Slope Stability Back Analysis using Rocscience Software

A question we are frequently asked is, “Can Slide do back analysis?”
The answer is YES, as we will discover in this article, which describes various methods of back analysis using Slide and other Rocscience software.

In this article we will discuss the following topics:

- Back analysis of material strength using sensitivity or probabilistic analysis in Slide
- Back analysis of other parameters (e.g. groundwater conditions)
- Back analysis of support force for required factor of safety
- Manual and advanced back analysis
Introduction

When a slope has failed an analysis is usually carried out to determine the cause of failure. Given a known (or assumed) failure surface, some form of “back analysis” can be carried out in order to determine or estimate the material shear strength, pore pressure or other conditions at the time of failure. The back analyzed properties can be used to design remedial slope stability measures.

Although the current version of Slide (version 6.0) does not have an explicit option for the back analysis of material properties, it is possible to carry out back analysis using the sensitivity or probabilistic analysis modules in Slide, as we will describe in this article.

There are a variety of methods for carrying out back analysis:

- Manual trial and error to match input data with observed behaviour
- Sensitivity analysis for individual variables
- Probabilistic analysis for two correlated variables
- Advanced probabilistic methods for simultaneous analysis of multiple parameters

We will discuss each of these various methods in the following sections.

Note that back analysis does not necessarily imply that failure has occurred. Back analysis can also refer to the determination of required material properties or support force in order to achieve a specified factor of safety or reliability. Slide 6.0 does have an explicit option for back analysis of support force to achieve a specific factor of safety as described later in this article.
**Slope Model**

For the purpose of this discussion we will consider the following slope model. The model contains a weak layer (green material) surrounded by stronger material above and below. Failure has occurred along the red line which traverses through the weak layer.

The location of the water table at failure is known (blue line). The properties of the strong material are known (cohesion = 17.5 kPa, friction angle = 30 degrees). Using back analysis, we wish to determine the strength properties of the weak layer. This model can be downloaded here.

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**Sensitivity Analysis for Back Analysis of a Single Variable**

Sensitivity analysis allows you to determine the value of a single unknown variable (e.g. cohesion or friction angle of one material), if we assume that all other slope parameters are known (i.e. failure surface, safety factor, strength parameters, pore pressure).

For example, let’s assume that the friction angle of the weak layer is known (15 degrees) but the cohesion is uncertain. We can define a single variable (weak layer cohesion) in the material statistics dialog. We will guess at the mean value of cohesion (10 kPa) and enter relative min and max values of 10. This will effectively vary the cohesion between 0 and 20 kPa for the sensitivity analysis.
Now compute the analysis and view the sensitivity plot. Right click on the plot, select Sample Exact Value and enter a safety factor value = 1 (since failure has occurred the safety factor is by definition equal to 1). As you can see in the plot below, a weak layer cohesion of about 5.5 kPa corresponds to a safety factor = 1.

Or conversely, we could assume the cohesion was known and the friction angle was unknown. For example, if we set the mean cohesion = 5 kPa, and allowed the friction angle to vary, we would obtain the following sensitivity analysis results (friction angle = 15.3 for safety factor = 1).
Probabilistic Analysis for Back Analysis of Two Variables

If we assume that both cohesion and friction angle are unknown parameters for the weak layer, we can use probabilistic analysis to determine a relationship between cohesion and friction angle, which results in a safety factor of 1 for the particular failure surface. i.e. rather than a single exact answer, there are an infinite number of solutions (i.e. pairs of values for cohesion, friction) to the problem.

First turn on the probabilistic analysis in Project Settings. In the material statistics dialog, define both cohesion and friction angle of the weak layer as random variables. We will assume a Uniform distribution of both variables so that samples will be equally generated across the entire range of values for both variables.

![Material Statistics Dialog](image)

Note: in this example, the mean values (cohesion = 5 and friction angle = 15) result in a safety factor = 1, since we have already determined these values in advance. In general, if the strength parameters were entirely unknown, you would initially input a “best guess” for the mean, min and max values. Then based on the initial results, you could refine the input if necessary, to better match the slope behaviour (i.e. if a safety factor of 1 is not achievable for a known failure surface then you will have to modify the mean values or ranges to obtain the desired results).

Now run the probabilistic analysis and select the scatter plot option. In the scatter plot dialog, choose cohesion versus friction angle. Select the Hilight Data checkbox, choose Factor of Safety – Spencer, select the Range option, and enter a safety factor range of 0.99 to 1.01.
Now generate the scatter plot and you should see the following. This plot shows all values of cohesion and friction angle generated by the analysis. Since we used a uniform distribution with no correlation between the variables, the points are equally distributed over the entire range of possible values. Data points corresponding to a safety factor of about 1 are highlighted in red.

Right-click on the plot and select Hilighted Data Only from the popup menu and the plot should look as follows:
This plot gives you the relationship between cohesion and friction angle of the weak layer, for a safety factor of (approximately) 1 for the specified failure surface. The line through the data represents a (linear) best fit through all data points which resulted in a safety factor between 0.99 and 1.01. The alpha and beta values below the plot represent the y-intercept (friction angle) and slope of the line. Any point on this line represents a pair of values (cohesion, friction angle of the weak layer) which result in a safety factor of approximately 1 for the given slip surface.

By changing the range of safety factor values in the Scatter Plot dialog, you can determine a best fit curve for other values of safety factor. For example, if you changed the safety factor range to 1.19 to 1.21, you would obtain a curve of cohesion, phi values for a safety factor of 1.2. However note that the slip surface would remain the same, so these values would be hypothetical if the surface represented an actual failure.

For a more detailed tutorial covering the above steps see Slide Tutorial # 23.
Back Analysis of Other Variables

So far we have only considered the material strength properties for back analysis. Since Slide allows nearly all input variables to be used as random variables for a sensitivity or probabilistic analysis, you could use the procedure described above to determine the values of other variables from a back analysis (e.g. water table location, pore pressure parameters, loading conditions etc).

This is left as an additional exercise to explore. The user is referred to Slide tutorials 8, 9, 10 and 11 for further examples of sensitivity and probabilistic analysis capabilities of Slide.

Back Analysis of Support Force

Slide does have an explicit option for the calculation of the required support force, in order to achieve a minimum factor of safety for all potential slip surfaces. This option is found in the Support menu in the Slide Model program.

![Back Analysis of Support](image)

NOTE: Back analysis of reinforcement load only works for Bishop, Janbu and Janbu Corrected methods.

The support force which is determined from the back analysis can be used as the basis for a preliminary support design, which can then be refined using an iterative approach. For further information see the Back Analysis of Support Force topic in the Slide help system.

Also see the back analysis tutorial available in movie format.
Manual Back Analysis

Back analysis can also be performed “manually” using a trial and error procedure to determine a best fit of parameters to an existing slope failure. For example, the determination of a complex pore pressure scenario in the slope shown below, by manual back analysis using Slide is described here.

![Manual Back Analysis Diagram](image)

Advanced Back Analysis

An important practical use of material strength back analysis is to determine strength parameters which are then used as input into a remedial design of a failed slope. However, as pointed out in chapter 12 of Ref. 1 (Duncan and Wright), real slope failures may involve progressive failure, time dependent material properties or pore pressure conditions, multiple materials, complex or anisotropic shear strength, residual strengths etc. The simple analysis procedures described in this article do not necessarily account for all of the complex conditions encountered in real slope failures, and this must be taken into consideration if back analysis parameters are to be used in a remedial slope design.

Procedures have been described for probabilistic back analysis of multiple parameters (more than two variables). This is beyond the scope of this article; however the reader is referred to Ref. 2 for a description of multi parameter back analysis of slope stability using probabilistic methods.
Use of Other Rocscience Programs for Back Analysis

The slope stability programs RocPlane (2D plane failure analysis) and Swedge (3D wedge analysis) both contain sensitivity and probabilistic analysis options, and could be used for back analysis in a similar manner to that described in this article. In the figure below Swedge is used for sensitivity analysis of joint cohesion.

Most other Rocscience programs can be used for back analysis using a manual “trial and error method” to match input parameters with known model behaviour. For example this is discussed for the finite element stress analysis program Phase2 in this article and also in Ref.3.

References