Stabilizing a slope using anti-slide piles

Program: Slope Stability, Anti-Slide Pile

File: Demo_manual_19.gst

Introduction

The anti-slide piles are used to stabilize large landslides. This structure is similar to the pile wall, which is wholly (or almost wholly) realized in the slope. This pile wall intersects a slip surface and helps prevent further landslide. The piles usually have a large cross-section, which is circular or square.

The slope, which we want to stabilize using anti-slide piles, should meet several conditions. Firstly, we should know the location of the slip surface (its depth under the terrain in the place of the anti-slide pile). Another important thing is the condition of the rock (soil) under the slip surface. It should not be eroded or impaired, because it has to transfer the surcharge from the piles.

The solution of anti-slide piles can be divided into two steps. Firstly, we have to solve the global stability of the slope. In this step, we use the *GEO5 – Slope Stability* program*.* Using this program, we obtain the forces, which have to act on the piles to meet the required safety factor. If we do not know the exact position of the slip surface (for example from the geotechnical investigation), we can determine it in this program using optimization. Optimization can find the worst position of slip surface (critical with the lowest safety factor). The second part of the solution is done in the program Anti-Slide Pile. In this program, we have to design and verify the piles. The result of this analysis is the distribution of the internal forces and the horizontal displacement of piles.

An example using anti-slide piles to stabilize a slope with a road is shown in the picture below. A step-by-step solution of a similar example will be shown in this engineering manual.

Anti-slide piles (all below the terrain)

Task specification

Design a slope stabilization solution using anti-slide piles according to the scheme below. The safety factor of the **overall** slope stability must be at least SF=2,0. Consider this stabilization as a permanent design situation.
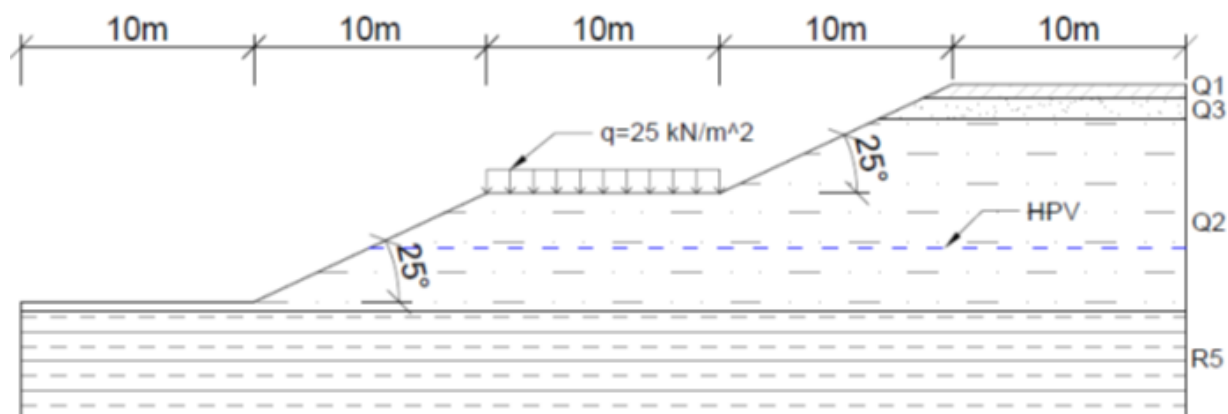
Task scheme

The surcharge from the road has a value of 25 kN/m².

The geotechnical parameters in the solved location are described in the following table:

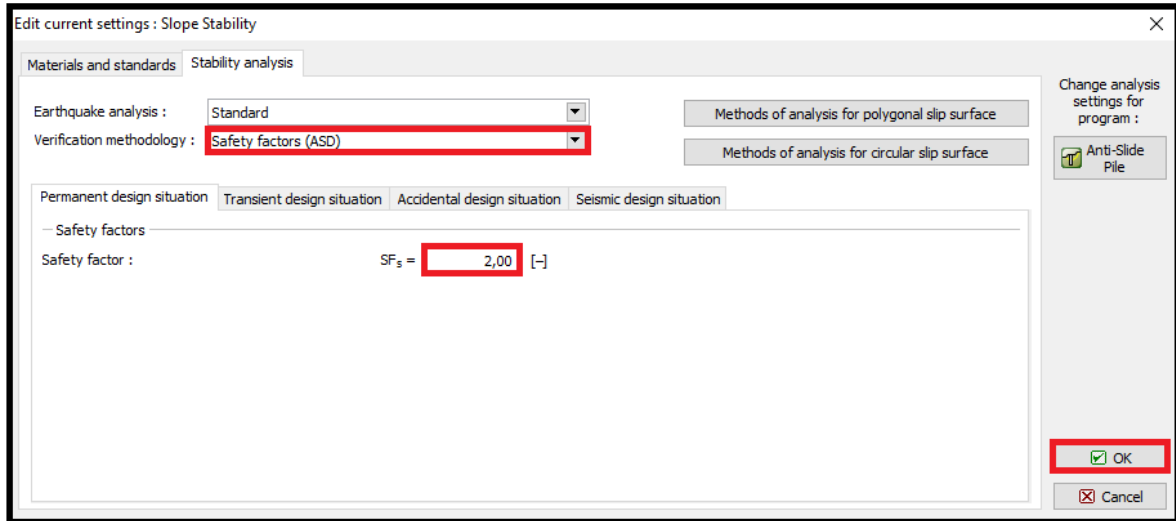| Layer	Depth (m)	ČSN 73 1001	γ/γ_{sat} (kN/m³)	ϕ_{ef} (°)	C_{ef} (kPa)	E_{def} (Mpa)	ν (-)
Silt with low plasticity F5/ML0 (Q1)	0,0 - 0,6	F5/ML	21/22	20	14	4	0,4
Clayey sand (Q3)	0,6 - 1,5	F4/CS	18,5/19,5	26	4	8	0,35
Sandy clay (Q2)	1,5 - 9,72	S5/SC	18/18,5	22	5	5	0,35
Strongly weathered slate (R5)	9,72 - 17	R5	24/24,2	29	30	15	0,35

Geotechnical parameters

The groundwater table is situated in a depth of 7 m.

Solution

The first part of the solution is modelling the whole task in the GEO5 – Slope stability program. The process of modelling the task in this program is already explained in engineering manual *No. 8 (Analysis of slope stability)*. For this reason, only the parts connected with analysis of an anti-slide pile are described here.

GEO5

Assessment of an existing slope – construction stage 1

Firstly, we change the basic settings of the task using the "Edit" button in the "Settings" frame. We set "Safety factors (ASD)" as the verification methodology and increase the value of the Safety factor to **SF$_S$=2,0**.

Edit current settings : Slope Stability   ✕

Materials and standards | Stability analysis

Change analysis settings for program :

Earthquake analysis :   Standard   ▼   Methods of analysis for polygonal slip surface

Verification methodology :   Safety factors (ASD)   ▼   Methods of analysis for circular slip surface

Anti-Slide Pile

Permanent design situation | Transient design situation | Accidental design situation | Seismic design situation

Safety factors

Safety factor :   SF$_S$ =   2,00   [–]

☑ OK
☒ Cancel

"Settings" Frame

In the "Interface" frame we set the ranges and model the shape of the terrain and the interfaces between the geological layers using the coordinates of each point. The coordinates of points are described in the table below:
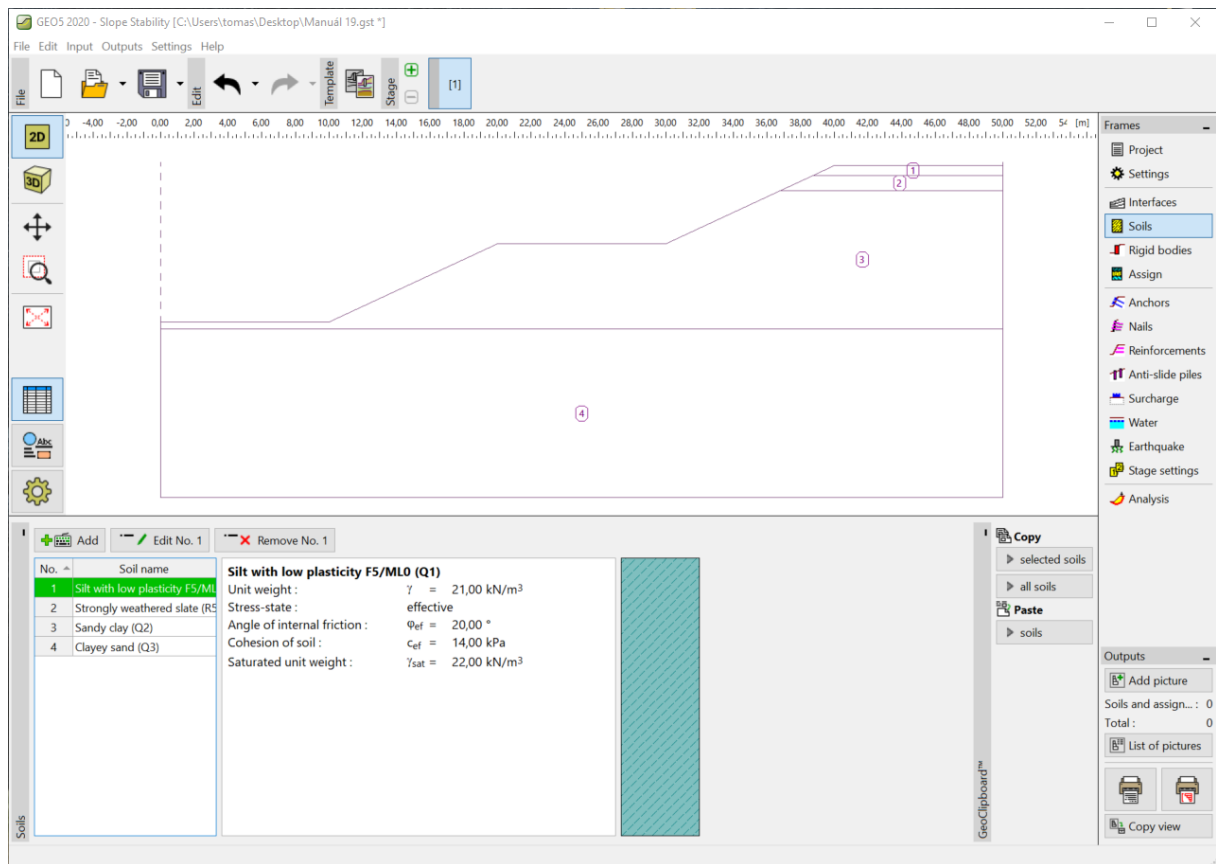
| Interface 1			Interface 2			Interface 3			Interface 4		
➤	1	0,00	0,00	➤	1	38,71	8,72	➤	1	36,78	7,82	➤	1	0,00	-0,40
	2	10,00	0,00		2	50,00	8,72		2	50,00	7,82		2	50,00	-0,40
	3	20,00	4,66												
	4	30,00	4,66												
	5	36,78	7,82												
	6	38,71	8,72												
	7	40,00	9,32												
	8	50,00	9,32												

Interface coordinates
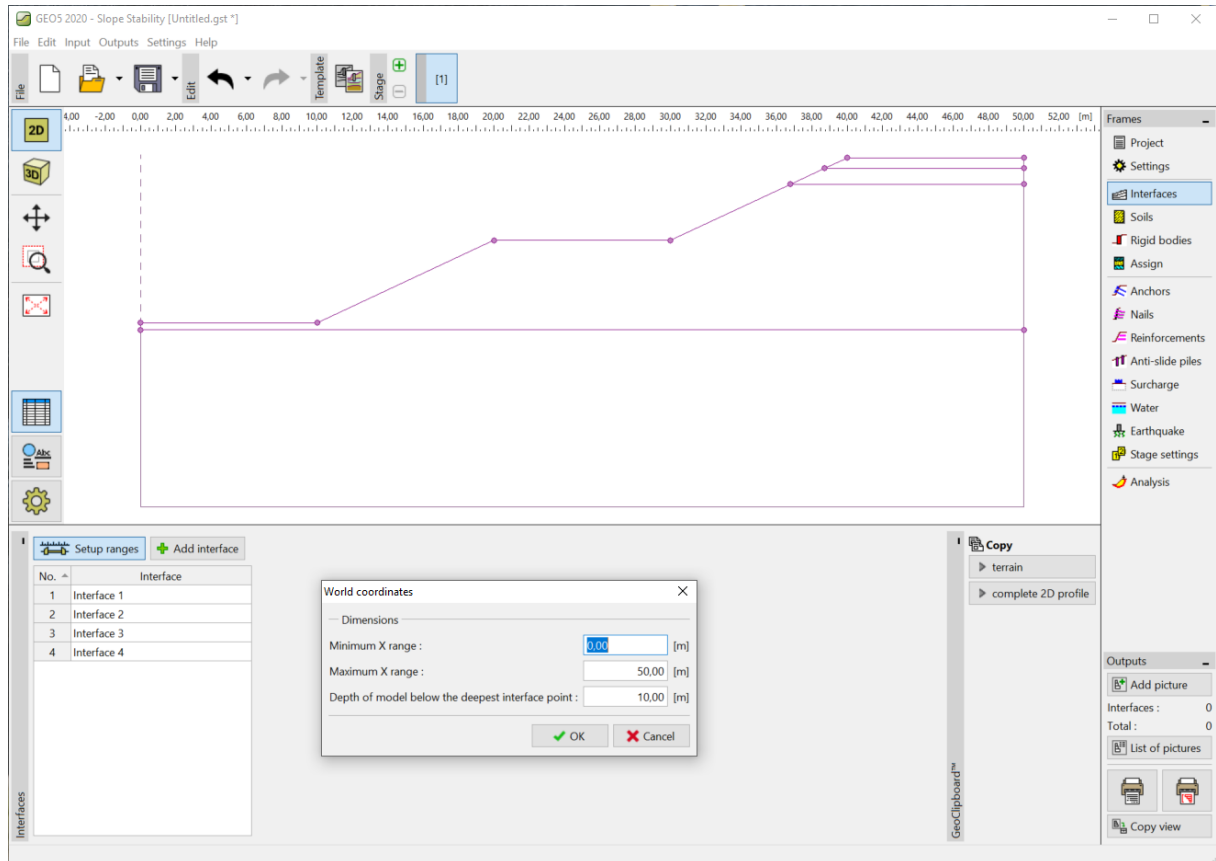
"Interface" Frame – Setup ranges

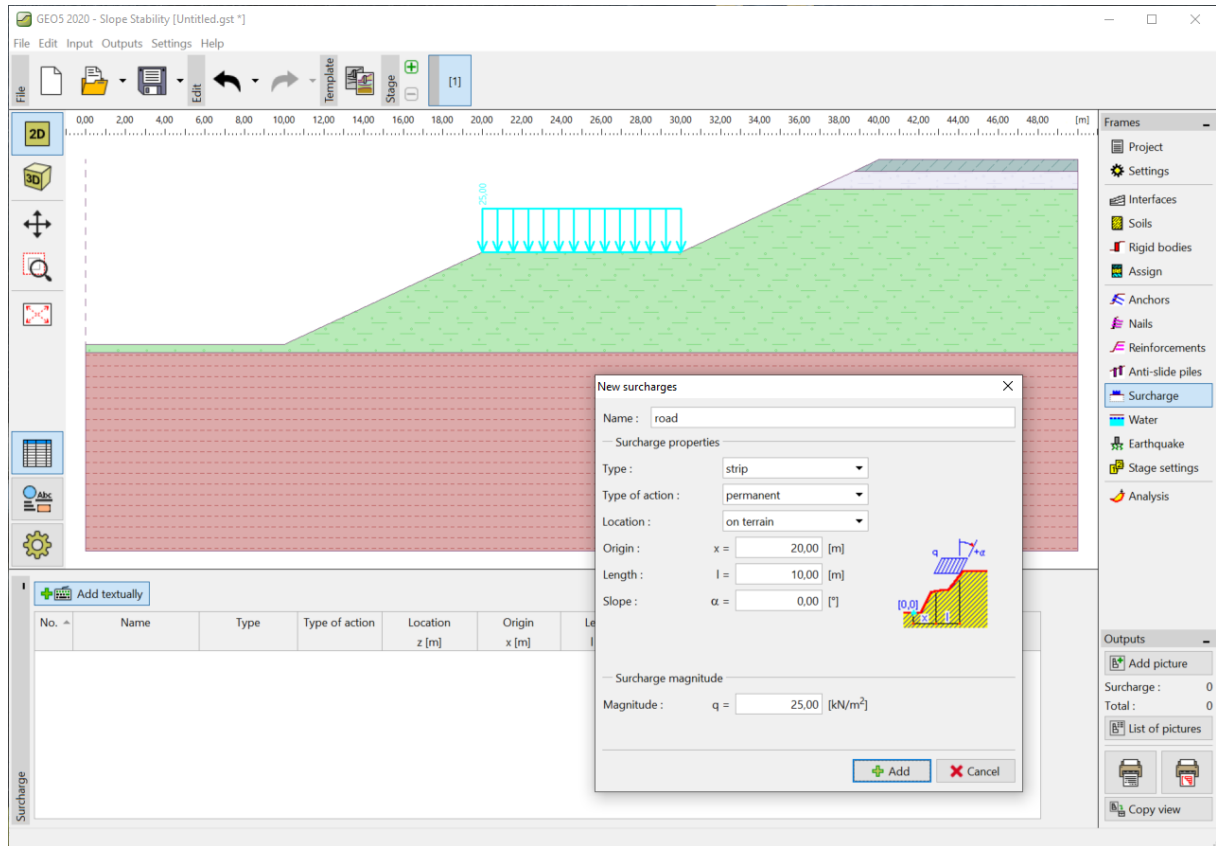Then we have to input the soils according to the task specification.

"Soils" Frame

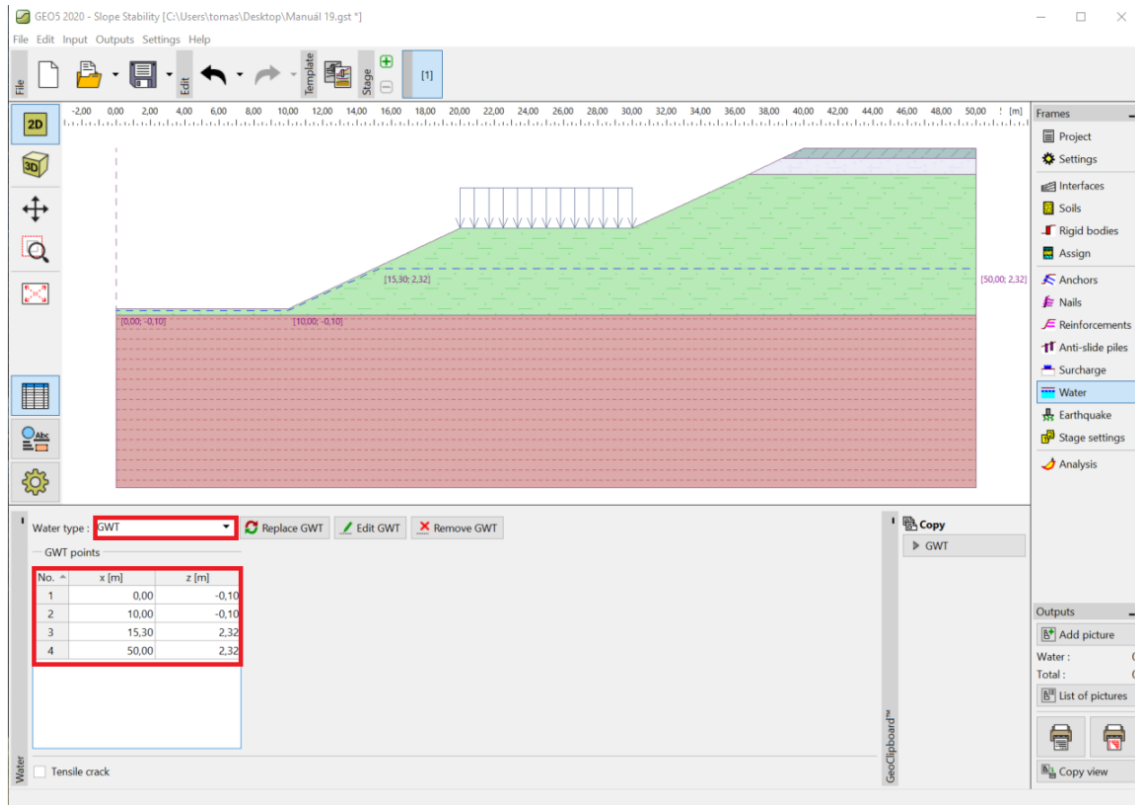In the "Assign" frame we assign the added soils to the geological layers.
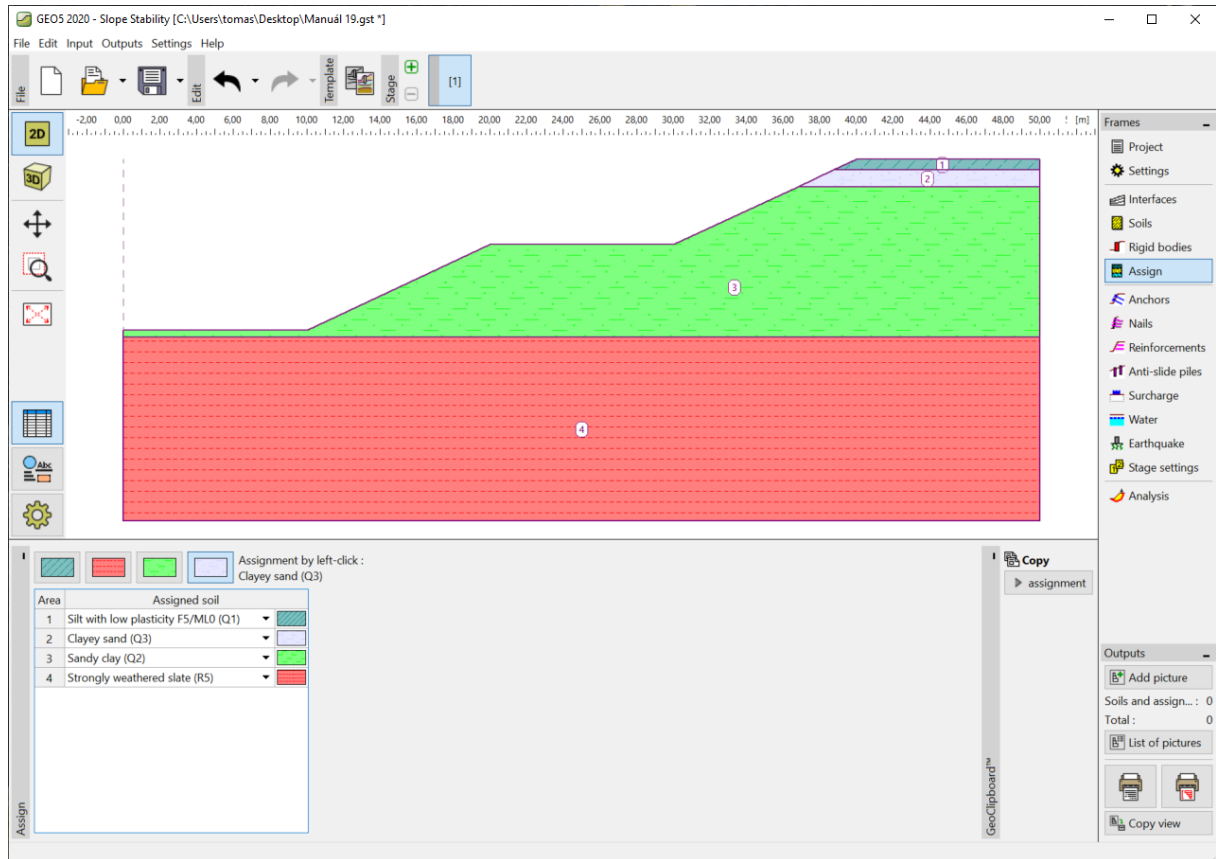
"Soils" Frame

In the next step, we define the surcharge from the road. It acts as a strip permanent surcharge and its value is 25 kPa.
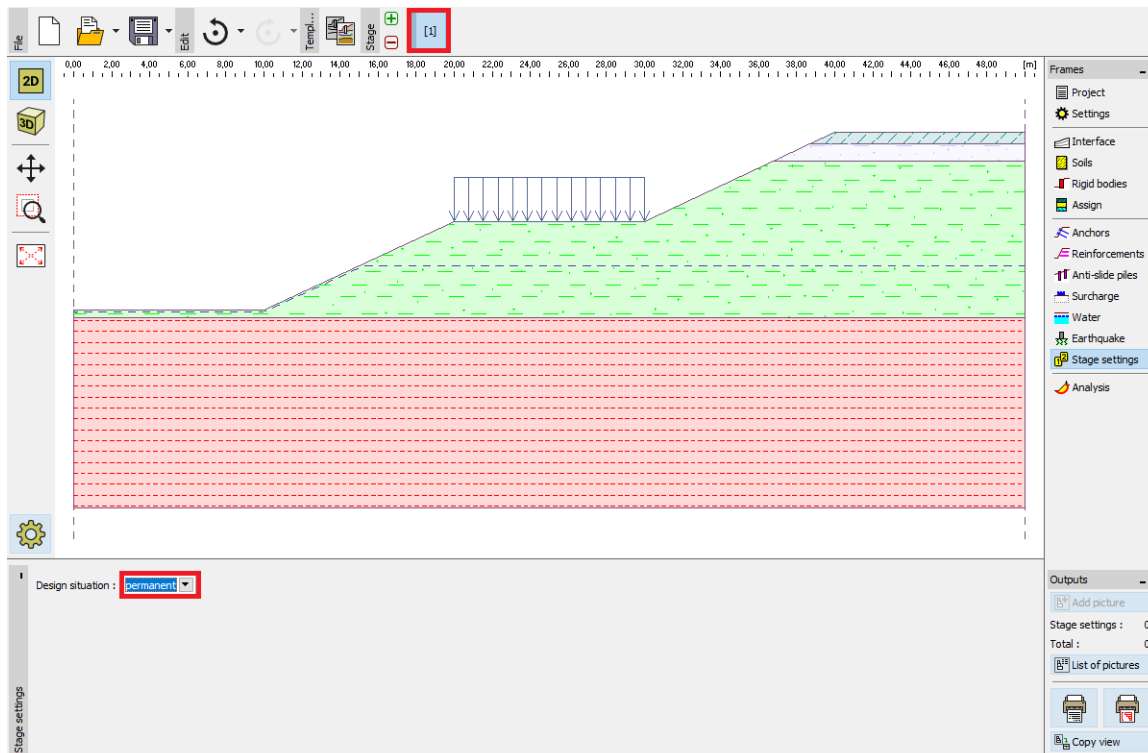
"Surcharge" Frame

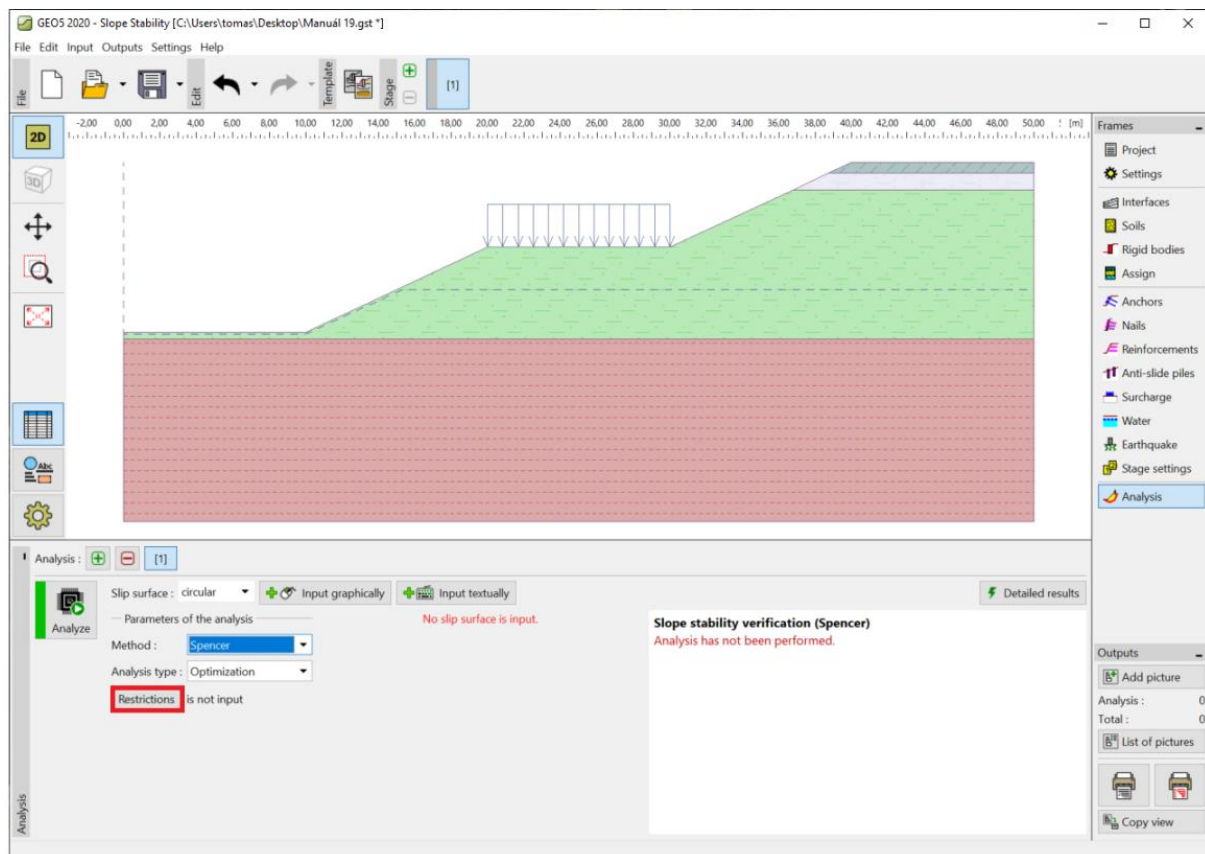In the "Water" frame add the coordinates of the GWT points.

"Water" Frame

We are looking for a solution, in the long run, so we set the design situation as "permanent".
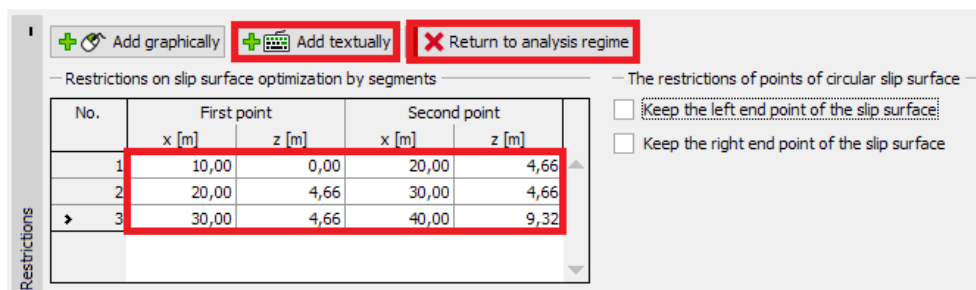

"Stage settings" Frame

Then we move to the "Analysis" frame. We can use several different analysis methods for slope stability. Comparison and more information for each method is a part of engineering manual *No. 8 (Analysis of Slope Stability)*.

We are going to solve the **overall** stability of the slope. We don't want to analyze partial upper or bottom slope. For this reason, we will define restriction lines on the terrain of the slope. It means that the global slip surface will be found during the optimization.
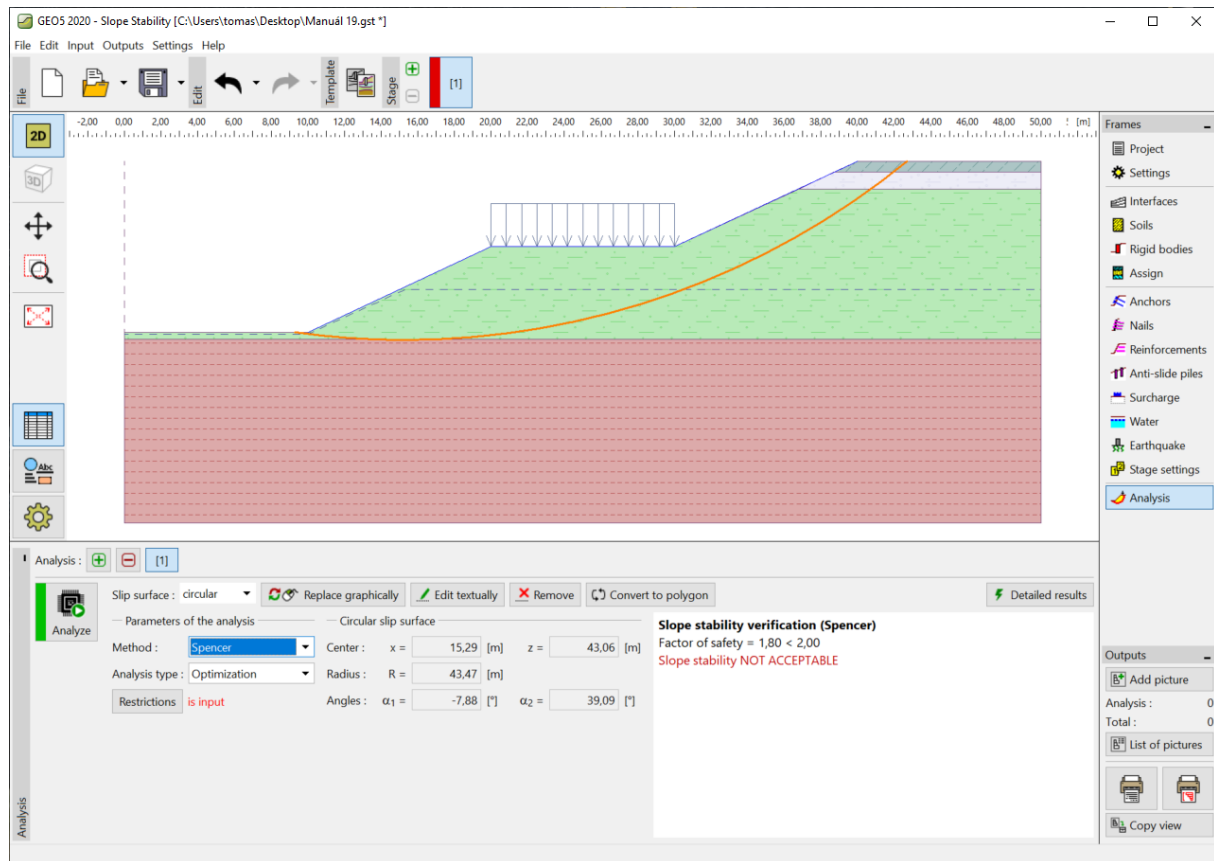

"Analysis" Frame - restrictions

No.	First point		Second point	
	x [m]	z [m]	x [m]	z [m]
1	10,00	0,00	20,00	4,66
2	20,00	4,66	30,00	4,66
3	30,00	4,66	40,00	9,32

Restriction input

We choose Spencer's analysis method for an optimized circular slip surface. We can enter a random initial shape of the slip surface. The optimization finds the worst state.

"Analysis" Frame

Note: It is necessary to know the forces acting on the piles for the next calculation. Not all methods can be used to analyze these forces in the Slope stability program. The user must use one of these methods: Spencer, Janbu, Morgenstern-Price or ITFM.

Note: The choice of the analysis method and the shape of the slip surface is always the decision of the designer and depends on his knowledge and experience. In the engineering praxis, it is good to perform several analyses using different methods and compare the results.

Note: If we know the exact position of the slip surface, we do not use optimization. We would choose "Standard" as the "Analysis type" and enter the slip surface manually.
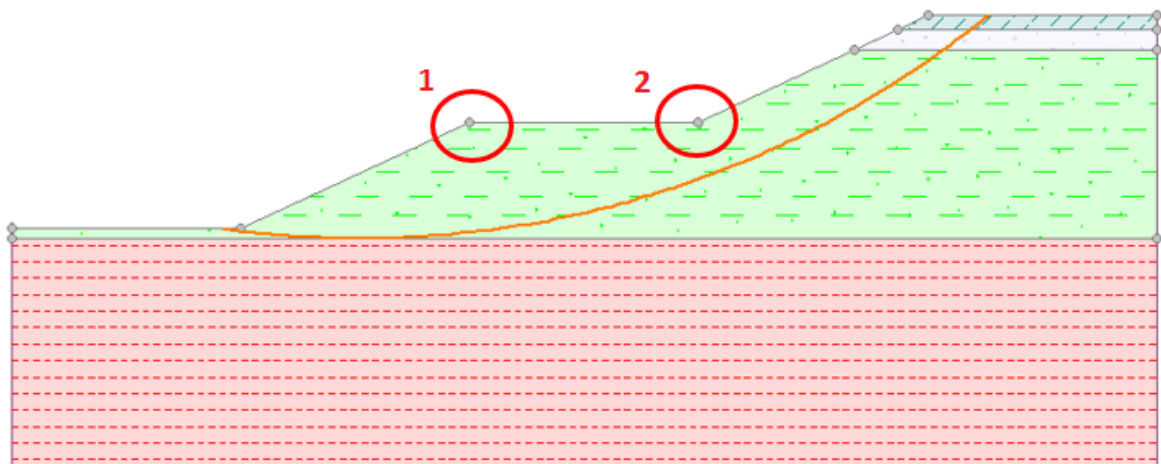
Designing anti-slide piles

Before designing, we move to the next construction stage. It will enable us to compare the results with and without piles.

In the "Anti-slide piles" frame we have two different ways how to add the piles. It is possible to add piles graphically by mouse or textually by inputting the pile head coordinates and its length. It is also possible to combine these two ways – to enter a graphical approximation and edit the exact position textually.

Note: Usually we do not know the ideal position for inserting an anti-slide pile. The pile must always intersect a slip surface and it should go all the way into the geological layers with a greater bearing capacity. It is also important to consider the technological possibilities of pile realization or anchoring. A pile in the middle of a steep slope can improve its stability but the question is how to realize it…

In our example, we have two ways how to insert the anti-slide piles. It is shown on the picture below.

Possible locations for the realization of anti-slide piles

We will show a solution for the first point. The decision regarding the location of an anti-slide pile is always on the designer.

Note: In the case of over-loaded piles, or if we want to make the cross-section of the piles smaller, it is also possible to realize the piles in two rows (in both points).
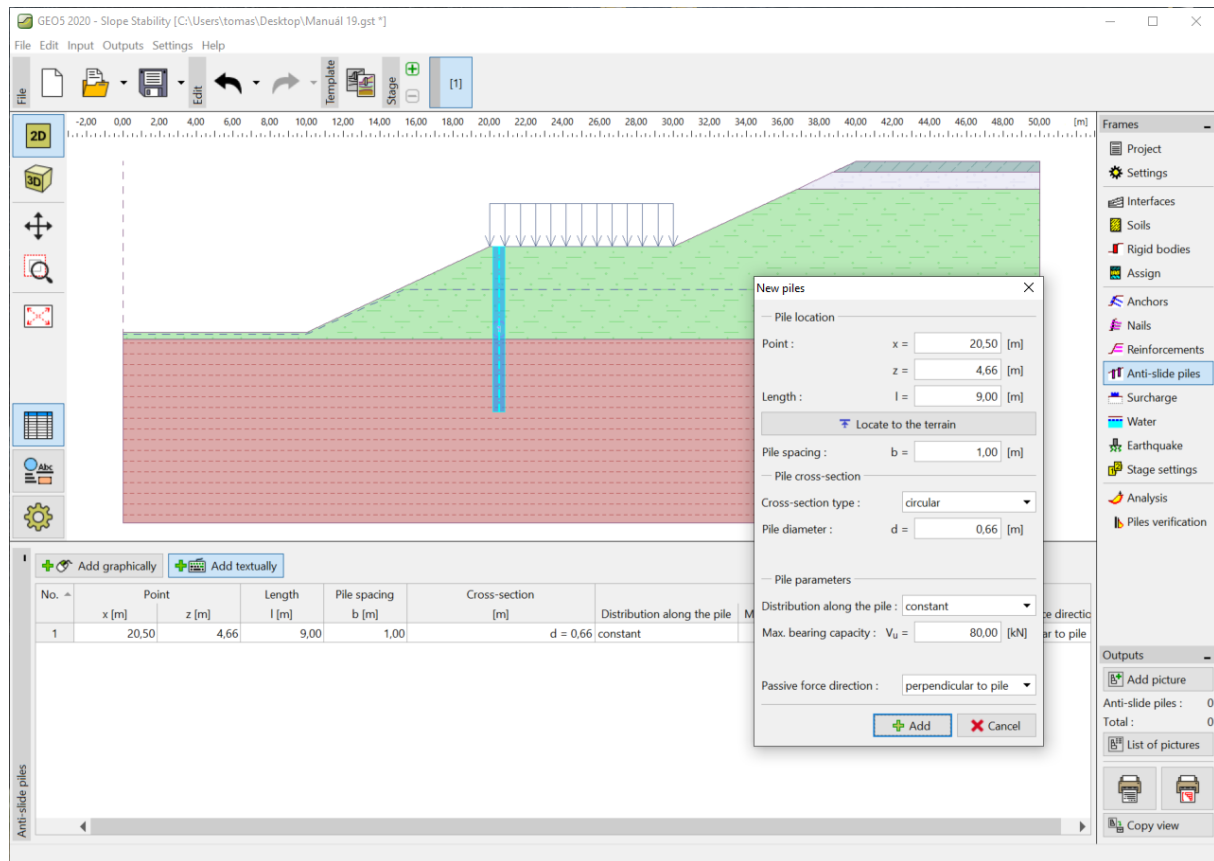
"Anti-slide piles" Frame – adding a new pile

Note: Besides the position, spacing and diameter of each pile we also have to input their additional parameters. The maximal bearing capacity of a pile is the force, which acts against the landslide. We will verify this value in the next assessment in the program "Anti-slide pile". The bearing capacity can be specified as a constant or as linearly increasing from the toe of the pile upwards. The passive force acts on the pile horizontally or in the direction of the slip surface. It is possible to find more information in the help (F1).

We use circular piles with a diameter of 0,66 m and length 9 m. The spacing between piles is 1 m and their presumed bearing capacity (V_u) is 80 kN.

After adding the piles, we move to the "Analysis" frame. We select "Standard" as the analysis type. In this type of analysis, the program is not looking for a new slip surface. It just calculates the safety factor for the inserted slip surface (in our case taken from the previous construction stage). The rest of the settings is left unchanged.
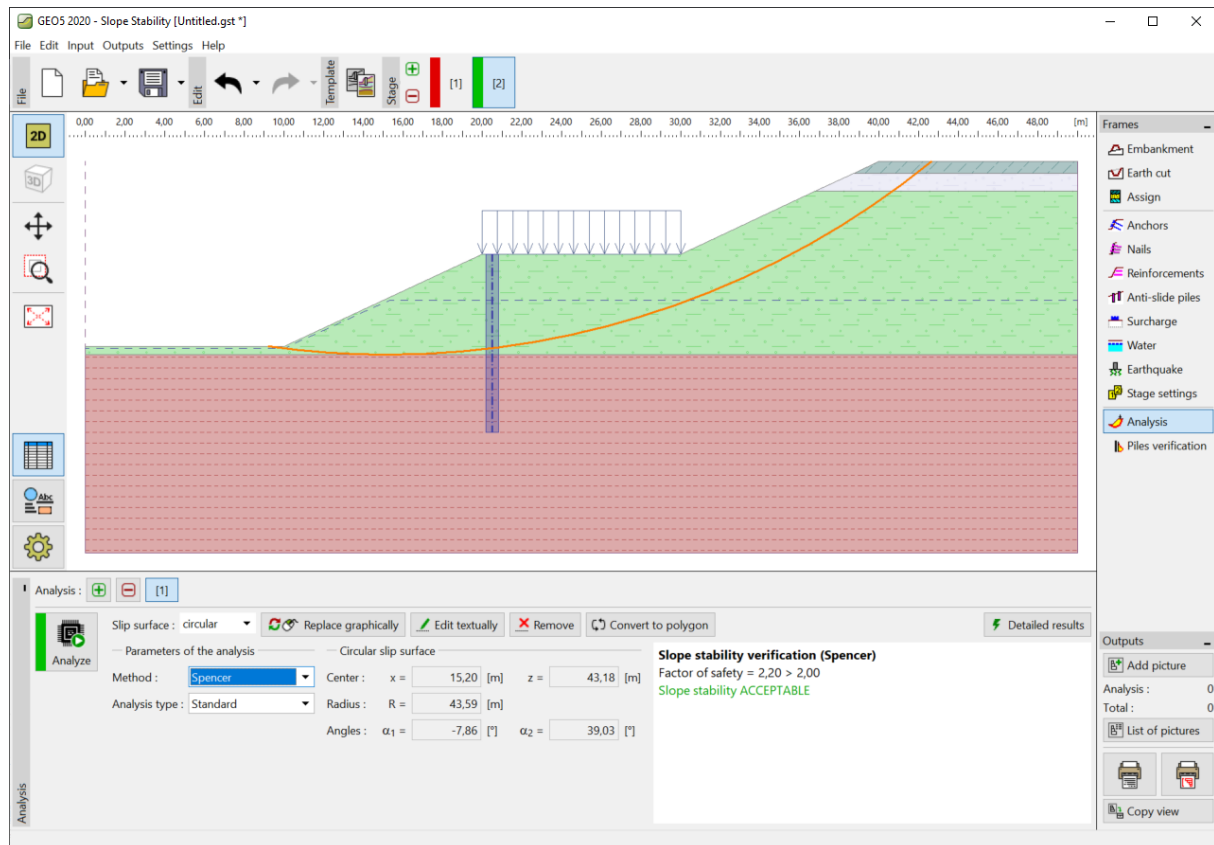
"Analysis" Frame - influence of anti-slide piles

It is obvious, that using the anti-slide piles improves the slope stability and now it is acceptable for the required safety factor.

After clicking on the "Detailed results" button we see a dialog window with slope stability analysis information.
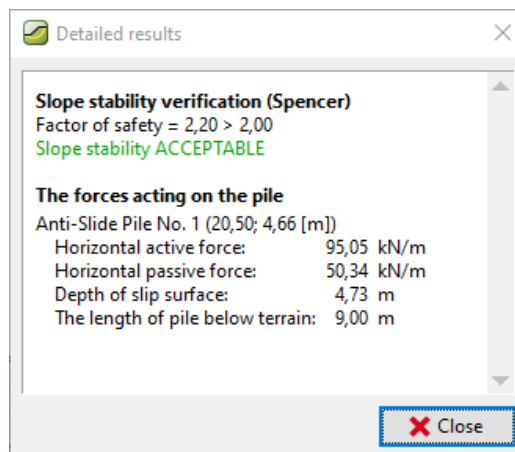
"Detailed results" – Dialog window

Note: We obtain the depth of the slip surface in the pile location and the values of the two forces acting on the pile.

Active force acts on the pile from the upper part of slope. It destabilizes the slope.

Passive force acts against the landslide and helps the pile to stabilize the slope. (In case the passive force is equal to zero it means that the slope in front of the pile is not stable and it is necessary to solve its stability separately.)

The difference between the active and passive force is, in fact, the force, which the pile must transfer to reach the required safety factor of the slope. In a more simplified way, it is the minimal bearing capacity, which the pile must carry out.

The safety factor always depends on the position and the shape of the slip surface. The critical slip surface, found in the slope without piles, has a safety factor **SF=1,8**. The same slip surface in the slope with anti-slide piles has **SF=2,20**. But it is also possible, that there is another slip surface, which was not critical before installing the piles but became critical after this stabilization. This slip surface had **SF>1,8** before installing the pile and after the stabilization **SF<2,20**.

We check this possibility in the next phases of analysis using optimization on the slope with piles.
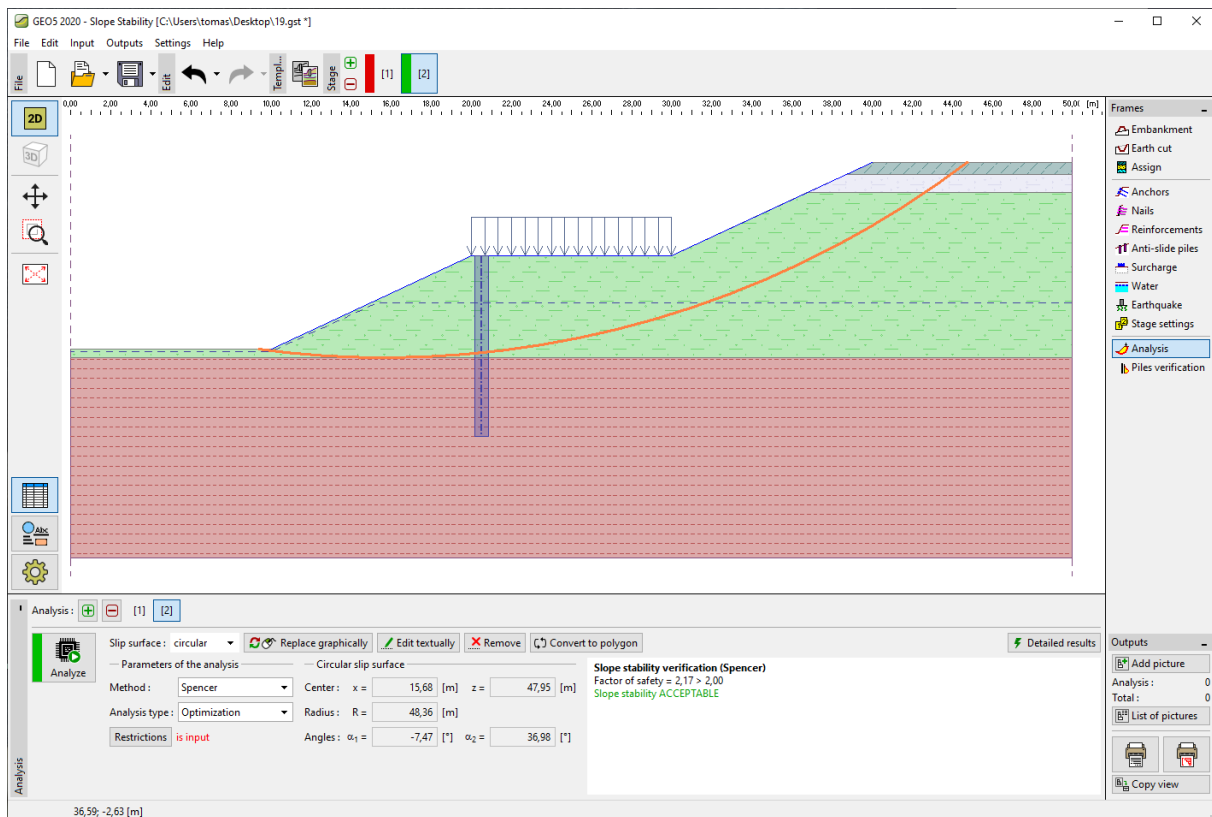
"Analysis" Frame – optimization of slip surface after installing anti-slide piles

We can see, that the slope stability is acceptable for the required safety factor even with this new slip surface. The difference between the old and the new slip surface is minimal in our case, but it does not have to be like every time. It is always good to check the new critical slip surface even after installing the piles.

This state after installing piles is critical. For this reason, we will use it for our next dimensioning and analyzing of piles.

Analyzing and dimensioning the piles

We choose analysis No. 2 in the "Piles verification" frame and press the button "Launch program Anti-Slide Pile".

Note: In the case of more than one row of piles, it is necessary to specify, which row are we performing the analysis for.
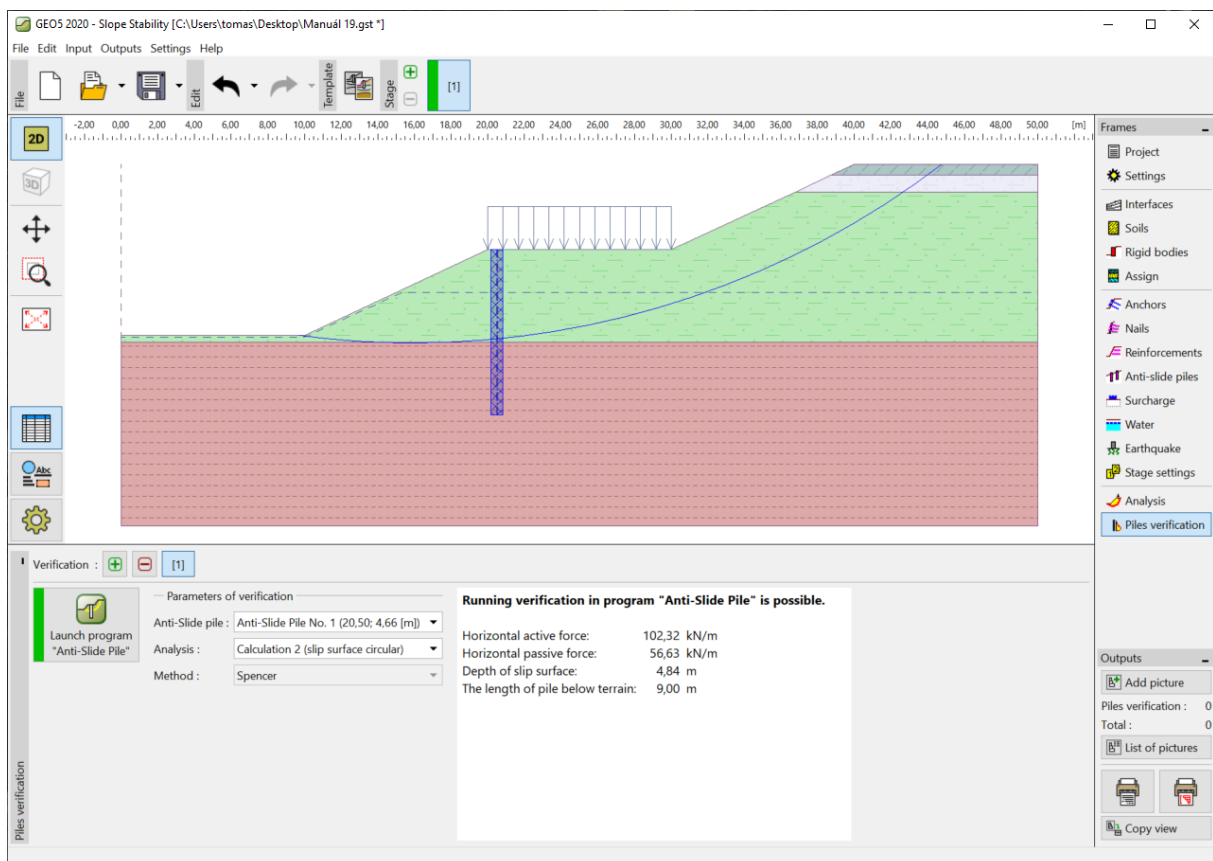

"Piles verification" Frame

The program *Anti-Slide Pile* is used to determine any deformations and internal forces on the pile. This program is similar to the program *GEO5 – Sheeting Check*. The main difference between them is the way a load on a pile wall is determined. In the program *Sheeting Check,* the structure is loaded by earth pressures on the whole length of the pile. In the program *Anti-Slide Pile*, the load is divided into two parts. In the section above the slip surface, the pile is loaded based on the difference between the active and passive force. Under the slip surface, the load is determined by the earth pressures.

All data from the program *Slope Stability* are automatically transferred to the program *Anti-Slide Pile.*

Note: Inputting most of the basic data in the program Anti-Slide Pile is the same as in the program Sheeting Check. It is described in the engineering manuals to this program (No. 6 and No. 7) in detail.

Note: If we want to change some settings of the analysis in the program Anti-Slide Pile (earth pressure method analysis, standards for materials etc.) we have to make these changes in the "Settings" frame in the program Slope Stability.

In the "Modulus Kh" frame we choose a method of analysis of the modulus of reaction. We choose the calculation according to Schmitt. It is possible to find more information about modulus Kh in the engineering manuals to the program Sheeting Check or in the program help (F1).
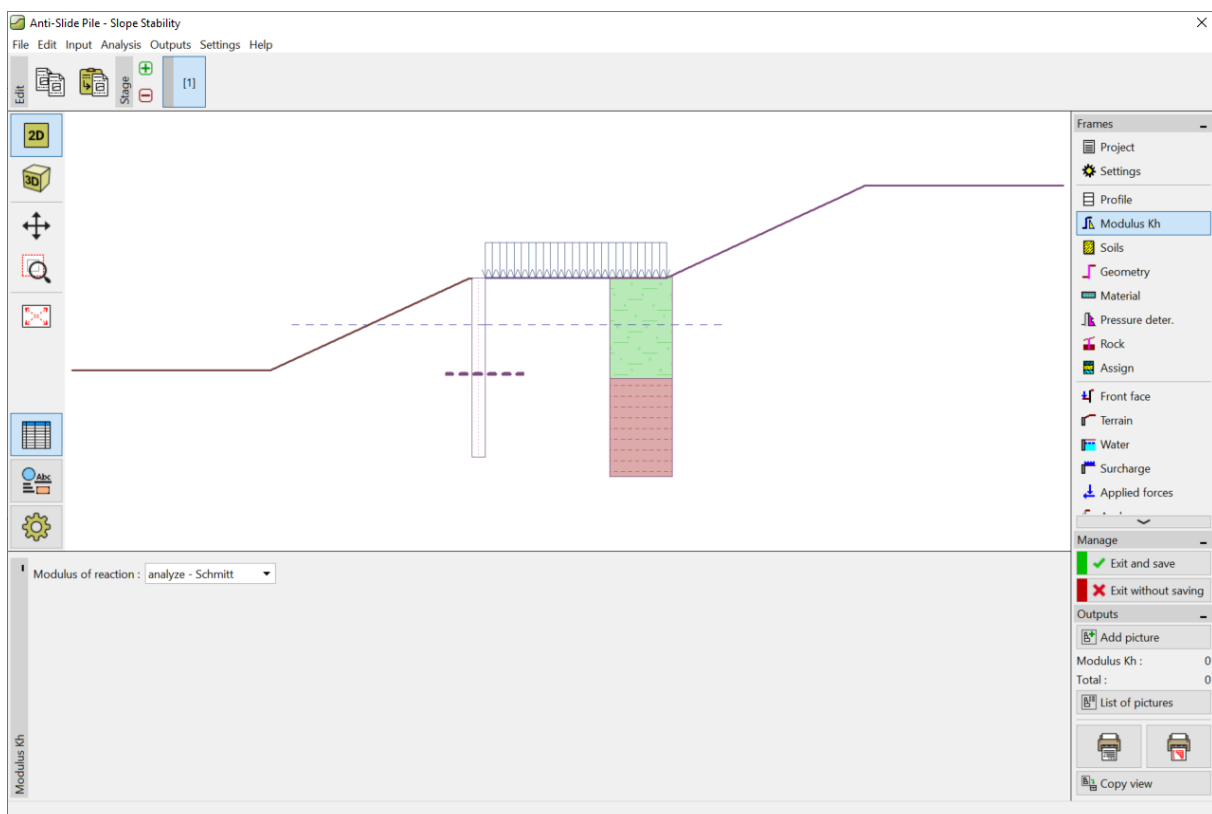
The "Anti-Slide Pile" program –"Modulus Kh" frame

In the "Soils" frame we must add deformation modulus and poisson ratio for each soil according to the table on the 2nd page. These parameters are necessary for determining of modulus Kh. We consider angle of friction between soil and structure as **δ=15°** for each soil.

We set the type of concrete and steel in the "Material" frame. It is possible to choose the parameters from the catalogue of materials or enter it manually. We choose the C20/25 concrete and longitudinal reinforcement B500.
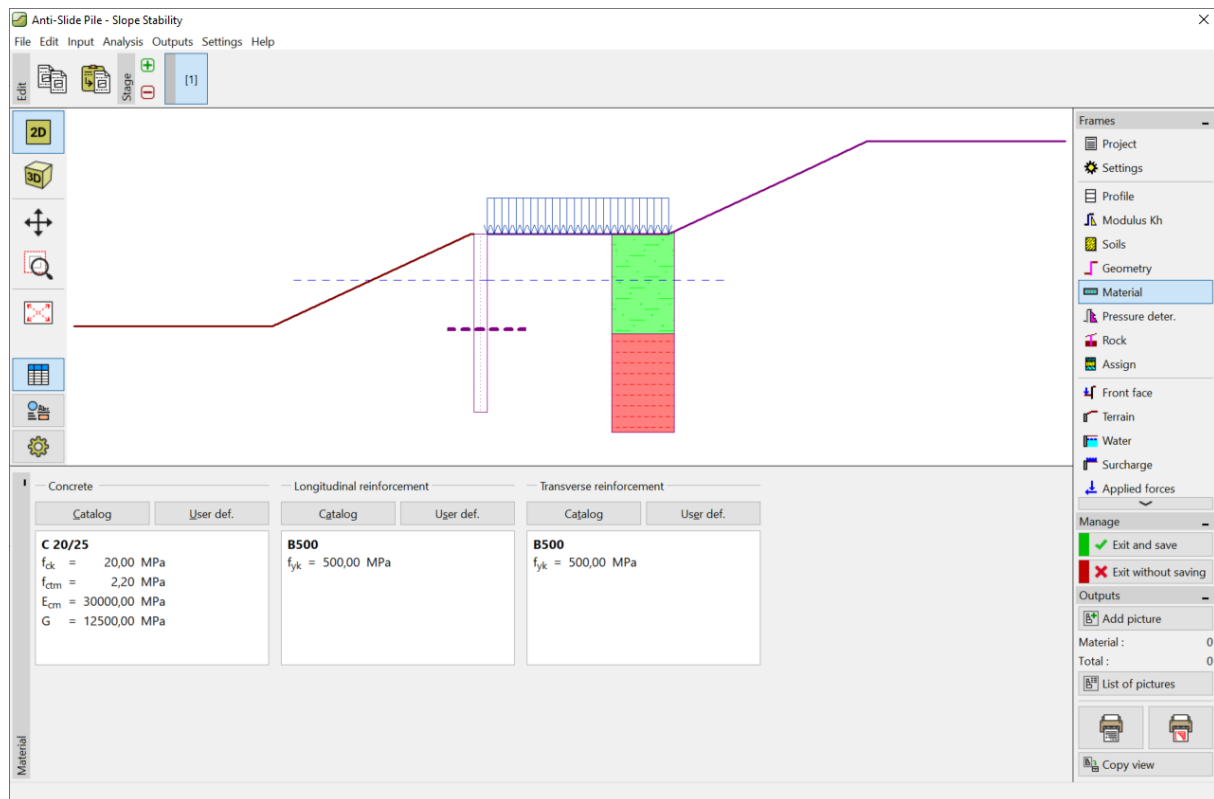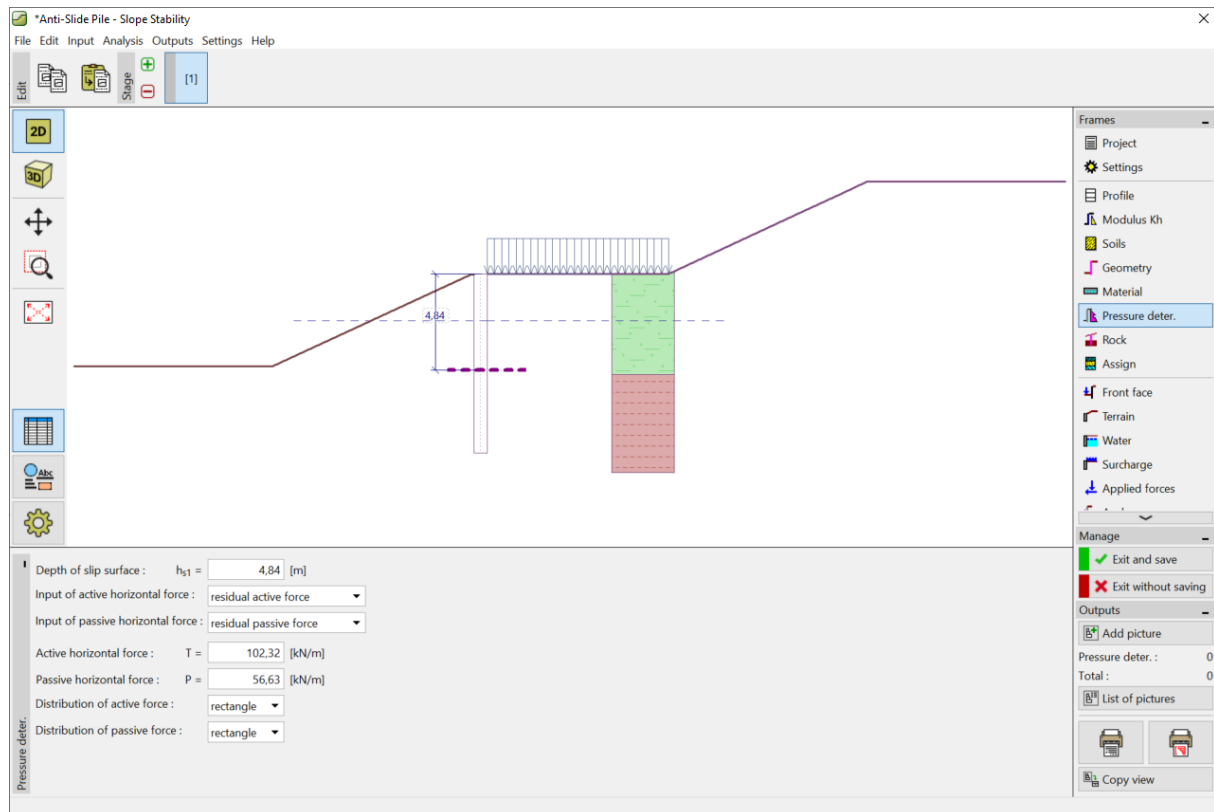

The "Anti-Slide Program" –"Material" frame

The next important frame for us is "Pressure determination". In this frame, we will find automatically inserted values of active and passive forces and the depth of the slip surface. We obtained these data from the analysis of slope stability.

We have three possible ways how the pressures acting on the pile in the section above the slip surface are distributed. The active force can be distributed according to three basic shapes (triangle, rectangle, trapezoid), the passive force can be distributed the same way as the active or according to a simplified parabola. The distribution of pressure is explained in the GEO5 help (F1) in detail.

Note: In general, the pressure distribution depends on the type of soil above the slip surface. In our case, the main soil is sandy clay – for fine-grained soils, it is recommended to use the distribution according to a rectangle. The distribution of the passive force is then a decision of the designer of the structure.
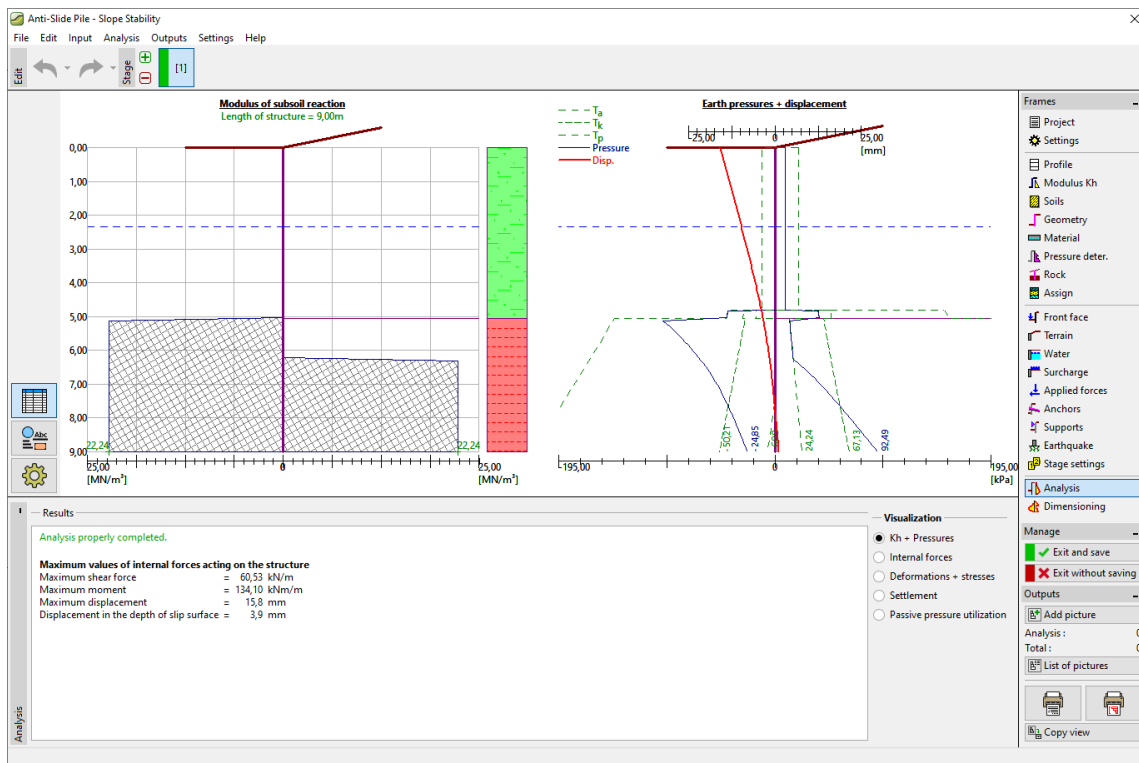
*The "Anti-Slide Program" –"Pressure determination" frame*

Note: It is also possible to determine the pressure acting above the slip surface manually. It is possible to use it when we do not want to calculate the load on the pile according to the difference between the active and passive force.

Note: If we considered a cantilevered pile in a rock layer, we would set it in the "Rock" frame. In this case, it would be necessary to enter the length of the pile in the rock and the bearing capacity of the rock. Then the maximal stress would not be considered as the passive earth pressure; instead, it could reach any value. This value of stress would then be compared to the bearing capacity of the rock in the "Analysis" frame. We do not use this frame in our example.
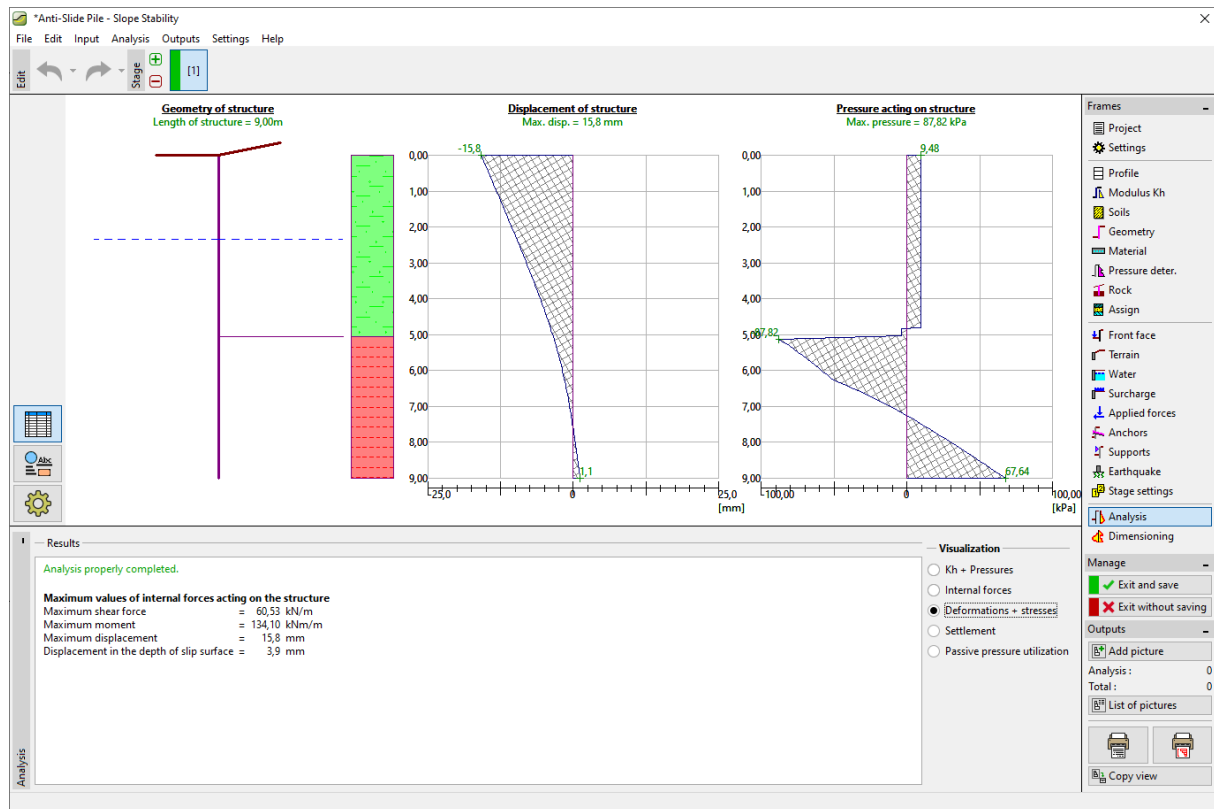
Now we have to move to the "Analysis" frame.

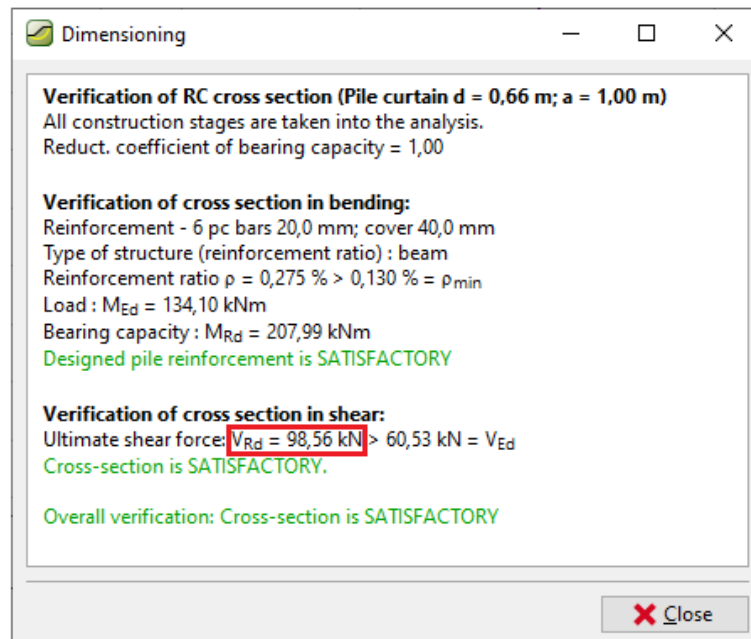*The "Anti-Slide Program" –"Analysis" frame – Kh + pressures*
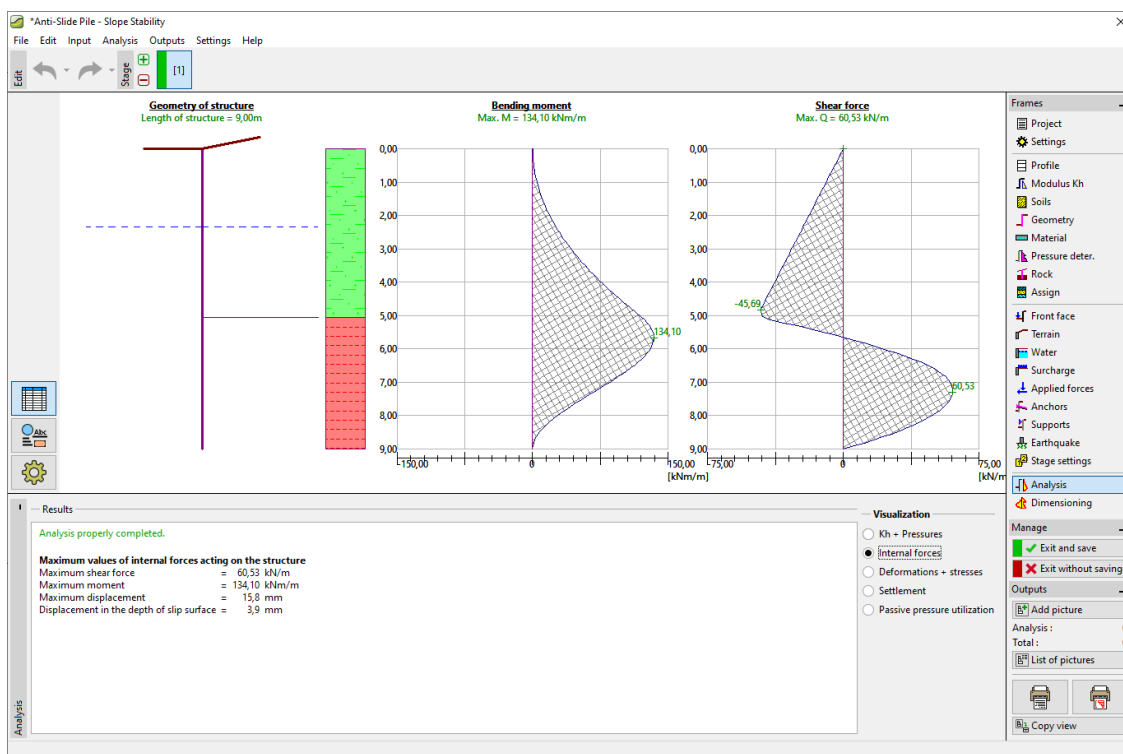
*The "Anti-Slide Program" – frame "Analysis" – Internal forces*

The "Anti-Slide Program" – frame "Analysis" – Deformations + stresses

In the "Dimensioning" frame we design pile reinforcements.

The "Anti-Slide Program" – frame "Dimensioning"

![GEO5 logo]

The design of our pile is satisfactory for all verifications. If we want to know the maximal bearing capacity of the pile in the shear, we can open the "in detail" dialog window.
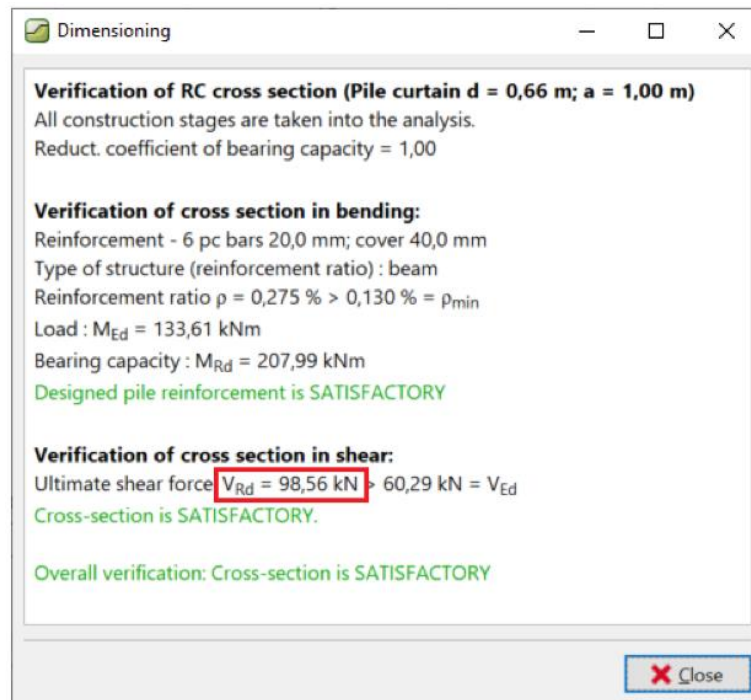

The "Anti-Slide Program" –"Dimensioning" frame – "In detail"

We considered the maximal bearing capacity of piles as V_u=80 kN in the program *Slope Stability*. Now we check it and see that the real bearing capacity is bigger (98,56 kN). If we want to know the real safety factor of the slope, we have to go back to the program *Slope Stability (using "Exit and save" button)* and change the value of V_u from 80 kN to 98,56 kN.
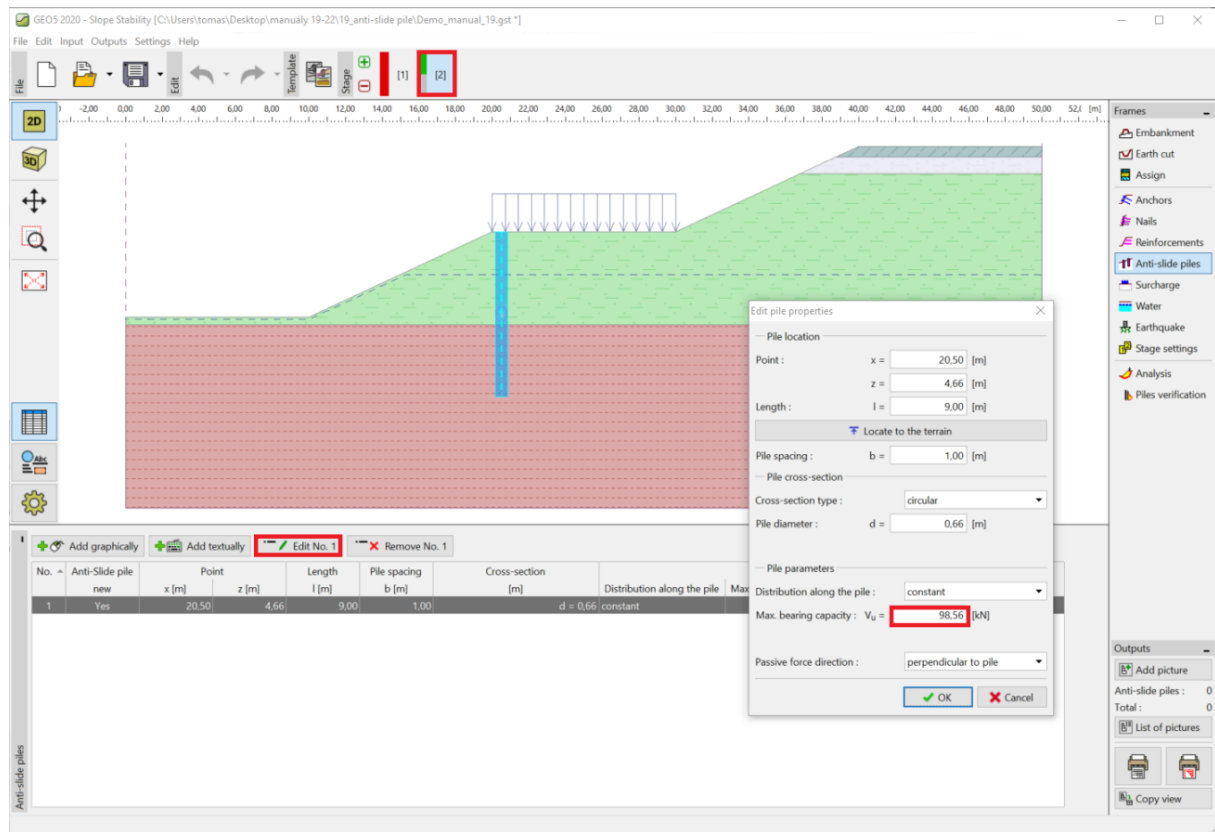
The "Slope Stability" program – editing the parameters of the pile

Now we perform an analysis with this modification.
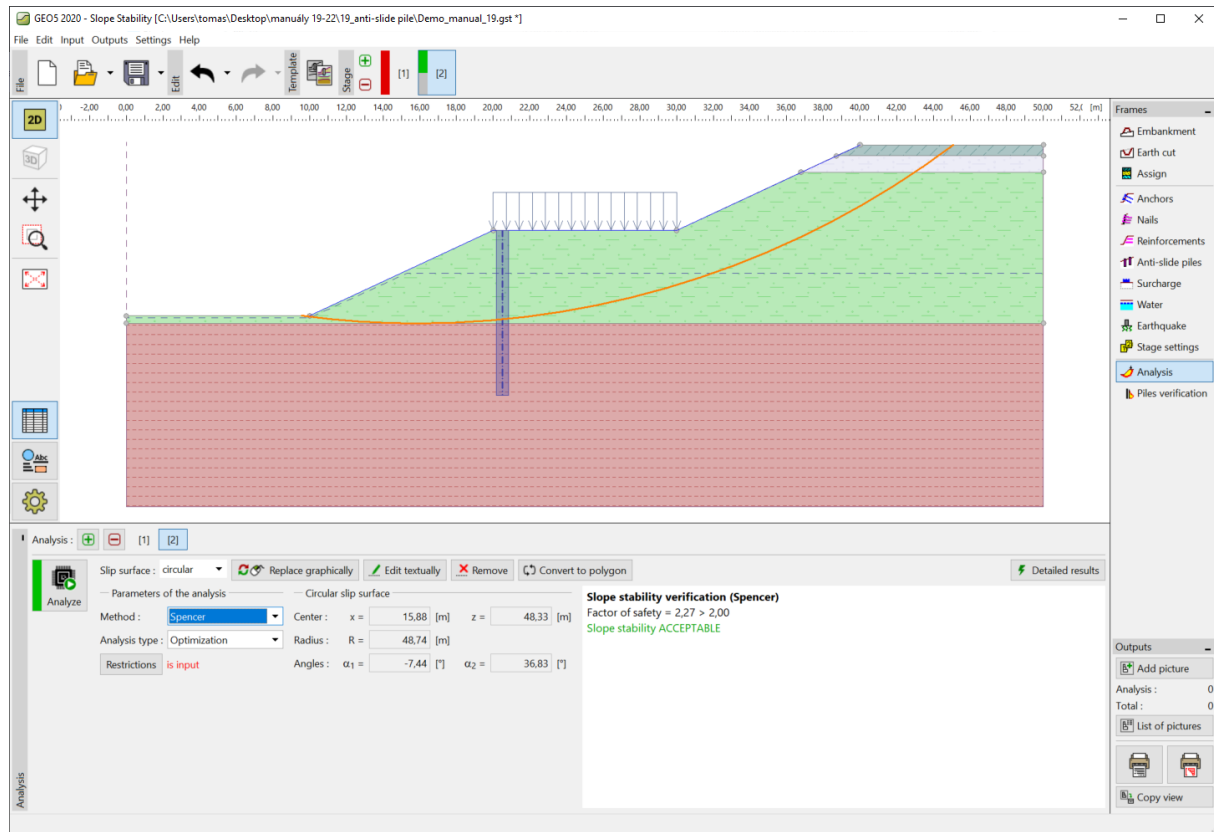
The "Slope Stability" program – analysis with the real bearing capacity of the piles

Note: The shape and position of the critical slip surface can change when the bearing capacity of the piles is modified. The values of the forces acting on the piles are different. In our example, the changes are minimal and the forces are almost the same. If the changes were bigger, a new analysis in the program Anti-Slide Pile would have to be performed.

Conclusion

The required safety factor of the slope was **SF=2,0**. We have improved the slope stability factor using anti-slide piles from **SF=1,8** to **SF=2,27**.

The pile design is satisfactory (in terms of shear and bending) and the maximal displacement of piles is 15,8 mm. This value of displacement is acceptable.