Slope Stability

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Exercise 4a

LEM software application

EXERCISE AND TUTORIAL OF GEOSTUDIO SLOPE/W

Introduction

The goal of this exercise is to perform slope stability analyses by using the commercial software GeoStudio 2018 (student version). Let $F(s_i)$ the safety factor computed with reference to a specific surface s_i. By considering that the actual failure surface is unknown, a certain number of potential failure surfaces s_i needs to be considered. The actual safety factor is defined as $F = min_i\{F(s_i)\}$.

GeoStudio 2018 can be downloaded at the following website: https://www.geoslope.com/learning/downloads/alternate-downloads. A tutorial is presented in section 1.2 in order to guide the student through the basic steps of GeoStudio. The tutorial refers to the GeoStudio 2018 version (if you would like to download a newer version there might be some small differences compared to this tutorial but it should be quite easy to understand them).

1.1 Description of the exercise

In Exercise 3 the slope given in Figure 1 was analyzed by applying the simplified Bishop's method. The slope stability analyses were performed by referring to a given failure surface. The geometry and soil properties are recalled in Table 1.

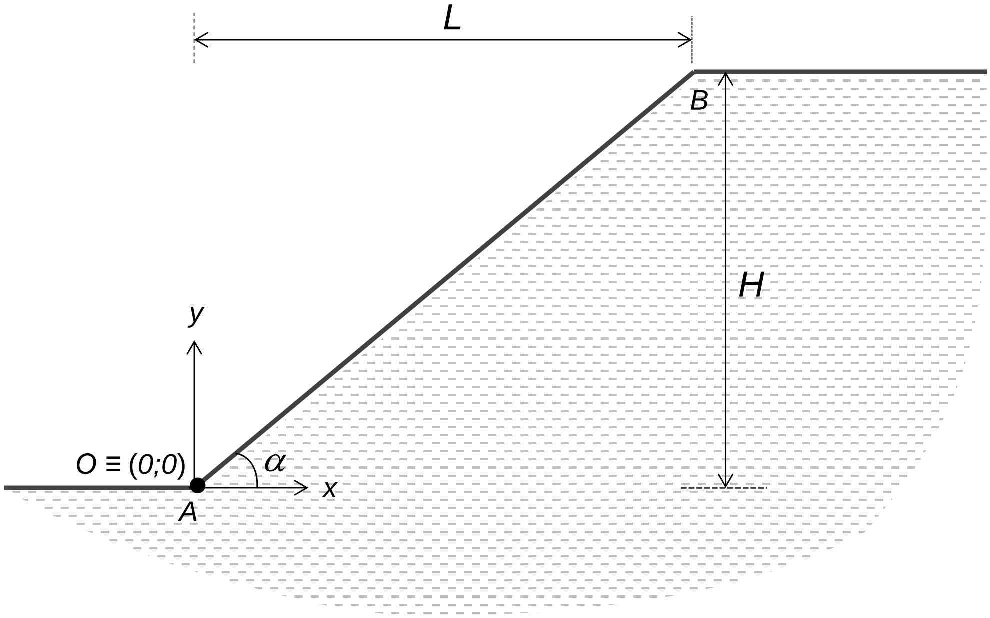

Figure 1: slope geometry.

Table 1: geometry and soil properties of the slope given in Figure 1.

γ_{sat} (kN/m^3)	γ_d (kN/m^3)	α (°)	H (m)	L (m)	φ' (°)	c' (kPa)
21.0	18.0	30.0	8.0	13.9	22.0	5.0

Subdivide the slope in a number of slices equal to 20 and perform the stability analyses by using the simplified Bishop's method and the Morgenstern-Price method.

Part a

By referring to the simplified Bishop's method, evaluate the safety factor of the failure surface given in Exercise 3 (i.e. check the consistency between the results obtained by using the software and the results obtained by using the Excel file for the provided failure surface).

Part b

Evaluate the actual safety factor $F = min_i \{F(s_i)\}$ of the given slope, in the dry and submerged conditions; evaluate if the failure surface provided in Exercise 3 coincides with the actual one (i.e. the one providing the minimum safety value).

Write in Table 2, for the dry and submerged conditions and for each applied method, the results of the analyses in terms of:

- safety factor F;
- characteristics of the failure surface (coordinate of the center C and radius r).

Make final comments on the obtained results. Can the slope be considered stable for each condition? Consider satisfactory a safety factor $F \geq 1.3$ in order to keep into account uncertainties due, for example, to the estimation of the geotechnical parameters.

Table 2: summary of results obtained by using GeoStudio SLOPE/W.

	BISHOP simplified	*MORGENSTERN-PRICE*
dry slope	F = (x_C ; y_C) = r =	F = (x_C ; y_C) = r =
submerged slope	F = (x_C ; y_C) = r =	F = (x_C ; y_C) = r =

1.2 GeoStudio SLOPE/W tutorial

In the following sections a step-by-step tutorial is presented to solve the proposed exercise. Three different steps must be followed:

1. a pre-processing step, in which all the input data are introduced (geometry, material properties, type of analysis...);
2. a processing step, in which the problem is solved with the Limit Equilibrium Method according to the selected approach (i.e. simplified Bishop's method or Morgenstern-Price method);
3. a post-processing step, in which the obtained results are displayed and analyzed.

Creation of a new project, basic settings and saving

Open the software and select the option "Student license" (Fig. 2).
For creating a new project select the option SLOPE/W as shown in Figure 2.

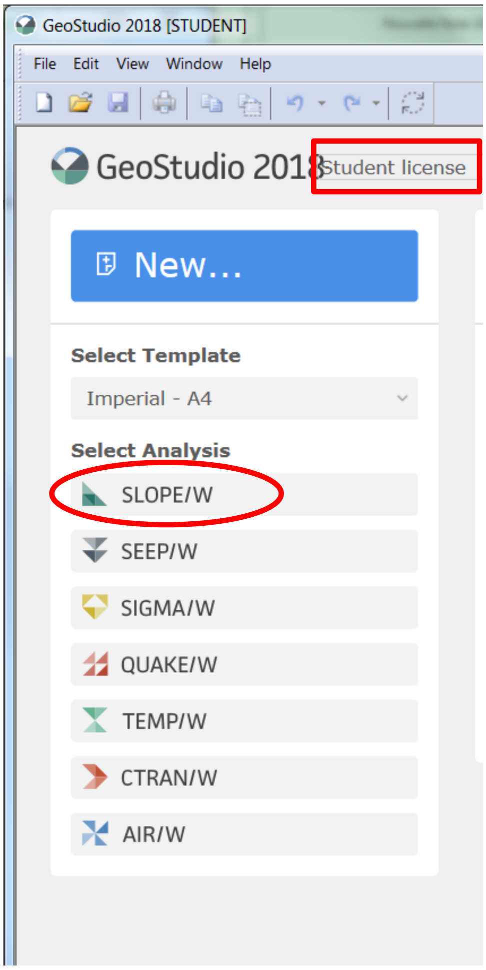

Figure 2: GeoStudio 2018 starting interface.

The specificities of the analysis to be performed can be set thanks to the "Define Analyses" interface. Before doing that, it is suggested to choose the basic units of measurements: 'View→ Units' (Figure 3).

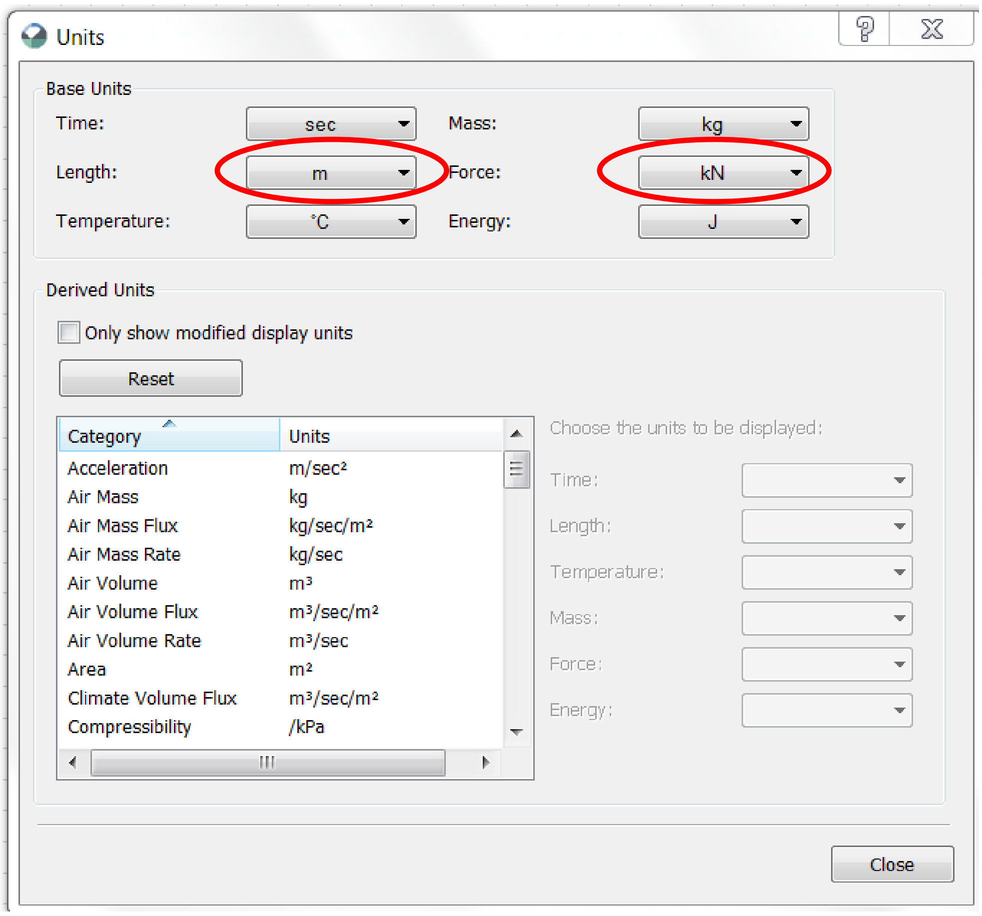

Figure 3: Units window.

The Grid spacing can be changed by using the command 'View→ Grid' (Figure 4).

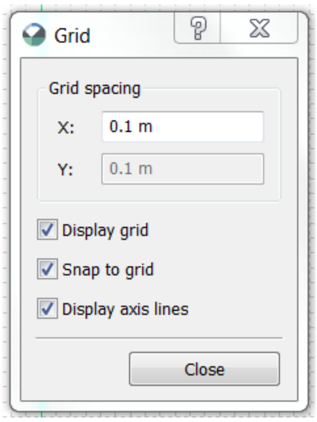

Figure 4: Grid window.

Afterwards, save the project in your working folder: *namefile*.gsz, as a GeoStudio file (*.gsz). Remember to save regularly your project (File→Save).

Pre-processing step

Define analyses

For defining the options of the analysis to be performed, use the "Define Analyses" interface by following the path: 'Define→ Analyses'.

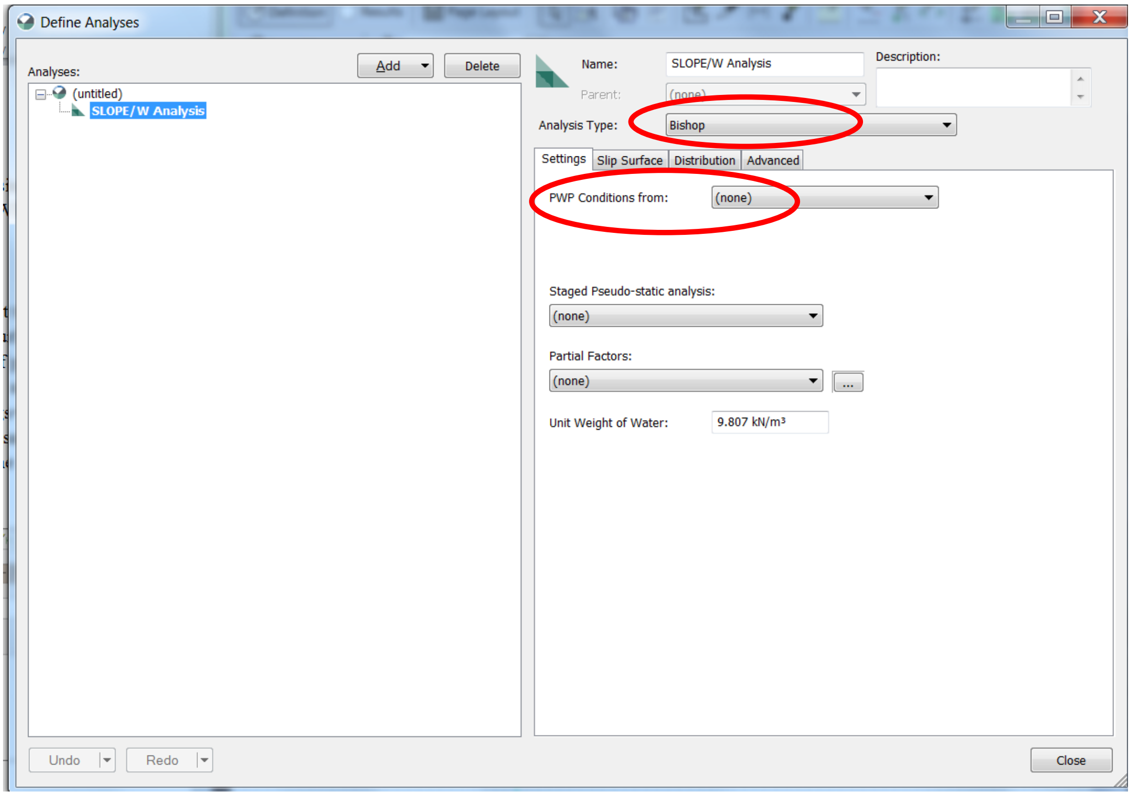

Figure 5: *Define Analyses* interface.

The method for performing the analysis can be chosen: 'Define→ Analyses → Analysis Type→Bishop'. For the current study, the pore water pressure conditions are not kept into account: 'PWP conditions from→(none)' (Figure 5).

Slip surface

'Define→ Analyses → Slip surface'

The direction of movement has to be defined, according to Figure 1, going from 'right to the left'. A 'Grid and Radius' slip surface option is set (Figure 6). It means the potential slip surfaces will be defined during computation with a grid of possible centers of rotation and a series of parallel lines tangential to slip surfaces.

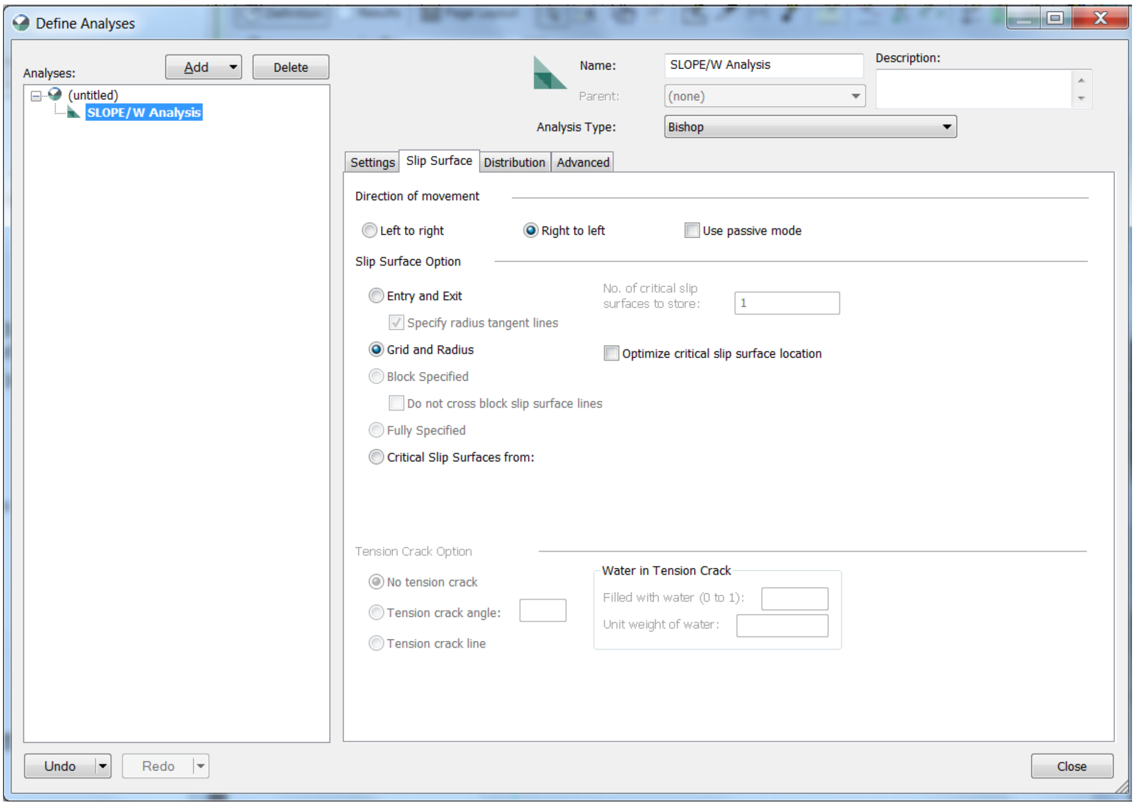

Figure 6: *Slip surface* window.

Distribution

'Define→ Analyses → Distribution→ Constant'

GeoStudio 2018 with Student license allows only a constant *F* distribution calculation (Figure 7).

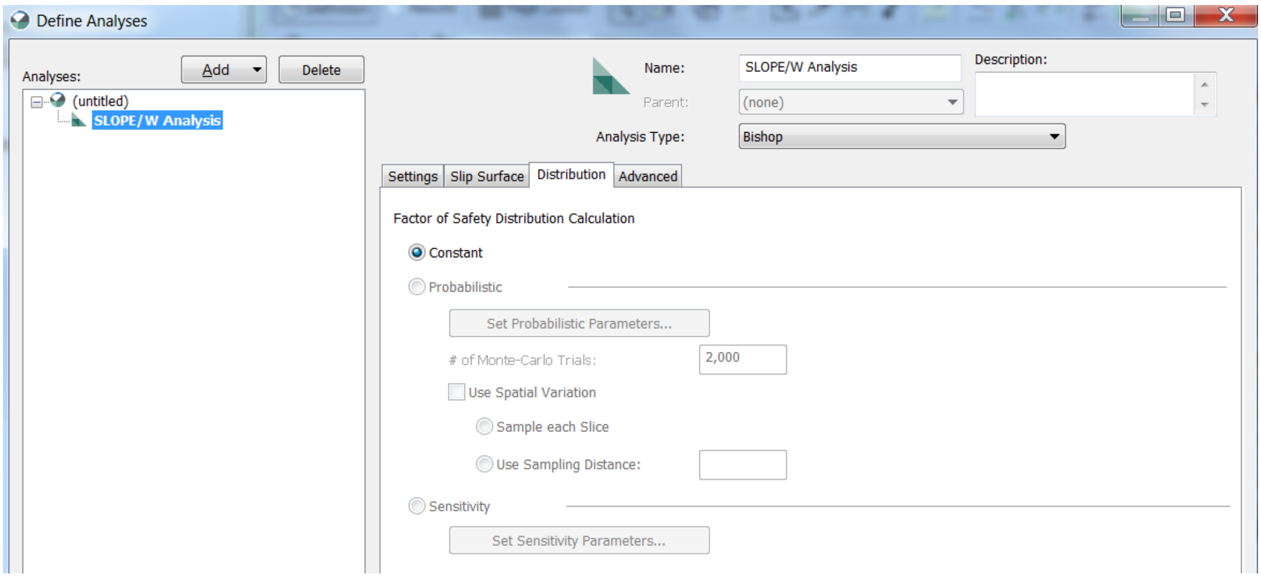

Figure 7: *Distribution* window.

Advanced
'Define→ Analyses → Advanced→ Number of slices→20' (Figure 8).

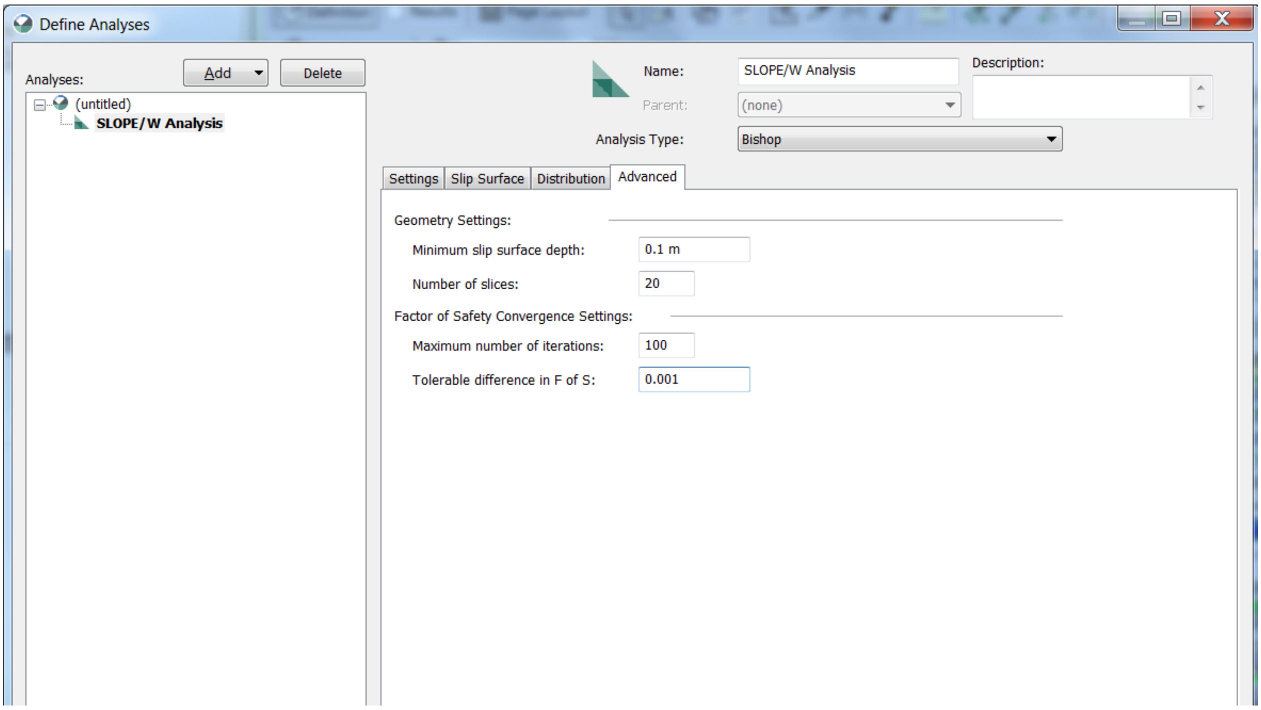

Figure 8: *Advanced* window.

Define geometry

The command 'Draw→Regions→Polygonal' allows the geometry to be defined manually (Figure 9). Then, the 'Enter coordinate' cell in the bottom left can be used for this purpose. Starting from the origin *O*, referring to the given geometry (Figure 1), the following points must be added: (0;0), (13,9;8), (40;8), (40;-15), (-25;-15), (-25;0) (0;0). The last point needs to be connected to the origin. Afterwards, the axes of the reference system can be displayed by setting their minimum and maximum values of interest (Figure 10): 'Sketch→Axes'.

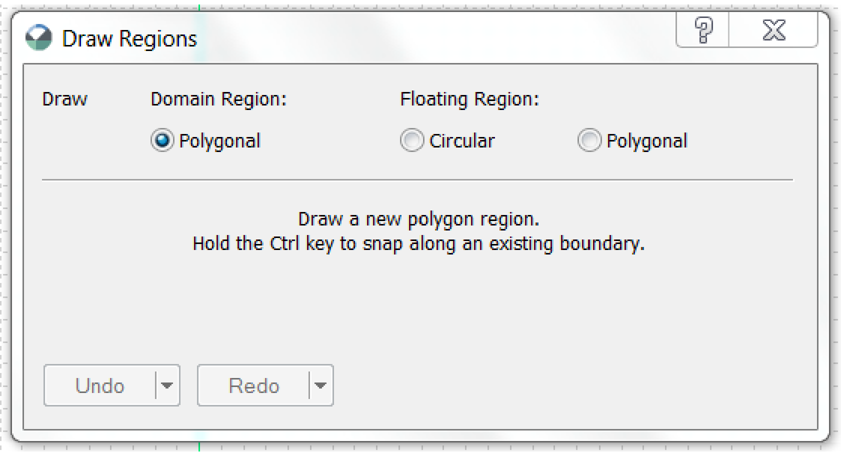

Figure 9: *Draw regions* window.

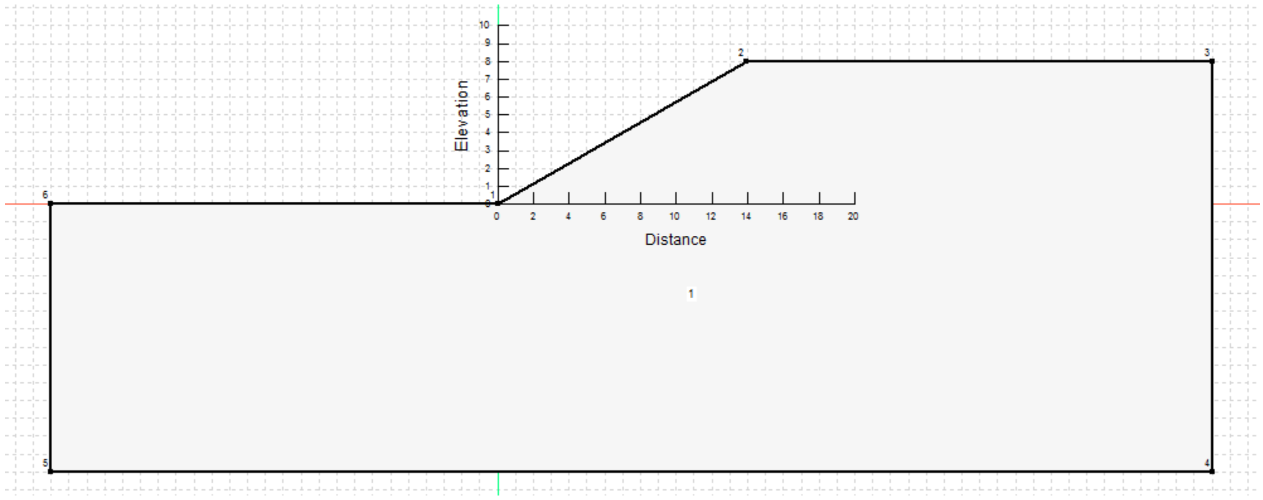

Figure 10: Geometry according to Figure 1 and Table 1.

Define and assign materials

The command 'Define→Materials' allows defining the properties of the materials. For the case under study, select Mohr-Coulomb material model and write the basic information of the *Sandy silt* according to the given data (Table 1). Note that the first computation has to be performed for the dry condition (γ_{dry} = 18 kN/m^3). Click on "Show legend"

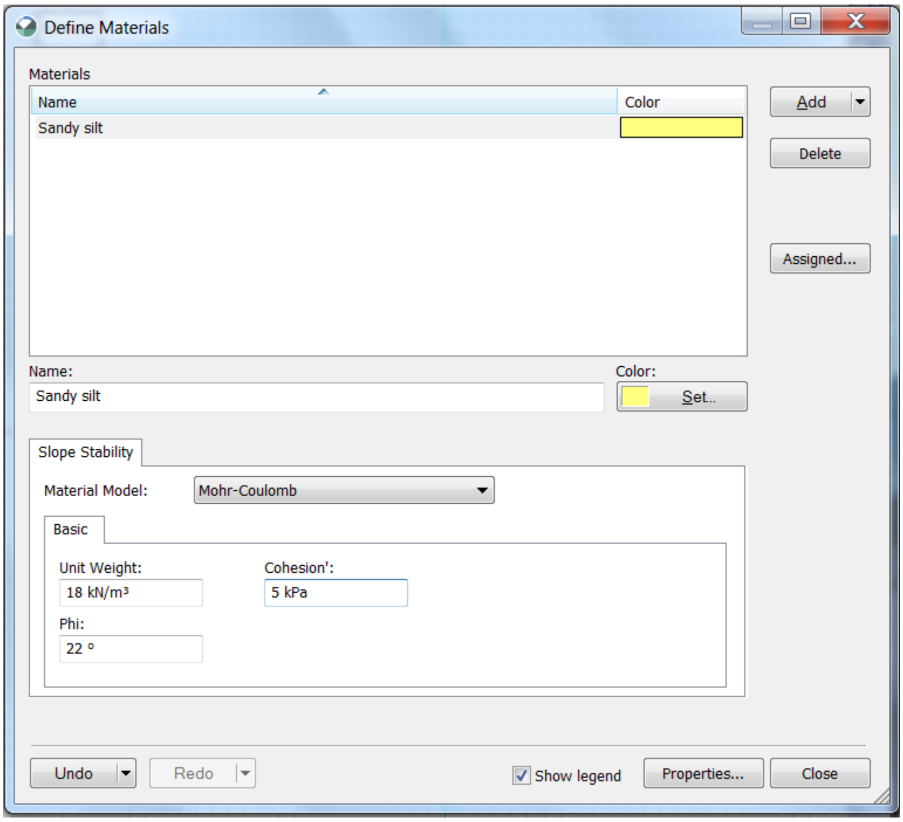

Figure 11: *Define materials* window.

The defined material can be assigned to the specific region of interest. For the case under study, the defined material has to be assigned to the whole domain. In order to assign the material do 'Draw →

Materials → Assign' and select the slope. If the assignment is successful, the region is colored with the color corresponding to the chosen material (Figure 12).

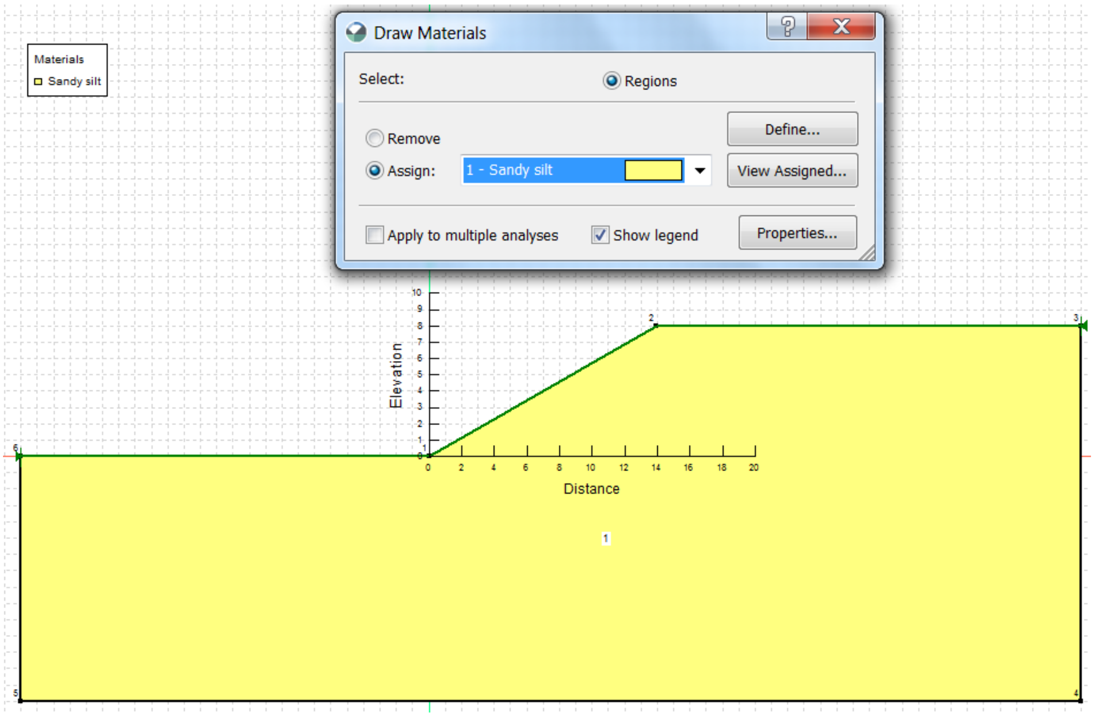

Figure 12: material assignment.

Part a:

The centers of rotation of the circular surfaces and the lines that control the slip surface radii can be selected by using the command ‘Draw slip surface grid’ and ‘Draw slip surface radius’ from the command bar (Figure 13 and 14).

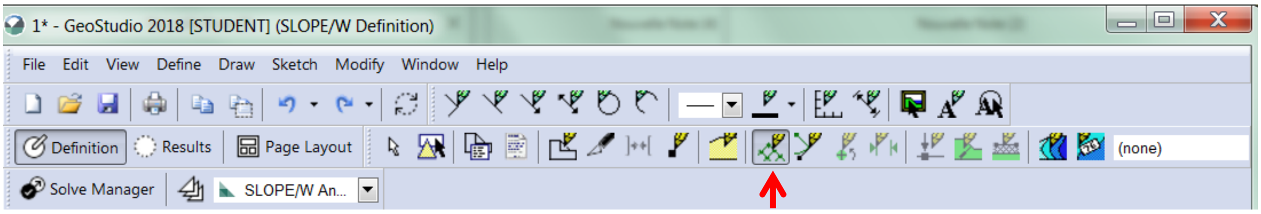

Figure 13: Draw slip surface grid.

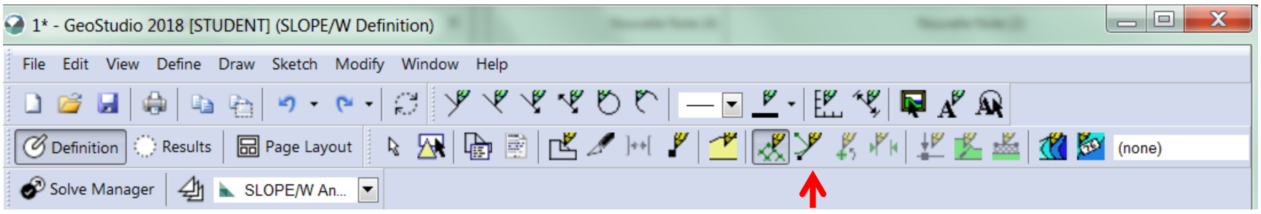

Figure 14: Draw slip surface radius.

Note that the grid must be defined by first clicking on the Upper-Left corner, then the Lower-Left corner and finally the Lower-Right corner.

In order to perform the case study proposed in Exercise 3 in which the failure surface was assigned, the grid of centers and the lines for defining the radii are chosen properly. In particular, a grid with a corner in (7,0; 10,0) and a tangent line set at y = -2.2 m are drawn (Figure 15).

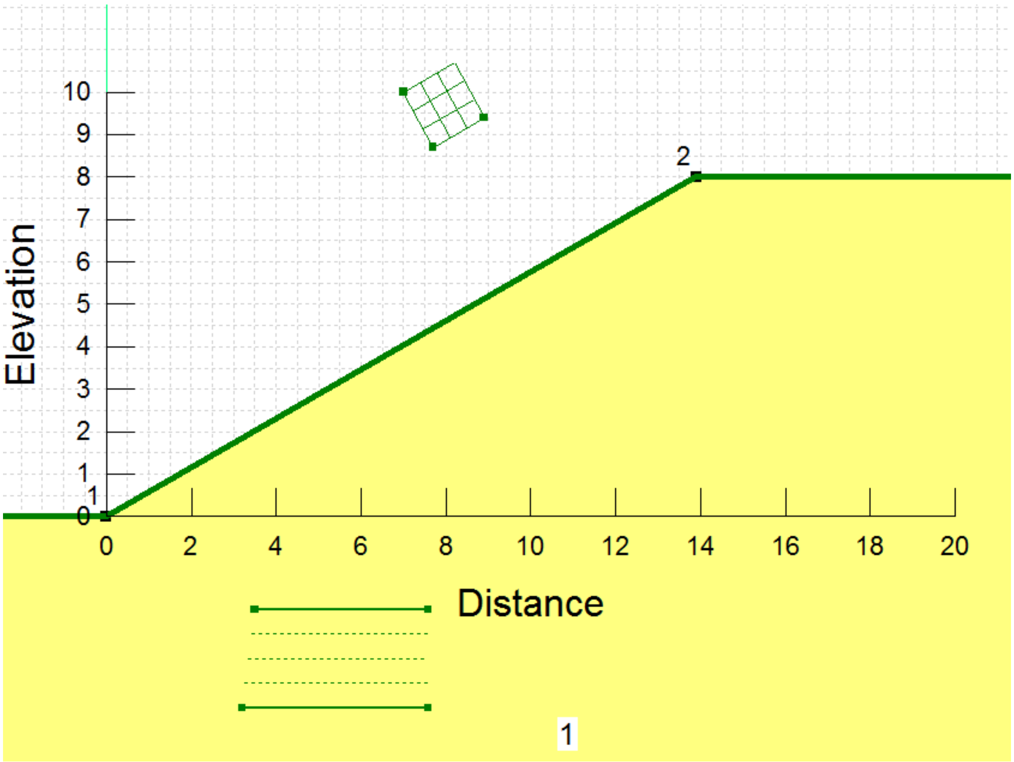

Figure 15: ‘Grid and Radius’ settings for validating the analysis performed in Exercise 3 (dry material and Bishop method).

Processing step

The processing step can be performed by launching the Solve Manager (Figure 16).

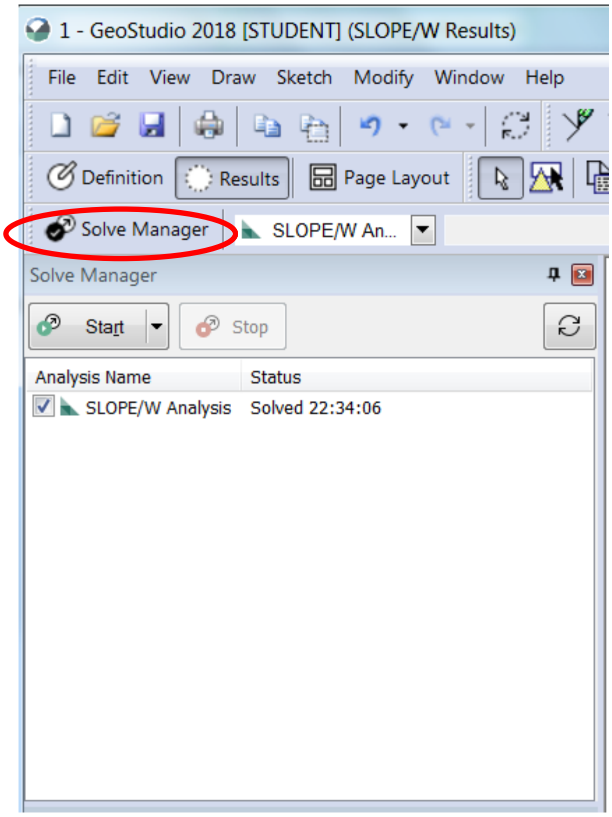

Figure 16: *Solve manager* window.

Post-processing step

At the end of the computation step, the interface automatically turns in the ‘Results’ mode: the ‘Definition’ button is de-selected. This is the post-processing interface of SLOPE/W which allows displaying and analyzing the results. For identifying the critical slip surface and analyzing the safety factors values follow the path: ‘Window → Slip Surfaces’.

Figure 17 shows the slope stability analysis performed for verifying the safety factor value achieved in Exercise 3 for the slip surface defined by a center C (x_C; y_C) = (7; 10) and a radius r = 12.2 m. The safety factors results to be F=1.71 instead of F=1.68. The small difference between the two results can be justified simply by the numerical procedure.

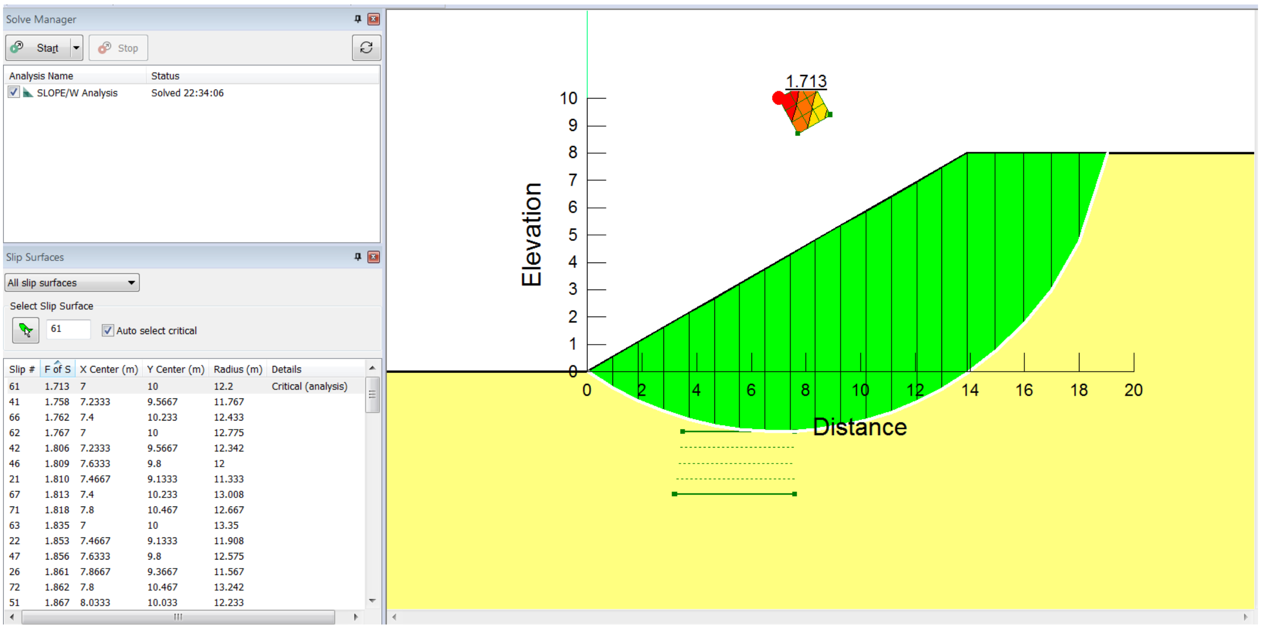

Figure 17: slope stability analysis performed for verifying the safety factor value achieved in Exercise 3 (slip surface defined by: $(x_C, y_C) = (7, 10)$, $r = 12.2$ m).

Part b:

For the more general case, the actual failure surface needs to be identified. For this purpose, it is necessary to consider a wider grid of centers and a greater variation of the tangent lines in order to be sure to identify the slip surface which corresponds to the lower safety factor.

Pre-processing step

In order to define a new analysis for the same geometry and material, return to the Definition mode by clicking on the 'Definition' button. Follow the path 'Define → Analyses → Add'. The grid of rotation centers and the tangent lines are defined by using the same commands indicated in Figure 13 and 14. A possible configuration of the grid and of the tangent lines is given in Figure 18.

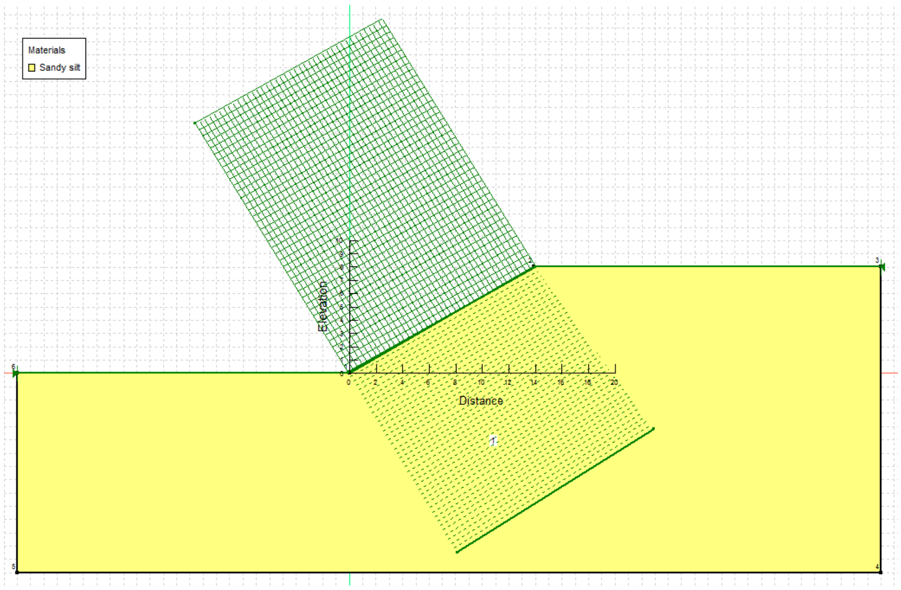

Figure 18: grid and radius definition.

Processing step

The processing step can be performed by launching the Solve Manager.

Post-processing step

At the end of the computation step, the interface automatically turns in the 'Results' mode: the 'Definition' button is de-selected. This is the post-processing interface of SLOPE/W which allows displaying and analyzing the results. For identifying the critical slip surface and analyzing the safety factors values follow the path: 'Window → Slip Surfaces'. For setting the options of the Color Map (change colors, show the legend…), select the bottom 'Draw slip surface color map' on the command bar (Figure 19).

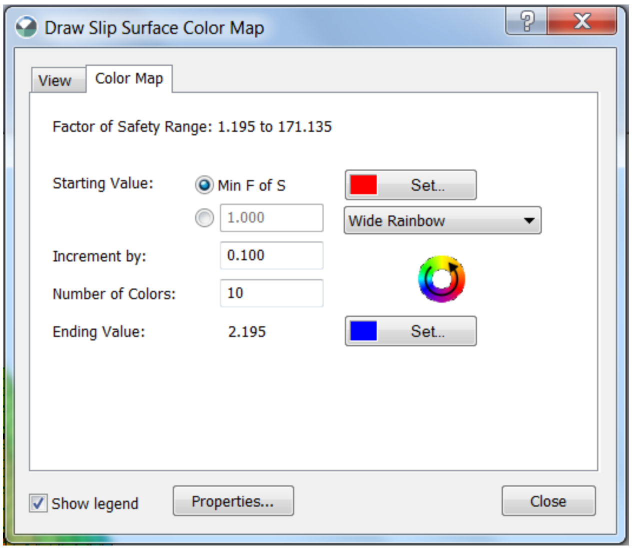

Figure 19: *Draw slip surface color map* window.

The actual safety factor of the slope according to the Bishop's method results to be F=1.195 (Figure 20), which is lower than the one achieved for the assigned slip surface of Exercise 3. The analysis allows understanding the importance of performing a slope stability analysis by using an appropriate computational tool. Several failure surfaces need to be analyzed iteratively in order to identifying the one which correspond to the minimum safety factor value (the corresponding failure mechanism should also be shown to be significant in terms of involved volume of soil).

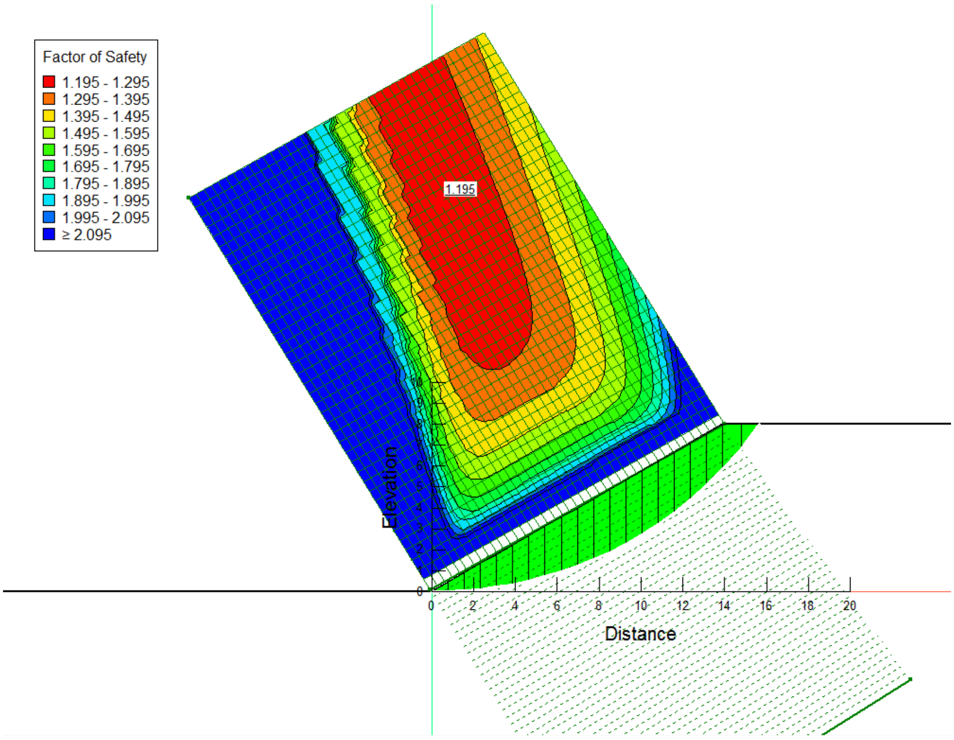

Figure 20: iso-*F* contour map according to the Bishop simplified method for the dry slope. The critical failure surface and the corresponding safety factor are also displayed.

As a conclusion of the present tutorial, we remind you to change the type of analysis if the Morgenstern-Price method has to be performed (‘Define→ Analyses → Analysis Type → Morgenstern-Price’; keep the *constant function* as default settings). Moreover, in the case of the submerged slope, the buoyant dry density has to be used $\gamma' = \gamma_{sat} - \gamma_w$.

Useful references:

1. Krahn, John. Stability Modeling with SLOPE/W - An Engineering Methodology. 2004.

2. Stability Modeling with GeoStudio (http://downloads.geoslope.com/geostudioresources/books/9/0/SLOPE%20Modeling-20180124.pdf