

Design of a cantilever wall

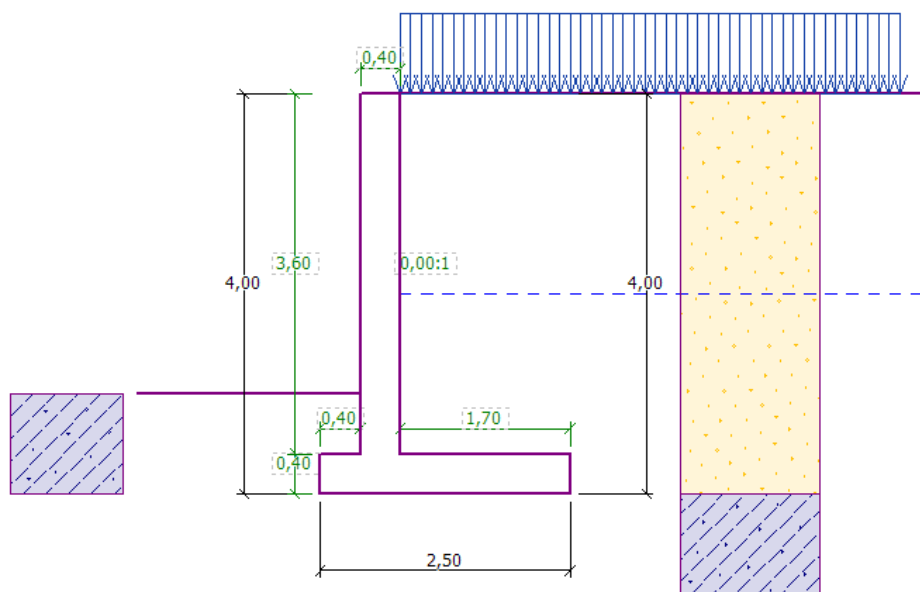
Program: Cantilever wall

File: Demo_manual_02.guz

This engineering manual describes how to design and analyze a cantilever wall.

Assignment:

Design a cantilever wall with a height of 4,0 m and analyze it according to the EN 1997 - DA1 (EC 7-1, Design approach 1) standard. The terrain behind the structure is horizontal. The groundwater table is 2,0 m deep under the surface. Behind the wall acts a strip surcharge with a length of 5,0 meters and a magnitude of 10 kN/m². The foundation soil consists of Sandy silt (MS), with an allowable bearing capacity of 175 kPa. The soil behind the wall is made by Sand with trace of fines (S-F). The cantilever wall will be made of reinforced concrete of class C 20/25.



Scheme of the cantilever wall – Assignment

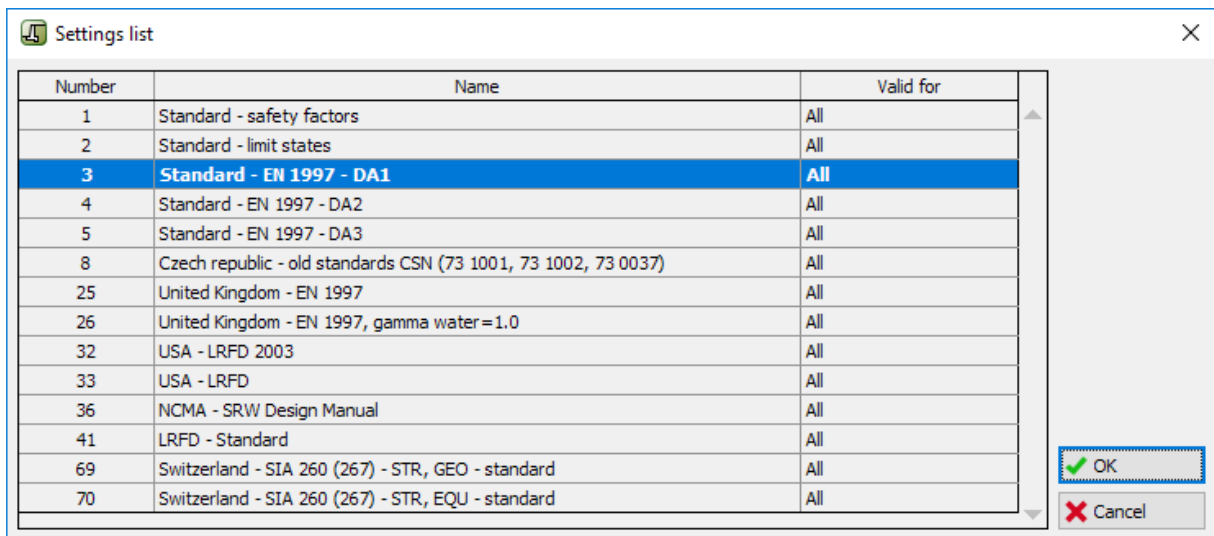
The parameters of the soils are defined as follows:

Soil	Profile [m]	Unit weight γ [kN/m ³]	Angle of internal friction φ_{ef} [°]	Cohesion of soil c_{ef} [kPa]	Angle of friction structure – soil δ [°]	Saturated unit weight γ_{sat} [kN/m ³]
S-F	0,0 – 4,0	17,5	28,0	0,0	18,5	18,0
MS	from 4,0	18,0	26,5	5,0	17,5	18,5

Solution

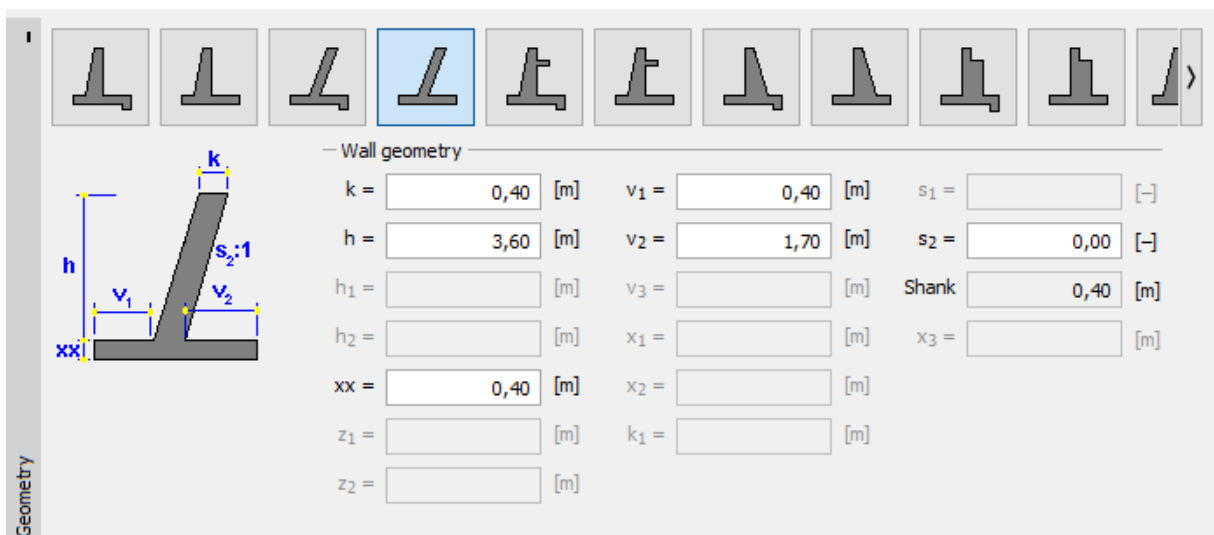
To solve this problem, we will use the GEO5 “Cantilever wall” program. In the following text, we will explain the solution step by step.

Firstly, in the “Settings” frame click on the “Select settings” button and choose the analysis setting No. 3 – “Standard – EN 1997 – DA1”.



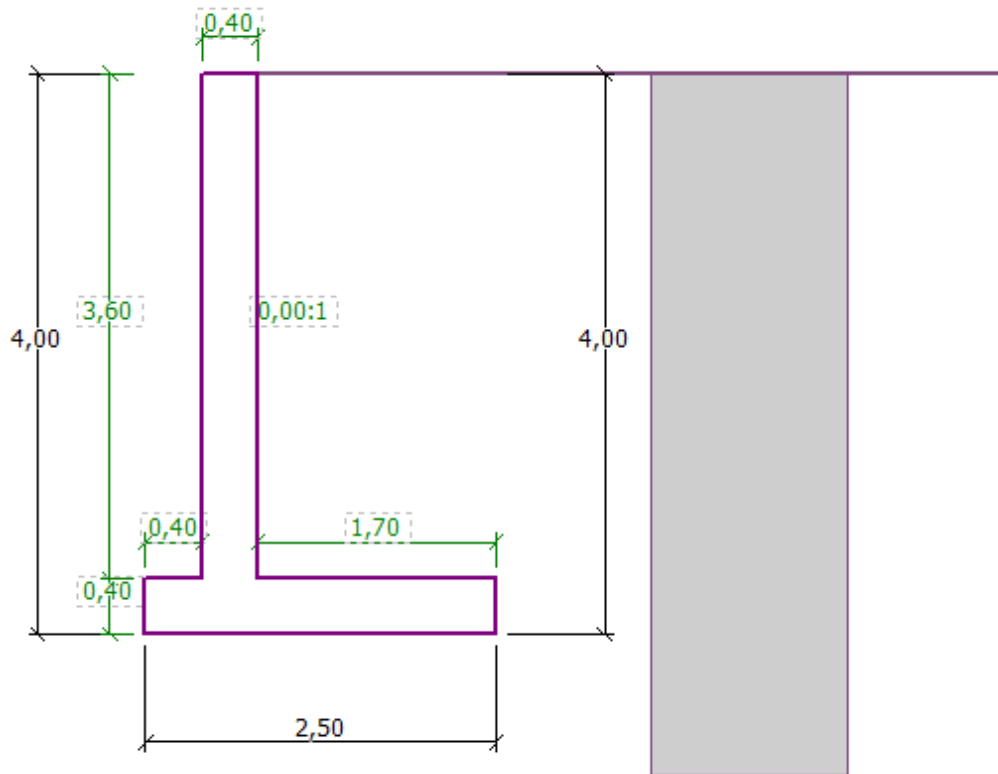
“Settings list” Dialog window

In the “Geometry” frame choose the 4th shape and enter its dimensions as shown in the picture.



“Geometry” Frame

The structure now looks like this:



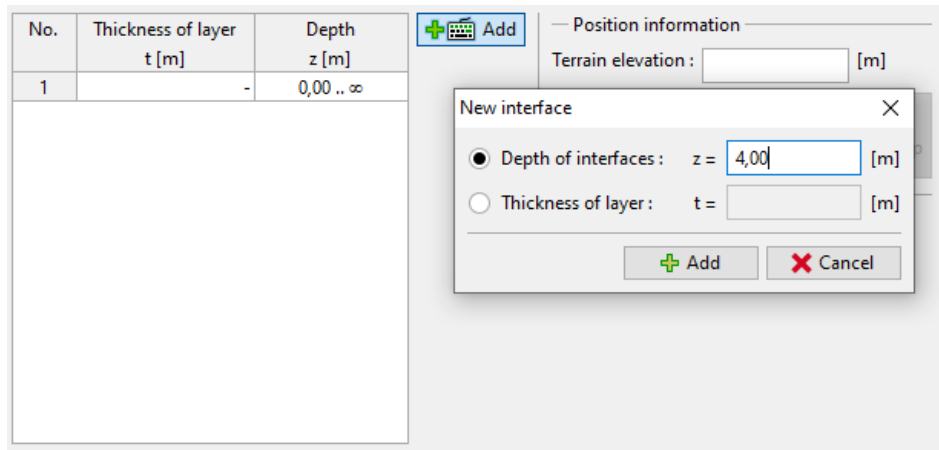
“Geometry” Frame – scheme of the cantilever wall

In the “Material” frame, enter the material of the wall. The wall will have a unit weight of $\gamma = 25 \text{ kN/m}^3$, and it will be made from concrete of class C 20/25 and steel of class B500.

Unit weight of wall : $\gamma =$ <input type="text" value="25,00"/> [kN/m ³]	
<div> <div>Concrete</div> <div> <input type="button" value="Catalog"/> <input type="button" value="User def."/> </div> <div> C 20/25 $f_{ck} = 20,00 \text{ MPa}$ $f_{ctm} = 2,20 \text{ MPa}$ </div> </div>	
<div> <div>Longitudinal reinforcement</div> <div> <input type="button" value="Catalog"/> <input type="button" value="User def."/> </div> <div> B500 $f_{yk} = 500,00 \text{ MPa}$ </div> </div>	

“Material” Frame – Input of the material characteristics of the structure

In the “Profile” frame, we will define the soil interference at a depth of 4 m, using the “Add” button.



No.	Thickness of layer t [m]	Depth z [m]
1	-	0,00 .. ∞

Position information
Terrain elevation : [m]

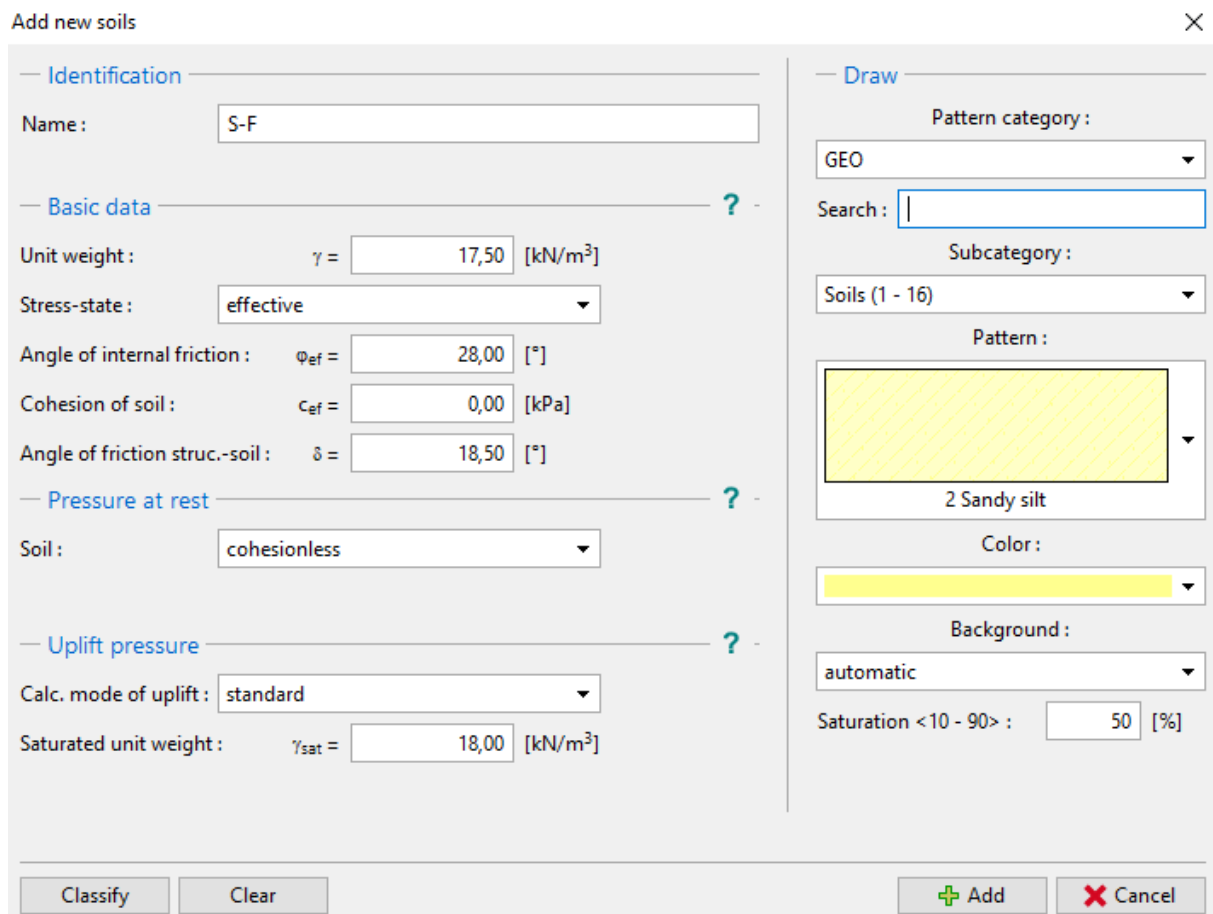
New interface

☒ Depth of interfaces : z = 4,00 [m]
☐ Thickness of layer : t = [m]

+ Add ✖ Cancel

“Profile” Frame

Then, we will move to the “Soils” frame. Here, we will define the parameters of the soil, as shown in the following pictures, by clicking the “Add” button. Firstly, we will add the S-F soil, which will be behind the wall. Next, we will add the MS soil, which will form the foundation.



Add new soils

Identification
Name : S-F

Basic data
Unit weight : $\gamma = 17,50$ [kN/m³]
Stress-state : effective
Angle of internal friction : $\varphi_{ef} = 28,00$ [°]
Cohesion of soil : $c_{ef} = 0,00$ [kPa]
Angle of friction struc.-soil : $\delta = 18,50$ [°]

Pressure at rest
Soil : cohesionless

Uplift pressure
Calc. mode of uplift : standard
Saturated unit weight : $\gamma_{sat} = 18,00$ [kN/m³]

Draw
Pattern category : GEO
Search :
Subcategory : Soils (1 - 16)
Pattern : 2 Sandy silt
Color :
Background : automatic
Saturation <10 - 90> : 50 [%]

Classify Clear + Add ✖ Cancel

“Add new soils” Dialog window– adding soil S-F

Add new soils

Identification

Name : MS

Basic data

Unit weight : $\gamma =$ 18,00 [kN/m³]

Stress-state : effective

Angle of internal friction : $\varphi_{ef} =$ 26,50 [°]

Cohesion of soil : $c_{ef} =$ 5,00 [kPa]

Angle of friction struc.-soil : $\delta =$ 17,50 [°]

Pressure at rest

Soil : cohesionless

Uplift pressure

Calc. mode of uplift : standard

Saturated unit weight : $\gamma_{sat} =$ 18,50 [kN/m³]

Draw

Pattern category : GEO

Search :

Subcategory : Soils (1 - 16)

Pattern : 2 Sandy silt

Color :

Background : automatic

Saturation <10 - 90> : 50 [%]

Classify

Clear

IFC data

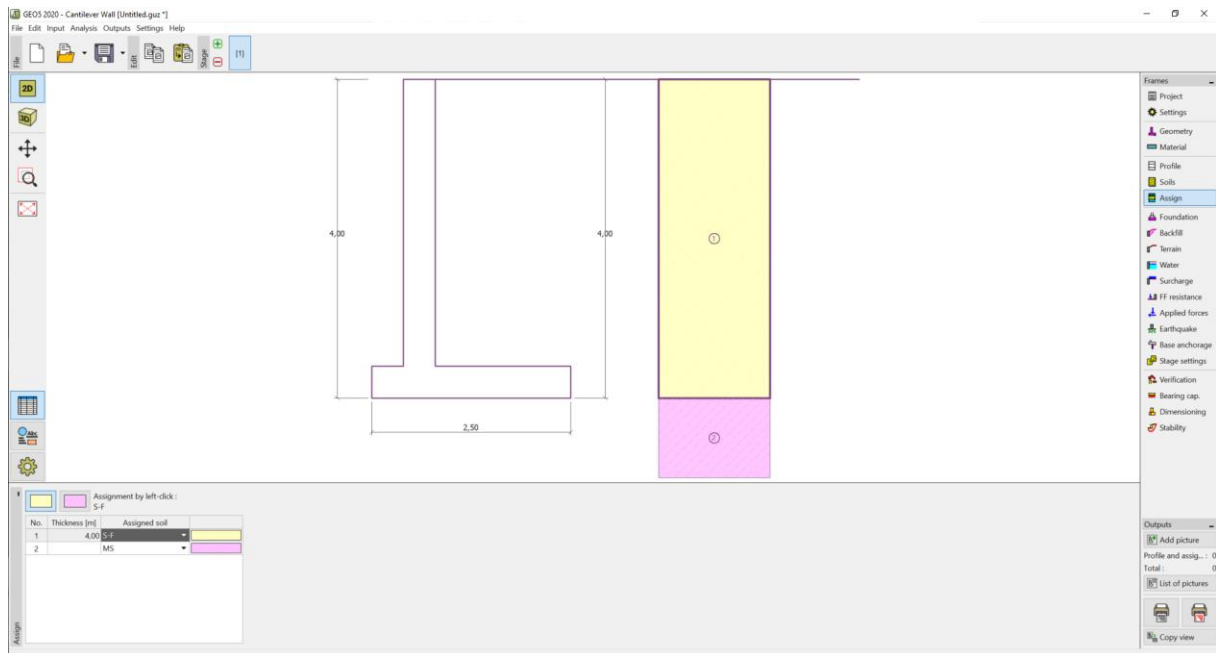
+ Add

✗ Cancel

"Add new soils" Dialog window – adding the MS soil

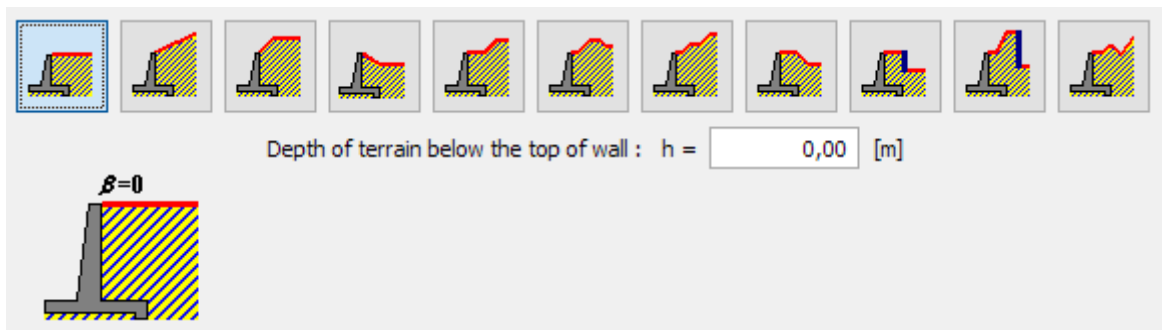
Note: The magnitude of the active pressure also depends on the friction between the structure and the soil. The friction angle depends on the material of the structure and the angle of the internal soil friction – normally entered in the interval $\delta \approx \left(\frac{1}{3} \div \frac{2}{3}\right) \cdot \varphi_{ef}$

We will now assign the soils to the geological layers in the “Assignment” frame.



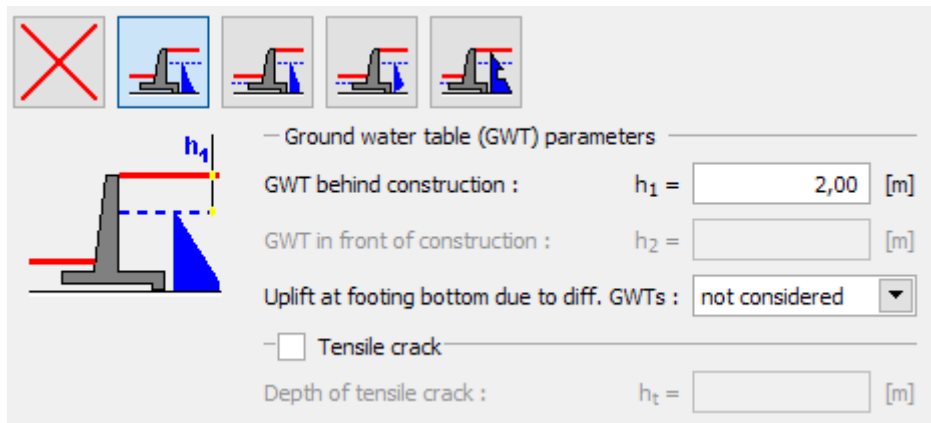
“Assignment” Frame

In the “Terrain” frame choose the horizontal terrain shape.



“Terrain” frame

Now we will move to the “Water” frame and select the type of water close to the structure and fill in its parameters, as shown in the picture below.



— Ground water table (GWT) parameters —

GWT behind construction : $h_1 =$ [m]

GWT in front of construction : $h_2 =$ [m]

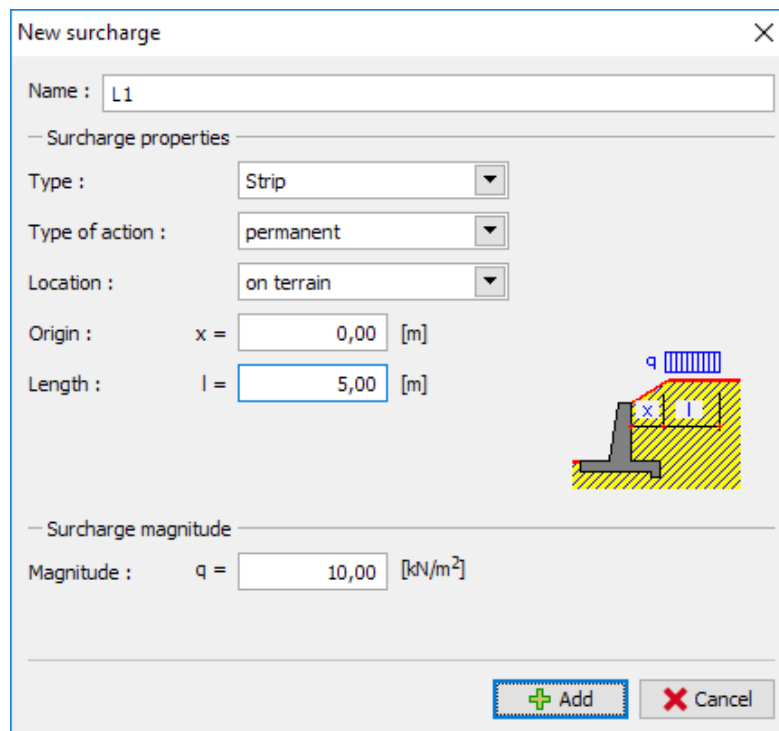
Uplift at footing bottom due to diff. GWTs : ▼

☐ Tensile crack

Depth of tensile crack : $h_t =$ [m]

“Water” frame

Then, move on to the “Surcharge” frame. Click the “Add” button and select a permanent strip surcharge with a magnitude of 10 kN/m³ acting as a dead load on the terrain over a 5 meter distance, as shown in the picture below.



New surcharge

Name :

— Surcharge properties —

Type : ▼

Type of action : ▼

Location : ▼

Origin : $x =$ [m]

Length : $l =$ [m]

— Surcharge magnitude —

Magnitude : $q =$ [kN/m²]

“New surcharge” Dialog window

In the “FF resistance” frame select the terrain shape in front of the wall. and then define other parameters of the resistance on the front face.

“FF resistance” frame

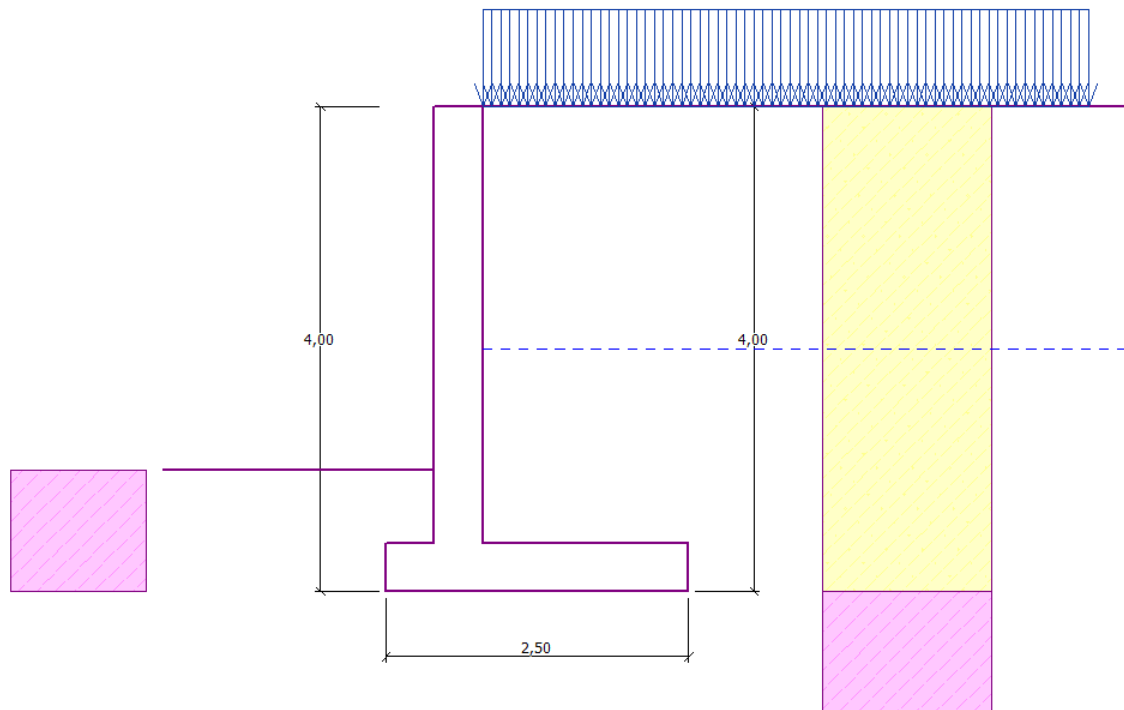
Note: In this case, we do not consider the resistance on the front face, so the results will be conservative. The FF resistance depends on the quality of the soil and the allowable displacement of the structure. We can consider the pressure at rest for the original soil, or well-compacted soil. It is only possible to consider passive pressure if the displacement of the structure is allowed. (for more information, see HELP – F1)

Then, in the “Stage settings” frame choose the “Design situation” as permanent, and the pressure acting on the wall as: The wall can deflect (active pressure), since the wall can move.

“Stage settings” frame

Note: A wall stem is usually dimensioned on earth pressure at rest, i.e., the wall can't be moved. Evaluating the stem and the wall for active pressure is done only in exceptional circumstances - such as the effects of an earthquake (seismic design situation with a partial coefficient equal to 1.0).

Now the task looks like this:



Analyzed structure

Now, open the “Verification” frame, where you can see the results for overturning and slip of the cantilever wall.

Verification : + - [1]						
No. ^	Force	F_x [kN/m]	F_z [kN/m]	Applic. point		Minor load
				x [m]	z [m]	
1	Weight - wall	0,00	61,00	0,87	-1,38	<input type="checkbox"/>
2	Weight - soil	0,00	4,32	0,20	-0,70	<input type="checkbox"/>
3	Weight - earth wedge	0,00	23,55	1,31	-1,54	<input type="checkbox"/>
4	Active pressure	-42,28	60,25	1,80	-1,46	<input type="checkbox"/>
5	Water pressure	-20,00	0,00	0,80	-0,67	<input type="checkbox"/>
6	Uplift pressure	0,00	0,00	0,80	-4,00	<input type="checkbox"/>
7	L1	-7,99	8,67	1,61	-2,08	<input type="checkbox"/>

Verification

OVERTURNING : SATISFACTORY (52,5%)

SLIP : NOT OK (119,7%)

“Verification” frame

Note: The “In detail” button in the right section of the screen opens a dialog window with detailed information about the analysis result.

Analysis results:

The verification of the slip is not satisfactory. The utilization of the structure is:

Check for overturning stability

Resisting moment $M_{res} = 209,03 \text{ kNm/m}$

Overturning moment $M_{ovr} = 109,75 \text{ kNm/m}$

Wall for overturning is SATISFACTORY

Check for slip

Resisting horizontal force $H_{res} = 68,37 \text{ kN/m}$

Active horizontal force $H_{act} = 81,83 \text{ kN/m}$

Wall for slip is NOT SATISFACTORY

Overall check - WALL is NOT SATISFACTORY

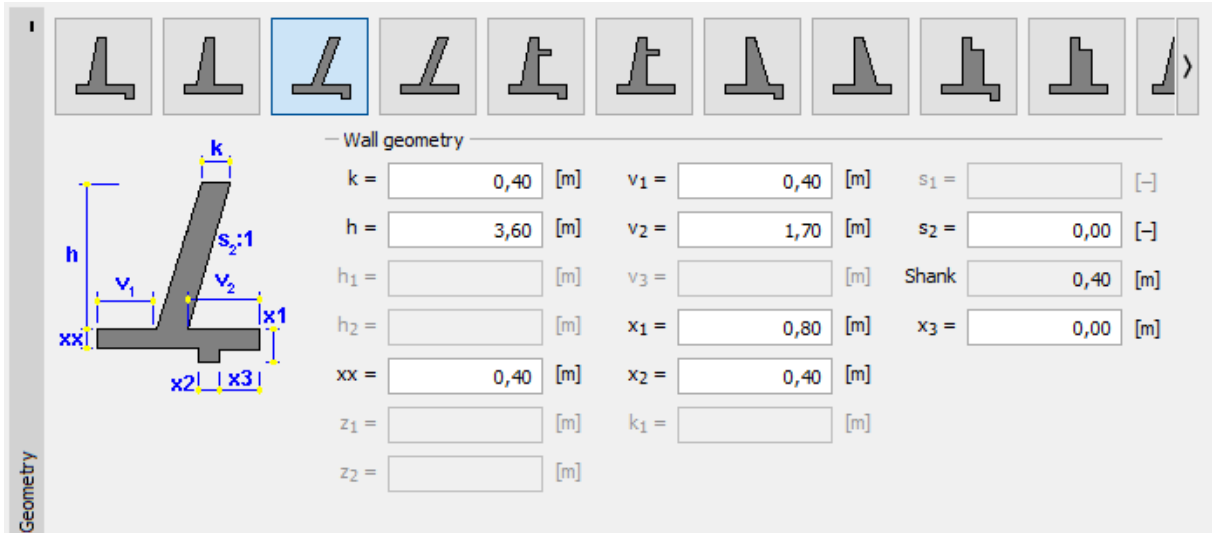
The slip has turned out as not satisfactory, so we need to change the design. There are several possibilities, how to improve the design. For example, we can:

- Use soil with better characteristics behind the wall
- Anchor the base
- Increase the friction by bowing the footing bottom
- Anchor the stem

These changes would be economically and technologically demanding, so we will instead choose the most convenient alternative, which is to change the geometry of the wall and introduce a wall jump.

Changing the design: change the geometry of the wall

Return to the “Geometry” frame and change the shape of the cantilever wall. To increase the resistance against the slip, we will introduce a feature called wall jump. Change the shape of the wall and put in the values of x_1 and x_2 as shown in the picture.



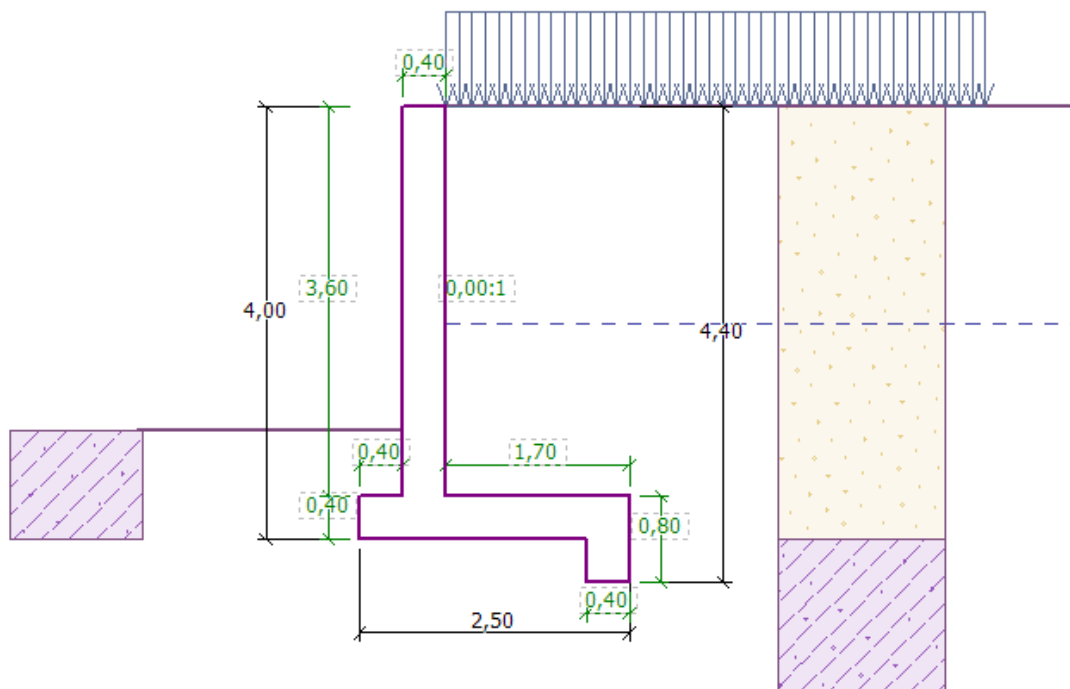
The screenshot shows the 'Geometry' frame in GEO5. On the left, a diagram of a cantilever wall with a wall jump is shown. The wall has a total height h and a base width xx . The wall jump is defined by its height v_1 and width x_1 . The main wall body has a height v_2 and width x_2 . The wall jump is inclined with a slope of $s_2:1$. The base of the wall is divided into segments x_2 and x_3 . The wall jump is defined by its height v_1 and width x_1 . The wall jump is inclined with a slope of $s_2:1$. The base of the wall is divided into segments x_2 and x_3 .

On the right, the 'Wall geometry' parameters are listed:

Parameter	Value	Unit
k	0,40	[m]
h	3,60	[m]
h_1		[m]
h_2		[m]
xx	0,40	[m]
z_1		[m]
z_2		[m]
v_1	0,40	[m]
v_2	1,70	[m]
v_3		[m]
x_1	0,80	[m]
x_2	0,40	[m]
k_1		[m]
s_1		[-]
s_2	0,00	[-]
Shank	0,40	[m]
x_3	0,00	[m]

“Geometry” Frame (Changing the dimensions of the cantilever wall)

Note: A wall jump is usually analyzed as an inclined footing bottom. If the influence of the base jump is evaluated as front face resistance, the program will analyze it with a straight footing bottom, but the FF resistance of the construction is going to be analyzed up to the depth of the bottom part of the wall jump (More info in HELP – F1)



The new shape of the structure

Now we can analyze the newly designed structure

Verification : + - [1]						
No. ^	Force	F _x [kN/m]	F _z [kN/m]	Applic. point x [m] z [m]		Minor load
1	Weight - wall	0,00	65,00	0,95	-1,28	<input type="checkbox"/>
2	Weight - soil	0,00	4,32	0,20	-0,70	<input type="checkbox"/>
3	Weight - earth wedge	0,00	23,55	1,31	-1,54	<input type="checkbox"/>
4	Active pressure	-47,11	61,78	1,82	-1,29	<input type="checkbox"/>
5	Water pressure	-28,80	0,00	0,80	-0,40	<input type="checkbox"/>
6	Uplift pressure	0,00	0,00	0,80	-4,00	<input type="checkbox"/>
7	L1	-9,28	9,07	1,65	-1,76	<input type="checkbox"/>

Verification

— Verification —

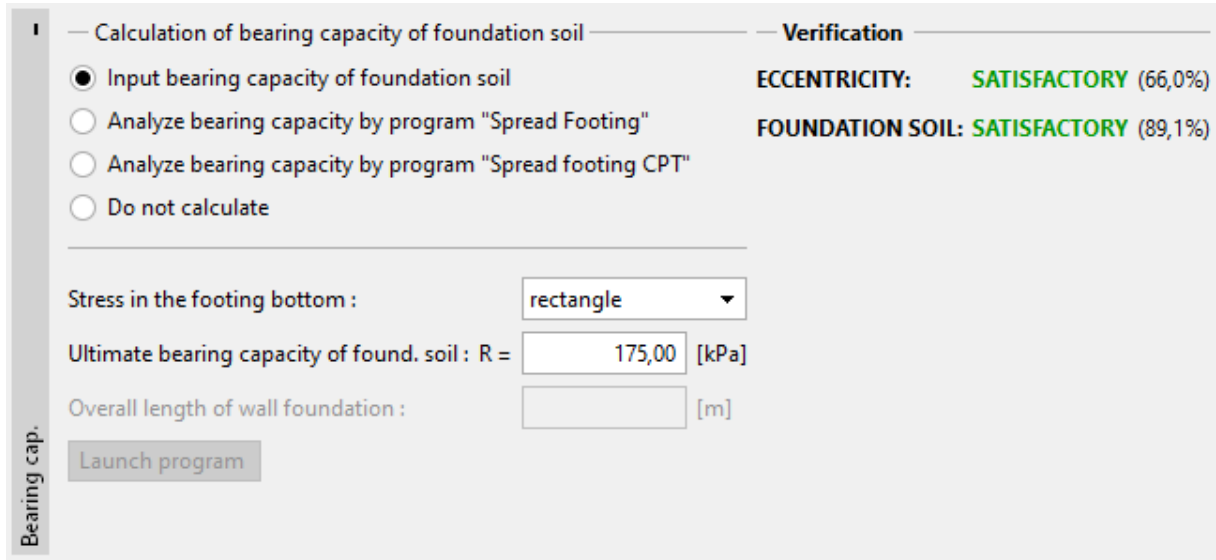
OVERTURNING : SATISFACTORY (47,6%)

SLIP : SATISFACTORY (93,5%)

Frame "Verification"

Now, the overturning and slip of the wall are both satisfactory (Utilization: 47.6 % and 93.5%)

Then, in the “Bearing capacity” frame, perform an analysis for the foundation soil, if the bearing capacity of the foundation soil is 175 kPa



— Calculation of bearing capacity of foundation soil — — Verification —

☒ Input bearing capacity of foundation soil
☐ Analyze bearing capacity by program "Spread Footing"
☐ Analyze bearing capacity by program "Spread footing CPT"
☐ Do not calculate

Stress in the footing bottom : rectangle

Ultimate bearing capacity of found. soil : R = 175,00 [kPa]

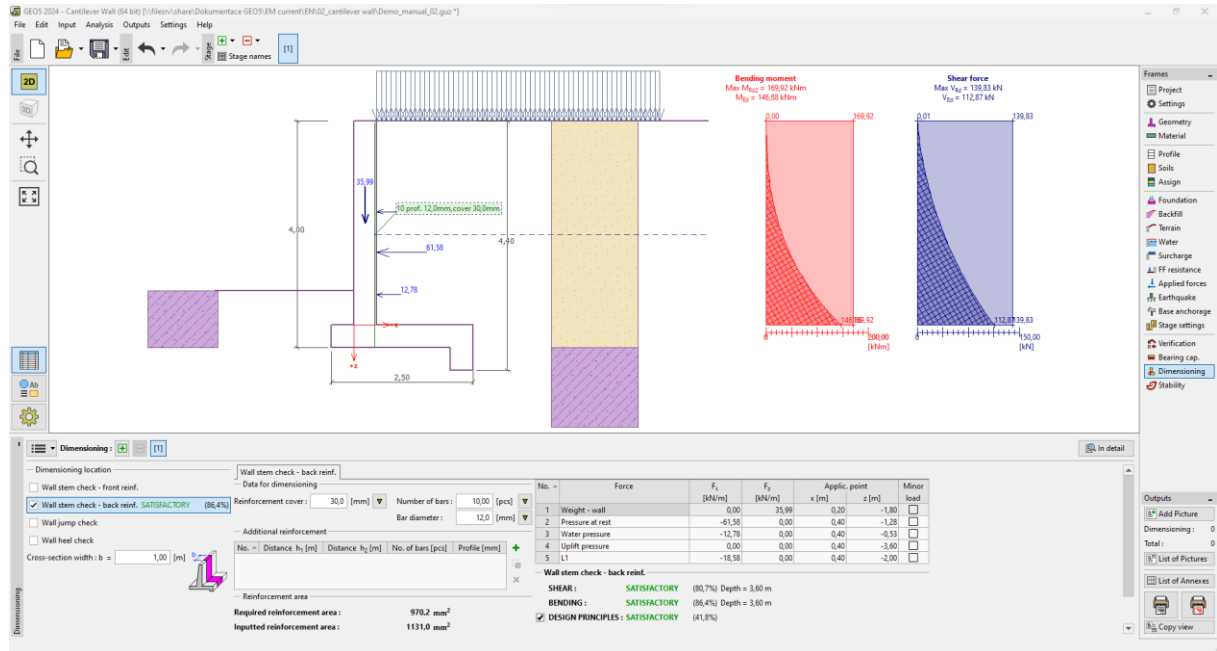
Overall length of wall foundation : [m]

Launch program

“Bearing capacity” Frame

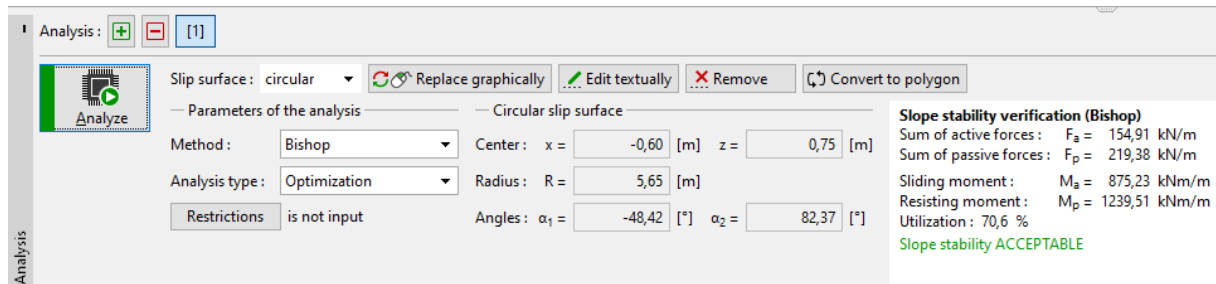
Note: In this case, we analyze the bearing capacity of the foundation soil as an input value, which we can get from a geological survey, or from some standards. These values are usually highly conservative, so it is generally better to analyze the bearing capacity of the foundation soil in the “Spread footing” program, which takes other influences such as the inclination of the load, the depth of the foundation etc. into account.

Next, in the “Dimensioning” frame, we will do a wall stem check. Design the main reinforcement into the stem – 10 pcs. $\varnothing 12\text{ mm}$, which satisfies all the design principles.



“Dimensioning” frame

Then, go to the “Stability” frame, where we will analyze the overall stability of the wall. This will open the “Slope stability” program, where we will move on to the “Analysis” frame. In our case, we will use the “*Bishop*” method, which has conservative results. Perform the analysis with optimization of circular slip surface, click “Analyze” to perform the calculations and when the calculation is complete, leave the program by clicking “Exit and save”. The results will be imported to the analysis report in the “Cantilever wall” program.



“Slope stability” program – “Analysis” frame

Conclusion:

Result of the analysis:

– Overturning:	47.6 %	SATISFACTORY
– Slip:	93.5 %	SATISFACTORY
– Bearing capacity:	89.1 %	SATISFACTORY
– Wall stem check:	86.4 %	SATISFACTORY
– Overall stability:	70.6 %	SATISFACTORY

This design of cantilever wall is SATISFACTORY.