# GeoStudio Example File
# Pit Slope Design using Multiple Geometries

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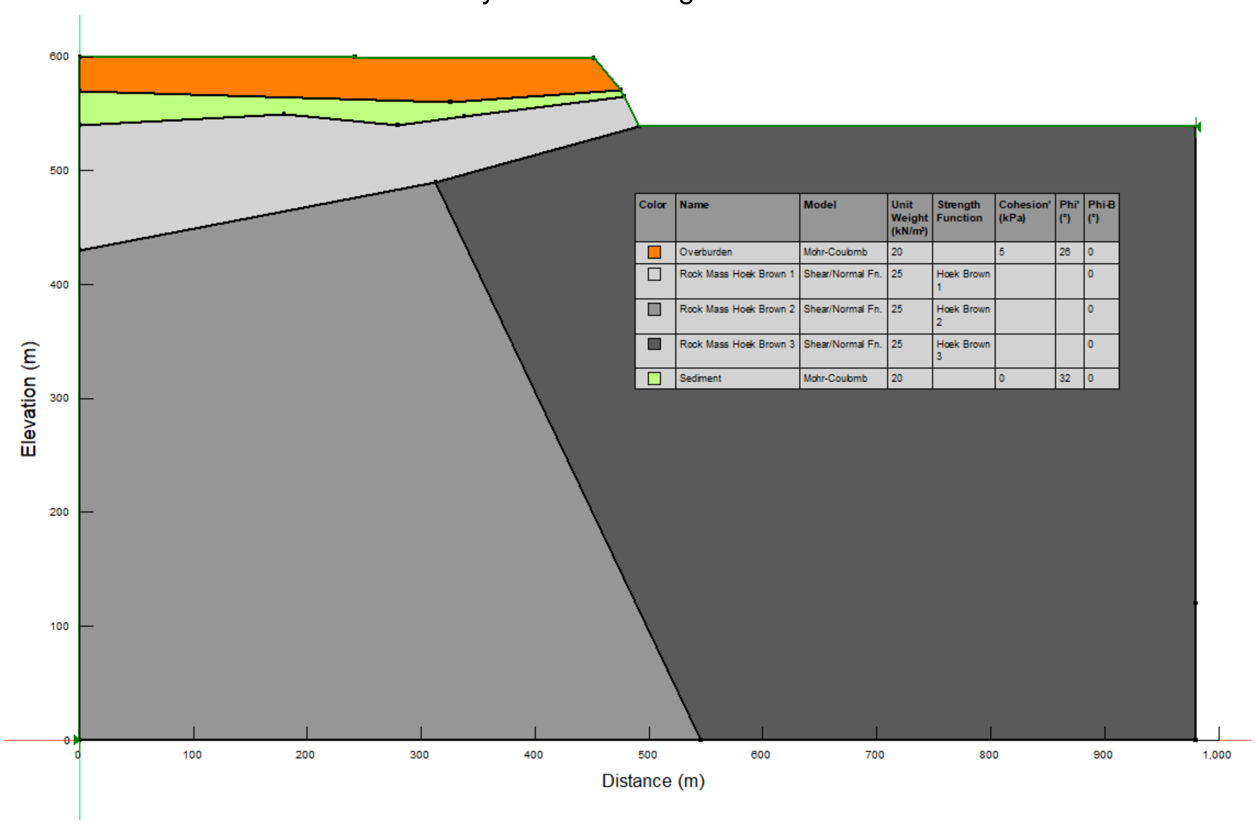
## Introduction

The design of open pit mines involves various facets of engineering analysis including slope stability and groundwater flow analysis. These two analysis types are combined to create a design that maximizes pit slope angles. The stability is often divided into kinematic and limit equilibrium types of analyses. The kinematic stability analysis is concerned with planar, wedge, and toppling modes of failure for the discontinuous rock mass. A stereographic analysis is used to identify the critical mode(s) of failure. The kinematic stability analysis generally governs the bench configuration and maximum bench slope angle.

A conventional limit equilibrium analysis is conducted to determine the maximum overall pit slope angle. The target factor of safety is typically 1.3 or greater. The analysis also involves a sensitivity analysis for groundwater depressurization and rock blasting disturbance. The objective of this example is to demonstrate how GeoStudio can be used to explore pit slope angle design. Specifically, multiple geometries are included in a single GeoStudio file, each having a unique geometric configuration.

## Numerical Simulation

Figure 1 presents the approximate pre-mining geology. The geology comprises overburden soil, sediments, and three rock units. Table 1 presents the inputs for the material strength definitions. The overburden and sediment layers were modeled using a Mohr-Coulomb material model, while the rock units were defined as Hoek-Brown materials. The Hoek-Brown materials were created by entering the Uniaxial Compressive Strength (UCS), intact rock parameter ($m_i$), Geological Strength Index (GSI), and the disturbance factor (D). For simplicity, this example assumes that the disturbance factor is equal to 0.8 for all rock mass units, although a sensitivity analysis could be conducted to account for variability due to blasting.




| Color | Name | Model | Unit Weight (kN/m³) | Strength Function | Cohesion' (kPa) | Phi' (°) | Phi-B (°) |
|---|---|---|---|---|---|---|---|
| | Overburden | Mohr-Coulomb | 20 | | 5 | 26 | 0 |
| | Rock Mass Hoek Brown 1 | Shear/Normal Fn. | 25 | Hoek Brown 1 | | | 0 |
| | Rock Mass Hoek Brown 2 | Shear/Normal Fn. | 25 | Hoek Brown 2 | | | 0 |
| | Rock Mass Hoek Brown 3 | Shear/Normal Fn. | 25 | Hoek Brown 3 | | | 0 |
| | Sediment | Mohr-Coulomb | 20 | | 0 | 32 | 0 |

**Figure 1. Pre-mining geometry and geology.**

**Table 1. Soil properties associated with each material.**

| Material | $c'$ | $\varphi'$ | $\gamma\ (\frac{kPa}{m})$ | UCS (MPa) | $m_i$ | GSI | D |
|---|---|---|---|---|---|---|---|
| **Overburden** | 5 | 26 | 20 | | | | |
| **Sediments** | 0 | 32 | 20 | | | | |
| **Rock Mass 1** | | | 25 | 100 | 18 | 40 | 0.8 |
| **Rock Mass 2** | | | 25 | 150 | 20 | 50 | 0.8 |
| **Rock Mass 3** | | | 25 | 100 | 17 | 45 | 0.8 |

There are three analyses in the GeoStudio project. Each analysis has a unique geometry. The geometry for each analysis could have been created using a variety of approaches, including the import of a cross section from AutoCad (i.e. DWG file). In this example, the following procedure was followed to generate the geometry of each analysis:

1. The geometry and geology presented in Figure 1 was created as a sacrificial analysis – it was deleted from the file once the other three analyses were created (analysis ‘a’ in Figure 2).
2. Each analysis was created by clicking on Define Analyses and selecting the option to Clone the ‘Analysis and Geometry’ (Figure 3). As the terminology implies, this operation creates a duplicate of the analysis, and it also creates a new and unique geometry that can be modified independent from any other geometry (Figure 4).
3. The Sketch Tools (sketch angular dimension, sketch linear dimension, etc) were used to outline the overall pit slope angle in the three analyses. For simplicity, the toe of the open pit was set to the same x-y coordinate in each analysis (770 m, 100 m).
4. The Split Tool was then used to create the pit wall geometry. This procedure is facilitated by the coordinate entry feature, which is available while in the Draw (Regions, Lines, Points) Mode, and the Split tool. For example, the benches were assumed to be 140 m in height. If the slope is 43° from horizontal (i.e. 137° for a right-to-left analysis with counter-clockwise as positive), the coordinate entry was “@y140<137”, which causes the mouse click to be positioned 140 m vertically upward and along a path that is 137° from horizontal relative to the starting point (Figure 5).

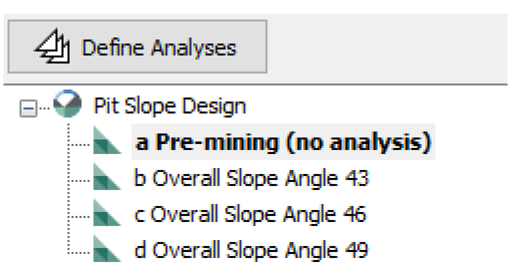



**Figure 2. Analysis tree in the GeoStudio Project.**

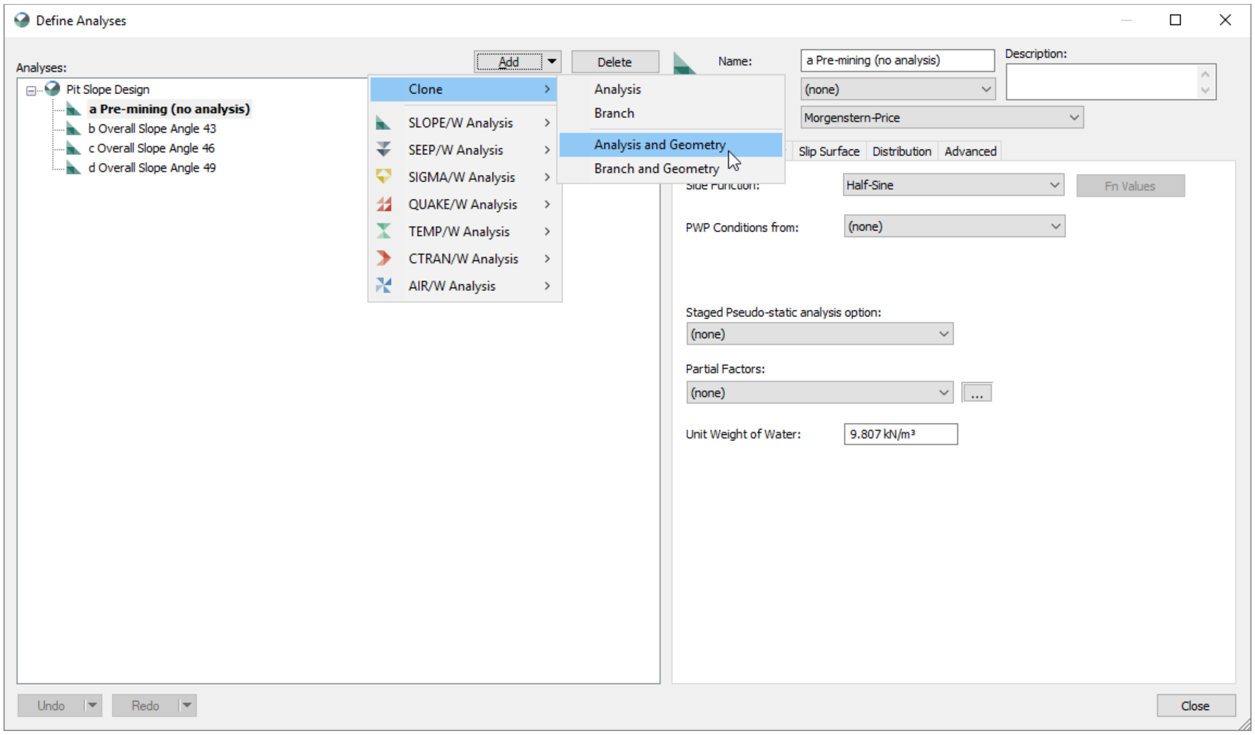



Figure 3. Define analyses window demonstrating ability to Clone both an analysis and geometry.

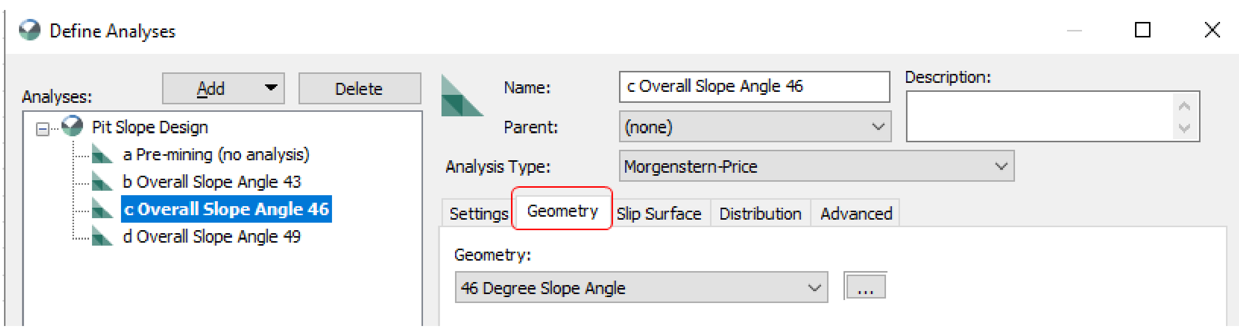



Figure 4. Geometry tab in Define Analyses.

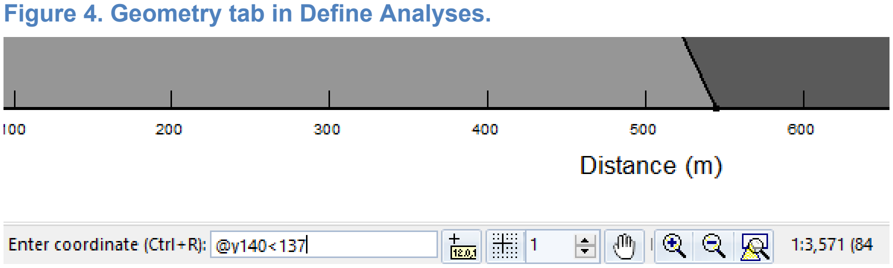



Figure 5. Example of coordinate entry to rapidly define the pit wall geometry using the Split Tool.

The pore-water pressure conditions were defined using a piezometric line (Figure 6). The location of the piezometric line was assumed to be controlled by the depressurization design, with the de-watering wells maintaining a horizontal distance into the slope of 35 meters near the crest and 50 meters near the toe. The slope angle in the overburden and sediments was reduced to approximately 30° and 35°, respectively. Finally, the entry-exit slip surface definition was drawn to ensure that a deep-seated mode of failure was analyzed.

| Color | Name | Model | Unit Weight (kN/m³) | Strength Function | Cohesion' (kPa) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Overburden | Mohr-Coulomb | 20 | | 5 | 28 | 0 | 1 |
| | Rock Mass Hoek Brown 1 | Shear/Normal Fn. | 25 | Hoek Brown 1 | | | 0 | 1 |
| | Rock Mass Hoek Brown 2 | Shear/Normal Fn. | 25 | Hoek Brown 2 | | | 0 | 1 |
| | Rock Mass Hoek Brown 3 | Shear/Normal Fn. | 25 | Hoek Brown 3 | | | 0 | 1 |
| | Sediment | Mohr-Coulomb | 20 | | 0 | 32 | 0 | 1 |

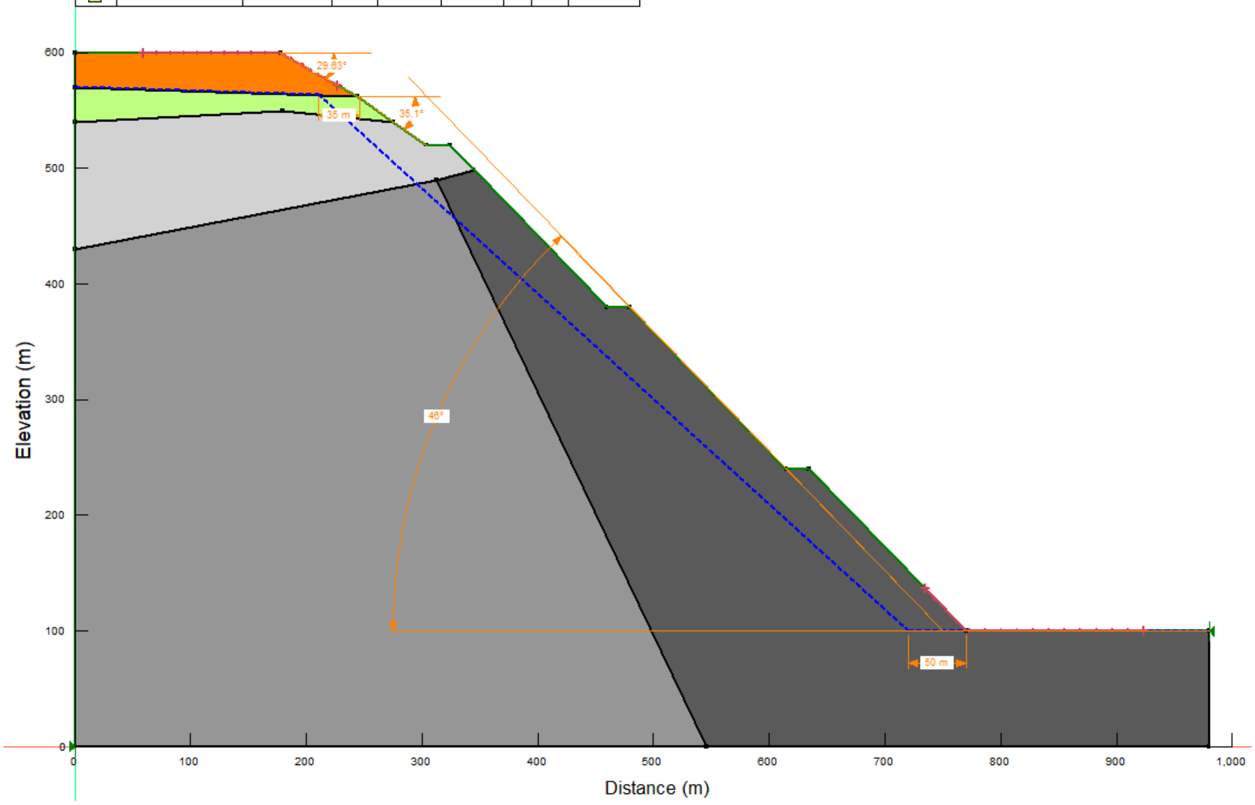



Figure 6. Location of piezometric line.

# Results and Discussion

Figure 7 to Figure 9 present the factor of safety for overall pit slope angles of 43°, 46°, and 49°, respectively. The factor of safety decreases from about 1.5 to 1.3 as the slope angle is increased from 43° to 49°, given the assumed piezometric conditions and rock mass disturbance.

# GeoStudio Example - Pit Slope Design using Multiple Geometries

| Color | Name | Model | Unit Weight (kN/m$^3$) | Strength Function | Cohesion' (kPa) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Overburden | Mohr-Coulomb | 20 | | 5 | 26 | 0 | 1 |
| | Rock Mass Hoek Brown 1 | Shear/Normal Fn. | 25 | Hoek Brown 1 | | | 0 | 1 |
| | Rock Mass Hoek Brown 2 | Shear/Normal Fn. | 25 | Hoek Brown 2 | | | 0 | 1 |
| | Rock Mass Hoek Brown 3 | Shear/Normal Fn. | 25 | Hoek Brown 3 | | | 0 | 1 |
| | Sediment | Mohr-Coulomb | 20 | | 0 | 32 | 0 | 1 |

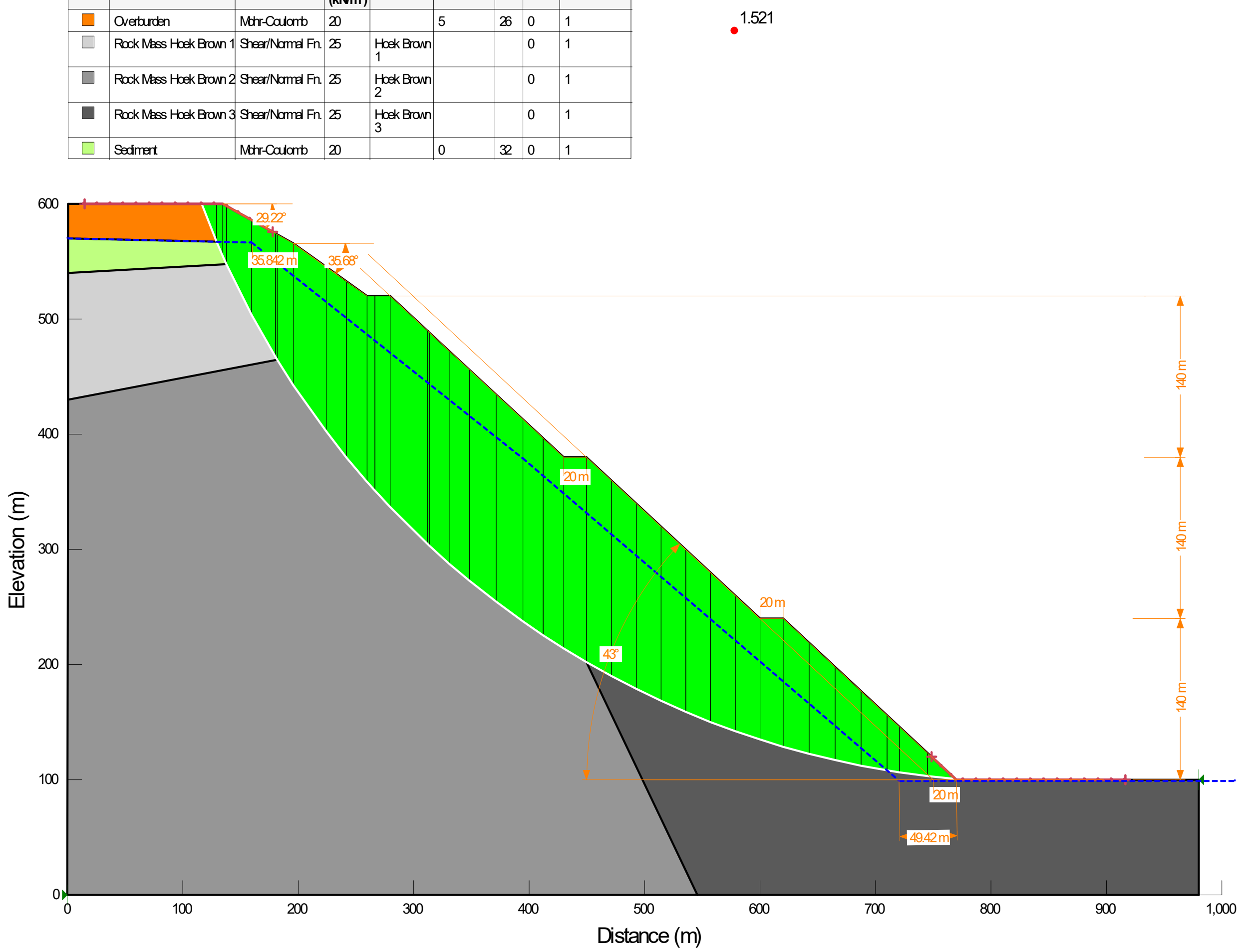
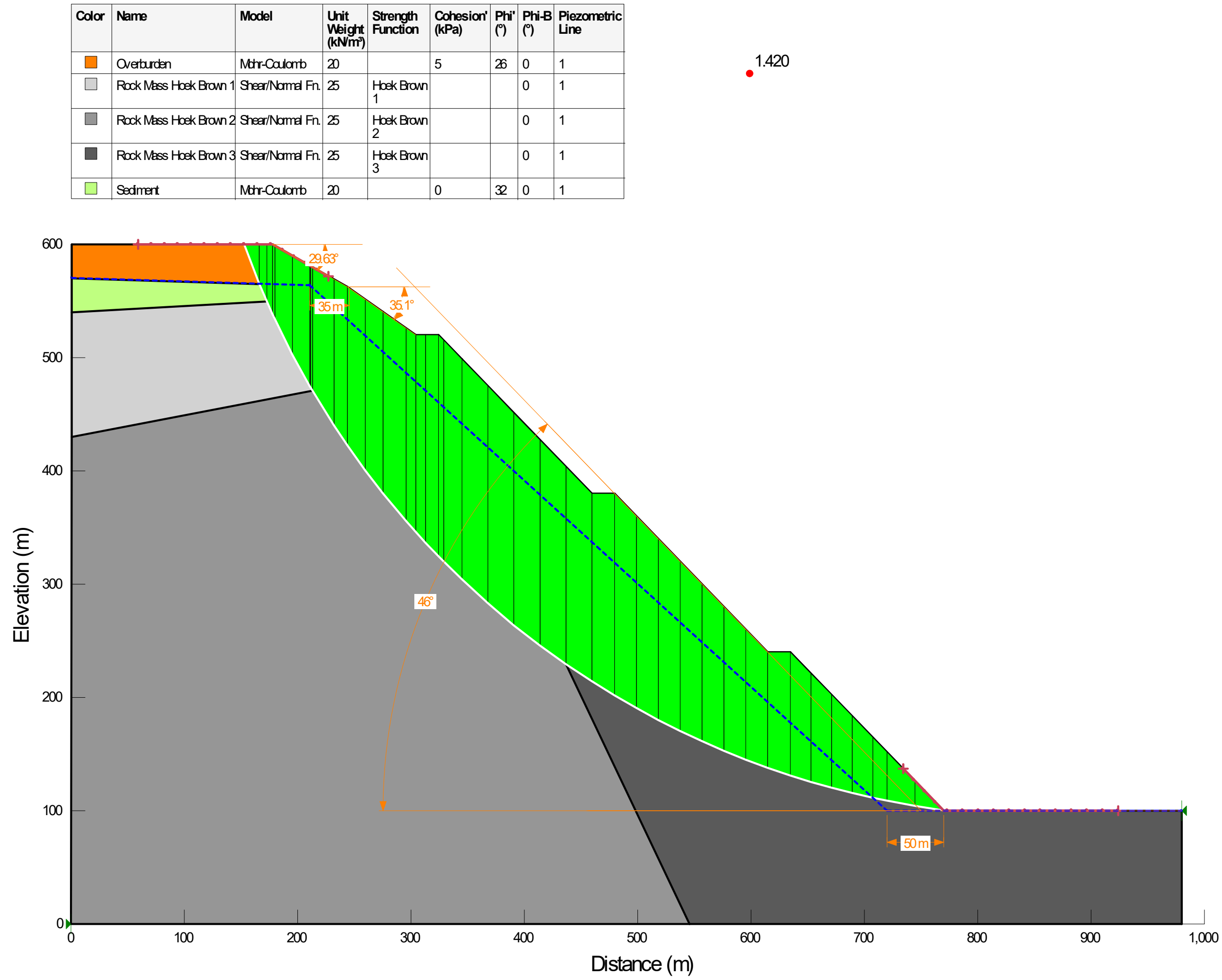



Figure 7. FOS for a pit slope angle of 43°.

# GeoStudio Example - Pit Slope Design using Multiple Geometries



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| | Rock Mass Hoek Brown 2 | Shear/Normal Fn. | 25 | Hoek Brown 2 | | | 0 | 1 |
| | Rock Mass Hoek Brown 3 | Shear/Normal Fn. | 25 | Hoek Brown 3 | | | 0 | 1 |
| | Sediment | Mohr-Coulomb | 20 | | 0 | 32 | 0 | 1 |



Figure 8. FOS for a pit slope angle of 46°.

| Color | Name | Model | Unit Weight (kN/m³) | Strength Function | Cohesion' (kPa) | Phi' (°) | Phi-B (°) | Piezometric Line |
|---|---|---|---|---|---|---|---|---|
| | Overburden | Mohr-Coulomb | 20 | | 5 | 26 | 0 | 1 |
| | Rock Mass Hoek Brown 1 | Shear/Normal Fn. | 25 | Hoek Brown 1 | | | 0 | 1 |
| | Rock Mass Hoek Brown 2 | Shear/Normal Fn. | 25 | Hoek Brown 2 | | | 0 | 1 |
| | Rock Mass Hoek Brown 3 | Shear/Normal Fn. | 25 | Hoek Brown 3 | | | 0 | 1 |
| | Sediment | Mohr-Coulomb | 20 | | 0 | 32 | 0 | 1 |

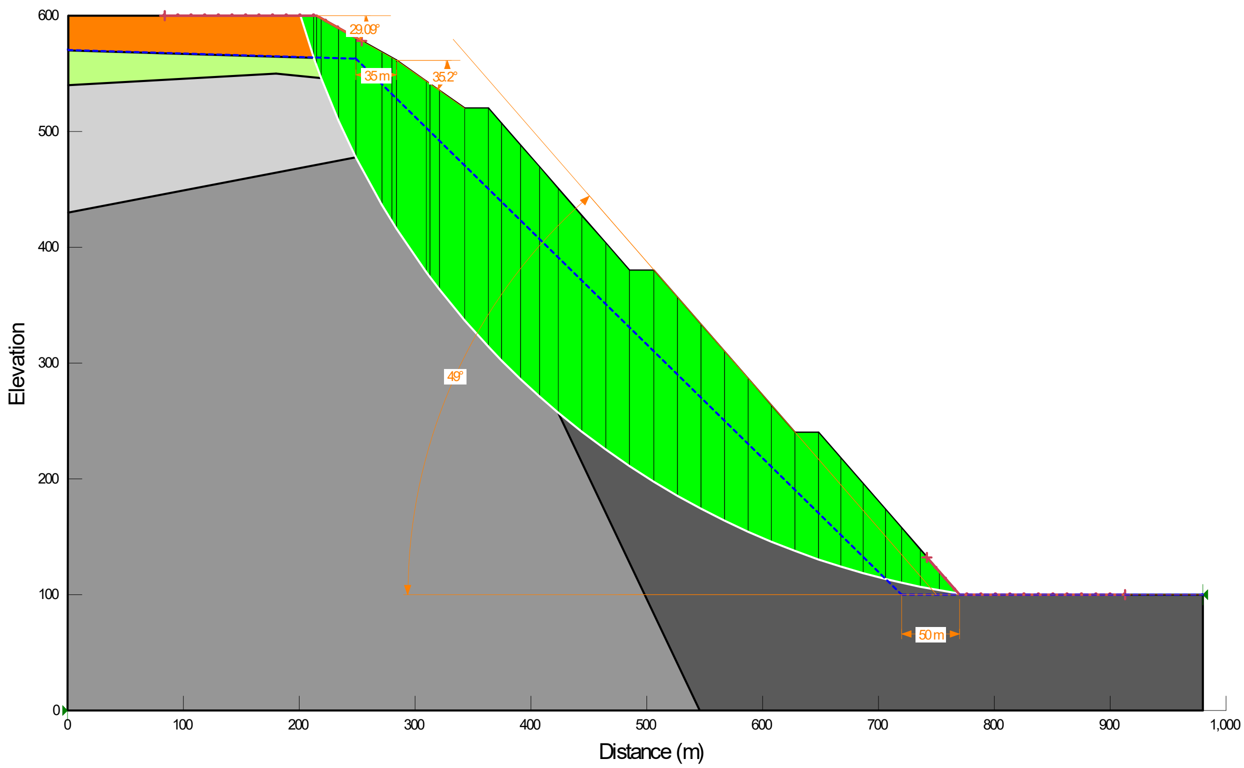


Figure 9. FOS for a pit slope angle of 49°.

## Summary

A GeoStudio Project file can include multiple analyses, each having unique geometry, allowing an engineer to explore the effect of geometry on the solution results. In the case of slope stability, changes in slope angle, or the introduction of stabilization measures (such as a toe berm), can all be analyzed within the same file. This eliminates the need for multiple GeoStudio files and it provides a transparent means of presenting the results of a geometric sensitivity analysis.