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### Design of a non-anchored retaining wall

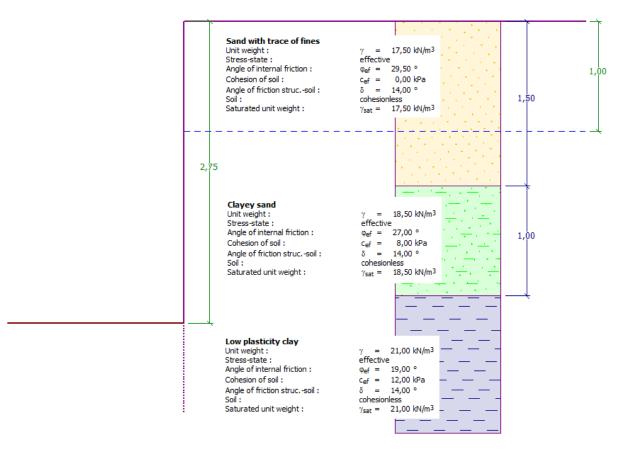
Program: Sheeting design

File: Demo\_manual\_04.gp1

This engineering manual describes the design of a non-anchored retaining wall for permanent and accidental loads (flooding).

### Assignment

Design a non-anchored retaining wall from a pile sheeting *VL 601* using the EN 1997-1 (EC 7-1, DA3) standard in non-homogenous geologic layers. The material of the sheet pile is a steel of type *S 240 GP*. The depth of the excavation is 2,75 m. The groundwater table is in a depth of 1,0 m. Furthermore, analyze the construction for flooding, when the water is 1,0 m above the top of the wall (mobile anti-flood barriers should be installed).



Scheme of a non-anchored wall from pile sheeting – assignment

#### Solution:

To solve this problem, we will use the GEO5 "Sheeting design" program. In this manual , we will explain each step in solving this problem:

- 1<sup>st</sup> construction stage: permanent design situation
- 2<sup>nd</sup> construction stage: accidental design situation
- Dimensioning of a cross-section
- Stability verification
- Analysis result and conclusion

#### Construction stage 1

In the "Settings" frame click on "Select settings" and then choose No. 5 – "Standard – EN 1997 – DA3".

Number	Name	Valid for		
1	Standard - safety factors	All		
2	Standard - limit states	All		
3	Standard - EN 1997 - DA1	All		
4	Standard - EN 1997 - DA2	All		
5	Standard - EN 1997 - DA3	All		
6	Standard - LRFD 2003	All		
7	Standard - no reduction of parameters	All		
8	Czech republic - old standards CSN (73 1001, 73 1002, 73 0037)	All		
9	Slovakia - old standards CSN (73 1001, 73 1002, 73 0037)	All	<u> </u>	
10	Slovakia - EN 1997	All		
69	Switzerland - SIA 260 (267) - STR, GEO - standard	All		
70	Switzerland - SIA 260 (267) - STR, EQU - standard	All		

"Settings list" Dialog window



Firstly, go to the "Profile" frame and add two new interfaces using the "Add" button. One will be in the depth of 1,5 m and the other one in the depth of 2,5 m.

No.	Thickness of layer	Depth	🕂 🎬 Add	- Position information
	t [m]	z [m]		Terrain elevation : [m]
1	1,50	0,00 1,50		
2	1,00	1,50 2,50		Coordinates GPS / S-JTSK View
3	-	2,50 ∞		GPS : (not specified) on map
			_	S-JTSK : (not specified)

### "Profile" frame – Add new interface

Then, go to the "Soils" frame and add new soils by clicking the "Add" button, input the parameters of the soils according to the following table or pictures and assign them to the profile. The stress state is considered as **effective**, the pressure at rest is calculated for **cohesionless** soils and the calculation of uplift is selected as **standard** for each soil. We will not consider a change of unit weight due to saturation.

Soil (Soil classification)	Profile [ <i>m</i> ]	Unit weight $\gamma \left[ kN/m^{3} ight]$	Angle of internal friction $\varphi_{ef}$ [°]	Cohesion of soil $c_{ef} [kPa]$	Angle of friction structure – soil $\delta = [\circ]$
S-F – Sand with trace of fines, medium dense soil	0,0 - 1,5	17,5	29,5	0,0	14,0
SC – Clayey sand, medium dense soil	1,5 – 2,5	18,5	27,0	8,0	14,0
CL, CI – Clay with low or medium plasticity, firm consistency	from 2,5	21,0	19,0	12,0	14,0

Table – soil parameters

## **GEO5**

Add new soils	×
Identification	— Draw —
Name : Sand with trace of fines	Pattern category :
	GEO 🗸
— Basic data — ?	Search :
Unit weight : $\gamma = 17,50 \text{ [kN/m}^3\text{]}$	Subcategory :
Stress-state : effective	Soils (1 - 16) 🔻
Angle of internal friction : $\phi_{ef} = 29,50$ [°]	Pattern :
Cohesion of soil : $c_{ef} = 0,00$ [kPa]	
Angle of friction strucsoil : $\delta = 14,00$ [°]	
- Pressure at rest - ?	9 Sand
Soil : cohesionless	Color :
	<b>C</b> OIOT .
— Uplift pressure — ?	Background :
Calc. mode of uplift : standard	automatic
Saturated unit weight : $\gamma_{sat} = 17,50 \text{ [kN/m}^3\text{]}$	Saturation <10 - 90> : 50 [%]
Classify Clear	🕂 Add 🗙 Cancel

"Add new soils" Dialog window – Sand with traces of fines

# **GEO5**

Add new soils	×
- Identification	— Draw —
Name : SC - Clayey sand	Pattern category :
	GEO 🗸
— Basic data — ?	Search :
Unit weight : $\gamma = 18,50 \text{ [kN/m^3]}$	Subcategory :
Stress-state : effective 🗸	Soils (1 - 16) 👻
Angle of internal friction : $\phi_{ef} = 27,00$ [°]	Pattern :
Cohesion of soil : c <sub>ef</sub> = 8,00 [kPa]	
Angle of friction strucsoil : $\delta = 14,00$ [°]	■ 100 100 100 100 100 100 100 100 100 10
Pressure at rest ?	11 Clayey sand
Soil : cohesionless	Color :
	▼
— Uplift pressure — ?	Background :
Calc. mode of uplift : standard	automatic 💌
Saturated unit weight : $\gamma_{sat} =$ 18,50 [kN/m <sup>3</sup> ]	Saturation <10 - 90> : 50 [%]
Classify Clear	♣ Add X Cancel

"Add new soils" Dialog window – Clayey sand

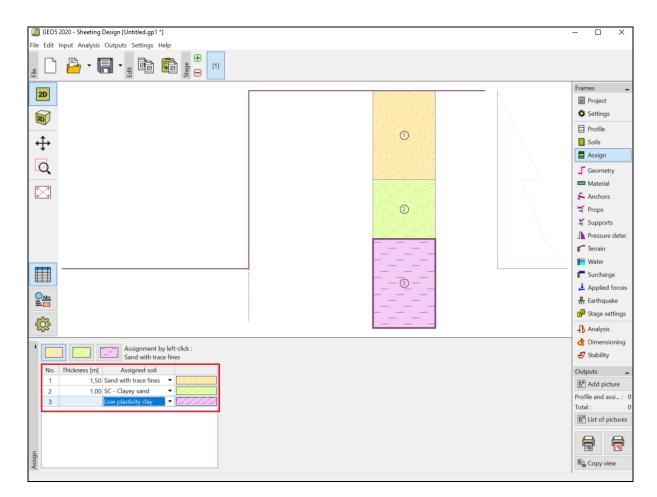
## **GEO5**

Add new soils		×
- Identification	I	Draw
Name :	Low plasticity clay	Pattern category :
		GEO 🗸
— Basic data —		? Search :
Unit weight :	γ = 21,00 [kN/r	m <sup>3</sup> ] Subcategory :
Stress-state :	effective	▼ Soils (1 - 16) ▼
Angle of internal frict	ion : φ <sub>ef</sub> = 19,00 [°]	Pattern :
Cohesion of soil :	c <sub>ef</sub> = 12,00 [kPa]	
Angle of friction strue	csoil : δ = 14,00 [°]	-1-1-1-1-1-1-1-1-1-1-1
— Pressure at re	est	?. [
Soil :	cohesionless	▼ 4 Clay
		Color :
— Uplift pressu	re	Background :
Calc. mode of uplift :	standard	<ul> <li>✓</li> <li>automatic</li> </ul>
Saturated unit weight	t: γ <sub>sat</sub> = 21,00 [kN/r	m <sup>3</sup> ] Saturation <10 - 90> : 50 [%]
Classify	Clear	🕂 Add 🛛 🗙 Cancel
Classify	Clear	T- Adu 🔨 Cancer

"Add new soils" Dialog window – Low plasticity clay

Then, in the "Assign" frame, assign the soils to the layers as shown in the picture below.





"Assign" frame – soil assignment

In the "Geometry" *frame*, select the shape of the bottom of the excavation and input its depth (2.75 m). Then, click on "edit" to select the type of the cross-sections. For our example, we will consider a sheet pile VL 601.

				Frames _
2D				Project
30				🔅 Settings
				Profile
↔			$\backslash$	Soils
• • • • • • • • • • • • • • • • • • •			$\backslash$	Assign
	2,75	1 1 N	$\mathbf{X}$	_ Geometry
	200		$\sim$	- Material
$\mathbf{\Sigma}$		Edit section	×	Anchors
				Props
		Type of wall : Sheet pile		Supports
	<del>_</del>	Cross-section name : Sheet pile :	VL 601 User def.	Terrain
				Water
- <del>(</del>		Cross-section		Surcharge
		<u>C</u> atalog		- <u>' - S</u>
		Name : VL 601		Outputs _
				Add picture
- Excavation	- Cross-section -		0	Excavation: 0
Depth of ditch : h = 2,75 [m]	Sheet pile : VL 602	- Information		Total: 3
Ditch bottom surcharge : f = 0,00 [kPa]	·-/ Edit	A = 9,83E-03 [m <sup>2</sup> /m]	I = 1,15E-04 [m <sup>4</sup> /m]	B <sup>III</sup> List of pictures
		W <sub>y1</sub> = 7,420E-04 [m <sup>3</sup> /m]	$W_{pl,\gamma} = 8,580E-04 \ [m^3/m]$	
Excavation		T the future is a state of	Cancel	
Exc		Intersection Inte	Cancel	Copy view

"Geometry" frame

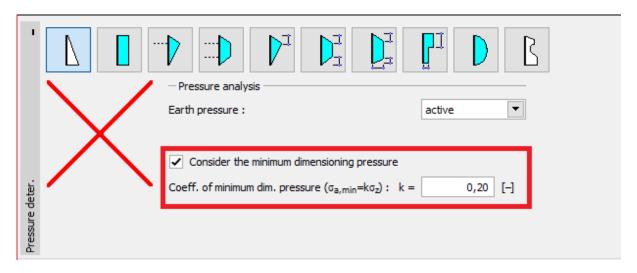
In the "Material" frame we set the required type of steel to S 240 GP (sheet pile steel).

Structural steel     Catalog     User_def.	Catalog of materials - Structur	
EN 10248-1:5 240 GP f <sub>Y</sub> = 240,00 MPa E = 210000,00 MPa G = 81000,00 MPa	Structural steel EN Sheetpile steel EN	EN 10248-1 : S 240 GP EN 10248-1 : S 270 GP EN 10248-1 : S 320 GP EN 10248-1 : S 355 GP EN 10248-1 : S 390 GP EN 10248-1 : S 430 GP
		✓ OK X Cancel

"Material" frame

In this case, we do not use the "Anchors", "Props", "Supports", "Surcharge" or "Applied forces" frames. The frame "Earthquake" is also not important in this analysis, because the structure is not located in a seismically active area. In the "Terrain" frame, the setting remains horizontal.

Then we move to the "Pressure determination" frame. In this frame we will choose the possibility "Consider the minimum dimensioning pressure".



"Pressure determination" frame

Note: For cohesive soils it is recommended by some standards to use the minimal dimensioning pressure acting on the retaining wall. The standard value for the coefficient of minimal dimensioning pressure is Ka = 0.2. It means that the minimum pressure on the structure is at least 20% of the geostatic stress – never less.

Note: In the case of anchored retaining walls, it is recommended to use the redistribution of acting pressure because of anchoring. If we want to reduce the deformation of the sheet pile, it is also possible to increase the pressure acting on the structure (increased active, at rest) in the same frame. Both of these possibilities are described in the program help (F1) or the next engineering manual <u>No.</u> <u>5 - Design of an anchored retaining wall</u>.



In the "Water" frame input the GWT value as 1,0 m.

1	× 🖃 =			
	h <sub>1</sub>	- Ground water table (GWT) p	arameters	
		GWT behind construction :	h1 =	1,00 [m]
		GWT in front of construction :	h <sub>2</sub> =	[m]
		Tensile crack		
		Depth of tensile crack :	h <sub>t</sub> =	[m]
Water				

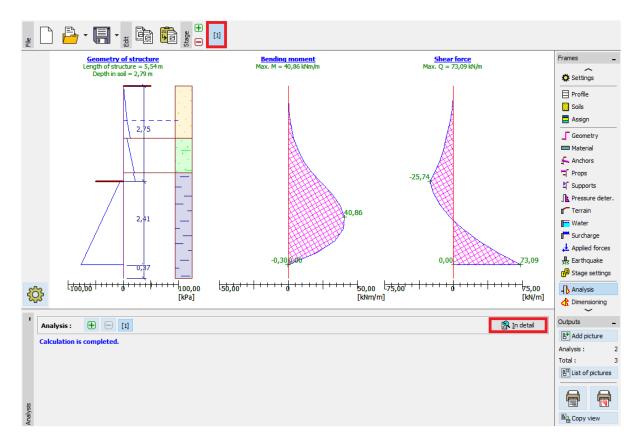
"Water" frame –  $1^{st}$  construction stage

Then, in the "Stage settings", select the permanent design situation.

Design situation :	permanent	•
	Design situation :	Design situation : permanent

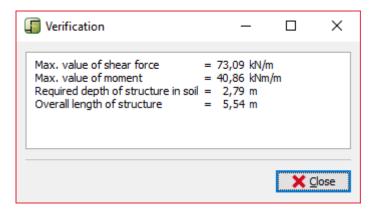
"Stage settings (1)" frame

Now, open up the "Analysis" frame. In this frame the program will automatically calculate the internal forces and the necessary depth of the structure in the soil.



"Analysis" frame

All results can be displayed using the "In detail" button.



"Analysis" frame – construction stage 1 – "In detail" dialog window

In the next stage, we are going to show you, how to analyze the minimum in-soil depth and the internal forces in case of an accidental design situation – floods.



#### Basic input – Construction stage 2

Now, add a new construction stage on the "Construction stage" toolbar in the upper left corner of your screen.



"Construction stage" toolbar

In the "Water" frame, change the GWT behind the structure to -1,0 m. We will not consider water in front of the structure.

1	× =			
	h <sub>1</sub>	- Ground water table (GWT) p	arameters	
		GWT behind construction :	h <sub>1</sub> = -1,00	[m]
		GWT in front of construction :	h <sub>2</sub> =	[m]
		Tensile crack		
Water		Depth of tensile crack :	h <sub>t</sub> =	[m]
Wa				

"Water" frame

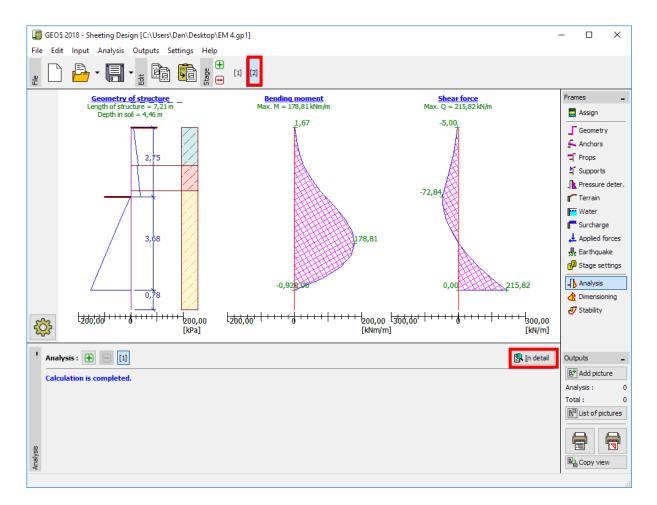
Then, in the "Stage settings" frame, select the "Accidental" design situation.



"Stage settings (2)" frame

All of the other values are the same as in the 1<sup>st</sup> construction stage, so we do not have to change anything else. Therefore we can go straight to the "Analysis" frame and see the detailed results.





"Analysis" frame

Verification		_		×
Max. value of shear force Max. value of moment Required depth of structure in soil Overall length of structure	=		kNm/m m	
			X <u>C</u> los	e

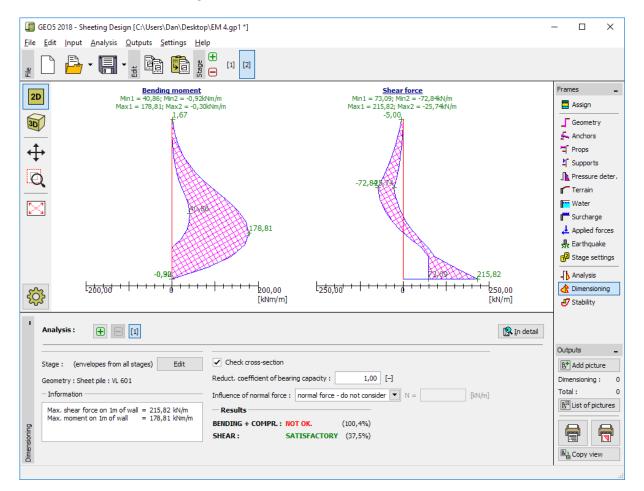
"Analysis" frame – construction stage 1 – "In detail" dialog window

Now it is necessary to verify the cross-section of the sheet pile for bending + compression and shear.



### Verification of the cross-section

#### Move to the "Dimensioning" frame.



"Dimensioning" frame

•	Analysis :	
	Stage : (envelopes from all stages) Edit Geometry : Sheet pile : VL 601 - Information	Check cross-section Reduct. coefficient of bearing capacity : 1,00 [-] Influence of normal force : normal force - do not consider
Đ.	Max. shear force on 1m of wall = 215,82 kN/m Max. moment on 1m of wall = 178,81 kNm/m	Results         BENDING + COMPR.:       NOT OK.       (100,4%)         SHEAR:       SATISFACTORY       (37,5%)
Dimensioning		

"Dimensioning" frame - verification results



Note: The maximum values of internal forces from all stages are displayed in the "Dimensioning" frame. If we want to use the results from specific construction stages, we have to select them using the "Edit" button.

We see, that our cross-section is not OK for "Bending + compression" verification, the utilization is more than 100 %. Detailed results can be displayed using the "In detail" button.

Dimensioning –		×
<b>Verification of steel section according to EN 1993-1-1</b> All construction stages are taken into the analysis. Reduct. coefficient of bearing capacity = 1,00		
Internal forces per 1 m of wall $M_{max} = 178,81 \text{ kNm/m};  Q = 2,08 \text{ kN/m}$ $Q_{max} = 215,82 \text{ kN/m};  M = 0,92 \text{ kNm/m}$		
Verification of max. moment M <sub>max</sub> + Q:         Verification of bending:         M <sub>max</sub> /M <sub>c.Rd</sub> = 1,004 > 1		
Verification of shear: $Q/V_{c,Rd} = 0,004 \le 1$ Is satisfactory Verification of plane state of stress:		
Normal stress $\sigma_{x,Ed} = 229,42$ MPa Shear stress $\tau_{Ed} = 0,29$ MPa Verification: $(\sigma_{x,Ed}/(f_y/\gamma_{M0}))^2 + 3^*(\tau_{Ed}/(f_y/\gamma_{M0}))^2 = 0,914 \le 1$	ls satisfa	actory
Verification of max. shear force $Q_{max}$ + M: Verification of bending: $M/M_{c,Rd} = 0,005 \le 1$ Is satisfactory		
Verification of shear: $Q_{max}/V_{c,Rd} = 0,375 \le 1$ Is satisfactory Verification of plane state of stress: Normal stress $\sigma_{x,Ed} = 1,19$ MPa		
Shear stress $\tau_{Ed} = 30,51$ MPa Verification: $(\sigma_{x,Ed}/(f_y/\gamma_{M0}))^2 + 3*(\tau_{Ed}/(f_y/\gamma_{M0}))^2 = 0,049 \le 1$ Cross section is NOT SATISFACTORY	ls satisfa	actory
CLOSS SECTOR IS NOT SATISFACTORY		
	<b>X</b> <u>C</u>	lose

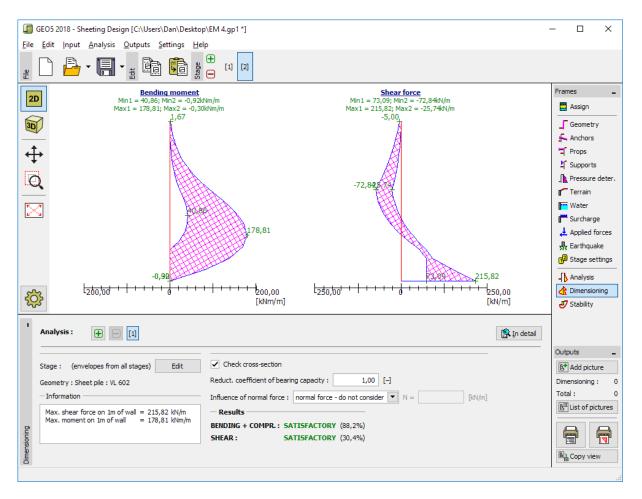
Detailed results

Because the verification of the cross-section is not satisfactory, we have to go back to the "Geometry" frame and select a bigger sheet pile – VL 602.

		Frames _
20		assign
D		Geometry
	Edit section X	F. Anchors
<b>↓</b>	Edit section X	T Props
	Type of wall : Sheet pile	▲ Supports
Q	Cross-section name : Sheet pile : VL 602 User def.	Pressure deter.
		Terrain
	- Cross-section	Water
	Catalog	Applied forces
	Name : VL 602	Earthquake
		1 <sup>2</sup> Stage settings
	d 6	
	- Information	
	$A = 1,15E-02 [m^2/m]$ I = 1,31E-04 [m <sup>4</sup> /m]	J Stability
	$W_{v1} = 8,450E-04 \text{ [m}^3/\text{m]}$ $W_{pl,v} = 9,900E-04 \text{ [m}^3/\text{m]}$	
~~~		-
I IIIIII IIIIIII IIIIIIII IIIIIIIIIIII	Image: Second secon	
		Outputs _
- Excavation		Et Add picture
Depth of ditch : h = 2,75 [	m] Sheet pile : VL 601	Excavation: 0
Ditch bottom surcharge : f = 0,00 [	kPa] Edit	Total: 0
		EII List of pictures
atton atton		
Excavation		E Copy view

"Geometry" frame – changing the cross-section

After editing the cross-section, we will return to the "Dimensioning" frame. The verification of the new bigger cross-section pile is now satisfactory.



Frame "Dimensioning" - verification of a new cross-section

Analysis : 🛨 📄 [1]	
Stage : (envelopes from all stages) Edit Geometry : Sheet pile : VL 602 — Information	Check cross-section Reduct. coefficient of bearing capacity : 1,00 [-] Influence of normal force : normal force - do not consider  N =
Max. shear force on 1m of wall = 215,82 kN/m Max. moment on 1m of wall = 178,81 kNm/m	Results         BENDING + COMPR.: SATISFACTORY (88,2%)         SHEAR :       SATISFACTORY (30,4%)

"Dimensioning" frame – new verification results

Note: Changing the cross-section has no influence on the analysis of the internal forces. The stiffness of the structure will only influence the analysis in the "<u>Sheeting check</u>" program, which can be used when analyzing more difficult anchored structures.

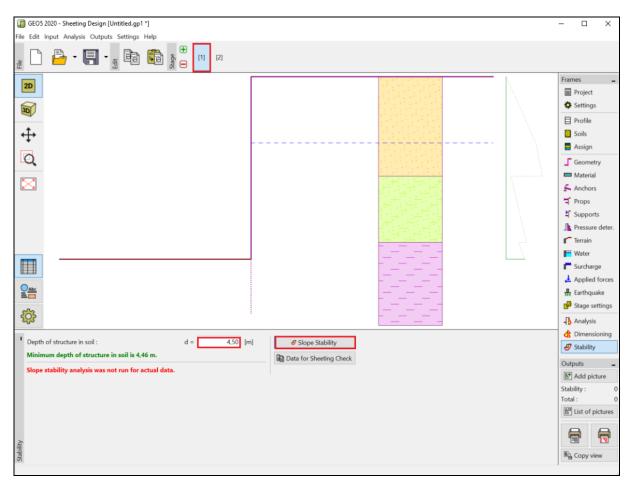


#### Verification of stability

Now it is necessary to verify that the structure is satisfactory in terms of overall stability. This verification is performed in the "Stability" frame.

In this frame the program shows the minimum depth of the structure in the soil. Stability analysis should be performed for each construction stage.

The minimum depth of the structure (based on an analysis in the 2<sup>nd</sup> construction stage) is 4,46 m. We will therefore design a sheet pile wall 4,5 m deep in the soil.

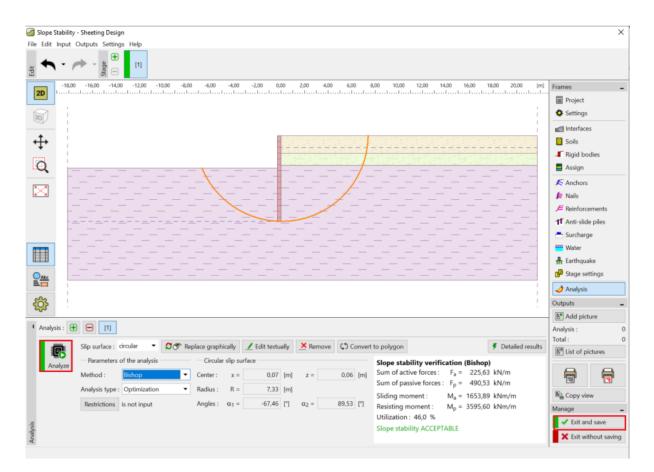


Firstly, we perform an analysis of the 1<sup>st</sup> construction stage.

"Stability" frame – construction stage 1

Clicking the "Slope Stability" button launches the "Slope Stability" program. All input parameters are transferred to this program automatically. In the program, go to the "Analysis" frame. Select the "Bishop" method with circular slip surface optimization as shown in the picture below and click the "Analyze" button.

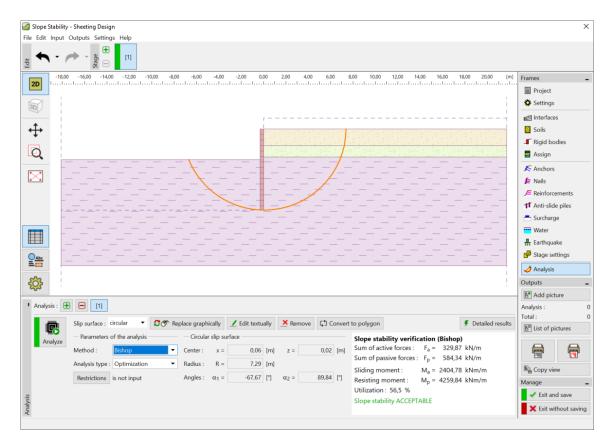




"Slope Stability" program – "Analysis" frame (construction stage 1)

When the analysis for the 1<sup>st</sup> stage is finished, click on "Exit and save" on the right side of the screen. Then, we will perform the same analysis for the 2<sup>nd</sup> construction stage.





"Slope Stability" program – "Analysis" frame (construction stage 2)

#### Analysis result and conclusion

The aim of this task was to design a sheet pile wall for a foundation pit with a depth of 2,75m.

When designing a non-anchored retaining wall, we obtain the value of the minimum depth of the structure in the soil. This depth is determined as the maximum value from all construction stages:

-	Minimum depth of the structure in the first stage:	2,79m
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Minimum depth of the structure in the second stage: 4,46m

So, we will design the sheet pile wall 4,5m deep in the soil with an overall length of 7,25m (4,46 m + 2,79m).

This structure is satisfactory for overall stability. The maximum utilization of the structure does not exceed 60 %.

The originally designed cross-section of sheet pile type *VL 601* was not satisfactory for bending verification. Because of this, the cross-section was replaced with a larger type VL 602, which was satisfactory.

The sheet pile wall (cross-section type *VL 602*, steel *S 240 GP*) with an overall length of 7,25m is satisfactory for all verifications.