

Rock stability – planar slip surface

Program: Rock stability

File: Demo_manual_29.gsk

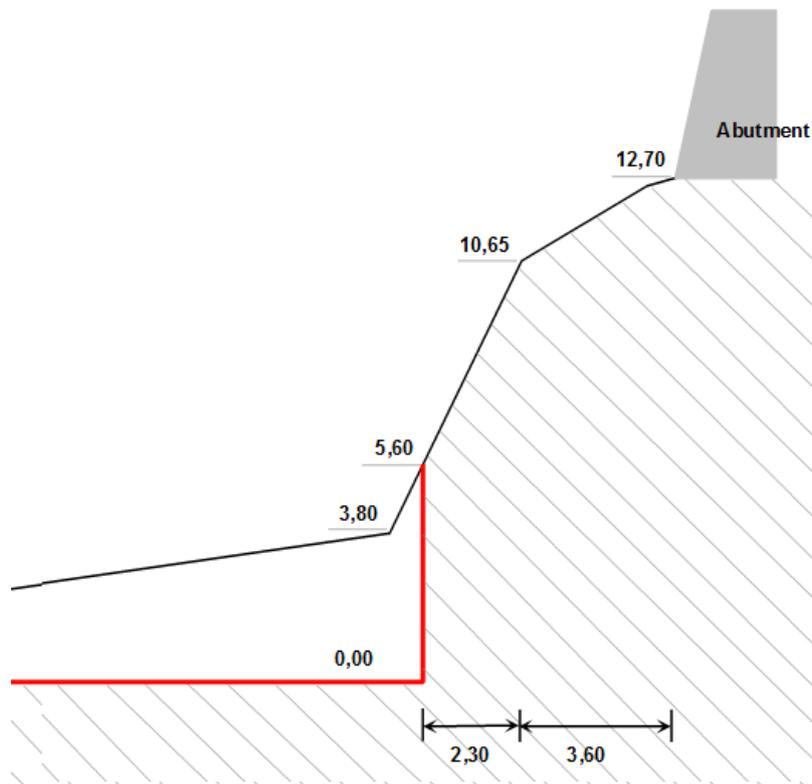
This engineering manual describes how to determine the stability of a rock slope formed by metabasalts in the selected cross section (at the left margin of the interest area). The calculated rock face is made by a cutting in the existing stable rock slope. An apartment building was formerly at the bottom of the rock slope and on the top edge of the rock slope is built a main road. The former geological investigation and the results of the current hydrogeological survey including the description of discontinuities systems and the strength of the rock.



View on the rock slope – solve cross section

Assignment

The desired final factor safety is 1.5 due to that the rock slope's stability is designed for a long time stability. If the slope has a smaller factor of safety than 1.5, it must be stabilized. The evaluation of slope's stability and a design of safety construction is arranged for the selected cross-section after excavation works.



Evaluated cross-section with red highlighted side hill cutting

The following geotechnical parameters of the rock mass (betabasalt) were determined on the basis of a geological and archival investigations:

Unit weight of the rock $\gamma = 26 \text{ kN/m}^3$

Effective angle of friction $\varphi' = 43^\circ$

Effective cohesion $c' = 423 \text{ kPa}$

The average unconfined compressive strength of the rock is 60 MPa and it was determined by a in situ measurment (Schmidt hammer).

In the hydrogeological survey were observed no underground water flows. Small water dampes situated at the bottom of the slope (in slightly weathered rock parts) are related to surface water during rains only.

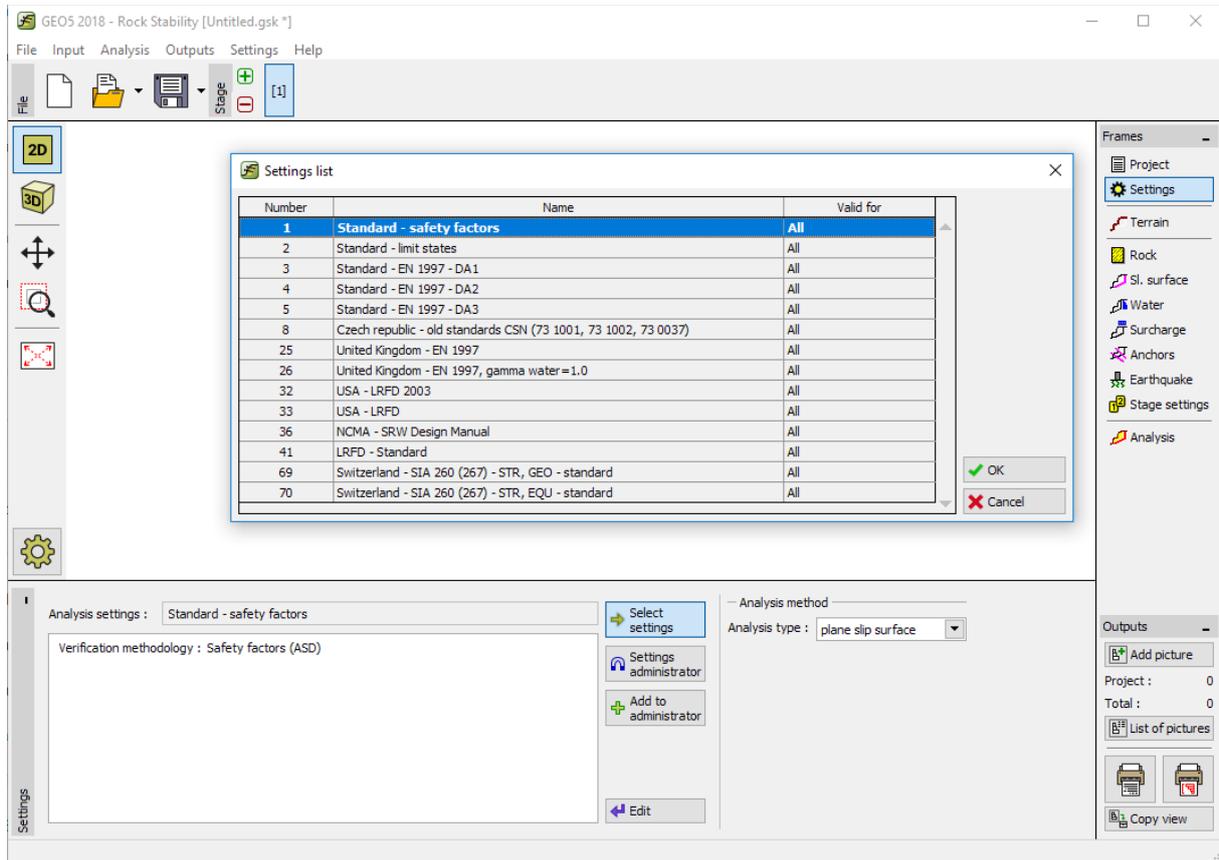
Solution

For solving of this problem, we will use the GEO5 program, Rock stability. Rock slope stability calculations in the evaluated cross - section will be performed according safety factors (due to the future control using the manual calculations and a finite element numerical model). We will explain solving of this example step by step in the following text - describing the task, own analyses and conclusions.

Defining the task

1) Settings of the required calculation according to the factors of safety and the type of rock slope failure choice.

In the frame **"Settings"** click on "Select settings" and then choose analysis setting No. 1 – "Standard – safety factors" and confirm by clicking „OK“.



"Settings list" dialog window

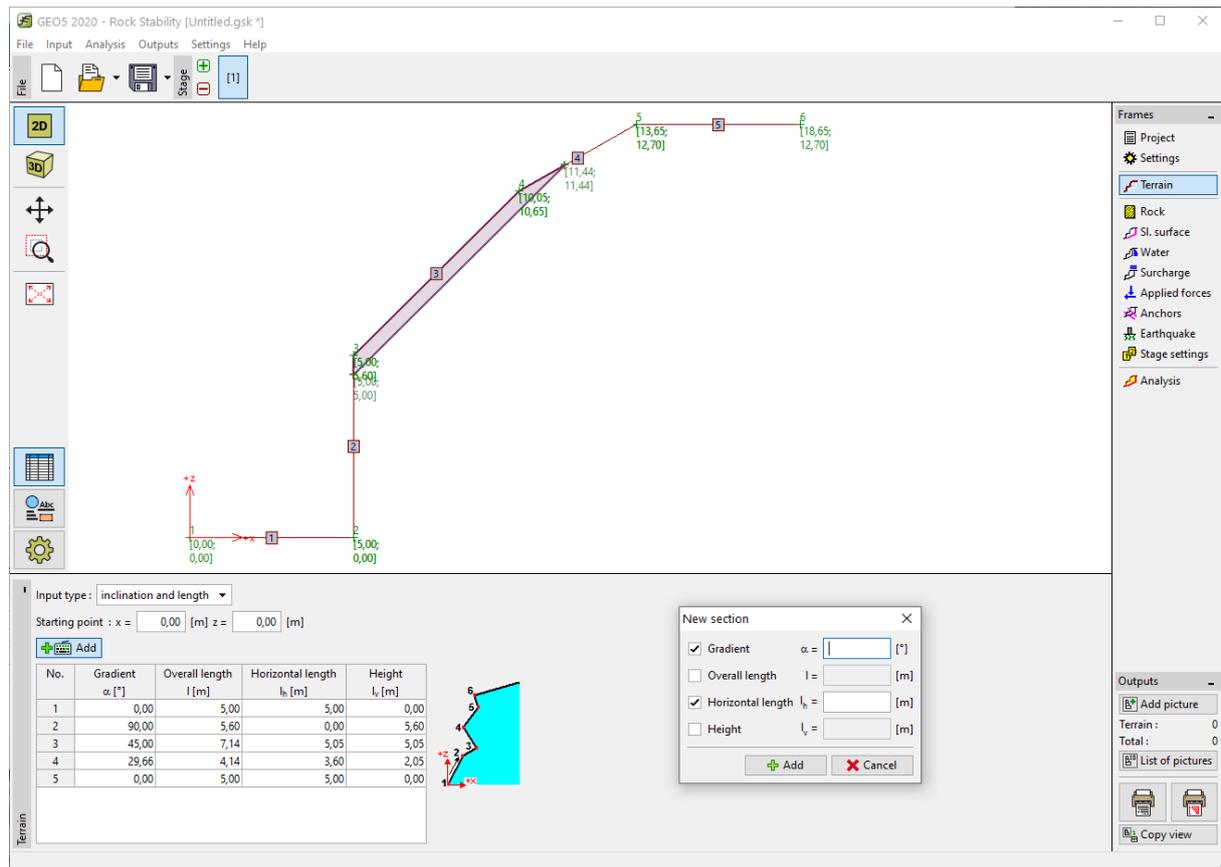
We select the analysis option in this frame. The program Rock stability allows to make a preliminary calculation of the rock slope failure evaluation by the use of a slide on a planar or a polygonal rock wall surface. Determination the unsafe plane of a sliding on the rock mass is difficult in all situations and requires cooperation with a structural geologist. In our case, the rock mass has a multiple system of discontinuities and thus the failure along the shear plane inclined to the horizontal at an angle of $45^\circ + \varphi^* / 2$ (φ^* is the angle of shear strength of the rock) may be considered. Therefore, we select the type of calculation: **plane slip surface**.

2) Entering the geometry of the terrain and the rock face

We input a geometry of the terrain and rock face in **the frame "Terrain"**. Before entering an own profile of the rock slope, we can modify the default the original set up values (starting point). The best option for the geometry set up is a use of the bottom of the rock slope or a point placed in a short distance on the ground in front of the rock face. In our case, the begin of the geometry lies on a

horizontal terrain in a distance of 5m in front of the heel of the rock slope, with the default coordinates ($x = 0, z = 0$).

By the use of the "Terrain" frame click on the "Add icon", it will display a dialog box for adding geometry points of the evaluated rock face (starts from the origin). We can enter the sections using combinations of the parameters defining the section geometry: (a gradient) a dip, an overall length, a horizontal height and a height. The program calculates required values automatically.



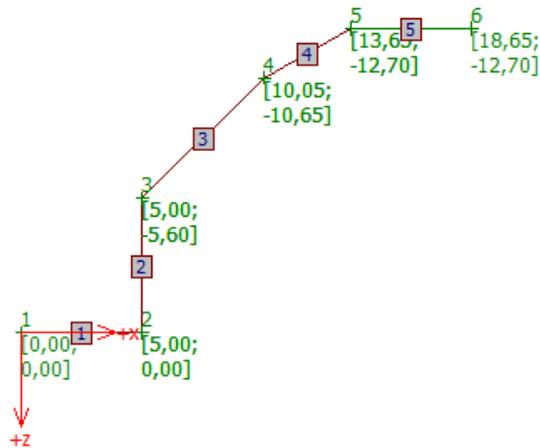
Entering a section of terrain and rock faces in the "Terrain" frame

We input the profile of the rock slope based on the coordinates selected from the calculated cross section:

Section number	Gradient α [°]	Overall length l [m]	Horizontal length l_h [m]	Height l_v [m]
1	-	-	5,0	0,0
2	90	-	-	5,60
3	-	-	5,05	5,05
4	-	-	3,60	2,05
5	-	-	5	0,0

Entering sections of terrain (input values)

Program displays entered terrain in the graphics window. The "Terrain" application shows a table with input sections.



Views input rock slope in the graph window

3) Input of the rock parameters

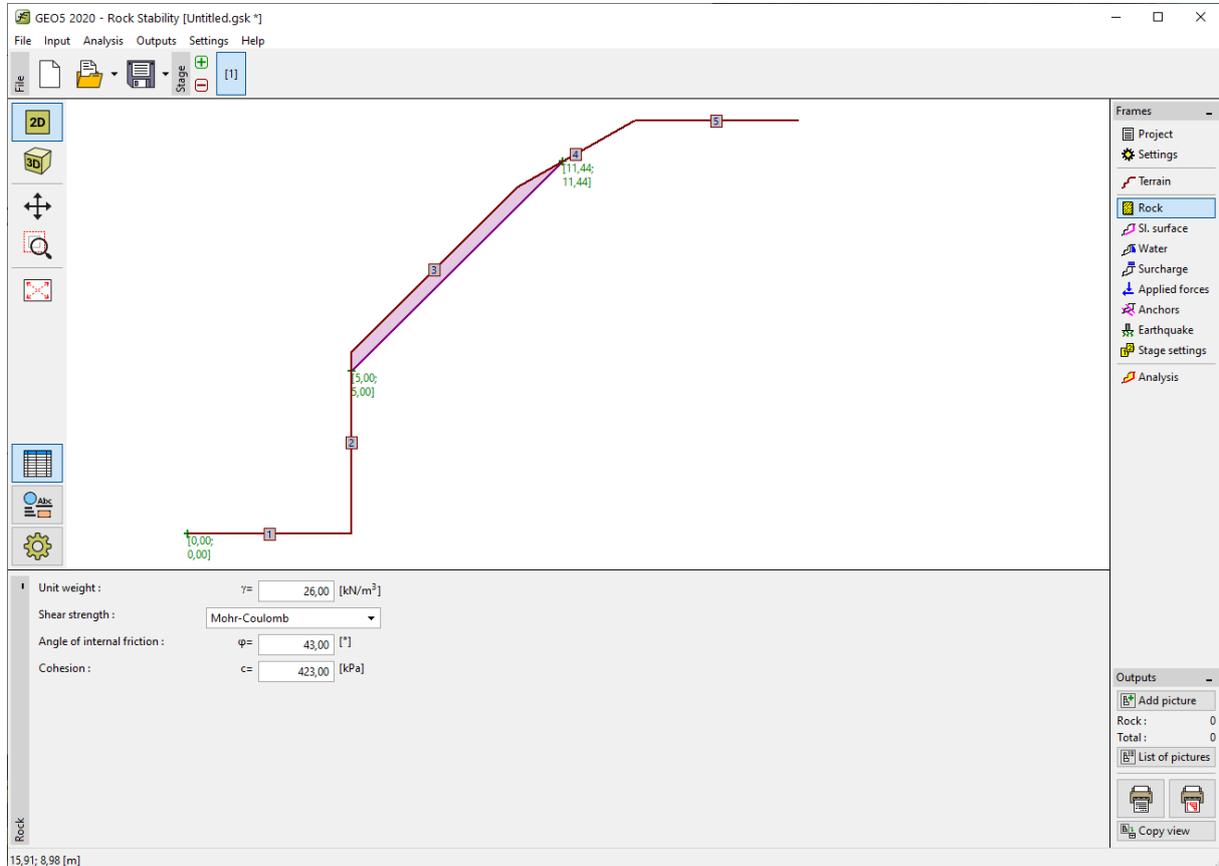
In the "**Rock**" frame we input the properties of the rock mass with a rock slope (material parameters). Based on the geological survey we have determined the unit weight of the rock and shear parameters by Coulomb criterion:

Unit weight of the rock $\gamma = 26 \text{ kN/m}^3$

Effective angle of friction $\varphi = 43^\circ$

Effective cohesion $c_{ef} = 423 \text{ kPa}$

Remarks: program allows set up of the material characteristics under the terms of the Barton-Bandis and the Hoek-Brown failure criterion.



“Rock” frame

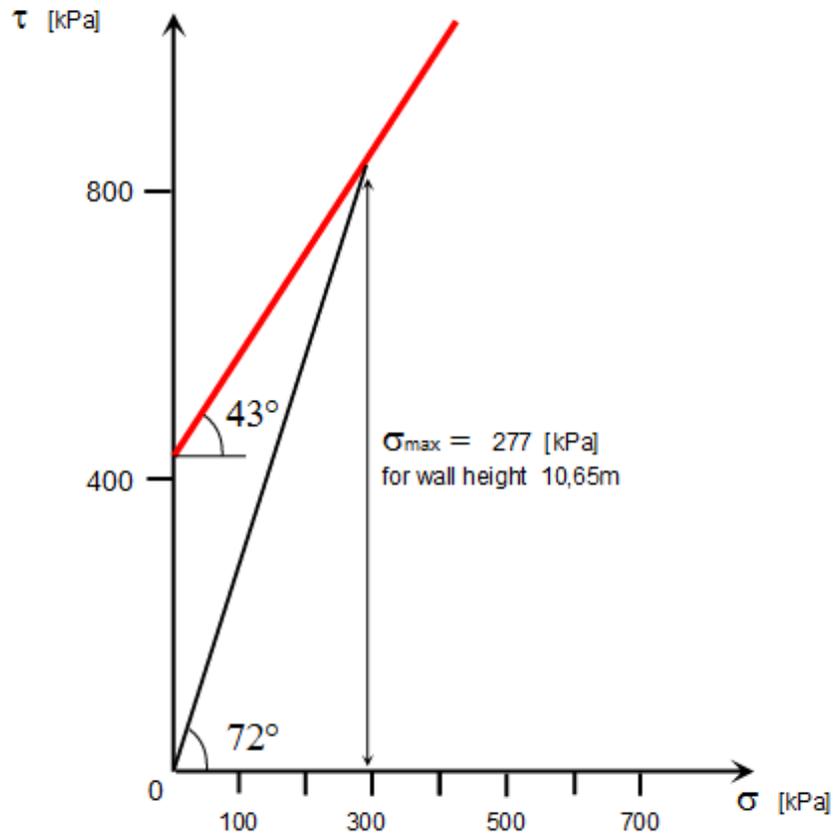
4) Input of a shear failure geometry and its properties

A shear failure plane and its properties are to be entered in the **frame "Sl. surface"**. Based on the geological investigation it was determined that the shear plane surface will start in an angle of $45^\circ + \varphi^* / 2$ from the horizont. The angle of shear strength of the rock is not constant but depends on the stress state of the rock mass and can be graphically determined by the angle of friction calculated as the tangent of non-linear Mohr envelope circles. Therefore we must determine its value for our calculated slope. At the beginning, we determine the normal stress in the evaluated wall bottom σ_{max} . It shows that the active height of the walls is $h = 10.65 \text{ m}$. So

$$\sigma_{max} = \gamma \cdot h_a = 26 \cdot 10,65 = 277 \text{ kPa.}$$

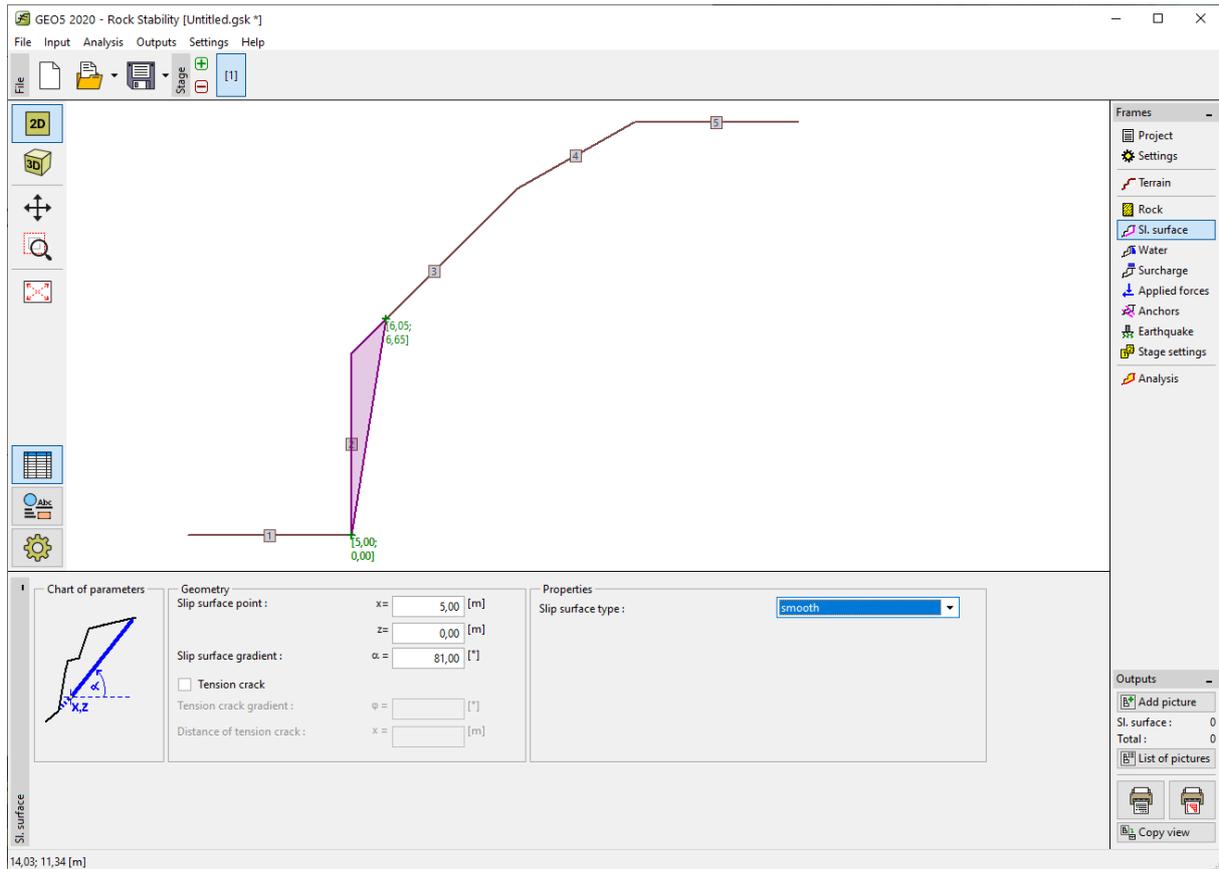
We know the effective cohesion of the rock $c' = 423 \text{ kPa}$ and the average unconfined compressive rock strength of 60 MPa from the geological survey. Therefore the max. normal stress $\sigma_{max} = 277 \text{ kPa}$ is smaller than the peak strength of metabasalt, so we can determine the angle of shear strength of the rock from a graphical representation of the Mohr envelope of our metabasalt rock slope $\varphi^* = 72^\circ$

(in the first stress interval). The shear failure surface inclination calculated from the horizon is an angle of $45^\circ + \varphi^* / 2 = 45 + 72/2 = 81^\circ$.



Peak shear strength line of the rock of rock slope

The shear failure plane inclination is $\alpha = 81^\circ$ and surface begin point (heel of the slope) will have coordinates $x = 5.0\text{m}$, $z = 0.0\text{m}$. A character of the shear plane will be default (smooth), because we have no detailed information about shear surface (dilatancy). The formation of a tension crack is not considered on the basis of geologist opinion.



Entering slip surface in the "Sl. surface" frame

5) Influence of the groundwater

Influence of the groundwater is entered in the **"Water" frame**. No water-bearing joint was observed and we keep the default settings - without a calculation of the impact of the groundwater.

6) Input of the surcharge

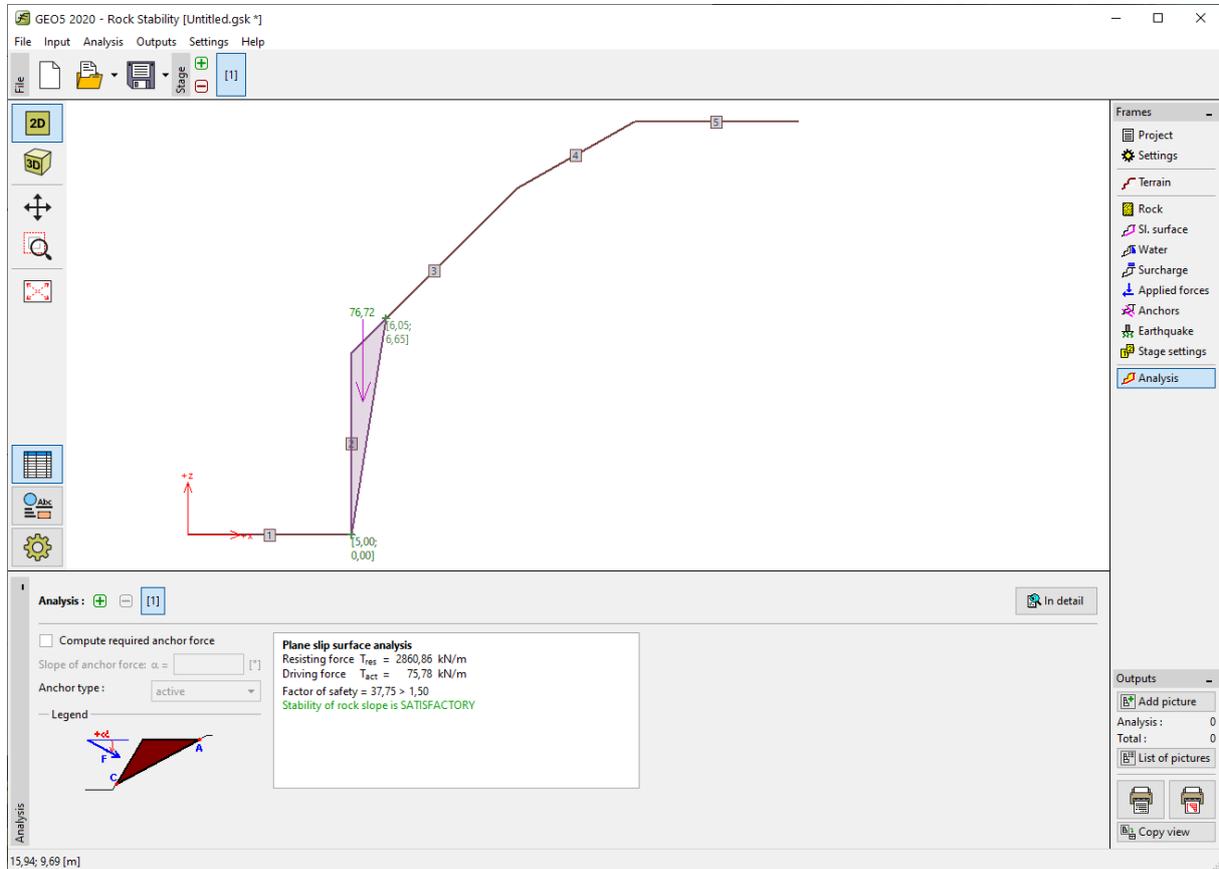
In the **"Surcharge" frame** we can input the load acting on the rock slope and the surface terrain. A reinforced concrete gravity wall and a pavement are situated at the edge of the rock slope. This surcharge is not necessary considered to be use within the calculation, because the surcharge do not act on the active rock wedge.

7) Design situations settings

In the **"Stage setting" frame** we can select the suitable design situation for the calculation. In our situation, we determine the slope excavation factor of safety based on the construction lifetime, so we select the permanent design situation.

Task analysis

Basic results and other possible options will appear in the frame "Analysis". For our schedule based on the degree of stability $F = 37.75 \gg 1.5$.



"Analysis" frame

More detailed results can be obtained by press on the "In detail" icon or in the program printout.

Partial results	
Slip surface length	= 6,74 m
Slip surface gradient	= 81,00 °
Gravity force	$W_z = 76,72 \text{ kN/m}$
Normal force on slip surface N	= 12,00 kN/m
Shear stress on slip surface τ	= 424,66 kPa
Plane slip surface analysis	
Resisting force T_{res}	= 2860,86 kN/m
Driving force T_{act}	= 75,78 kN/m
Factor of safety	= 37,75 > 1,50
Stability of rock slope is SATISFACTORY	

Detailed list of results in the "Analysis" frame

Conclusion

For our task is considered the factor of safety $FS = 37.75 \gg 1.5$. It means that the long-term stability of the proposed rock slope is satisfactory to the requirement of the factor of safety 1.5 for (with large time-scale) and do not require any further design to increase its stability. In a situation when water flows into the discontinuity systems and causes a change of the rock slope conditions, it is not important due to following reasons:

- metabasalt is a solid rock and is not significantly affected by joints (ie. do not change their shear parameters) and in an addition the discussed joints do not contain any fill material
- GWT can theoretically rise up to the upper level of the active wedge (due to future build structure). This level of the groundwater maximally could reduce the calculated factor of safety in a range of units. It is possible to verify this by a calculation ($FS = 30.58$).
- For unrealistic GWT at the edge of the rock wall the factor of safety is to be = 20.32