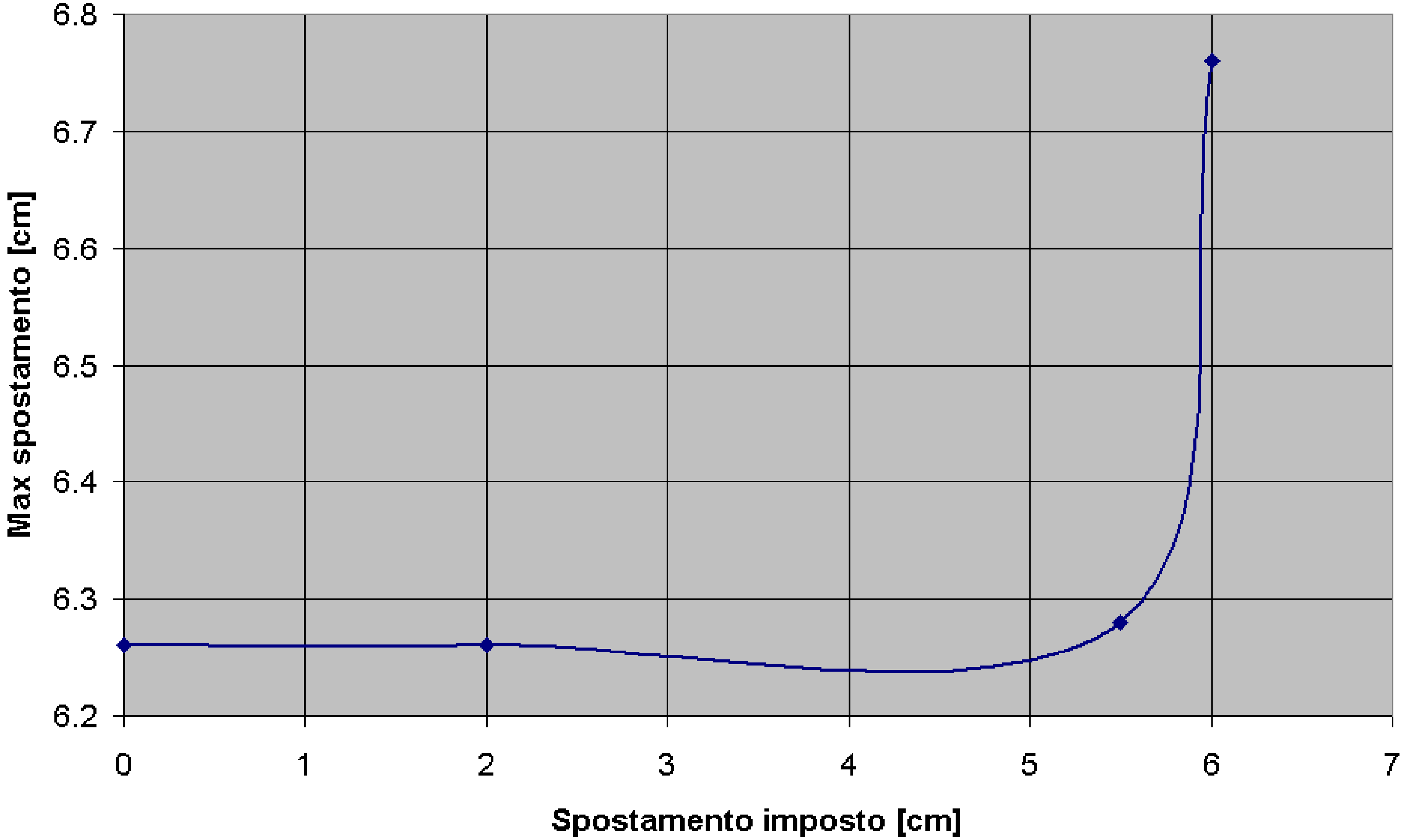
Basic analysis (no imposed displacement)

Max displacement: 6.26 cm

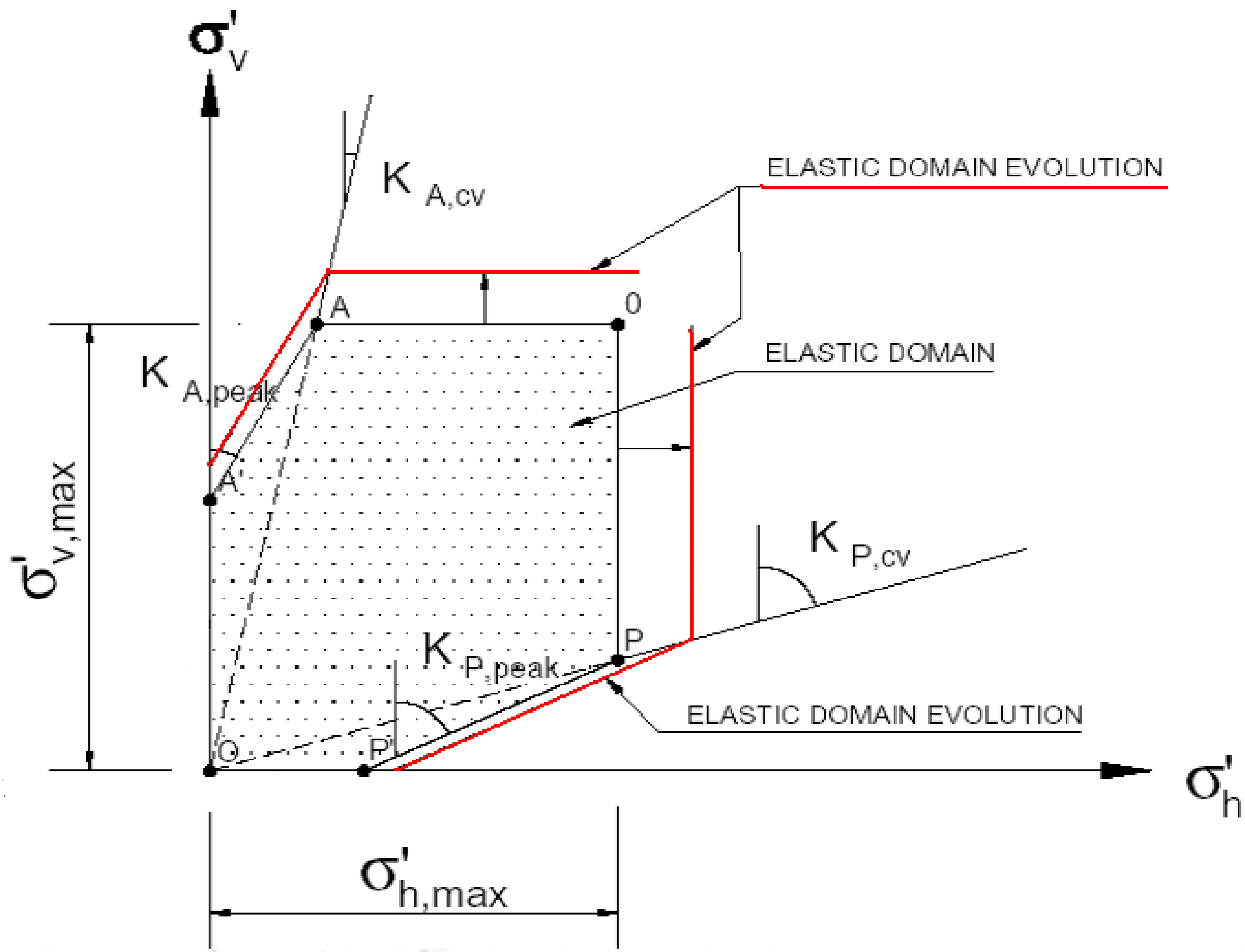




Example 4: Imposed displacement

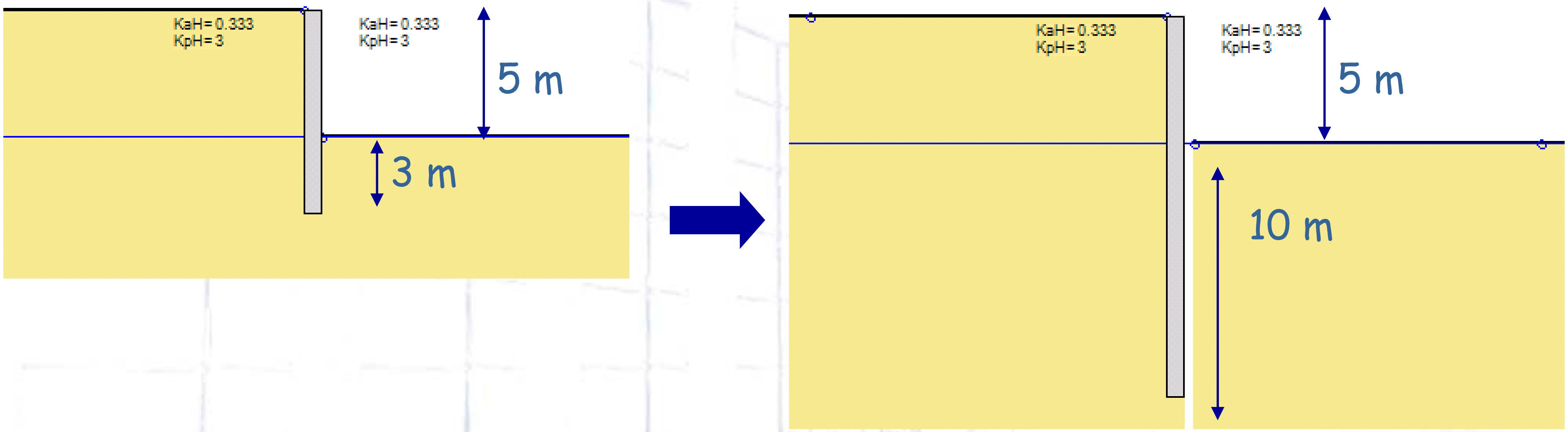


Example 4: Imposed displacement



Example 5: Conventional analysis

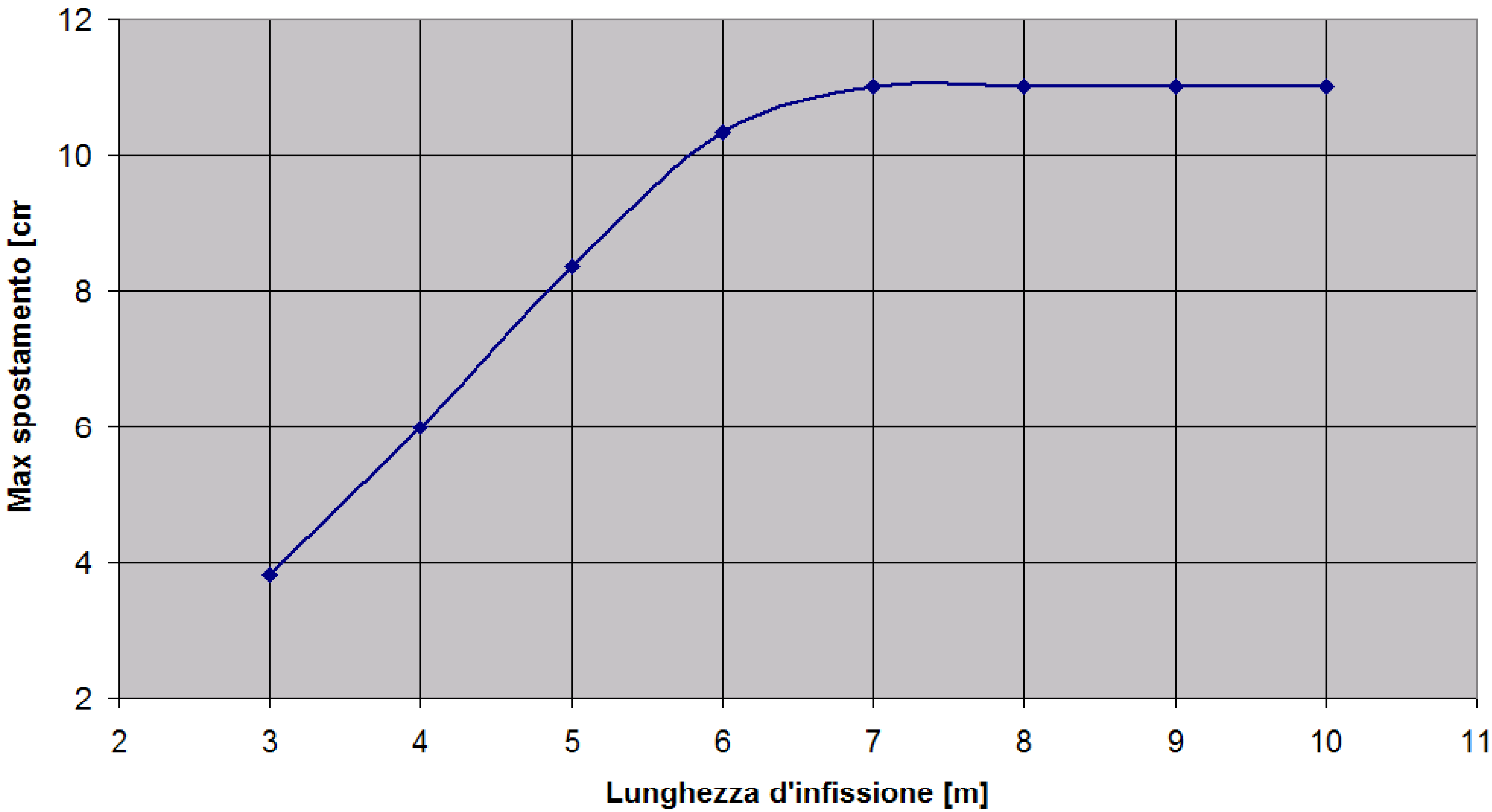
Excavation di 5.0 m in sand con parametri di default. Wall = diaphragm (default)



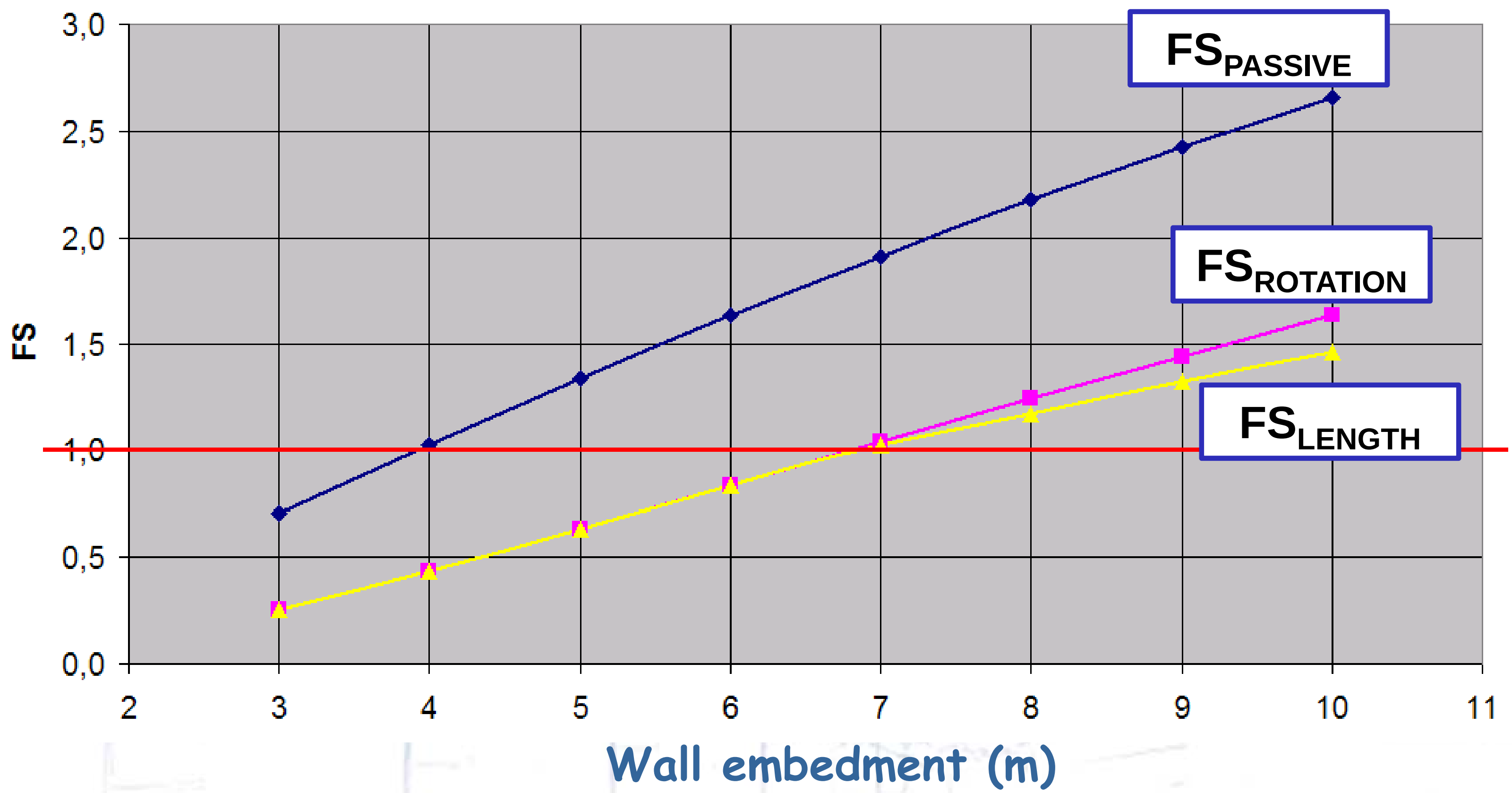
Eseguite 8 analisi convenzionali con diverse lunghezze d'infissione:

da 3 m a 10 m a passo 1 m

Example 5: Conventional analysis



Example 5: Conventional analysis



Note: Conventional analysis always converges!!!

ANALISI CONVENZIONALE + NL

Sommario esteso

	Risultati analisi	Spostamen paratia (cm)	Cedimen (cm)	Momento paratia (kN-m/m)	Momento paratia (kN-m)	Taglio paratia (kN/m)	Taglio paratia (k
Infissione = 3 m	Model collapses, ...	3.81	3.5	391.85	391.85	97.93	97.93

Model collapses +

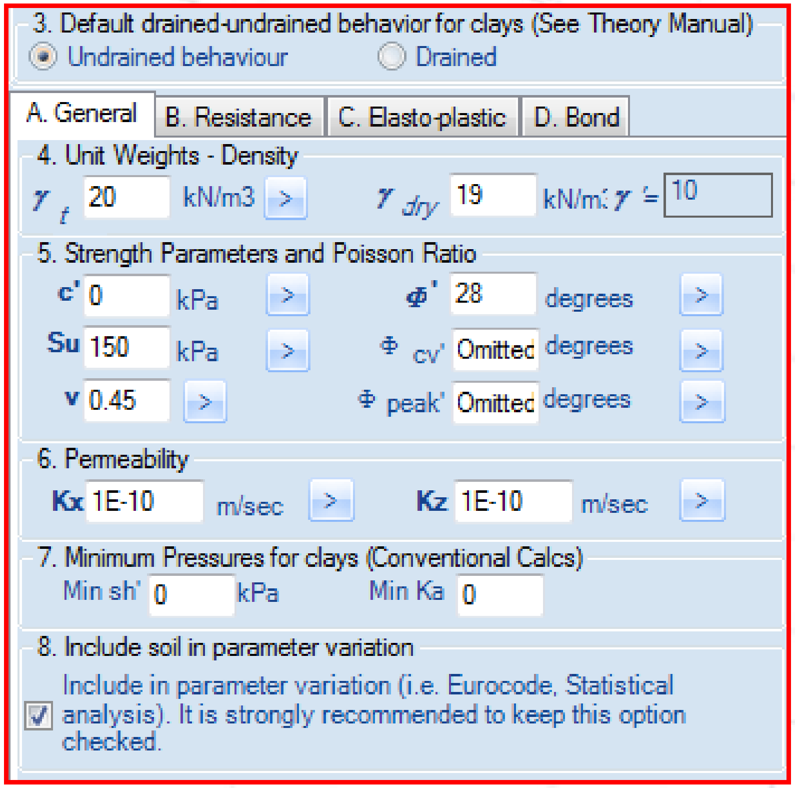
results do not include all stages in NL

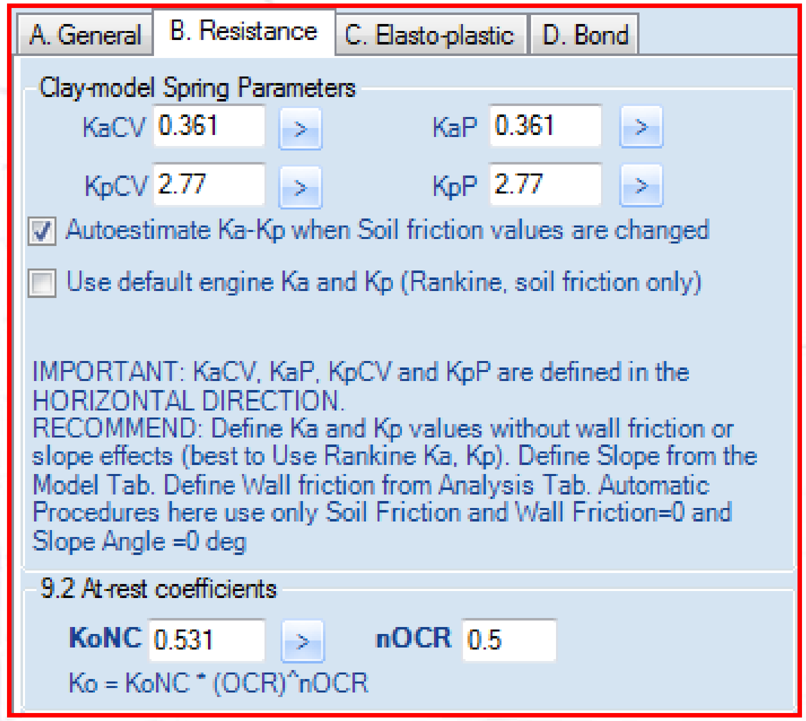
Review of the classic safety factors:

FS passiva (an. classica)	FS rotazione (an. classica)	FS infissione (an. classica)
0.689	0.256	0.256

Soil propertie dialog

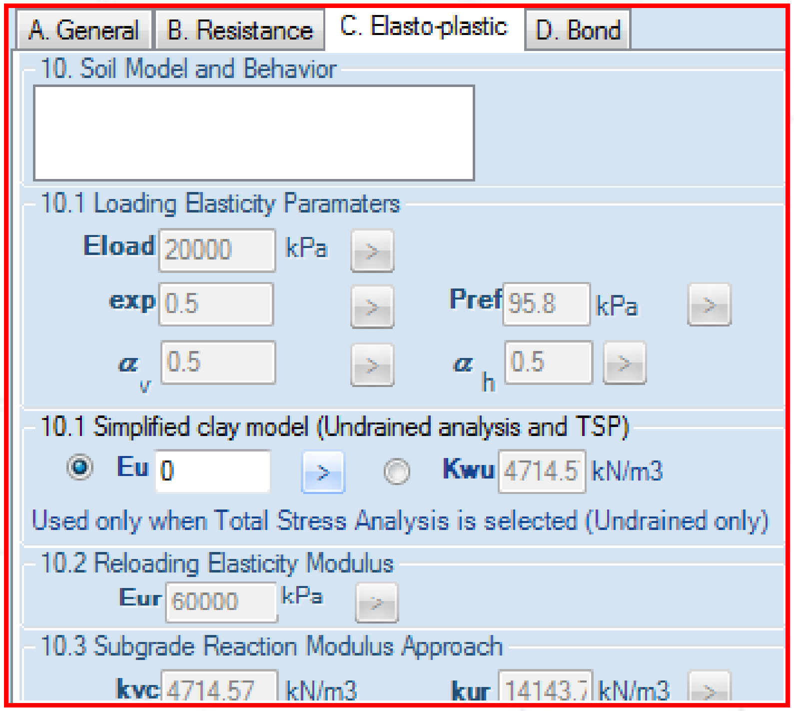
Soil type properties:

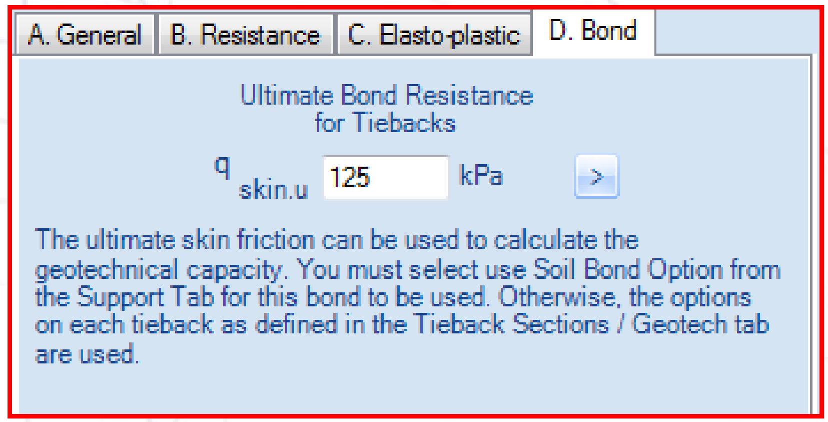




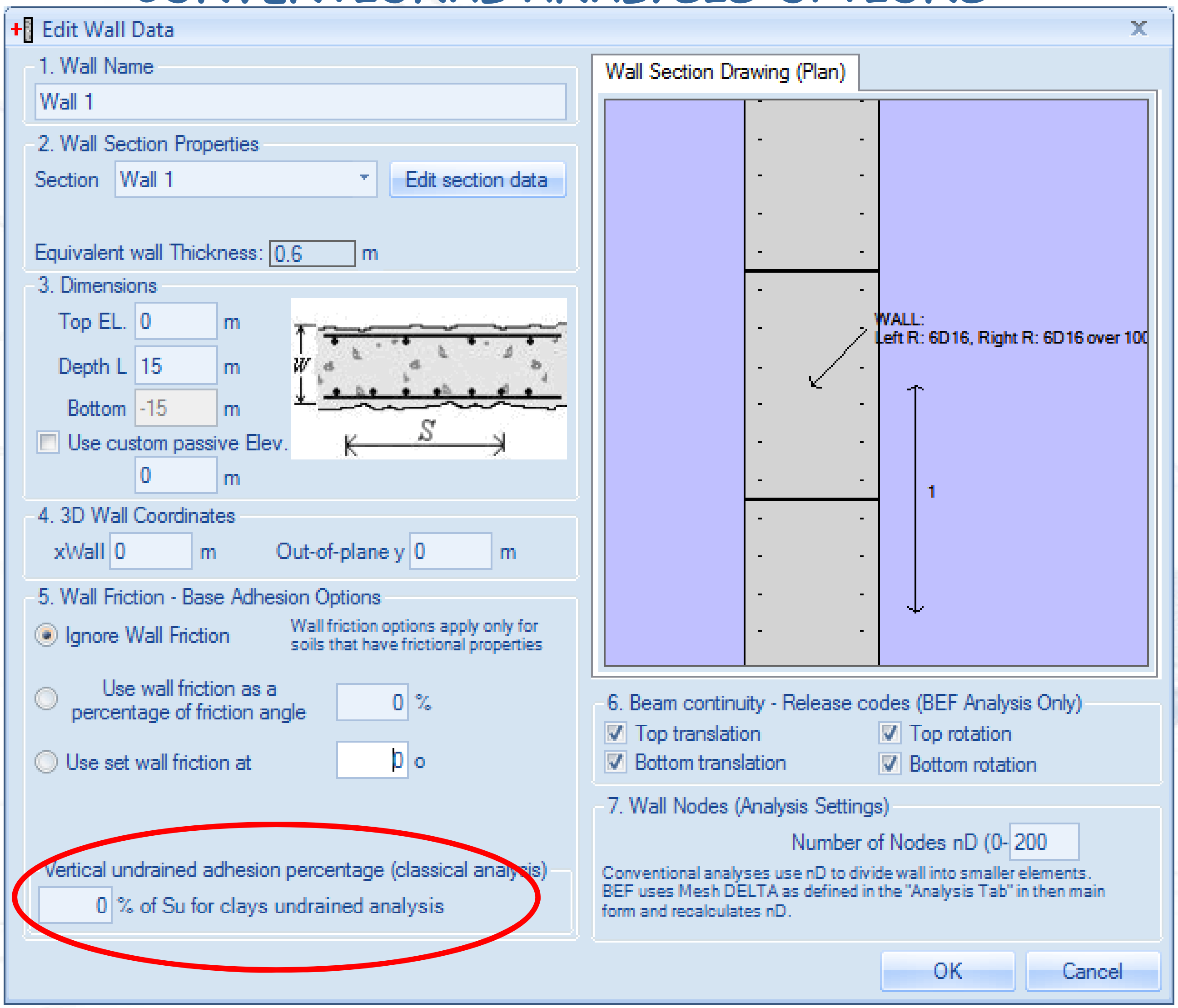
Elastic parameters disabled when only conventional analysis is used.

Soil properties:

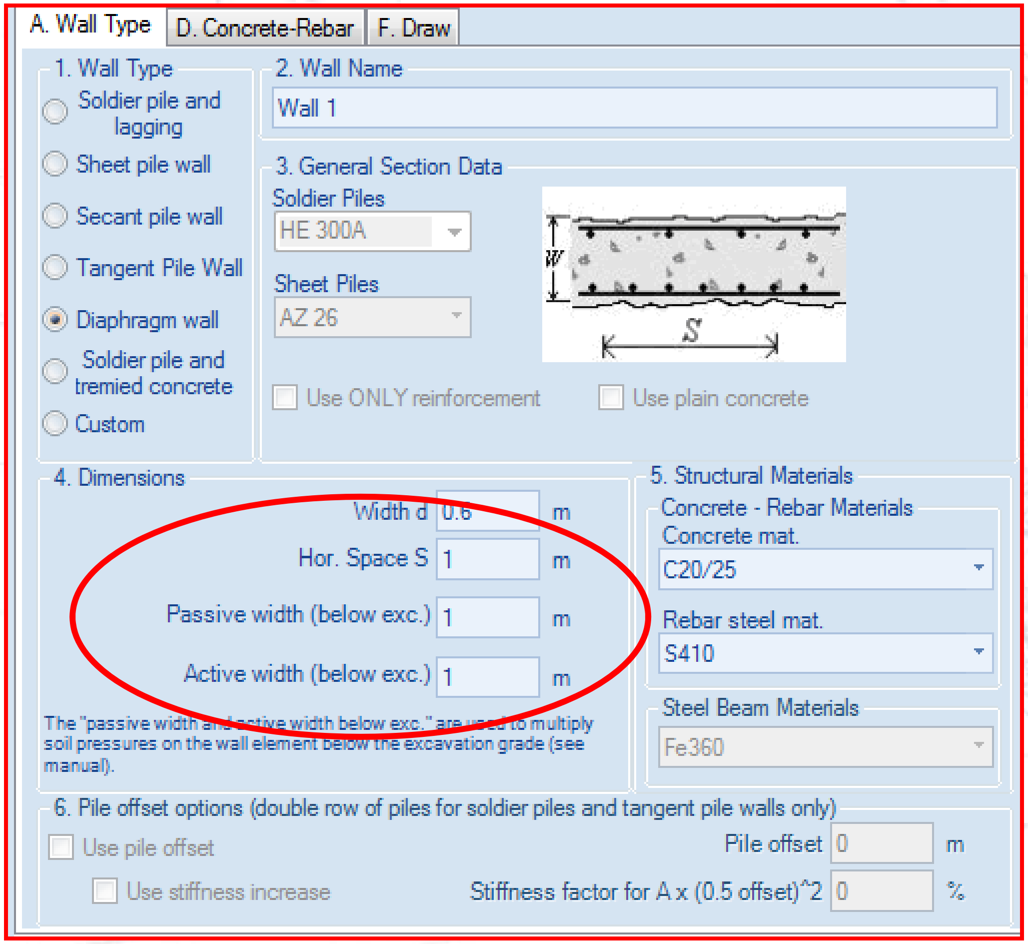




CONVENTIONAL ANALYSIS OPTIONS



PILE SPACING EFFECTS



Spacing can account for 3D effects.

In NL analysis the active width is used solely for the water pressures, and the same active and passive widths are used.

For continuous walls it is better to use the same spacing (1m or 1ft).

Important Command

HELLO

Hello by the development team

The development team would like to thank you for using our software.
This program has been created with a lot of love and effort :)
Deep Excavation LLC: Dimitrios Konstantakos
CeAS S.R.L: Bruno Becci, Pierangelo Fellotti
HarpaCeAS: Paolo Sattamino, Carlo Pucci, Ada Zirpoli, Michele Boatti
EFG Group: Marco Pezzela, Ghenadii, Andrea Massioli
Many thanks to everybody that also helped but is not mentioned here.
We wish that this program helps you finish this project soon so you can enjoy you weekend by the sea or mountain more often :)

OK