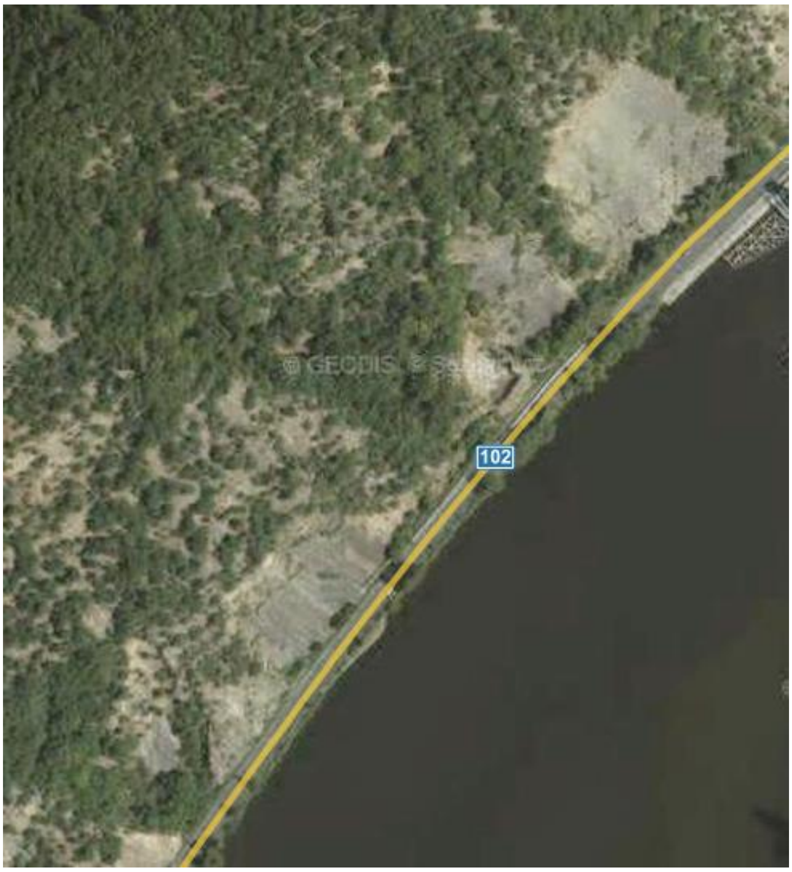
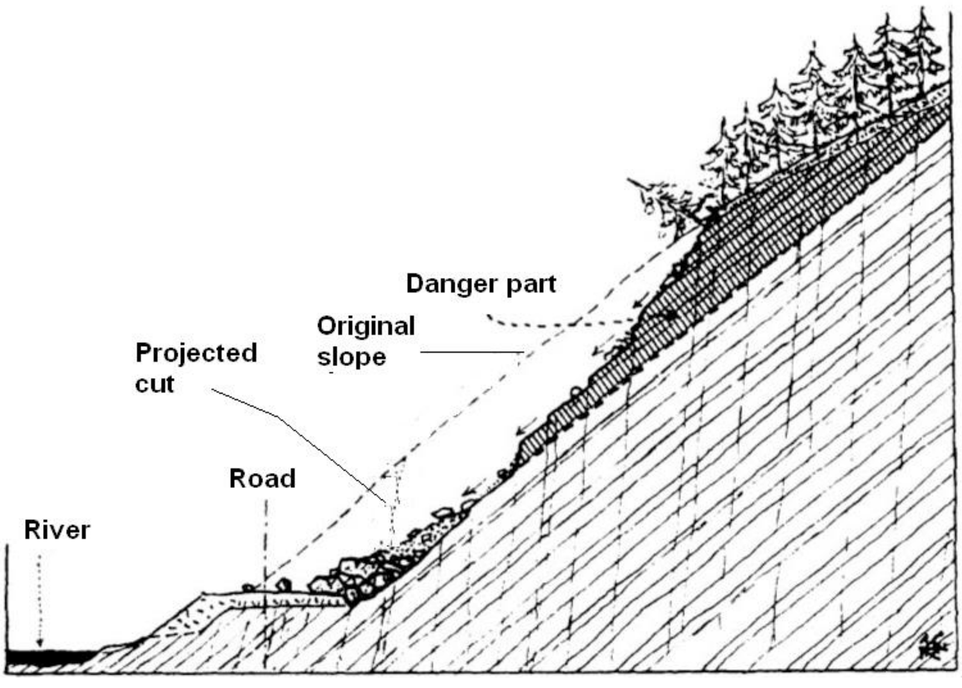
Rock slope stability – planar shear failure

This engineering manual describes a slope stability evaluation of an excavation situated next to the road number II/102 Strnady-Stechovice, which is located at the bottom of the Vltava river valley. The stability of the slope has been affected by crumbling stones, rock-layer slip down, underground water damps and unacceptable rock face stabilization since 1931, even though stabilization works are done frequently. The biggest slip failure happened in 1924, when 8,000 m^3 of rock mass slipped down. In 2011 a 2-ton block of stone rolled down on the road. A selected cross-section will be evaluated in the following text.

Picture of the most dangerous section – Vrane nad Vltavou part (photo S. Chamra)



Vrane nad Vltavou section – 3D map (Geodis, Seznam.cz)



Geological cross-section of the affected slope by a landslide from 1931 when the road near Stechovice was being built (in R. Kettner, 1955: Všeobecná geologie IV)

Setup

The selected section of the road can be found along the left bank of the Vltava river valley. The road was built partly in an excavation and partly was placed on a retaining wall inclining towards the river. The excavation is more than 10 m deep. There is a steep slope above the excavation. The evaluated rock-wall is created by bedded siltstones and shales which are fissured by joints perpendicular to the bedding. The surface morphology is determined by the sedimentary rock bedding orientation.

An example of the slope stability task is related to the selected rock-slope in the section with the highest sudden rock-block landslide possibility. The evaluation is done in the long run, the accepted factor of safety must therefore be at least 1,5. In a situation, when the factor of safety is lower than 1,5 a stabilization design of the failure would be necessary.

Rock-block with a translation movement presumption (photo Vaníček 2009)

Based on a geological investigation and archive documents, the following rock properties were determined (shale) – unit weight γ = 26 kN/m^3, shear failure - plane friction φ' = 38°, shear failure - cohesion 0,8 MPa (laboratory measurement on a drilled rock sample), deformation modulus Eo = 10 MPa.

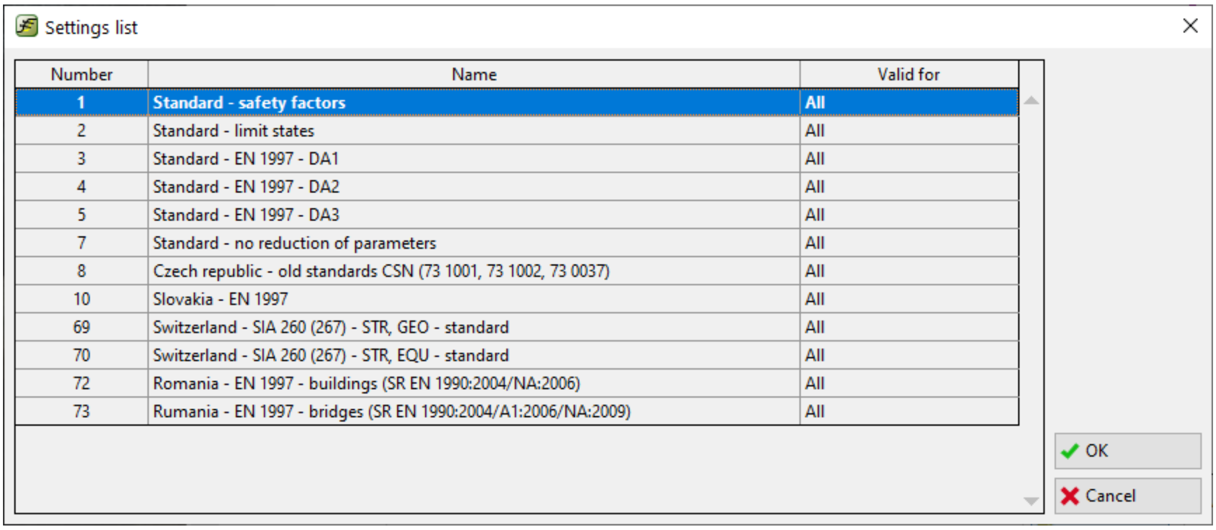
Solution

The selected cross-section slope stability evaluation will be done in accordance with factors of safety (as the result will be then checked using a FEM numerical model). A step-by-step description of the evaluation follows.

Task Setup

Numerical evaluation setup related to the factors of safety and a rock-slope failure.

In the frame Settings select “Select Settings” and select “Standard – Safety Factors“ and confirm via the „OK“ button.



Settings list

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
7	Standard - no reduction of parameters	All
8	Czech republic - 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
72	Romania - EN 1997 - buildings (SR EN 1990:2004/NA:2006)	All
73	Rumania - EN 1997 - bridges (SR EN 1990:2004/A1:2006/NA:2009)	All

"Settings" frame

Next we have to set the type of the computation. The "Rock Stability" application allows the assessment of a rock-slope shear failure stability via planar and polygonal shear failure and a rock-wedge failure. It is usually difficult to recognize a shear failure and a structural geologist's help is required. Our task settings are composed of the geological survey final report and photographs (moreover, personally evaluated outcrop visit). We can see that the bedding planes dip are inclined in a steep angle of 40 to 50 degrees and shale blocks can slip down to the road situated at the bottom of the hill. For this reason, a plane slip-surface type of the assessment is selected.

Rock-slope terrain geometry setup

The morphology of the cross-section is to be set up in the "Terrain" frame. The starting point of the rock-face cross-section could be changed from the default value. The slope bottom is a typical starting point. Another point could be in some distance in front of the rock-face. In our situation the starting point is placed on a horizontal surface 5 m in front of the slope bottom with coordinates (x=0, z=0). The evaluated geometry of the slope starts on the left and continues to the right.

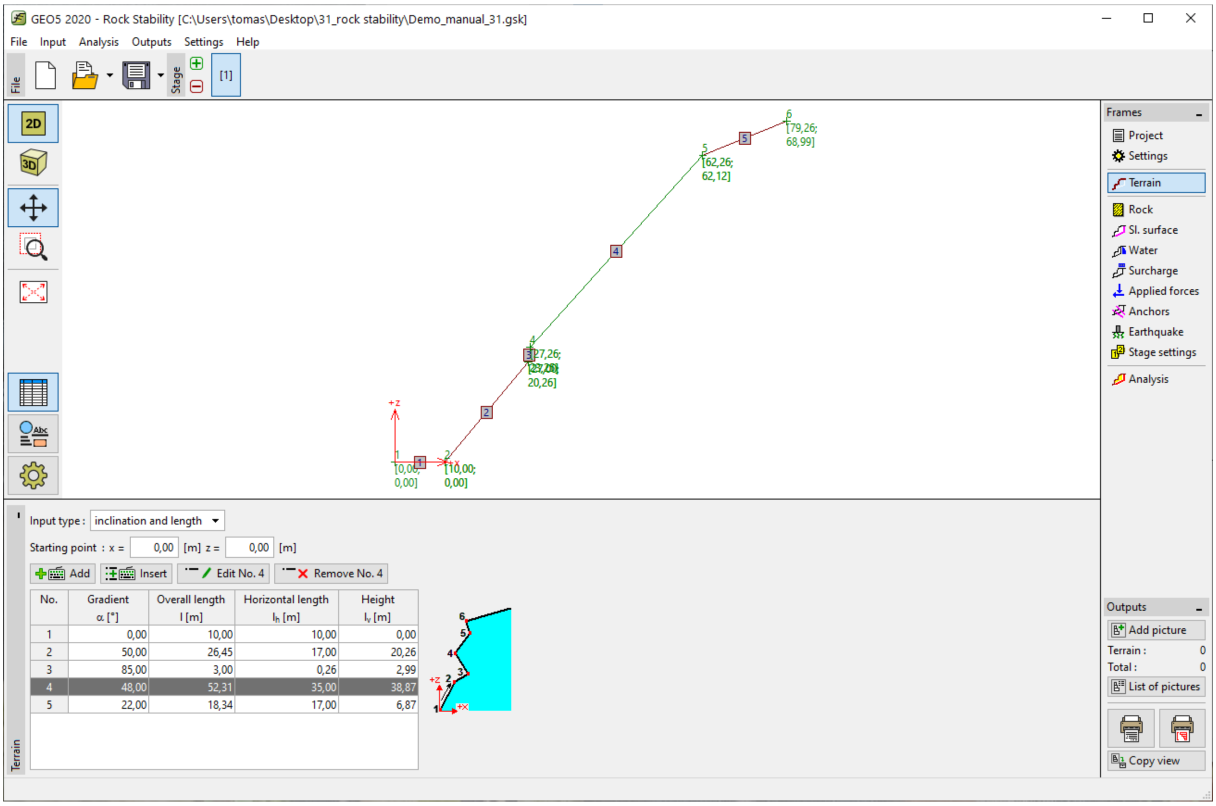
In the "Terrain" frame with the help of the "Add" button, we open a dialog window, where we input the morphology of the rock-slope cross-section (from the starting point). Line segments could be set using a combination of dip and length and/or the horizontal length and height. The software will compute the unset values creating the whole cross-section.

On the base of the morphological surface-bend coordinates we set the rock-slope geometry up:

Line segment Nr.	Dip α [°]	Overall Length l [m]	Horizontal Length l_h [m]	Height l_v [m]
1	0	-	10,0	-
2	50	-	17	-
3	85	3	-	-
4	48	-	35	-
5	22	-	17	-

Settings of line segments (set values)

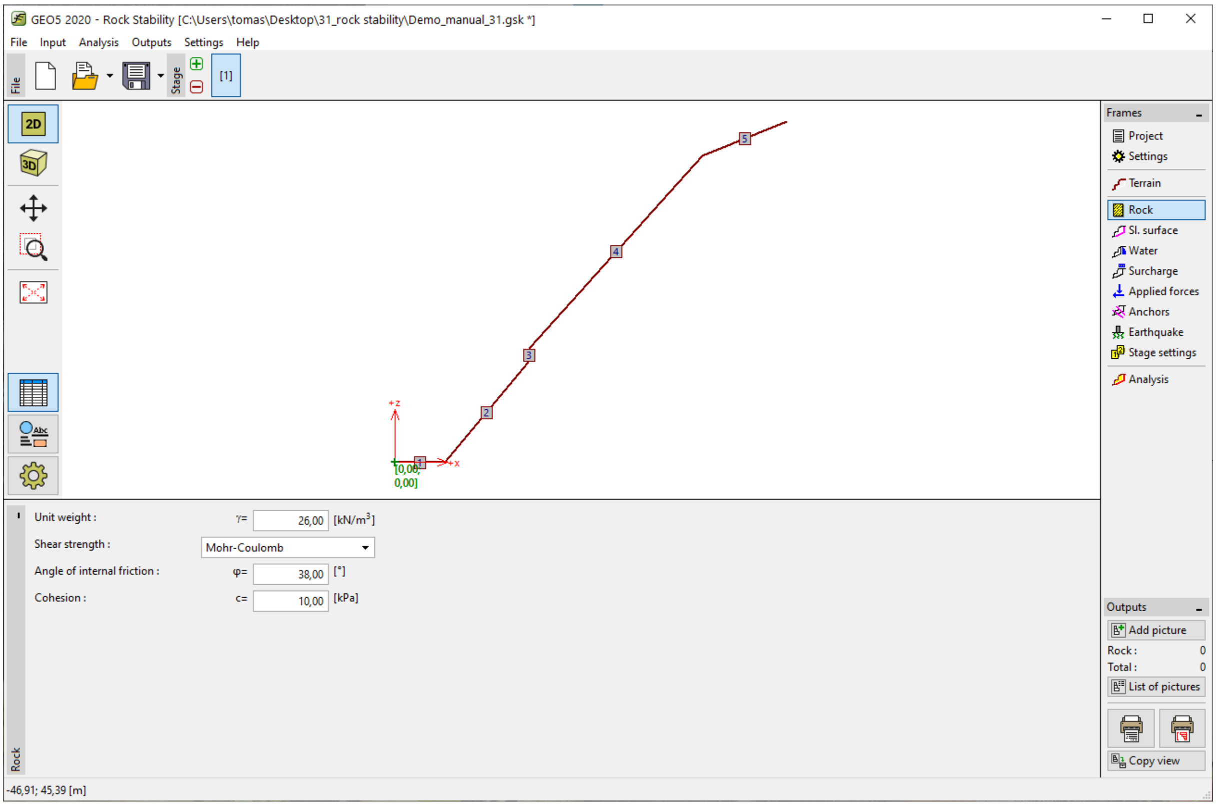
The software shows the cross-section in a graphical window and shows a table of segment line coordinates.



Cross-section setting of line segments in "Terrain" frame.

Rock Demerits Setup

We set the rock-mass cross-section up (mechanical properties) in the "Rock" frame. Based on the geological investigation, which was conducted, the following unit weight and shear demerits (Coulomb model) were recommended: unit weight γ = 26 kN/m^3, residual shear strength on bedding planes – residual friction angle φ'_r = 38 °, and residual cohesion c'_r = 10 kPa

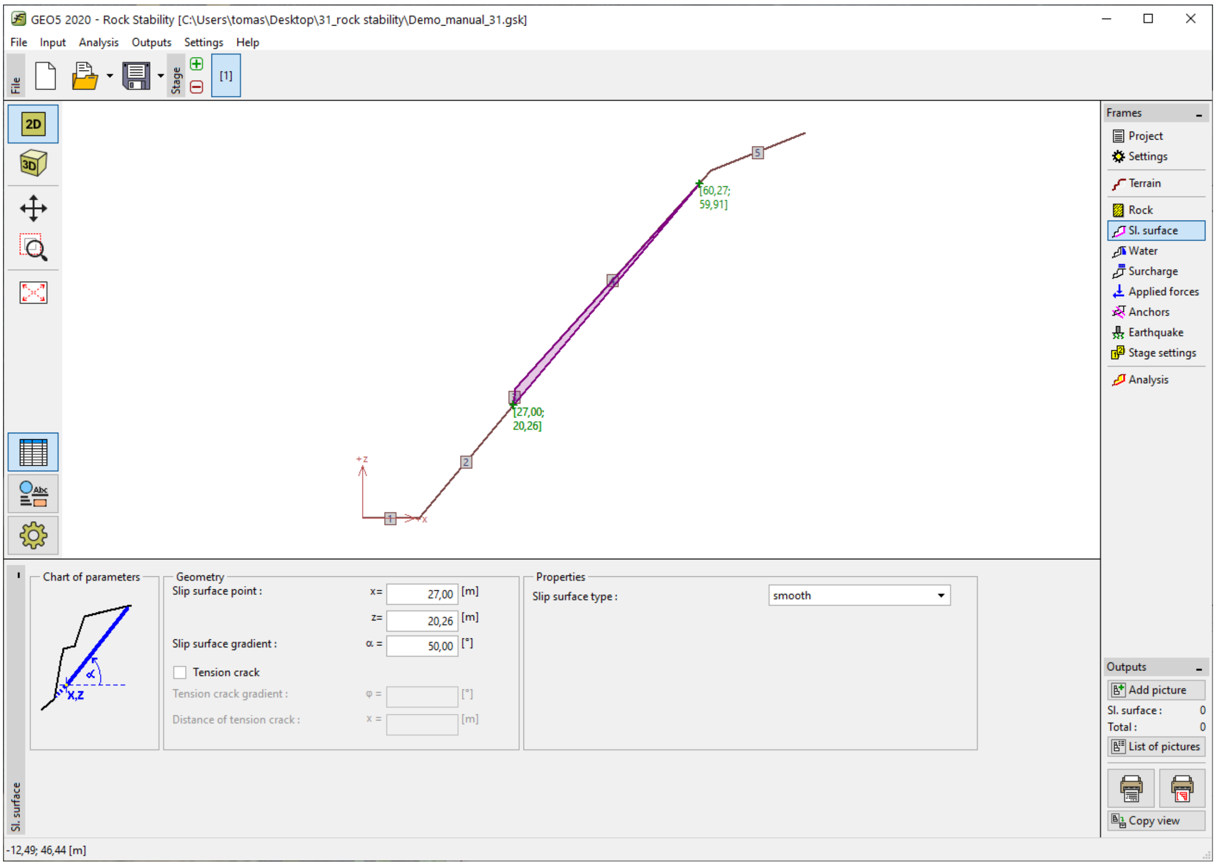


"Rock" frame

Notice: The software allows the set up of mechanical properties related to Barton-Bandis and Hoek-Brown models.

Settings of the shear plane geometry and its properties

The shear failure and its properties are to be set up in the "Sl. surface" frame. One point of the shear failure is equal with the bottom line of the evaluated rock-block x = 27 m, z = -20,26 m. On the base of the geological investigation the dip of the shear failure is 50 degrees.



Shear failure settings in the "Slip Surface" frame

Underground water Influence

The underground water influence is to be set in the "Water" frame. There are several damps of underground water recognized at the bottom of the wall, especially along the discontinuities parallel to the bedding. The freezing water then opens failure joints during winter. Simultaneously, ice creates a barrier against water flow and the accumulated water above the plug increases the hydrostatic pressure.

The evaluated block lies above the water table and according to the local survey, the stability is not affected by damping of underground water. Regarding this fact, the slope stability evaluation is done without counting the underground water influence.

Surcharge Settings

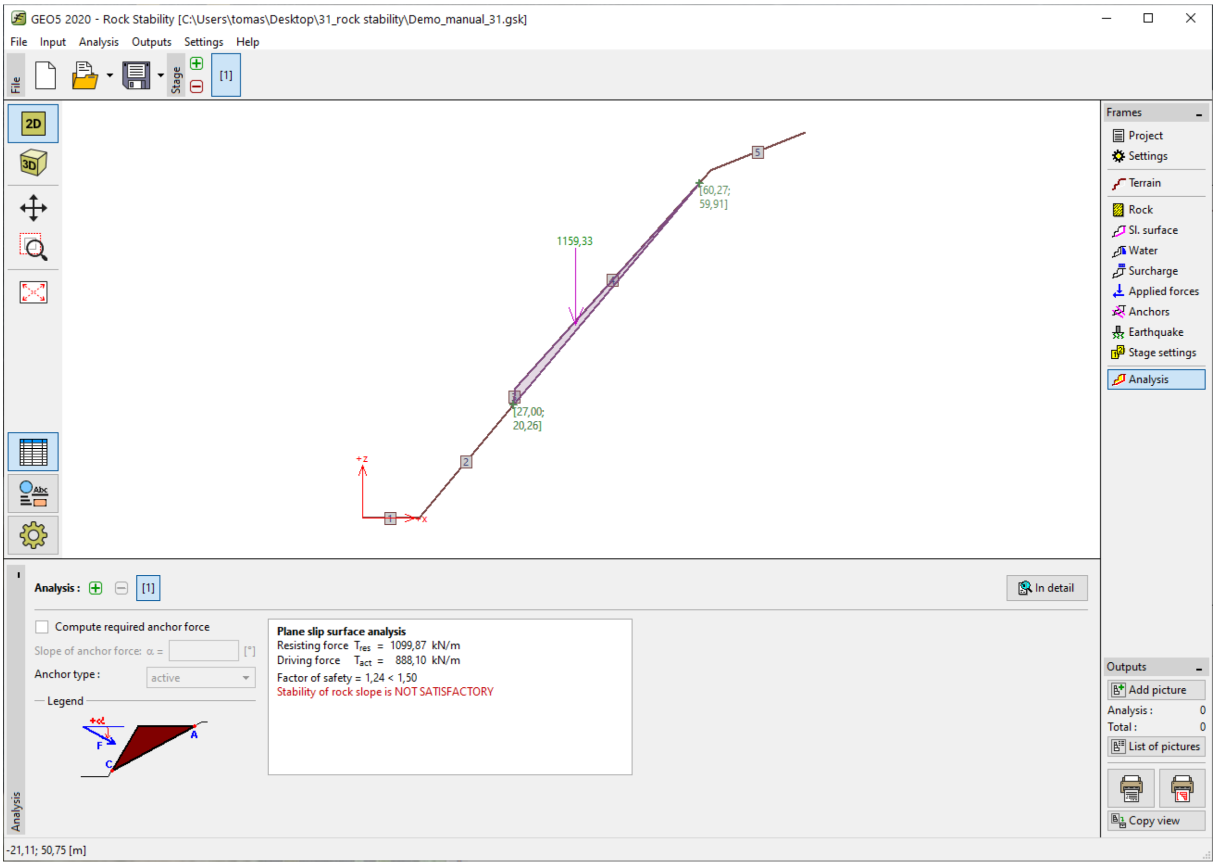
Surcharge affecting the rock face is to be set in the "Surcharge" frame. There is no external surcharge on the selected and evaluated block.

Stage Settings

Design situation is to be set in "Stage Settings". In our task, we evaluate the slope stability for long-time durability of the assessed structure situated on the slope bottom. Because of this, we choose "permanent situation".

Analysis

The task assessment will run after clicking the “Analysis“ button. The basic results are visible in the “Analysis“ frame. Our task slope stability result is F = 1.24 << 1.5. Detailed results are shown in the window “In detail“ and/or in the document print view.



“Analysis“ frame

Analysis

Partial results

Slip surface length = 51,77 m
Slip surface gradient = 50,00 °
Gravity force W_z = 1159,33 kN/m
Normal force on slip surface N = 745,20 kN/m
Shear stress on slip surface τ = 21,25 kPa

Plane slip surface analysis

Resisting force T_{res} = 1099,87 kN/m
Driving force T_{act} = 888,10 kN/m

Factor of safety = 1,24 < 1,50
Stability of rock slope is NOT SATISFACTORY

Detailed statement of the evaluation in the “Analysis“ window.

Conclusion

The results of our task show that the slope stability factor of safety is F=1.24, which is a smaller value than the required 1.5. It means that the rock-fall stability of the evaluated block is not acceptable for the required the factor of safety 1.5 (for a long-time) and it is necessary to work on more designs to increase the stability. Acquiring the required stability on the selected cross-section is impossible due to the large sliding rock-mass volume. Stabilization via rock bolts or nails is technically complicated given the difficult access and the necessity of specialized technical equipment. A suggested solution could be a combination of partial stabilization of the rock-block and an arrangement of barriers (dynamic barriers), which can protect the road against fallen blocks.

References:

VANÍČEK, I., HRUBÝ, V., CHAMRA, S., JIRÁSKO, D. (2009): *Posouzení geotechnických rizik v souvislosti s havarijním stavem skalního masivu a nebezpečím sesuvu na komunikaci II/102 v úseku Strnady – Štěchovice*, MS – Závěrečná zpráva, České učení technické v Praze, Fakulta stavební, Praha.

ZARUBA, Q., MENCL, V., 1957. Engineering Geology. (In Czech.) NCSAV, Prague, pp. 1—425.