Slope Stability Analysis using Particle Swarm Optimization (PSO) for Non-Circular Failure Surface

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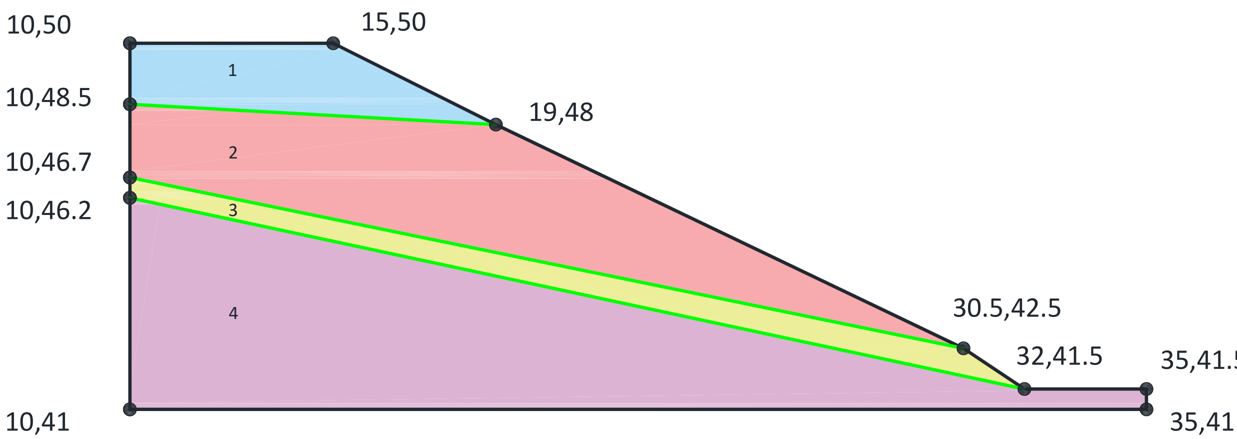


This tutorial presents a slope stability analysis using non-circular slip surfaces and the Particle Swarm Optimization (PSO) algorithm in HYRCAN. The example is based on the study by Zolfaghari et al. [1]. The geotechnical properties for soil layers 1 through 4 are provided in Table 1. All soil layers are modeled using the Mohr-Coulomb failure criterion.

Project Settings

Various important modeling and analysis options are set in the Project Settings dialog, including Failure Direction, Units of Measurement, Analysis Methods and Groundwater property. For this analysis make sure the failure direction is set to **"Left to Right"** and surface type is set to **"Non-Circular"** then press Apply. From the **Methods** tab you also will be able to select the limit equilibrium analysis method(s) to be used for the analysis.

Select: *Analysis* →  *Project Settings*

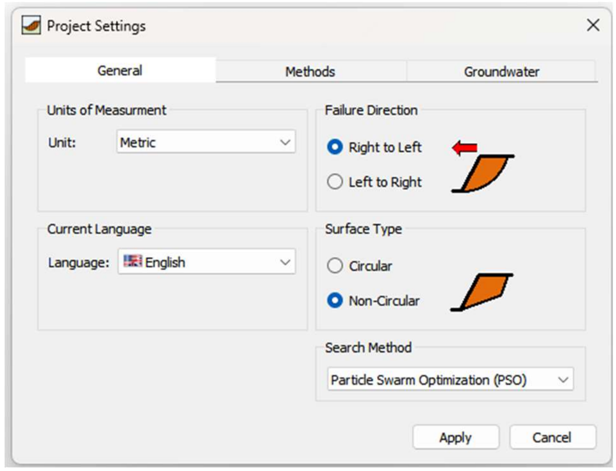
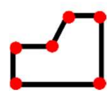


Figure 1- Project Settings dialog.

Create Geometry

- ***External Boundaries***

The first boundary that must be defined for every model, is the external boundary. To add the external boundary, select **External Boundary** from the toolbar or the Boundaries menu.

Select: *Geometry* → 

External Boundary

Enter the following coordinates in the prompt line at the bottom right of the main window.

Enter vertex [esc=cancel]: 10.0,41.0
Enter vertex [esc=cancel]: 10.0,50.0
Enter vertex [esc=cancel]: 15.0,50.0
Enter vertex [c=close,esc=cancel]: 19.0,48.0
Enter vertex [c=close,esc=cancel]: 30.5,42.5
Enter vertex [c=close,esc=cancel]: 32.0,41.5
Enter vertex [c=close,esc=cancel]: 35.0,41.5
Enter vertex [c=close,esc=cancel]: 35.0,41.0
Enter vertex [c=close,esc=cancel]: c

Note that entering **c** after the last vertex has been entered, automatically connects the first and last vertices (closes the boundary) and exits the External Boundary option. Your screen should now look as follows:

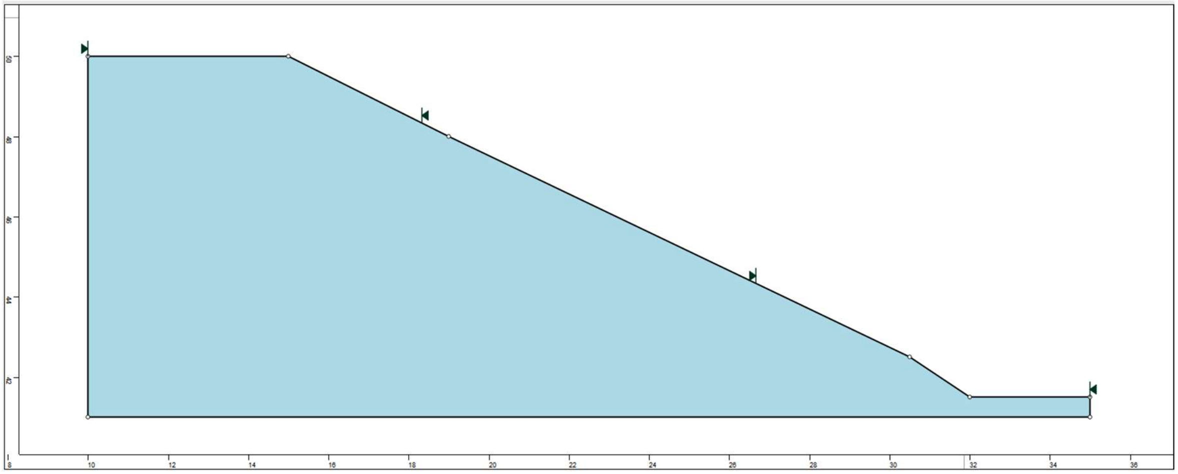
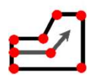


Figure 2- External boundary is created.

- ***Material Boundaries***

Material boundaries are used in ***HYRCAN*** to define the boundaries between different material regions within the External Boundary. Let’s add two material boundaries.

Select: *Geometry* →  *Material Boundary*

Enter the following coordinates in the prompt line at the bottom right of the main window.

```
Enter vertex [esc=cancel]: 10.0,46.2
Enter vertex [d=done,esc=cancel]: 32.0,41.5
Enter vertex [d=done,esc=cancel]: d
```

```
Enter vertex [esc=cancel]: 10.0,46.7
Enter vertex [d=done,esc=cancel]: 30.5,42.5
Enter vertex [d=done,esc=cancel]: d
```

```
Enter vertex [esc=cancel]: 10.0,48.5
Enter vertex [d=done,esc=cancel]: 19.0,48.0
Enter vertex [d=done,esc=cancel]: d
```

Your screen should now look as follows:

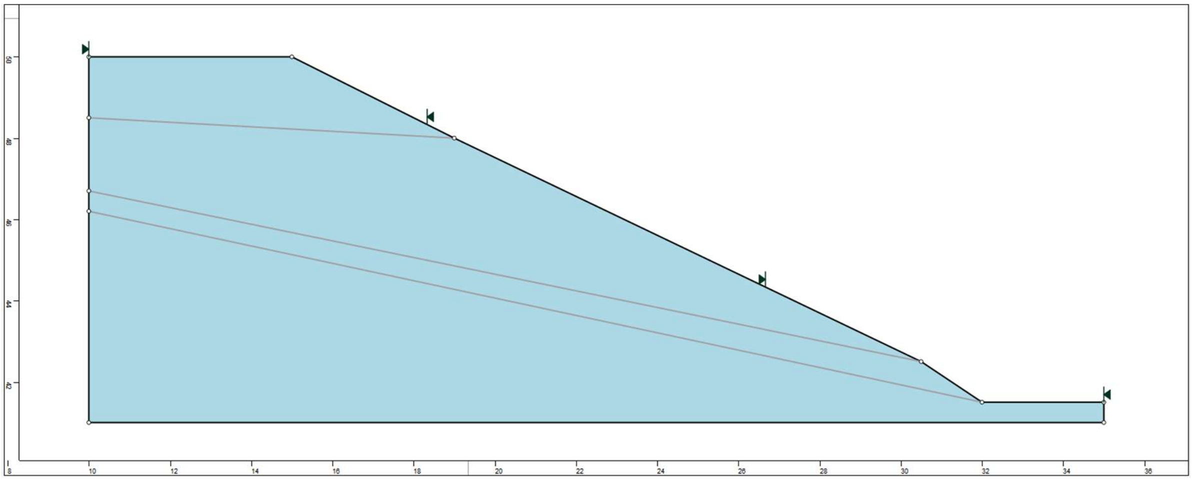


Figure 3- External and material boundaries added.

Properties

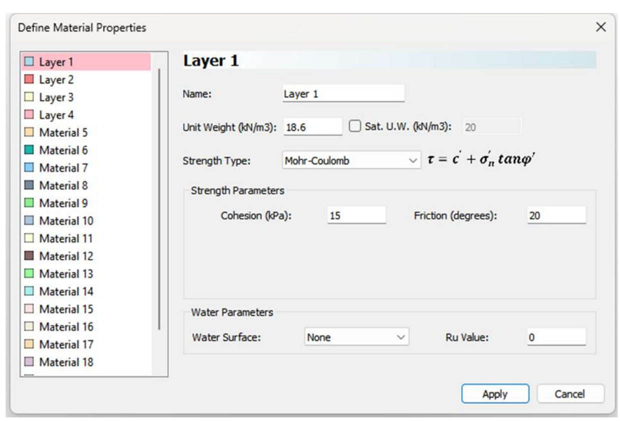
Table 1 summarizes the geotechnical properties of soil layers 1 through 4. All layers are modeled using the Mohr-Coulomb failure criterion. To begin defining the material properties, select *Define Materials* from the toolbar or the *Properties* men.

Select: *Properties* →  *Define Materials*

In the Define Materials dialog, enter the following properties:

Table 1- The geotechnical properties.

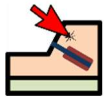
Material	*Strength Type*	γ (kN/m^3)	c (kN/m^2)	φ (degrees)
Layer 1	Mohr-Coulomb	18.6	15	20.0
Layer 2			17	21.0
Layer 3			5	10.0
Layer 4			35	28.0



When all parameters are entered press Apply.

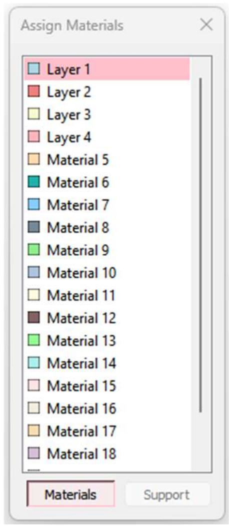
Assigning Properties

Since we have defined multiple materials, it will be necessary to assign properties to the correct regions of the model, using the Assign Properties option. Select Assign Properties from the toolbar or the Properties menu.

Select: *Properties* → 

Assign Properties

You will see the Assign Materials dialog, shown below.



To assign properties to the soil layers:

1. Use the mouse to select the soil material, in the Assign Materials dialog (notice that the material names are the names you entered in the **Define Material Properties** dialog).
2. Now place the cursor anywhere in the soil region and click the left mouse button. Repeat the same sequence for other soil materials until all the materials are assigned.

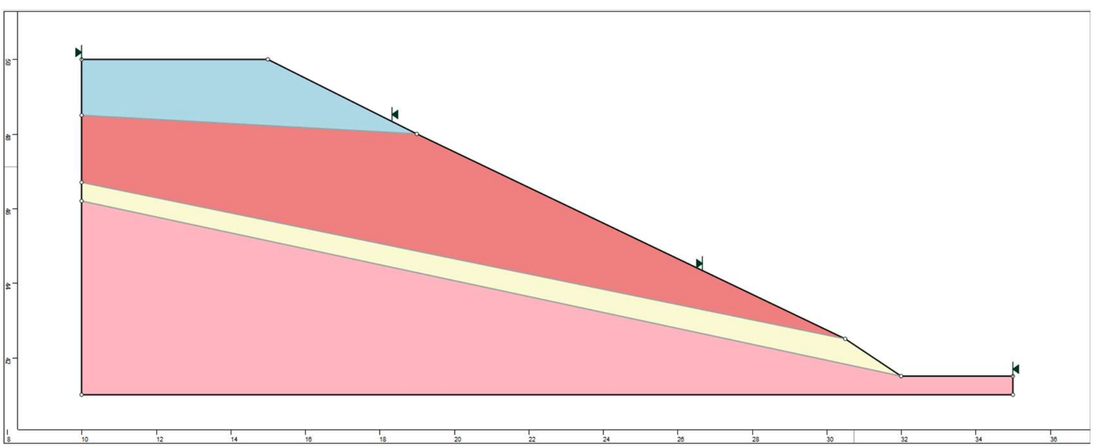
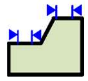
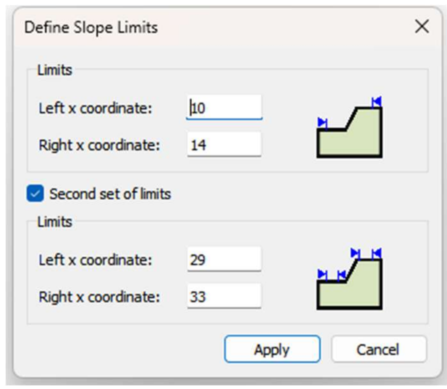


Figure 5- Geometry setup after assigning the properties.

Modifying the Slope Limits

The Slope Limits are automatically calculated by ***HYRCAN*** as soon as the **External Boundary** is created. If you wish to narrow the Slope Search to more specific areas of the model, the Slope Limits can be customized with the Define Limits dialog.

Select: *Surfaces* →  *Define Slope Limits*



In this tutorial, the left and right coordinates are initially set to 10 and 14, and the second set of limits is defined between 29 and 33. These limits can later be refined to improve the accuracy of the estimated global minimum slip surface. With the model setup complete, we can now proceed to run the analysis and interpret the results.

Compute

The model is now ready to run.

Select: *Analysis* →  *Compute*

The engine will proceed in running the analysis. When completed, you are ready to view the results in Result Tab.

Results and Discussions

Once the calculation is complete, you can view the results in the Results tab. By default, when the Results tab is opened, the global minimum slip surface from the first activated limit equilibrium analysis method is displayed. This analysis involved approximately 7,500 trial slip surfaces. The calculated factors of safety are presented in Figure 6, and Table 2 summarizes a comparison of the results with those reported by Zolfaghari et al. [1] and Cheng et al. [2].

Table 2- Comparison of Minimum Factor of Safety (Spenser Method)

Method	HYRCAN
Genetic Algorithm [1]	1.24
PSO [2]	1.1095
MPSO [2]	1.1174
HYRCAN	1.132

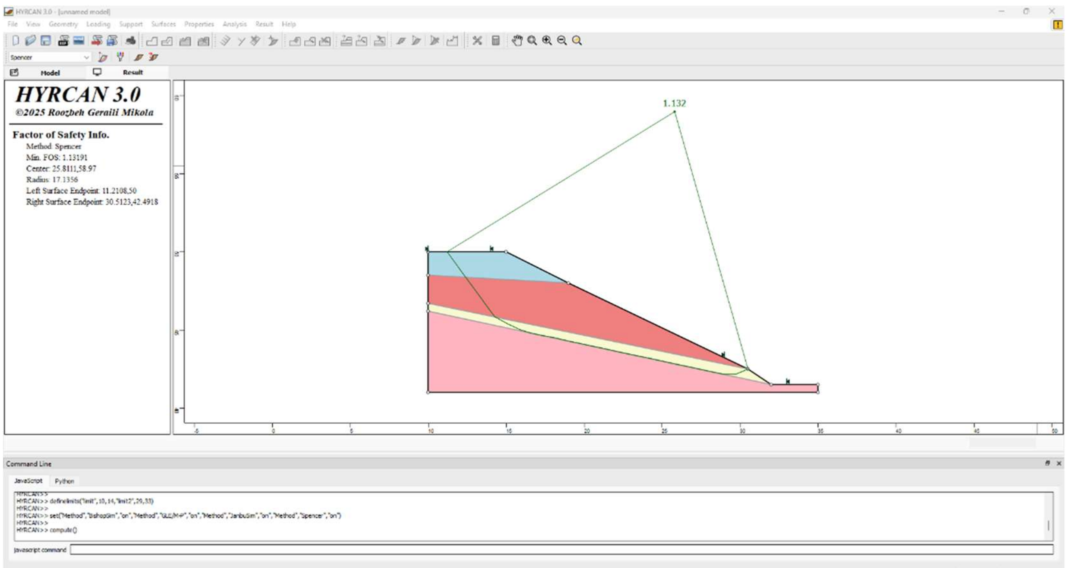


Figure 6- Result of automatic slope search.

To view ALL valid slip surfaces generated by the analysis, select the **All Surfaces** option from the toolbar or the Result menu.

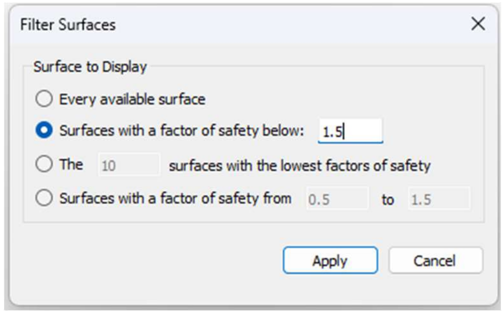
Select: *Result* → 

All Surfaces

The Filter Surfaces option in the toolbar or the menu can be used to filter the surfaces displayed by the minimum surfaces or all surfaces.

Select: *Result* → 

Filter Surfaces



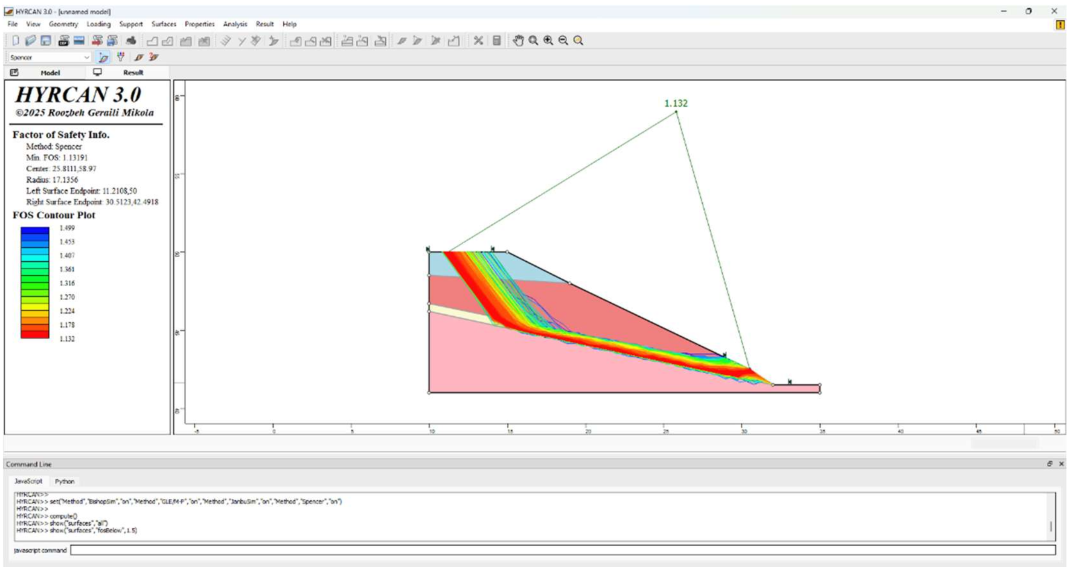


Figure 7- Non-Circular surface search – All surfaces shown.

Script

After finishing the model, you will be able to save the generated script by ***HYRCAN*** in the text file.

Select: 

The commands for this tutorial are listed below.

```
newmodel()

set("failureDir","l2r")
set("unit","metric","waterUW",9.81)
set("surfaceType","noncirc")

extboundary(10.0,41,10,50,15,50,19,48,30.5,42.5,32,41.5,35,41.5,35,41,10,41)
matboundary(10,46.2,32,41.5)
matboundary(10,46.7,30.5,42.5)
matboundary(10,48.5,19,48)

definemat("ground","matID",1,"matName","Layer 1","uw",18.6,"cohesion",15,"friction",20)
definemat("ground","matID",2,"matName","Layer 2","uw",18.6,"cohesion",17,"friction",21)
definemat("ground","matID",3,"matName","Layer 3","uw",18.6,"cohesion",5,"friction",10)
definemat("ground","matID",4,"matName","Layer 4","uw",18.6,"cohesion",35,"friction",28)

assignsoilmat("matid",1,"atpoint",14.5,49.0)
```

```
assignsoilmat("matid",2,"atpoint",16.0,47.0)
assignsoilmat("matid",3,"atpoint",15.5,45.5)
assignsoilmat("matid",4,"atpoint",15.0,44.0)

definelimits("limit",10,14,"limit2",29,33)

set("Method","BishopSim","on","Method","GLE/M-
P","on","Method","JanbuSim","on","Method","Spencer","on")

compute()
```

References

[1] Zolfaghari AR, Heath AC, McCombie PF. Simple genetic algorithm search for critical non-circular failure surface in slope stability analysis. Comput Geotechnics 2005;32:139–52.

[2] Cheng, Y.M., Li, L., Chi, S., and Wei, W.B. 2007. Particle swarm optimization algorithm for the location of the critical non-circular failure surface in two-dimensional slope stability analysis. Computers and Geotechnics, 34(2): 92–103.