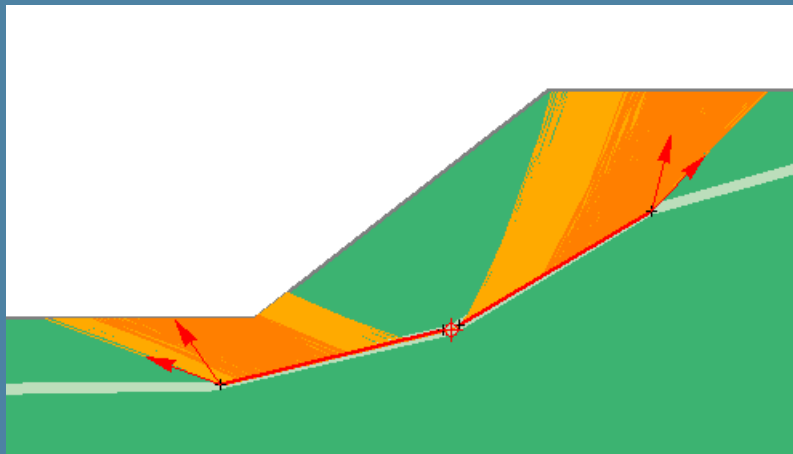
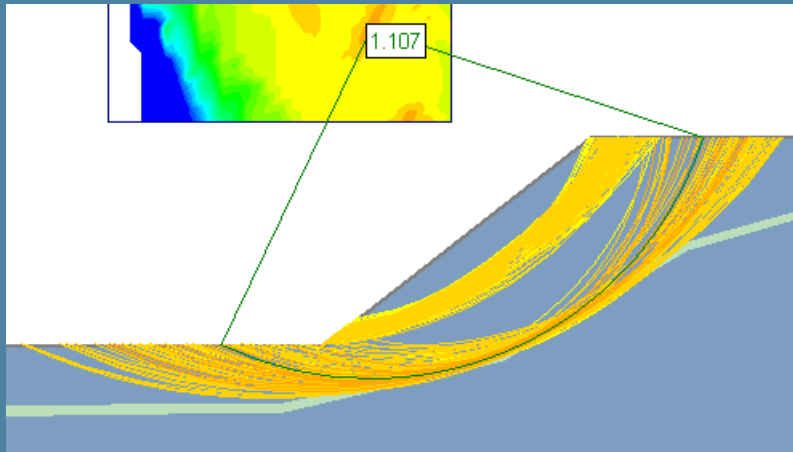


Critical Slip Surface Search Methods in *SLIDE*



Introduction

Since the release of SLIDE, we at Rocscience have been very impressed at the range of problems to which SLIDE has been applied. We have seen an amazing variety of models, from quite simple, to very complex, which users have successfully analyzed using SLIDE.

However, one trend we have also noticed, is that users do not always carry out the critical slip surface search, as thoroughly they should be doing. In particular:

1. Users do not always take advantage of the wide range of search methods and techniques which are available in SLIDE.
2. Users sometimes incorrectly apply searching techniques, or use inappropriate search methods for the problem they are trying to analyze.

The result is that *the most critical slip surfaces are not always located*. When we consider:

1. the importance and monetary value of most slope stability analyses,
2. the relatively LARGE amount of time and effort involved in assembling the input data required for a slope stability analyses,
3. the relatively SMALL effort involved, for the user to carry out a thorough critical slip surface search, given the very powerful, but easy to use tools provided in SLIDE,

the user should always make every effort to ensure that they have performed the critical slip surface search as thoroughly as possible.

The purpose of this article, is to:

1. Discuss some general principles which the user should keep in mind, while carrying out a critical slip surface search in SLIDE
2. Point out some specific problems and issues which are encountered by users, and discuss ways in which to improve or correct their searching techniques.
3. Point out certain features and capabilities of the search methods in SLIDE, which users may not be aware of, or may not take advantage of.

Search Methods in SLIDE

The primary goal of a slope stability analysis, is to determine the potential slip surface which has the overall minimum factor of safety, and therefore to determine the overall safety of the slope design.

In SLIDE, there are several different search methods which are available, which automate the task of searching, for either circular or non-circular slip surfaces.

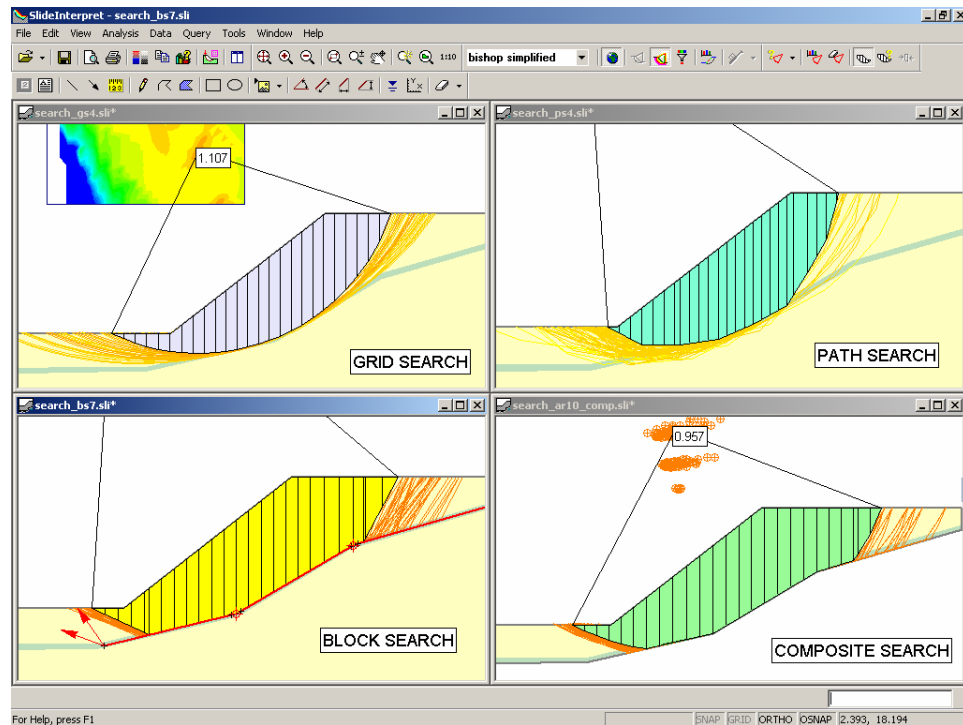


Figure 1: Different search methods applied to the same problem.

In the current version of SLIDE, there are THREE search methods available for CIRCULAR slip surfaces:

- Grid Search
- Slope Search
- Auto Refine Search

There are TWO search methods available for NON-CIRCULAR slip surfaces:

- Path Search
- Block Search

Each of these search methods have a number of different options available to the user. When taken as a whole, the different search methods and options in SLIDE, constitute a very powerful toolkit, enabling users to efficiently locate the most critical slip surfaces for a slope stability model.

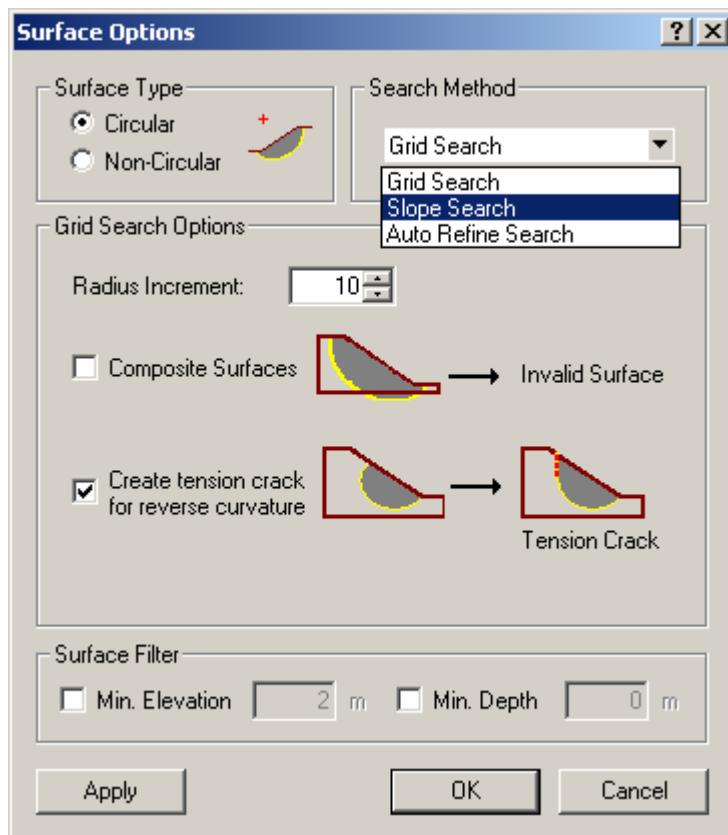


Figure 2: Dialog for selecting search method and search parameters.

Which Search Method To Use ??

The first question which presents itself, is of course, do I analyze for CIRCULAR or NON-CIRCULAR failure surfaces. The answer to this is not always obvious.

The following table provides some guidelines, for the selection of a search method.

MODEL	SEARCH METHODS
Homogeneous slope (1 material)	Circular Search*
Multi-material model WITHOUT well-defined weak layers	Circular Search Path Search Block Search
Model with well defined weak layer	Block Search Circular Search (with Composite Surfaces option turned on) Path Search

* Grid Search, Slope Search or Auto Refine Search

Table 1: Guidelines for selecting a search method.

Note that in Table 1, the search methods are listed in order, from most appropriate, to least appropriate, for a given model type.

In general, it is recommended that the user try MORE THAN ONE search method, and consider both CIRCULAR and NON-CIRCULAR slip surfaces, and search methods.

Since all of the search methods in SLIDE are very simple to use, and the time taken to run a complete analysis, with thousands of slip surfaces generated, is very short in most cases, it is HIGHLY RECOMMENDED that users ALWAYS EXPERIMENT with different search methods, and with the various options associated with each search method.

The user may be very surprised at the results, when a little extra effort and thought, is put towards the critical surface search. You may discover slip surfaces with significantly lower safety factors, simply by spending a little extra time with the search.

How Does Searching Work ??

Although the search methods in SLIDE are designed to be very simple to use, and are to a large degree “automatic”, they all require some input by the user, in order to be successful.

Four of the five methods (with the exception of the Block Search, which always requires search objects to be defined by the user), will run with virtually no input from the user. For the following methods:

- Grid Search
- Slope Search
- Auto Refine Search
- Path Search

the search method simply needs to be selected (in the Surface Options dialog), and the analysis can be run (the Grid Search requires a slip center grid to be defined, but this can be done automatically with the Auto Grid option).

The search results, using the default settings for a given method, may, in some cases be quite good. It is possible that you may locate the critical slip surface, simply by selecting a method, and running the analysis.

However, in general, this will not be the case, and some thought will have to go into the customizing of the search, to suit the model.

Another aspect of searching, that the user should appreciate, is that, of the five search methods available in SLIDE, only ONE -- the Auto Refine Search (circular slip surfaces) – is truly SEARCHING for the critical slip surface. The Auto Refine Search actually uses the results of one search iteration, in order to automatically narrow the search location, and thus locate the slip surface with the minimum safety factor.

All of the other search methods in SLIDE, are simply using either a regular pattern of slip surfaces (eg. the Grid Search), or random number generation (Slope Search, Path Search and Block Search), to generate the slip surface locations.

In any case, *for all search methods* in SLIDE, user input is very important, in order to be certain that the critical slip surfaces have been located.

Circular Search Methods

The three search methods in SLIDE for CIRCULAR slip surfaces:

- Grid Search
- Slope Search
- Auto Refine Search

should all, if they are utilized properly, locate the same (or very nearly the same) critical slip surface. If the searches have been carried out thoroughly, there is no reason that these three methods, should give different results, for the critical CIRCULAR slip surface.

Therefore, the choice of which method to use, is really a matter of user preference.

- Most users prefer to use a Grid Search, since it is a very commonly used method in slope stability analysis, and is familiar to most users.

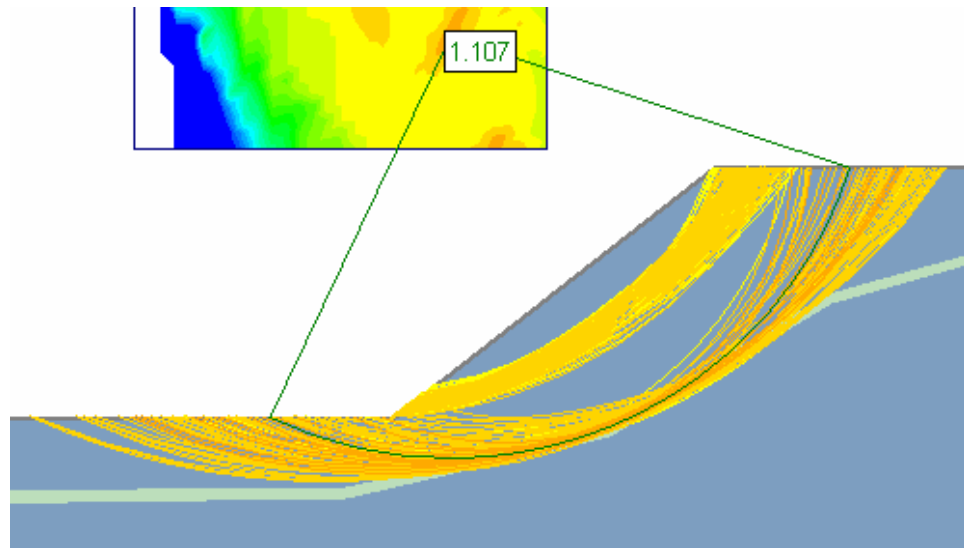


Figure 3: Grid Search for circular slip surfaces.

- The Slope Search is an alternative search method, which allows the user to define the search in terms of areas of the slope surface, rather than a grid of slip centers.

- The Auto Refine Search method is exclusive to SLIDE, and uses a simple but effective algorithm, for iteratively refining the search area on the slope, until the critical surface is located.

Each of the above methods can be used with the Composite Surfaces option, in order to search for composite circular / non-circular slip surfaces, such as those formed along a bedrock / soil interface.

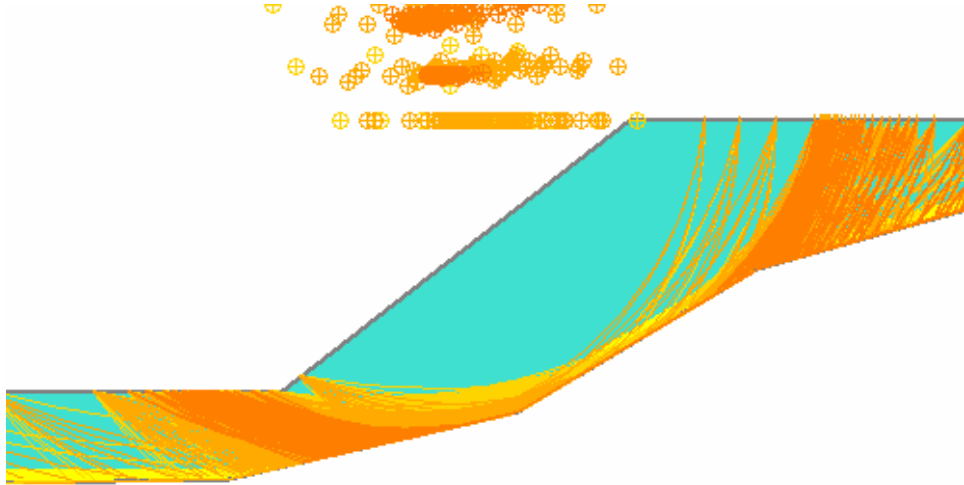


Figure 4: Auto Refine Search with Composite Surfaces option.

When searching for CIRCULAR slip surfaces, it can't hurt to try more than one method (or try all three !!) Compare results, and experiment with different search options and parameters. If each method gives very nearly the same critical slip surface, then this is a good indication that you have located the true critical circular slip surface.

NOTE: for further details about each search method, please see the SLIDE Help system. The information in the SLIDE Help system is also available as a PDF document, from the Rocscience website, or with the SLIDE program.

Non-Circular Search Methods

The two search methods in SLIDE for NON-CIRCULAR slip surfaces, are:

- Path Search
- Block Search

Unlike the CIRCULAR slip surface search methods, the Path Search and Block Search methods for NON-CIRCULAR slip surfaces, will not generally locate the same critical surfaces. This is because of the very different ways in which the surfaces are generated, and because of the different situations in which the two methods are typically used.

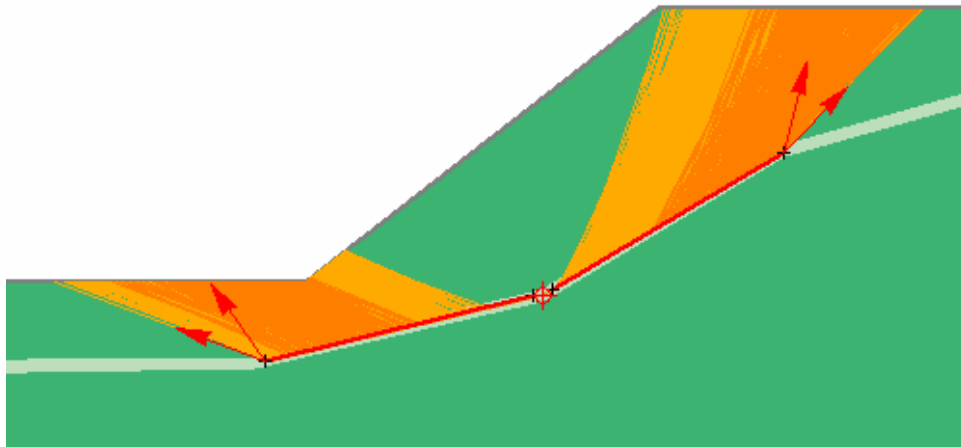


Figure 5: Block Search for non-circular slip surfaces.

The Block Search is the preferred method, when a well defined weak layer is present in a slope model. This is because the Block Search method allows the user to define any number of “Block Search Objects”, in order to precisely narrow the search within any material, area or layer of the slope. This will be demonstrated in the following tutorial.



Figure 6: Path Search for non-circular slip surfaces.

The Path Search is more appropriate, if a well defined weak layer does NOT exist. If you are really not sure about the shape, or location of slip surfaces for a model, then give the Path Search a try. If you simply use the default search parameters, with no user input at all, this will often at least give you an idea of where the critical slip surfaces are located. Then, based on the results using the default search parameters, you can begin to narrow the search, using the options provided with the Path Search.

Search Methods Tutorial 1 – Weak Layer Model

The following example will use a model with a non-linear weak layer, to demonstrate various issues related to searching.

If you wish to carry out the steps in this tutorial, [click here](#) to download the SLIDE file **search1block.sli**. Open the file in SLIDE.

Block Search

As we have already mentioned, the most appropriate search method, for a model with a well defined weak layer, is usually a Block Search. So we will start by doing a Block Search on this model.

One of the common errors in using the Block Search, is a misunderstanding of how the Block Search Objects should be used, to generate slip surfaces along a weak layer.

In particular, confusion sometimes arises when a Line Block Search object is used to generate slip surfaces along a weak layer. When you define a Line Block Search object within a weak layer, you must remember the following:

- Only ONE point along a slip surface, is generated by each Block Search object.
- When you define a Line Block Search object, you are simply constraining the generation of a single point, to the line you have defined.
- However, if a weak layer is not exactly linear, this does not guarantee that the *slip surface* will remain within the weak layer, since each slip surface is formed by joining each of the points created by each block search object.

This is demonstrated in the file you have just opened. Notice the following:

- The weak layer (green material), is not perfectly linear, but changes direction at a few locations.
- Two Line Block Search objects have been defined, within the weak layer.

Let's run the analysis for this model, and see the results of this search.

1. Select Compute.
2. Select Interpret to view the results in the SLIDE INTERPRET program.
3. Select the Show Slices option, to highlight the slip region.

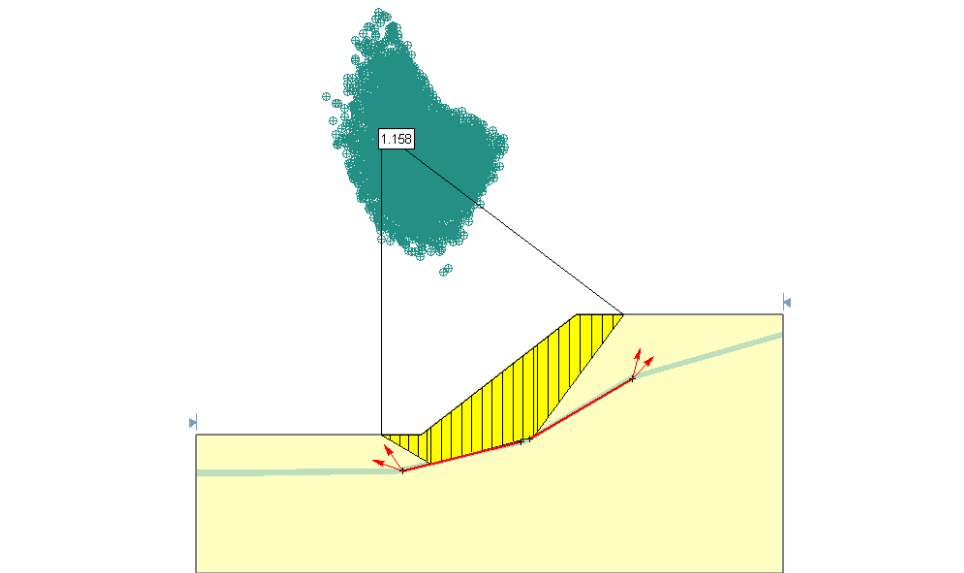


Figure 7: Results of improperly defined Block Search.

As you can see, defining the Block Search in this way, has not produced the desired results. The critical slip surface has not followed the weak layer as expected.

- Because each Block Search Line only generates a single point along the slip surface, the resulting section of slip surface which joins the two points, is, for most of the surfaces generated, actually OUTSIDE of the weak layer. This is illustrated in Figure 8.
- The result is that the search has located a surface which traverses only the lower section of the weak layer. (This is the result of a point being generated near the “bottom” of the upper line search object, and a point generated near the “bottom” of the lower line search object.)

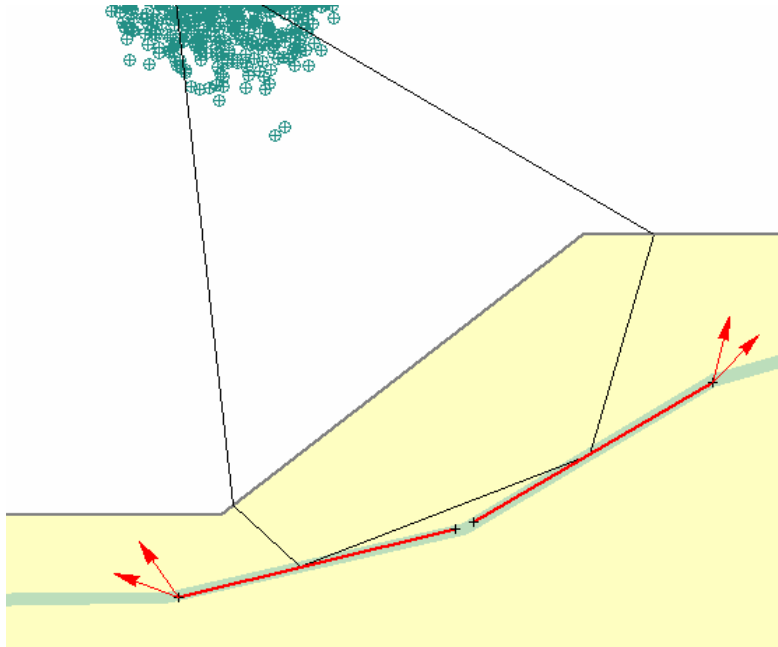


Figure 8: Slip surface generated by improperly defined Block Search within non-linear weak layer.

In order to carry out this search correctly, one simple modification is required – a single “Point” Block Search object, should be added, between the two line search objects, at the “bend” in the weak layer. This will then generate the correct search for this model.

Do this as follows:

1. Return to the SLIDE MODEL program. Zoom in to the area of the model where the weak layer and the line search objects are located. You can use the Zoom Window option, or simply rotate the mouse wheel forward.
2. Select the Add Block Search Point option from the toolbar, or from the Block Search sub-menu in the Surfaces menu.
3. Now add the Block Search Point object between the two line search objects, at the “bend” in the weak layer. The exact location is not critical, you can enter the point graphically by clicking with the mouse, or enter x-y coordinates of (12.05, 9.65) in the prompt line at the bottom right of the screen, and hit the Enter key.
4. You should see the Block Search Point object on the model.
5. Now press F2 to Zoom All.

Now select Compute, and then select Interpret to view the results. Select the Show Slices option, to highlight the slip region.

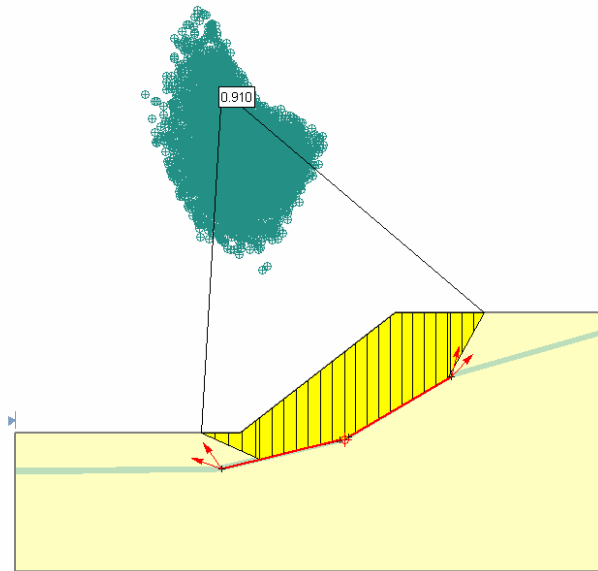


Figure 9: Results of corrected Block Search.

As you can see, the search has now generated surfaces correctly within the non-linear weak layer, because of the additional Block Search Point which we added to the model. This additional point, forces all of the slip surfaces which were generated, to correctly “follow” the weak layer, around the bend at that location.

The critical slip surface (Bishop analysis), now has a safety factor of 0.91, which is significantly less than the minimum surface shown in Figure 7 (FS = 1.158).

- The example demonstrated here, can be extended to follow any shape of irregular weak layer. Simply locate a Block Search Point at each “bend” in the weak layer.
- Then define two Block Search lines (one at each end of the weak layer), so that the search can determine the location of the critical slip surface.
- NOTE: since you may not know in advance where to locate the Block Search lines which denote the limits of the search, it may take some trial and error, to determine where the Block Search lines and points should be located within the weak layer.

Note that in Figure 9, you can see that the critical slip surface exits the weak layer at the uppermost point of the upper line search object. When this occurs, you should always extend the search, by either lengthening the existing line search object (if the weak layer is linear), or in this case, adding another point search object, and then an additional line search object, within the weak layer at the upper right of the model.

This is left as an optional exercise. If you carry this out, you will find that the critical slip surface is similar to that shown in Figure 9, however, the slip surface does extend slightly further up the weak layer. This is shown in Figure 10. Note that the safety factor is almost identical as well, indicating that we have, for practical purposes, determined the extents and location of the overall critical slip surface.

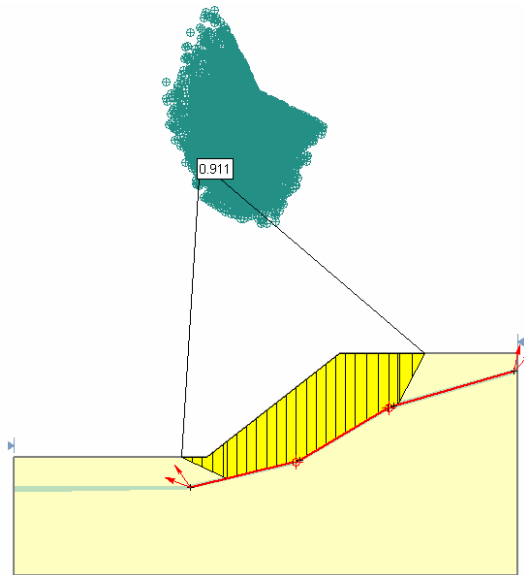


Figure 10: Additional search objects added to weak layer, to ensure that the overall critical slip surface has been located.

Finally, we will make one further comment about using a Block Search within a weak layer – if the weak layer has a substantial thickness, relative to the scale of the model, then you could try using narrow Block Search “Window” objects, rather than Line objects, in order to define the search within the layer. This will allow the search to cover the weak layer more thoroughly, rather than fixing the search along pre-determined lines.

Path Search

Although we have stated that the Path Search is not recommended for models with well defined weak layers, many users often attempt to use the Path Search method for this type of model.

Let's try out the Path Search for this model, and see what happens.

1. Return to the SLIDE MODEL program.
2. Save the current file as a new file called **search1path.sli**.
3. Select Surface Options from the Surfaces menu, and change the Search Method to Path Search. Select OK.
4. Select Compute.
5. Select Interpret.
6. Select the Show Slices option, to highlight the slip region.

You should see the following critical slip surface (Bishop analysis), with a safety factor of 1.087.

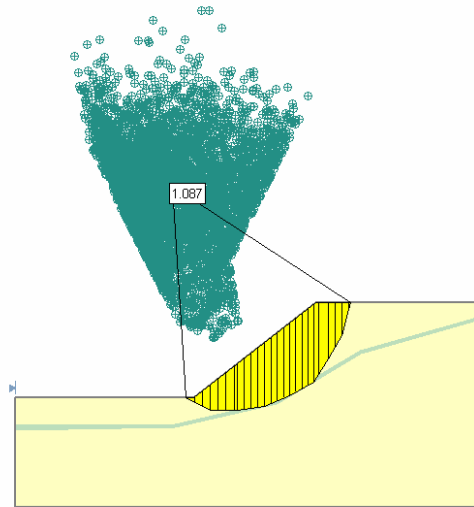


Figure 11: Critical surface (Bishop) determined by Path Search.

NOTE:

- The critical slip surface obtained from the Path Search has a significantly higher safety factor than the minimum slip surface from the Block Search
- This surface has located the weak layer, but only for a portion of the surface.
- It is interesting to note that this surface is actually quite nearly circular.

If you compare Figure 9 (Block Search) with Figure 11 (Path Search) you can see that the Path Search surface has not captured as much of the weak layer, as the Block Search. Let's examine this a bit further.

Do the following for EACH of the two files (**search1block** and **search1path**):

1. Right click the mouse anywhere on the slip surface, and select Graph Query from the popup menu.
2. In the Graph Slice Data dialog, select Base Cohesion from the Primary Data drop-down list. Select Create Plot.
3. View the plot of Cohesion versus Distance for each slip surface. (Note that the Cohesion of the weak layer is equal to 0 and the Cohesion of the rest of the slope material is equal to 5).
4. Tile the views (select Tile Vertically from the toolbar).

Compare the two graphs, and you can see that the Block Search surface has traveled a greater distance through the weak layer (Cohesion = 0), than the Path Search surface.

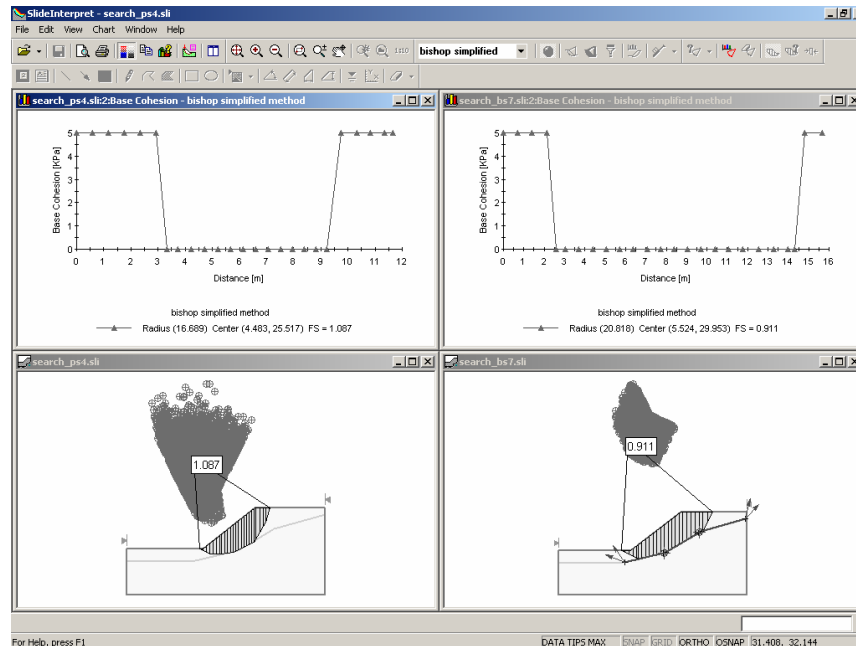


Figure 12: Comparison of Block Search and Path Search.

Now close the two graphs.

As a challenge, it is left to the user to experiment with all of the Path Search parameters, in order to try to locate a lower safety factor surface, using the Path Search. Try the following:

1. Narrow the slope limits, or use a double set of slope limits, to narrow the areas of the slope where slip surfaces are generated. Hint: use the Define Slope Limits option to specify a double set of limits, and then graphically move the slope limit markers to new locations with the Move Limits option.
2. In the Surface Options dialog, experiment with all of the Path Search parameters: try customizing the Initial Angle at Toe values and the Segment Length value. Turn Pseudo-Random OFF and Convex Surfaces Only ON. Hint: only change one parameter at a time, so that you can see the effects of individual parameter changes.
3. Increase the number of surfaces.

If you experiment with the parameters, you should be able to locate a slip surface with a safety factor less than 1, however, it may take a few tries !!

In Figure 13, we have managed to locate a slip surface, using the Path Search, with a safety factor of 0.987. See if you can do better!

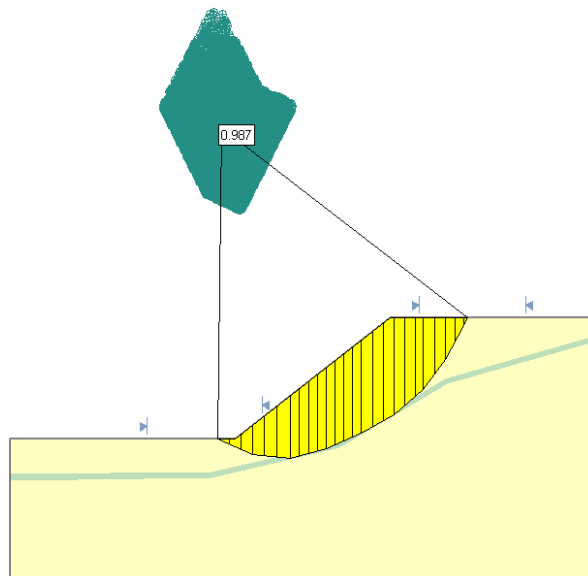


Figure 13: Results of customized Path Search.

Anyways, the point here is that, the Path Search is really not designed to search for slip surfaces within a narrow weak layer. As you will see, it takes a considerable amount of effort and experimentation with the Path Search, in order to find a surface which approaches the safety factor of the Block Search critical surface.

Remember that the Path Search is NOT ACTUALLY “SEARCHING” for a weak layer. The Path Search only “finds” the weak layer, by the random generation of many, many surfaces.

In conclusion, the Block Search is usually the best and most appropriate search method, for models with a well defined weak layer. (However, the Composite Surfaces option may also be quite effective, as discussed at the end of this tutorial).

The Path Search can be used for models with a weak layer, but requires more effort, and may not be effective at finding the true critical slip surface. It is important to note that, if the weak layer in this model were made slightly narrower (say, half as wide), then the Path Search might not be able to “find” the weak layer at all. Also, weak layers which are highly irregular in shape, will not generally be located by a Path Search, and will require the use of a Block Search.

Circular Surface Search Methods

For models with a well defined weak layer, the CIRCULAR surface search methods in SLIDE (Grid Search, Slope Search or Auto Refine Search), are generally not recommended.

Depending on the relative thickness of the weak layer, a circular search may or may not be able to locate a weak layer. In any case, even if a circular search does locate a weak layer, the resulting critical slip surface will almost always have a higher safety factor, than a NON-CIRCULAR surface generated by a Block Search or a Path Search, as described previously.

Let's try the circular search methods with the current model, and see the results.

1. Return to the SLIDE MODEL program.
2. Save the current file as a new file called **search1grid.sli**.
3. Select Surface Options from the Surfaces menu, and change the Surface Type to Circular, and the Search Method to Grid Search. Select OK.
4. Select the Auto Grid option, enter 30 x 30 as the number of grid intervals and select OK.
5. Select Compute.
6. Select Interpret.
7. Select the Show Slices option, to highlight the slip region.

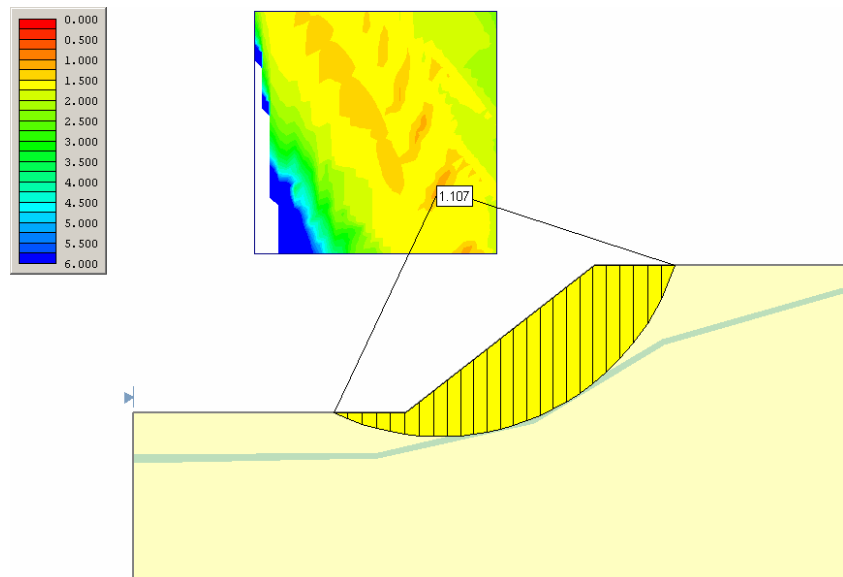


Figure 14: Grid search applied to model with weak layer.

As you can see in Figure 14, the Grid Search has detected the weak layer for this model. However, the safety factor is significantly higher than the surface obtained by the Block Search.

As an optional exercise, try the Slope Search and the Auto Refine Search methods, and compare results with the Grid Search.

Although the circular surface search methods will detect the weak layer for this model, if the weak layer had been defined more narrowly, this might not be the case, and the safety factors would be considerably higher.

Although a circular search is obviously not recommended for models with well defined, narrow weak layers, such as this example, there is an exception to this rule – the Composite Surfaces option.

Composite Surfaces Option

If you use any one of the three CIRCULAR surface search methods (Grid Search, Slope Search or Auto Refine Search), with the Composite Surfaces option turned ON, then this also allows you to automatically generate composite circular / non-circular slip surfaces, which follow the shape of the lower edge of the external boundary.

In order to use this method:

1. You will have to modify the model geometry, so that the lower boundary of the weak layer, is coincident with the lower edge of the external boundary (see Figure 15).
2. Then run the Grid Search, Slope Search or Auto Refine Search, with the Composite Surfaces option turned ON.
3. The results, in this case, should find a slip surface with a lower safety factor than the Path Search, but still NOT as low as the Block Search surface. This is shown in Figure 15.

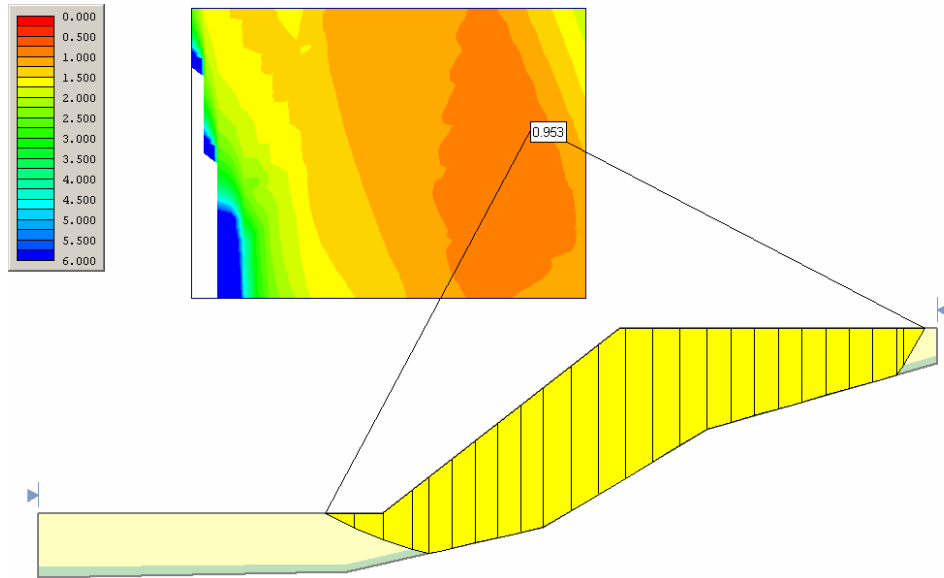


Figure 15: Grid Search used with Composite Surfaces option.

The Composite Surfaces option is left as an optional exercise for the user to experiment with.

It should be pointed out that, depending on the model, the Composite Surfaces option will sometimes result in a lower safety factor critical surface, than even the Block Search. So the Composite Surfaces option is another very useful and important option in the SLIDE searching toolkit.

More information about the Composite Surfaces option can be found in the SLIDE Help system, or the SLIDE User's Guide (Tutorial Manual).

Conclusion

That wraps up this article for now – check back in the future for more search tips and tricks !! And remember:

- Always try more than one search method.
- Use search methods which are most appropriate for the model.
- Remember that all of the search methods in SLIDE are only “automatic” up to a certain point, and a thorough search will always require some thought and effort by the user. Do not expect the search method to do the thinking for you.
- Spend a little extra time with the extensive toolkit of search options in SLIDE, and you will probably be rewarded with slip surfaces (and safety factors), that you never knew existed !!
- Compared to the large investment represented by any slope stability analysis, some extra effort with the search options, which is a critical component of the analysis, is a very small price to pay.