Slope stability analysis

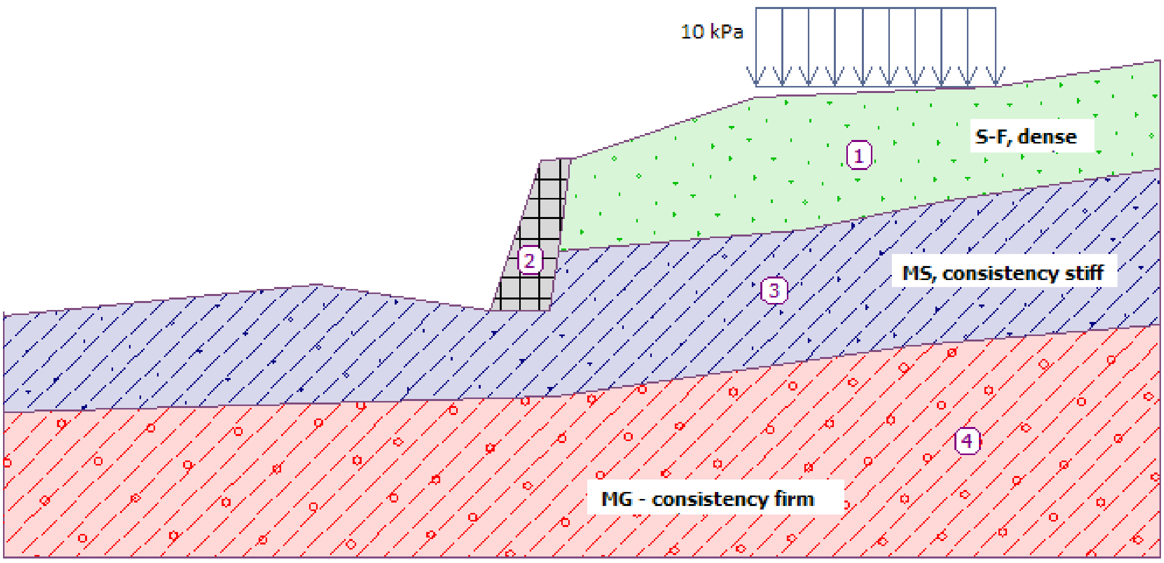
Program: Slope stability

File: Demo_manual_08.gst

This engineering manual shows how to verify the slope stability for a critical circular and a polygonal slip surface (using its optimization) and describes the differences between different methods of slope stability analysis.

Assignment

Perform a slope stability analysis for our designed slope with a gravity wall. This is a permanent design situation. The required safety factor is *SF = 1,50.* There is no water in the slope.



Scheme of the assignment

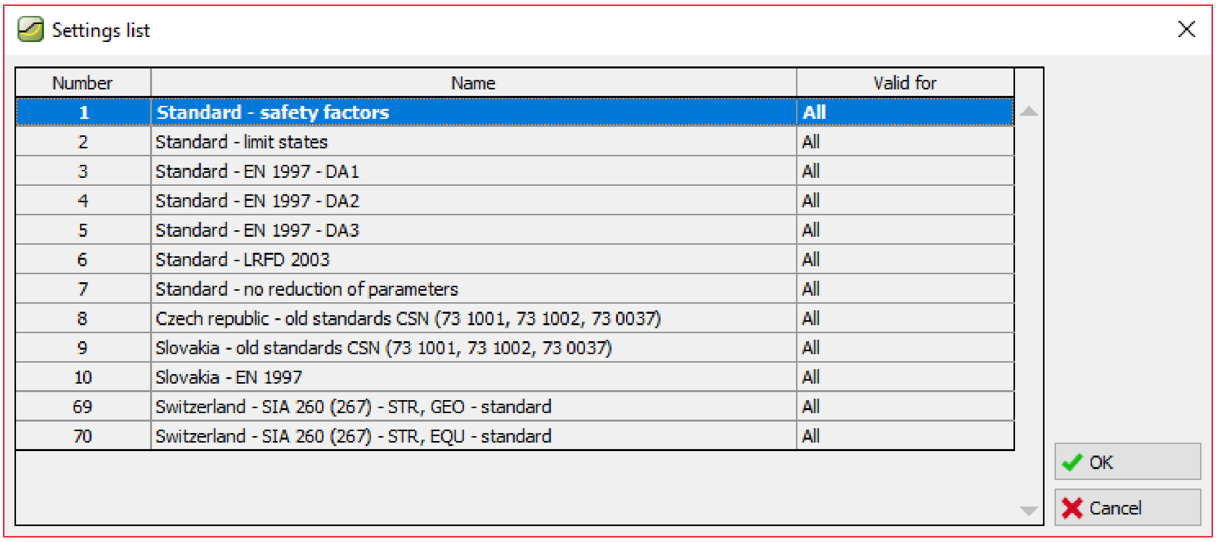
Solution

To solve this problem, we will use the GEO5 "Slope stability" program. In the following text, we will explain each step in solving this problem:

- Analysis No. 1: optimization of a circular slip surface (Bishop)
- Analysis No. 2: verification of slope stability for all methods
- Analysis No. 3: optimization of a polygonal slip surface (Spencer)
- Analysis result (conclusion)

Inputting geometry and other parameters

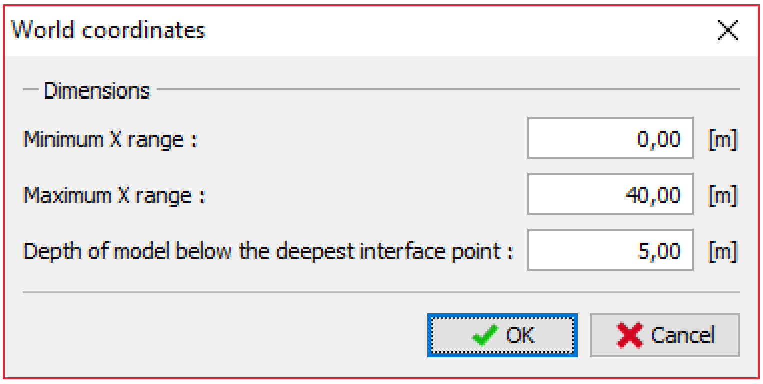
In the "Settings" frame click on "Select settings" and choose option No. 1 – "Standard – safety factors".



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
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

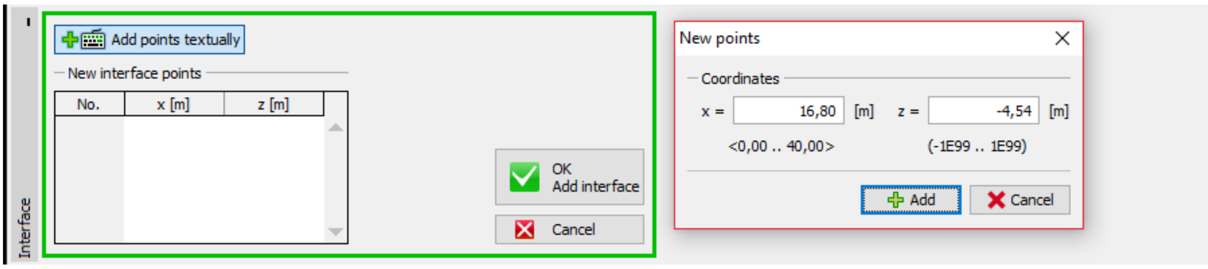
Then, in the "Interface" frame, click on "Setup ranges" and input the coordinate range of the assignment as shown in the picture below. "Depth of deepest interface point" only serves to visualize the example – it has no influence on the analysis.



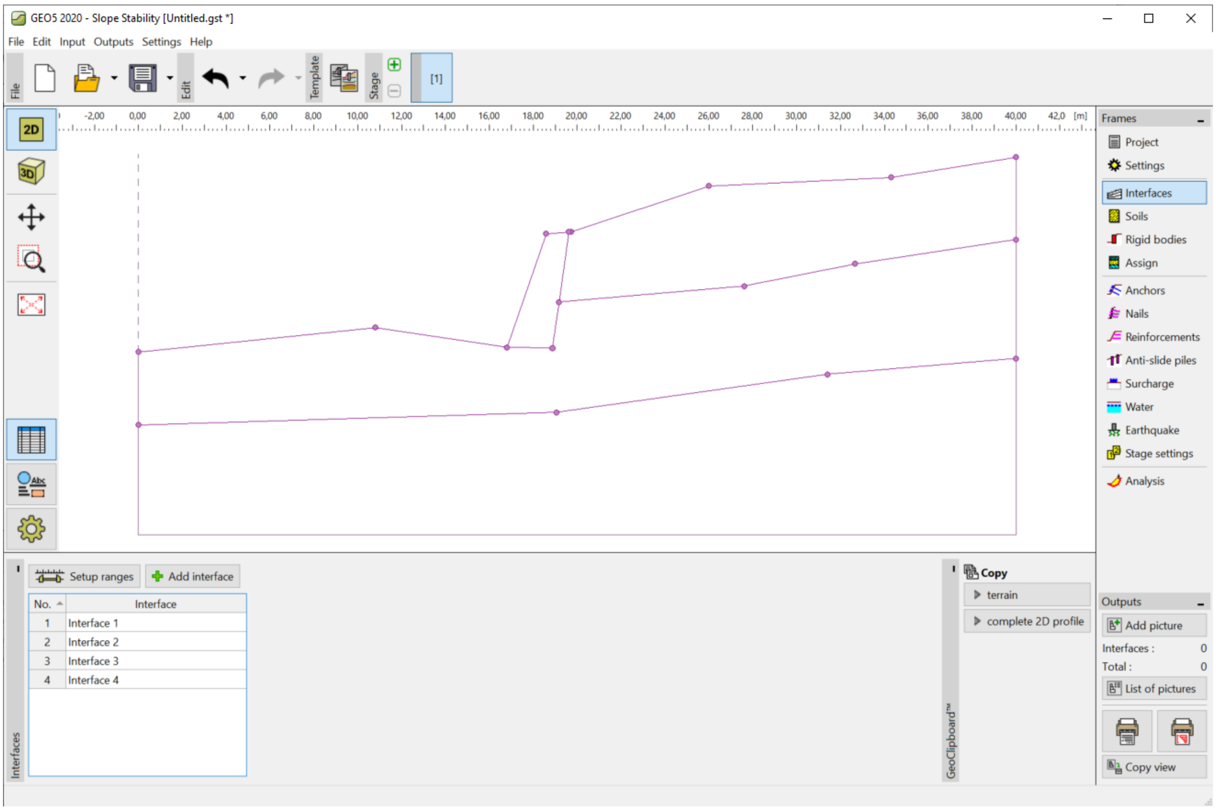
Then click on "Add interface" to model the interface of layers, or more precisely the terrain, using the coordinates described below. For each interface, add all points of the interface textually and then click on "OK Add interface".

	Interface 1		Interface 2		Interface 3		Interface 4	
	x [m]	z [m]	x [m]	z [m]	x [m]	z [m]	x [m]	z [m]
1	0,00	-4,75	16,80	-4,54	19,17	-2,48	0,00	-8,07
2	10,81	-3,64	18,87	-4,57	27,61	-1,75	19,06	-7,50
3	16,80	-4,54	19,17	-2,48	32,66	-0,74	31,40	-5,77
4	18,59	0,63	19,62	0,71	40,00	0,36	40,00	-5,05
5	19,62	0,71						
6	19,71	0,71						
7	26,00	2,80						
8	34,30	3,20						
9	40,00	4,12						

Adding interface points



"Interface" Frame – add points textually



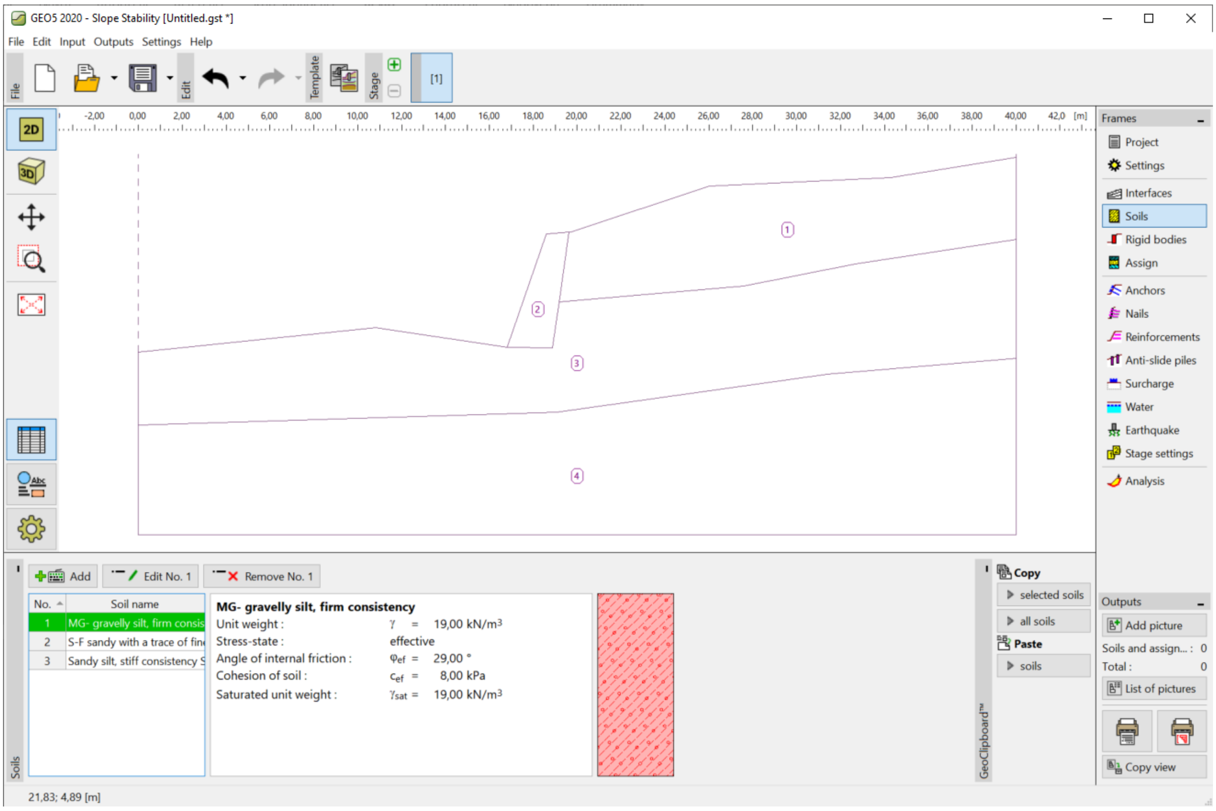
"Interface" Frame – added 4 interfaces

Then add 3 soils with the following parameters in the “Soils” frame using the “Add” button. The stress state will be considered as effective for all soils and soil foliation will not be considered.

Table with the parameters of soils

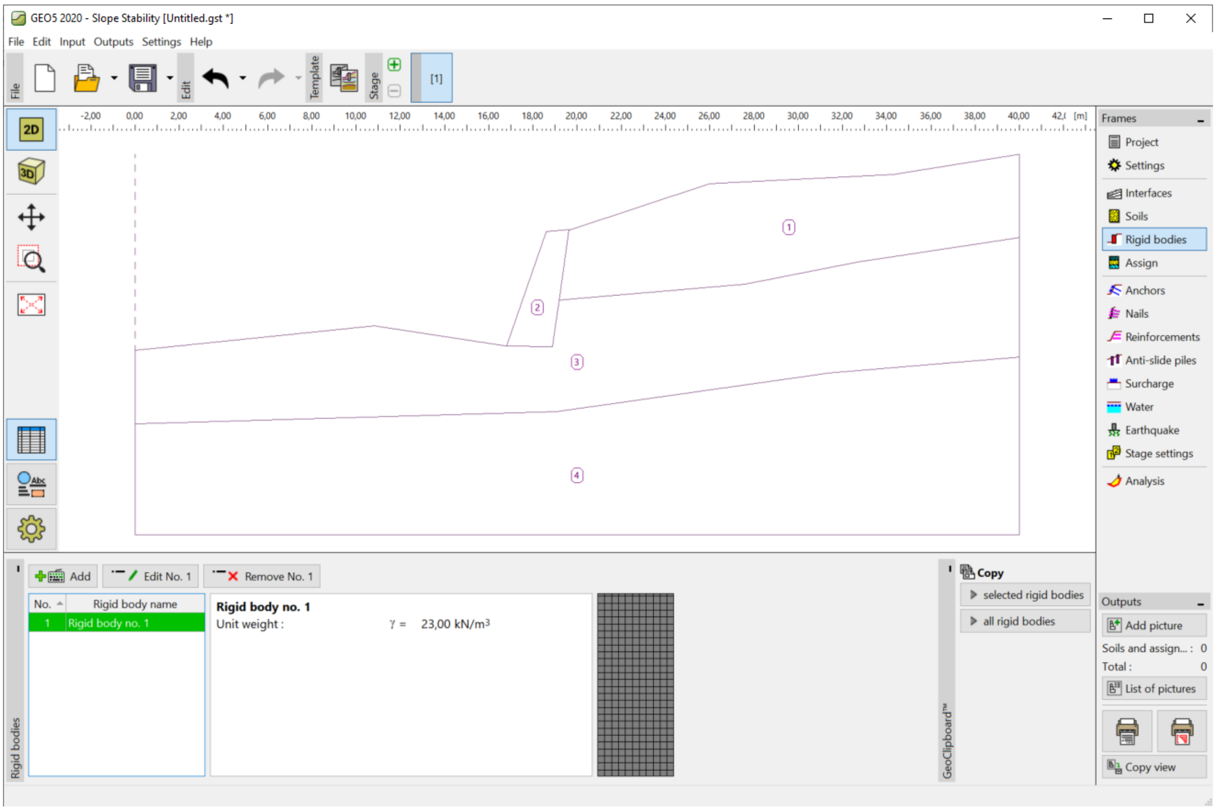
Soil (Soil classification)	Unit weight $\gamma \left[kN/m^3\right]$	Angle of internal friction φ_{ef} $[^\circ]$	Cohesion of soil c_{ef} $[kPa]$
MG – Gravelly silt, firm consistency	19,0	29,0	8,0
S-F – Sand with trace of fines, dense soil	17,5	31,5	0,0
MS – Sandy silt, stiff consistency, $S_r > 0{,}8$	18,0	26,5	16,0

Note: In this analysis, we are verifying the long-term slope stability. Therefore, we are solving this task with the effective parameters of the slip strength of the soils (φ_{ef}, c_{ef}). The foliation of the soils – worse or different parameters of the soil in one direction - is not considered in this assignment.



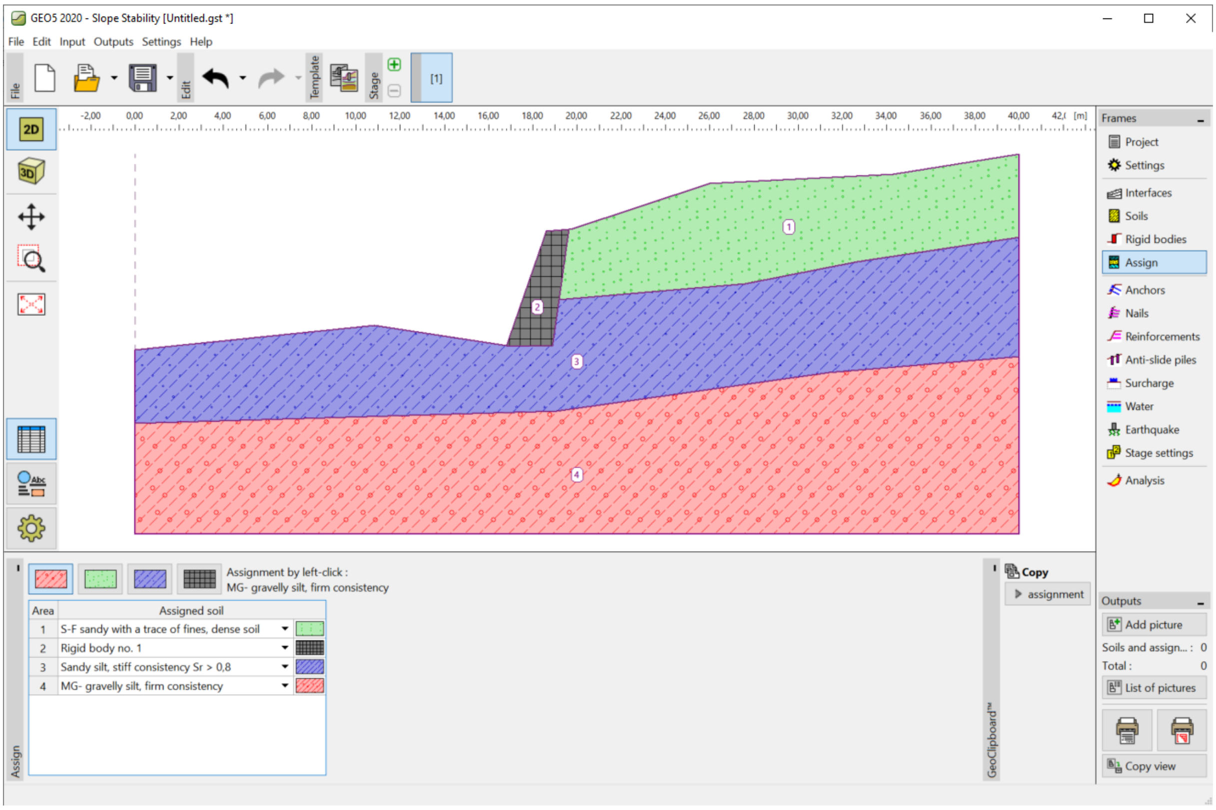
"Soils" Frame – added 3 new soils

Then, we'll move on to the "Rigid body" frame. Here we will model the gravity wall as a rigid body with a unit weight of $\gamma = 23{,}0\ kN/m^3$. The slip surface does not pass through this object because it is a very firm area (more info in the program help – F1).



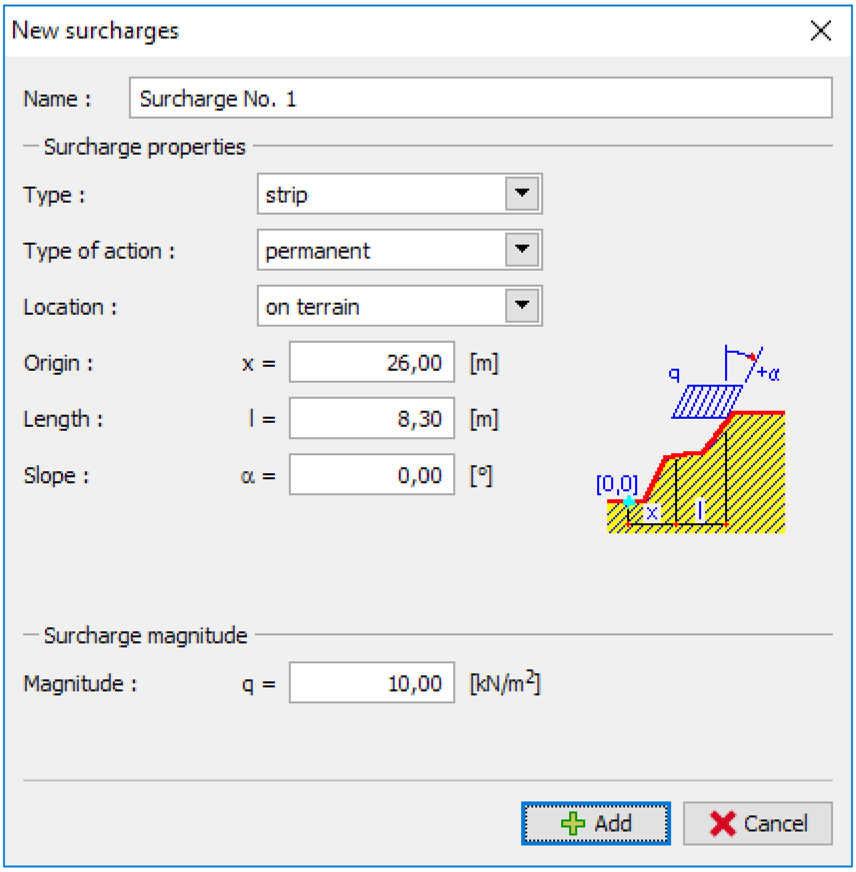
"Rigid bodies" Frame – new rigid body

Now we will assign the soils and the rigid body to the profile in the “Assign” frame.



“Assignment” Frame

In the next step, define a strip surcharge in the “Surcharge” frame, which we consider as permanent with its location on the terrain surface.



Dialog window “New surcharges.”

Note: The surcharge is entered at 1 m of the width of the slope. The only exception is a concentrated surcharge, where the program calculates the effect of the load on the analyzed profile. For more information, see the program help (F1).

Skip the “Embankment”, “Earth cut”, “Anchors”, “Nails”, “Anti-slide piles”, “Reinforcements” and “Water” frames. The “Earthquake” frame has no influence on this analysis, since the slope is not located in a seismically active area.

In the “Stage settings” frame, select the design situation. In this case, we consider it a “permanent” design situation.

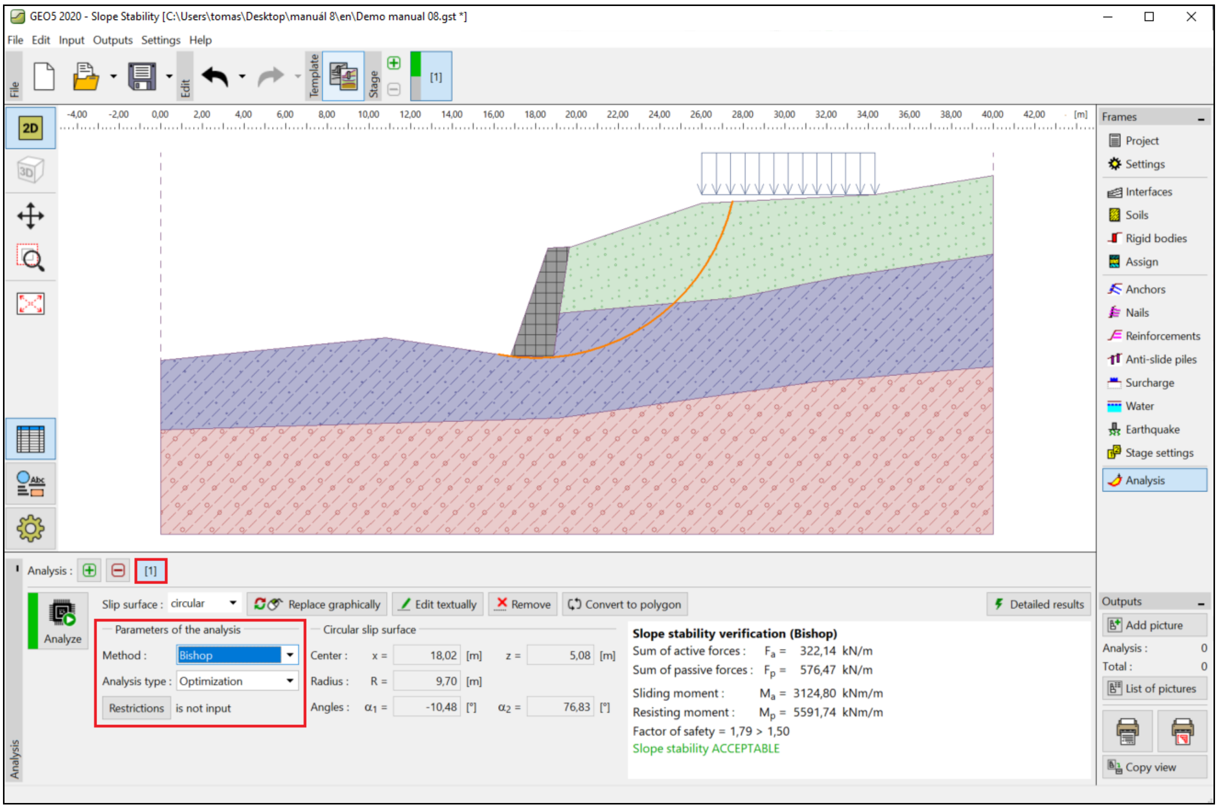
“Stage settings” Frame

Analysis 1 – circular slip surface

Now open the “Analysis” frame, where you can enter the initial slip surface using the coordinates of the center *(x, y)* and its radius or using the mouse – by clicking on the interface to enter three points through which the slip surface passes.

Note: In cohesive soils, rotational slip surfaces occur most often. These are modeled using circular slip surfaces. This surface is used to find the critical areas of an analyzed slope. For non-cohesive soils, an analysis using a polygonal slip surface should also be performed in order to verify the slope stability (see program help – F1).

After inputting the initial slip surface, select “Bishop” as the analysis method and then set the type of analysis to “Optimization”. Then perform the actual verification by clicking on “Analyze”.



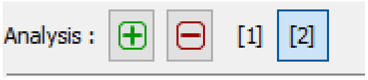
“Analysis” Frame – Bishop – optimization of circular slip surface

Note: Optimization consists of finding the circular slip surface with the lowest stability – the critical slip surface. The optimization of circular slip surfaces in the Slope stability program evaluates the entire slope and is very reliable. This way, we will get the same result for a critical slip surface even with different initial slip surfaces.

The level of stability defined for the critical slip surface using the “Bishop” evaluation method is satisfactory (SF = 1,79 > SF = 1,5).

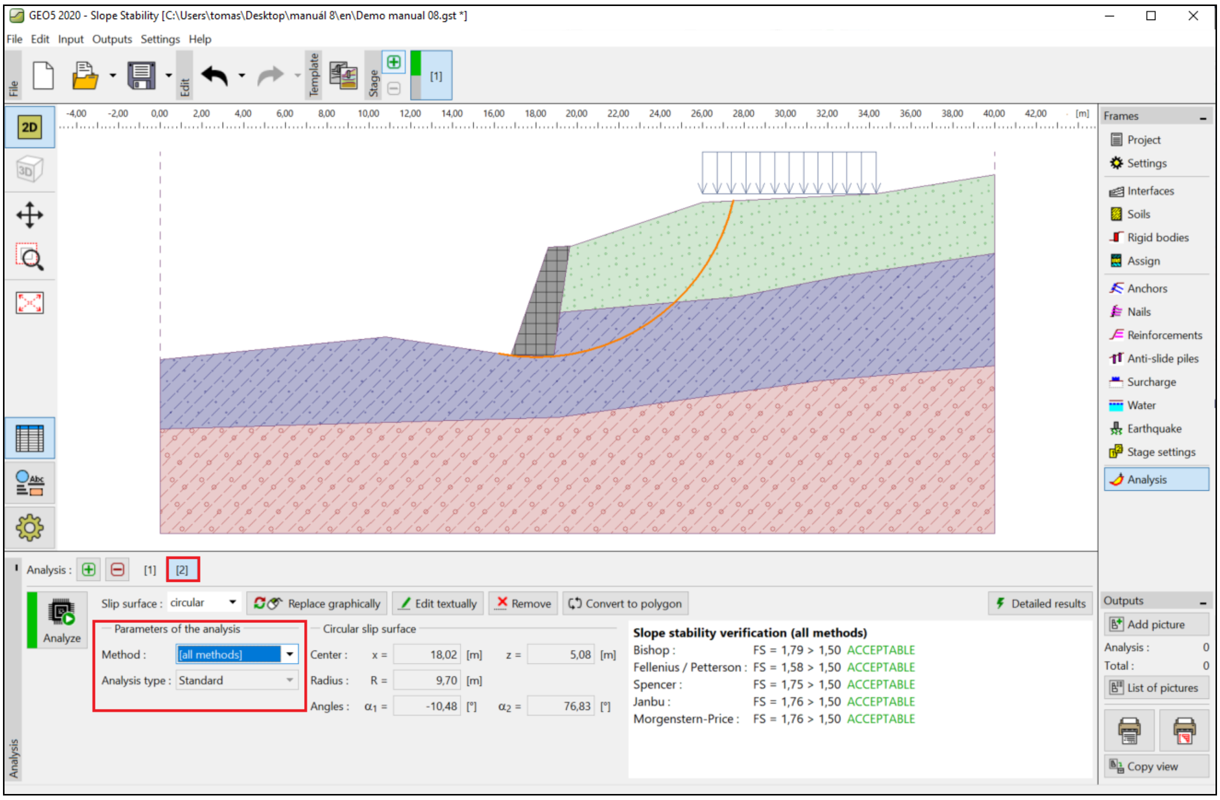
Analysis 2 – comparison of different analysis methods

Now add another analysis on the toolbar in the bottom left corner of the “Analysis” frame.



“Analysis” Toolbar

Then change the analysis type to “Standard” and select “All methods” as the method. Then click on “Analyze”.



“Analysis” Frame – All methods – standard type of analysis

Note: Using this procedure, the slip surface calculated for all methods corresponds to the critical slip surface from the previous analysis step using the Bishop method. To get better results, the user should choose the method and then perform an optimization of the slip surfaces.

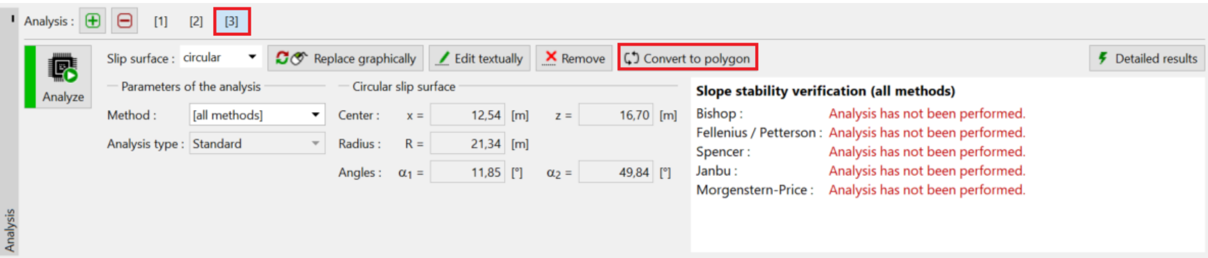
Note: The selection of the method of analysis depends on the experience of the user. The most popular methods are the methods of slices, from which the most used is the Bishop method. The Bishop method provides conservative results.

For reinforced or anchored slopes, other rigorous methods (Janbu, Spencer, and Morgenstern-Price) are preferable. These more rigorous methods meet all the conditions of balance and they describe the real slope behavior better.

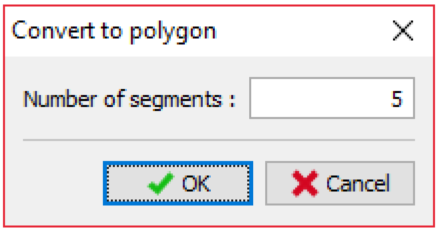
It is not needed (nor correct) to analyze a slope with all the methods of analysis. For example, the Swedish method Fellenius – Petterson provides very conservative results, so the safety factors could be unrealistically low as a result. However, because this method is very well-known and in some countries required for slope stability analysis, it is a part of the GEO5 software.

Analysis 3 – polygonal slip surface

In the last step, we add another analysis and convert the original circular slip surface to a polygonal slip surface using the "Convert to polygon" button. We insert a relevant number of segments – in this case, 5.

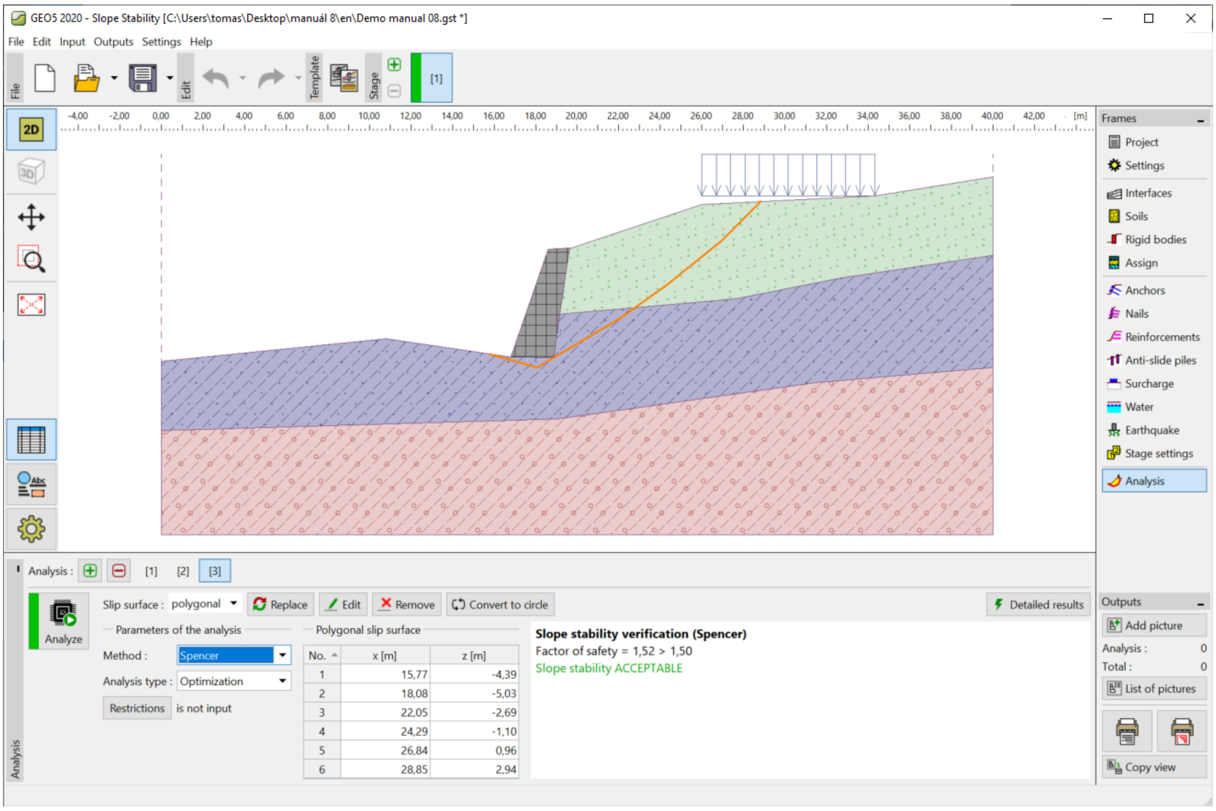


„Analysis" frame – converting to a polygonal slip surface



"Convert to polygon." Dialog window

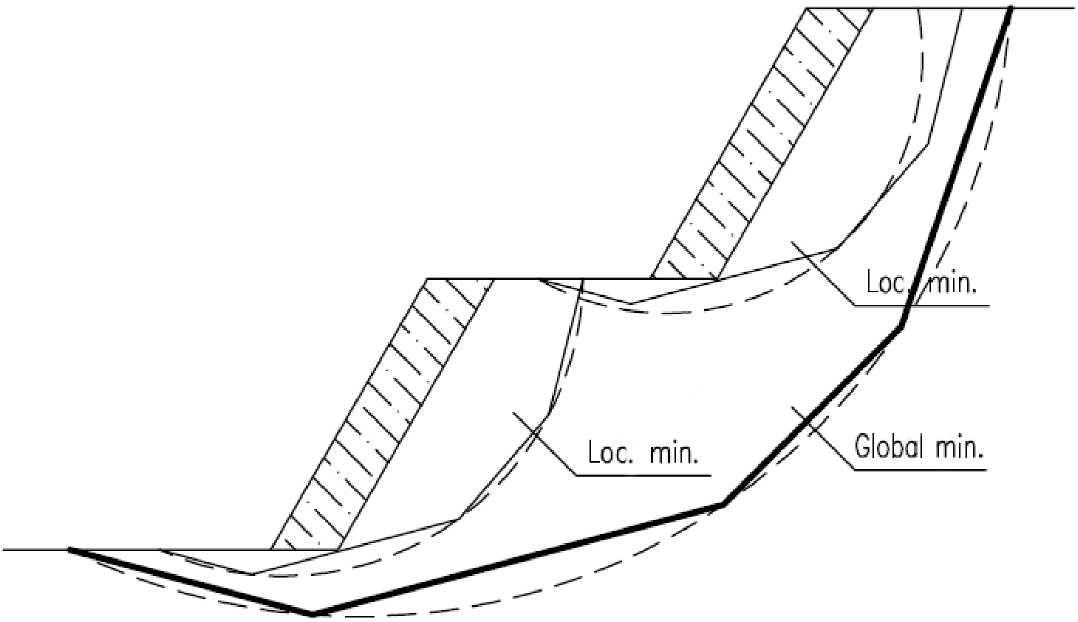
As a method of analysis, select "Spencer", as an analysis type select "optimization" and perform the analysis.



"Analysis" Frame – Spencer – optimization of a polygonal slip surface

The values of the level of slope stability for the polygonal slip surface are satisfactory (SF = 1,52 > SF = 1,5).

Note: The optimization of a polygonal slip surface is a gradual process and depends on the location of the initial slip surface. This means that it is better to make several analyses with different initial slip surfaces and with a different number of sections. Optimization of polygonal slip surfaces can also be affected by the local minimums of the factor of safety. This means that the real critical surface needs to be found. Sometimes it is more efficient for the user to enter the starting polygonal slip surface in a similar shape and place it as an optimized circular slip surface.



Local minimums – polygonal and circular slip surface

Note: We often get complaints from users that the slip surface "disappeared" after the optimization. For non-cohesive soils, where $c_{ef} = 0\ kPa$ *the critical slip surface is the same as the most inclined line of the slope surface. In this case, the user should change the parameters of the soil or enter restrictions, in which the slip surface cannot pass.*

Conclusion

The slope stability after the optimization is:

- Bishop (circular - optimization): SF=1,79 > SF=1,5 SATISFACTORY
- Spencer (polygonal - optimization): SF=1,52 > SF=1,5 SATISFACTORY

This designed slope with a gravity wall satisfies the stability requirements.