RocPlane

Planar sliding stability analysis for rock slopes

Reference Manual

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Introducing RocPlane

About RocPlane

ROCPLANE is a simple to use, interactive software tool for assessing the stability of planar sliding blocks / wedges in rock slopes. It also allows users to estimate the support capacity required to achieve a specified factor of safety.

A planar wedge is a wedge for which sliding occurs on a plane approximately parallel to the face of a slope. ROCPLANE analyzes a slice of unit thickness taken perpendicular to the strike of the slope face. In the program, users have the option of performing either DETERMINISTIC or PROBABILISTIC analyses.

In a DETERMINISTIC analysis, ROCPLANE calculates the Factor of Safety for a wedge of known orientation and other input parameters. For PROBABILISTIC analysis the program allows users to specify statistical distributions for various input parameters, and the number of simulations required. ROCPLANE then computes the Probability of Failure of the wedge by running the analysis the specified number of times, each time generating different values for the stochastic input parameters.

Other important features in ROCPLANE analysis include:

- Water Pressure
- External and seismic forces
- Active or passive bolt support

The theory and equations of planar rock slope stability analysis upon which ROCPLANE is based can be found in References 1 - 6. The equations used in the ROCPLANE analysis can also be found in the ROCPLANE Theory manual, which you should find in your ROCPLANE installation folder. The ROCPLANE Theory manual can also be downloaded from www.rocscience.com.

A Typical RocPlane Analysis

Creating a Model

To create a new planar wedge model, select the "New File" toolbar button or **File → New** from the menu. This will create a default wedge model. You can also open an existing project from file by selecting **File → Open** from the menu. ROCPLANE files have a **.pln** filename extension.

Project Settings

Select **Analysis → Project Settings** from the menu or the "Project Settings" toolbar button. The Project Settings dialog, which comes up, allows you to change the Project Title, Unit System, Analysis Type (Deterministic or Probabilistic). See Project Settings for more details.

Entering Model Parameters

To enter model parameters, select the "Input Data" toolbar button or **Analysis → Input Data** from the menu. This opens the Input Data dialog. This dialog allows you to define model parameters such as slope angle, slope height, failure plane angle, upper face angle, etc.

Viewing the Results

For a DETERMINISTIC analysis, the factor of safety computed for a sliding block is displayed on the toolbar. For a PROBABILISTIC analysis the probability of failure is displayed. Detailed information on analysis results and input parameters can be found in the Info Viewer option, available in the toolbar or the Analysis menu.

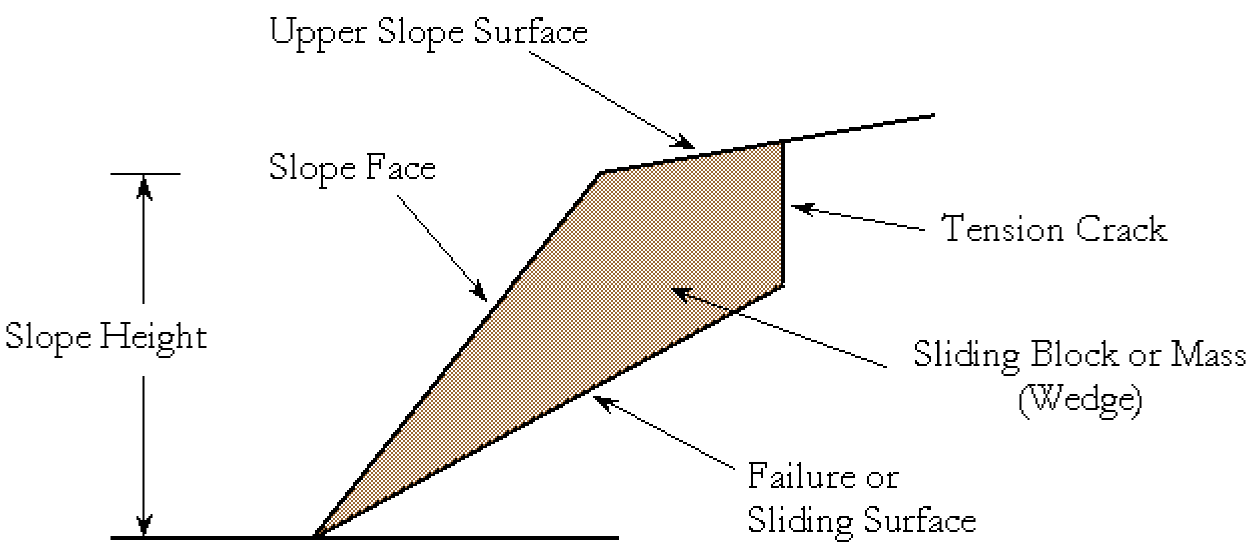
Adding Support

The factor of safety or the stability of a sliding block / wedge can be increased by adding bolt support. To add support, select the "Add Bolt" button on the toolbar or **Support → Add Bolt** from the menu. Next click on a point on the sliding block (in either the TOP, FRONT or SIDE view) where you want the bolt placed. The Bolt Properties dialog opens up from which you can specify the parameters of the bolt. (See the Adding a Bolt topic for more information.)

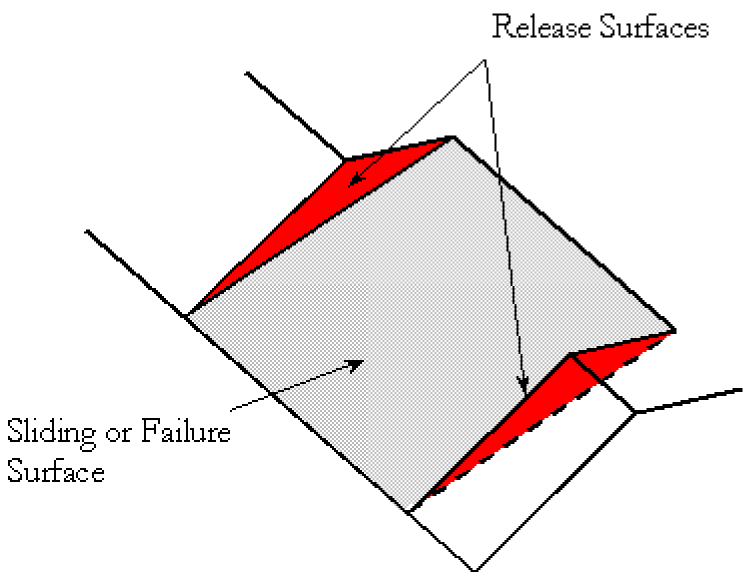
Program Assumptions

ROCPLANE assumes the following geometrical conditions:

- A sliding or failure plane that strikes parallel or approximately parallel (within 20 degrees) to the face of the slope.
- The failure plane daylights into the face of the slope. This condition occurs when the failure surface dips at angle shallower than the slope face.
- The presence of release surfaces at the lateral boundaries of the slide block that have insignificant resistance to sliding.

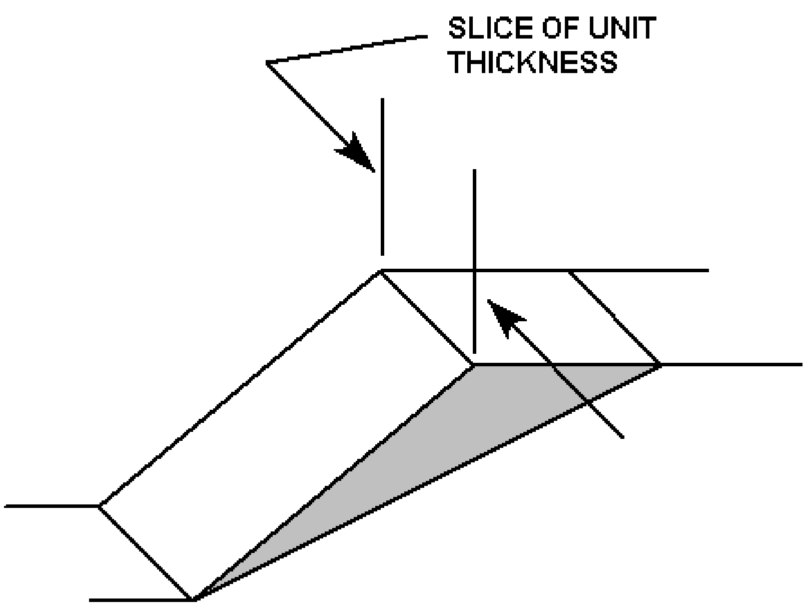


Typical planar geometry of a ROCPLANE model. Basic terminology used in the program is also shown on the figure.



The release surfaces of a sliding block.

In ROCPLANE, the slope slice analyzed is taken perpendicular to the face of the slope, and is assumed to have unit thickness.



ROCPLANE performs the limit equilibrium analysis of a sliding block. The factor of safety of the slope or sliding mass is defined as the ratio of the total forces resisting down-slope sliding to the total forces inducing sliding. The resisting forces comprise the shear strength of the sliding surface, artificial reinforcement of the slope or other stabilizing external forces, if present. The driving forces consist of the down-slope component of the weight of the sliding block, forces generated by seismic acceleration, forces due to water pressures acting on various faces of the block, and external forces on the upper slope surface.

The limit equilibrium model in ROCPLANE assumes that all forces operating on a sliding block act through the centroid of the block; it ignores overturning moments. When an analysis involves a tension crack, it is assumed that the tension crack, just as the failure plane, strikes parallel to the slope face.

Whereas many planar wedge analysis programs consider only vertical tension cracks, ROCPLANE allows for non-vertical tension cracks as well. Non-vertical tension cracks in ROCPLANE can have angles of inclination from the horizontal that are greater or less than 90 degrees.

Internet Update Feature

The following features are available in the **Help** menu, which allow you to make sure you always have the latest version of the RocPlane program.

Check for RocPlane Updates

From the RocPlane menu, select **Help** → **Product Updates** → **Check for RocPlane Updates**. This will connect you to the Rocscience website, and will determine if you have the latest version of the program. If not, you will be able to download the latest version for free, if it is a minor program upgrade (ie. bug fixes)

Check for Rocscience Updates

To check for the latest versions of ALL Rocscience software that you have installed on your computer, select **Help** → **Product Updates** → **Check for Rocscience Updates**.

Check for Updates Automatically

By default, each time you start RocPlane, the program will attempt to connect to the Rocscience website, in order to check for the latest version of the program.

To turn this feature OFF, select **Help** → **Product Updates** and DE-SELECT the **Check for Updates Automatically** checkbox. You may want to turn this feature off, if you are seeing a "Connect To" dialog when you start the program, and you do not wish to connect to the internet, or check for an update (eg. if you are using a laptop not connected to the internet, or you have a slow internet connection).

File

Starting a New File

To create a new ROCPLANE model, select the "New File" toolbar button, or select **File → New** from the menu.

A planar wedge model with four different views – TOP, FRONT, SIDE and PERSPECTIVE – will immediately appear on the screen (this view is known as the Wedge View). This new wedge is created using default input data in the program. You can then replace the default values with your own input data, through the Input Data dialog.

ROCPLANE files have a **.pln** filename extension.

Opening a File

ROCPLANE files have a filename extension of **.pln**.

To open an existing ROCPLANE file, click on the "Open" toolbar button, or select **File → Open** from the menu.

Whenever a ROCPLANE file is opened it is automatically executed using the data found in the file.

- If the Analysis Type in the file was set to DETERMINISTIC (Analysis Type = DETERMINISTIC), you will not notice the analysis since the calculation is instantaneous.
- If the Analysis Type is PROBABILISTIC (Analysis Type = PROBABILISTIC), it may take a few seconds to complete the analysis, depending on the Number of Samples. The progress of the analysis is indicated in the status bar.

Running the analysis each time a file is opened ensures that results can be immediately viewed. The user does not need to select **Compute** unless the Input Data is changed.

Saving a File

ROCPLANE files have a filename extension of **.pln**. To save a file at any time, click on the "Save" toolbar button, or select **File → Save** from the menu.

Only Input Data is saved in a ROCPLANE file; analysis results are NOT saved to a file. There is no need to save results since an analysis is automatically performed whenever a file is opened.

It should be noted, however, that:

- The Info Viewer provides a formatted summary of analysis results and input data, which can be copied to the clipboard or saved to a document.
- For a Probabilistic analysis, it is possible to export any or all of the analysis data to the clipboard, a text file, or Microsoft Excel, using the Export Dataset option in the **Statistics** menu.

Exporting Images

Various options are available for exporting image files in ROCPLANE.

Export Image File

The **Export Image File** option in the **File** menu allows the user to save the active view directly to one of two image file formats:

- JPEG (*.jpg)
- Windows Bitmap (*.bmp)

Copy to Clipboard

The active view can also be copied to the Windows clipboard using the **Copy to Clipboard** option in the **Edit** menu. From the clipboard, images can be pasted directly into word or image processing applications. See the Copy to Clipboard topic for details.

NOTE:

- To capture the entire screen to the Windows clipboard, you can use the *Print Screen* key on your keyboard. This is useful if you wish to capture multiple views in a single image, for example after tiling the views.
- Pressing the *Alt* + *Print Screen* keys together will capture *the application window only* to the clipboard (useful if the ROCPLANE program window is not maximized on your desktop).

Black and White Images (Grayscale)

The **Grayscale** option in the toolbar, the **View** menu or the right-click menu, automatically converts ALL VIEWS of the current document to Grayscale, suitable for black and white image requirements. This is useful when sending images to a black and white printer, or for capturing black and white image files. The **Grayscale** option works as a toggle, and all previous colour settings will be restored when Grayscale is toggled off.

Print

To print the active view, click on the "Print" toolbar button, or select **File → Print** from the menu.

When printing the 3D Wedge view, *only the active view within the 3D Wedge View is printed*.

1. The "active" view is indicated by the highlighted name of the view (Perspective, Top, Front, Side) in the lower left corner of the view.
2. To make a view active, click EITHER mouse button in the view.
3. On the Wedge View printout, the document name, job title, view name and Safety Factor or Probability of Failure will also appear.

When printing other views in ROCPLANE (e.g. Histograms, Scatter Plots, etc.), the entire contents of the view will be sent to the printer. When printing the Info Viewer listing, the entire listing will be printed.

Edit

Copy to Clipboard

The **Copy to Clipboard** option in the **Edit** menu or the toolbar, allows you to copy the contents of the active view to the Windows clipboard. This can then be pasted directly into word or image processing applications.

NOTE:

- If the 3D Wedge View is the active view, only the active view WITHIN the Wedge view (Top, Front, Side or Perspective) will be copied to the clipboard. You must first click the mouse in the desired view (Top, Front, Side or Perspective) to make it the active view.

- If you wish to copy the entire Wedge View (ie. all four views within the Wedge View) to the clipboard, you will have to capture the entire application window. To do this, you can use the *Print Screen* or *Alt + Print Screen* keys on your keyboard. See the Exporting Images topic for details.

- If the Info Viewer is the active view, then the **Copy** option will copy the Info Viewer text to the clipboard. By default, ALL text in the Info Viewer will be copied to the clipboard. If you only want selected text, then first highlight the desired text with the mouse, and then select **Copy**.

The **Copy to Clipboard** option is also available in the right-click menu on all views, except the 3D Wedge View.

Copy Data to Clipboard

The **Copy Data to Clipboard** option is available in the **Edit** menu, or by right-clicking on a Histogram, Cumulative, Scatter or Sensitivity Plot.

Copy Data to Clipboard will copy the raw data used to generate a plot to the Windows Clipboard. For Histograms and Cumulative Distributions, the data is automatically sorted (lowest to highest) before it is placed on the Clipboard. It can then be pasted into a spreadsheet program (Excel, for example), for further processing by the user.

Also note the following options:

- With the Export Dataset option in the Statistics menu, any or all data from a Probabilistic Analysis can be copied to the clipboard, saved to a file, or exported to Excel
- The Chart In Excel option allows the user to export data and automatically create a graph in Microsoft Excel, with a single mouse click.

View

3D Wedge View

In the 3D Wedge View, the wedge model is displayed in a four-view, split screen format showing:

- TOP
- FRONT
- SIDE and
- PERSPECTIVE

views of the planar wedge. The Top, Front and Side views are orthogonal, i.e. 90 degrees with respect to each other.

The user can perform the following actions on a wedge in the 3D Wedge View:

- Rotate the model in the Perspective View
- Move the wedge out of the slope
- Resize or maximize the views
- Zoom in or out of the model
- Change the display options
- Select an active view

NOTE: the 3D Wedge View can always be accessed by selecting the **3D View** option from the **Analysis** menu or the toolbar. This is useful if you have multiple views open, or if you have closed the 3D View, it will be re-opened when you select the **3D View** option.

Coordinates

Although a ROCPLANE model is not defined using absolute coordinates, a coordinate system is in effect for the TOP, FRONT and SIDE views of the model, within the 3D Wedge View. When the cursor is moved within the TOP, FRONT or SIDE views, coordinates, corresponding to the cursor location within the view, are displayed in the Status Bar in the lower right corner of the application window.

NOTE:

- The units of the coordinate system correspond to the system of units selected in the Project Settings dialog (i.e. meters or feet).
- The origin (0, 0, 0) of the coordinate system is defined as the mid-point of the lowermost edge of the wedge on the slope face (i.e. the midpoint of the intersection line of the slope face and the failure plane).
- Axes can be displayed in the TOP, FRONT and SIDE views with the Axes option in the **View** menu.
- Coordinates are NOT available in the Perspective view.

Rotating the Model

In the Perspective view in ROCPLANE, the user can rotate a model for viewing from different angles with the LEFT mouse button. To do so:

1. Press and HOLD the LEFT mouse button anywhere in the Perspective view. Notice that the cursor changes to a "circular arrow" symbol to indicate that you may rotate the model.
2. Keep the LEFT mouse button pressed, and move the cursor around. The model is rotated according to the direction of movement of the cursor.
3. To exit the rotation mode, release the LEFT mouse button. Notice that the cursor reverts to the normal arrow cursor.
4. Repeat the above steps to rotate the model for viewing at other angles.

NOTE:

- The wedge can also be moved out of the slope. In combination with rotation, this feature allows you complete flexibility in viewing the slope and wedge from all possible angles.
- Rotating the model only affects the Perspective view, while moving the wedge out of the slope affects all views (Top, Front, Side and Perspective).

Moving the Wedge

In the 3D Wedge View, the wedge can be moved out of the slope with the RIGHT mouse button in any of the four views (Top, Front, Side or Perspective). To do so:

1. Press and HOLD the RIGHT mouse button anywhere in ANY of the four views. Notice that the cursor changes to an "up-down arrow" symbol.
2. Keeping the RIGHT mouse button pressed, move the cursor UP or DOWN. The wedge will slide UP or DOWN out of the slope. Note:
   - If your model does NOT have a Tension Crack, then the wedge will slide UP or DOWN along the failure plane.
   - If your model DOES have a Tension Crack, then the wedge will slide DOWN along the failure plane, and UP along the plane of the Tension Crack.
3. To exit this mode, release the RIGHT mouse button. Notice that the cursor reverts to the normal arrow cursor.

TIP – If you have a mouse with a mouse wheel, rotating the mouse wheel will also move the wedge. You may find this more convenient than using the right mouse button.

Resetting the Wedge

To reset the wedge to its normal (default) position, click and RELEASE the RIGHT mouse button in any of the four views. The wedge will snap back to its normal position.

Resizing the Views

In the 3D Wedge View, you can change the relative sizes of the Top, Front, Side and Perspective views in a number of ways:

1. Double-clicking the LEFT mouse button in any view will maximize that view. Double-clicking again in the maximized view will restore the four-view display.
2. Alternatively, you can hover the cursor over the vertical or horizontal dividers between the views, or over the intersection point of the four views. The cursor will change to a "parallel line" or "four arrow" symbol. Press and HOLD the LEFT mouse button, and drag to re-size the views.
3. Maximizing views can also be accomplished with the **View → Layout** options. To reset the four views to equal size, select **View → Layout → All Views**.

Zooming

Zooming in the 3D Wedge View can be done in a variety of ways:

1. All four views (Top / Front / Side / Perspective) can be zoomed into or out of at once by selecting the desired view scale (from 50% to 800%) from the **View → Zoom** menu.

2. Individual views can be zoomed in or out independently of each other, using:
   - The Zoom buttons in the toolbar
   - The + or – numeric keypad keys
   - The Page Up / Page Down keys
   - The F2 (Zoom All), F4 (Zoom Out) or F5 (Zoom In) function keys

NOTE:

If you wish to zoom a particular view, you must first click in the view with EITHER mouse button to make it the active view. (When a view is active, you will notice that the name in the lower left corner of the view – Top, Front, Side or Perspective – is highlighted).

Layout

The **Layout** option in the **View** menu allows the user to maximize any one of the four views, or to reset the four-view display with the **Layout → All Views** option.

This can be also achieved by double-clicking with the LEFT mouse button in the desired view. See the Resizing the Views topic for more information.

Reset Wedge

The **Reset Wedge** option in the **View** menu performs three functions:

1. If the wedge has been moved out of the slope, **Reset Wedge** will reset the wedge back to its normal position in the slope. (This can also be achieved by a single RIGHT click of the mouse in any of the four views).

2. After a Probabilistic analysis, you may wish to view wedges OTHER THAN the mean wedge (see the Viewing Other Wedges topic for details). If you were previously viewing a non-mean wedge, the **Reset Wedge** option will re-display the mean wedge.

3. **Reset Wedge** also resets all zooming, so that the model is displayed at its default size.

Display Options

Display Options is available in the **View** menu and in the toolbar. It allows the user to change display options in both the 3D and 2D Wedge Views.

- The latest changes the user makes in the **Display Options** dialog automatically become the new program defaults. To restore the original program defaults select the *Defaults* button in the **Display Options** dialog.

NOTE:

- In the 3D Wedge View display options, the *Selection* colour refers to the colour of selected bolts while using the Delete Bolt and Edit Bolt options.
- ALL Force arrows represent only the DIRECTION of a given force. Arrow sizes are NOT scaled for magnitude; they only represent the presence and direction of a given force.
- **Display Options** is also available in the right-click menu on the 2D Wedge View.

Grayscale

The **Grayscale** option, in the toolbar or the **View** menu, is a toggle that automatically converts ALL VIEWS of the current document from colour to grayscale, or vice versa. When toggled on the **Grayscale** option is useful for sending images to a black and white printer, or for capturing black and white image files. When toggled off, the **Grayscale** option restores all previous colour settings.

Axes

The **Axes** option in the **View** menu, or the toolbar, can be used to toggle on or off the display of coordinate axes in the TOP, FRONT and SIDE views of the model, within the 3D Wedge View.

In the 2D Wedge View, the **Axes** option will toggle the display of the "ruler" at the left and bottom edges of the view.

NOTE:

- The units of the axes correspond to the system of units selected in the Project Settings dialog (i.e. either meters or feet).
- The origin (0, 0, 0) of the coordinate system is defined as the mid-point of the lowermost edge of the wedge on the slope face (i.e. the midpoint of the intersection line of the slope face and the failure plane).

Although a ROCPLANE model is not defined using absolute coordinates, the display of axes can help the user to estimate the dimensions of the wedge from various viewing angles.

Active View

In the 3D Wedge View, you will notice that when you click the mouse (either left or right button) in one of the four panes of the Wedge View (Perspective, Top, Front, Side), the name of the pane, in the lower left corner, becomes highlighted. This is an indication that the selected view has become the "active" pane. The active pane within the Wedge View serves the following purposes:

1. When printing the 3D Wedge View, only the active pane is printed.
2. When zooming with the keyboard shortcut keys (Page Up / Page Down, + / – numeric keys, F4 / F5 function keys), or the zoom options in the toolbar, only the active pane is zoomed. This allows each pane to be zoomed independently.
3. When using the Export Image File option, only the active pane is saved to a file.
4. When using the Copy option, only the active pane is copied to the clipboard.

Chart View Options

Markers

The **Markers** option displays interval markers on:

- Cumulative Distribution plots
- Histogram Plots, if the Input Distribution or Best Fit Distribution is displayed on the plot.
- Sensitivity Plots

The **Markers** option is available in:

- the **View** menu
- the right-click menu on Cumulative, Histogram or Sensitivity plots.

3D Histogram

A Histogram plot can be displayed with a "three-dimensional" effect, by selecting 3D Histogram from the **View** menu, or by right-clicking on a Histogram and selecting **3D Histogram**.

NOTE:

- When **3D Histogram** has been applied, you can change the "viewing angle" of the 3D Histogram, by clicking and HOLDING the LEFT mouse button on a 3D Histogram, and moving the mouse.

- If you have changed the viewing angle as described above, you can restore the default viewing angle of the 3D Histogram by selecting **Reset View** from the right-click menu or the **View** menu.
- The 3D Histogram option is not available if the Input Distribution is displayed (for Input Data variables) or if the Best Fit Distribution is displayed (for Calculated Data variables).

Sampler

The **Sampler** allows the user to obtain the coordinates of points on:

- Cumulative Distribution (S-curve) Plots
- Sensitivity Plots

The **Sampler** is displayed as a vertical dotted line on a Cumulative Distribution plot, or as a horizontal line on Sensitivity plots.

To use the **Sampler**:

- SINGLE click the LEFT mouse button anywhere on the plot, and the sampler will jump to that location, and display the results.
- Alternatively, press and HOLD the LEFT mouse button on the plot, and you will see the double-arrow icon. Move the mouse in the directions of the arrow, and the sampler will continuously display the values of points along the curve.

For example, plot the Cumulative Safety Factor distribution, and move the Sampler to Safety Factor = 1 (actually it appears here by default). The Y coordinate displayed will be the Probability of Failure (i.e. the probability that the Safety Factor < 1).

The display of the **Sampler** can be turned on or off in the right-click menu or the **View** menu.

Input Distribution

If the Data Type for a Histogram is one of your Input Data variables, then the **Input Distribution** option will display the Statistical Distribution, which you defined in the Input Data dialog for that input variable. This allows you to see how well the Statistical Distribution you defined was sampled.

The **Input Distribution** option is available in the right-click menu, the **View** menu, and in the Histogram Plot Parameters dialog that comes up when you initially generate a Histogram.

Interval markers can be displayed on the **Input Distribution** with the Markers option.

Best Fit Distribution

If the Data Type for a Histogram is one of the Calculated Data Types (i.e. Safety Factor, Wedge Weight, etc.), then a **Best Fit Distribution** can be determined, using the Kolmogorov-Smirnov Goodness of Fit test.

The Goodness of Fit test will determine which one of the Probability Density Functions available in ROCPLANE (Normal, Uniform, Triangular, Beta, Exponential, Lognormal) best fits (or best describes) the data. The distribution that best fits the data will be displayed on the histogram, and listed at the bottom of the plot. The Kolmogorov-Smirnov test is described in Ref. 7.

The **Best Fit Distribution** option is available in the right-click menu, the **View** menu, and in the Histogram Plot Parameters dialog, when you initially generate a Histogram.

Interval markers can be displayed on the **Best Fit Distribution** with the Markers option.

NOTE: the **Best Fit Distribution** option is NOT available for Histograms of Input Data variables, since samples of an Input Data variable are generated from the Probability Density Function already specified in the Input Data dialog. For Input Data variables, the Input Distribution can be displayed.

Relative Frequency

The **Relative Frequency** option allows the user to scale the Frequency axis of Histograms in terms of Relative Frequency.

- When the Relative Frequency option is toggled ON, the Frequency axis of a Histogram will be scaled such that the AREA under the distribution is equal to one.
- If **Relative Frequency** is OFF, then the Frequency axis will be in terms of the actual number of samples.

The **Relative Frequency** option is available in the right-click menu and the **View** menu.

Reset View

The **Reset View** option can be used to reset the appearance of Histogram, Cumulative, Scatter or Sensitivity Plots, if the view has been zoomed or panned.

Reset View will also reset certain other chart viewing options, such as the Sampler on Cumulative Distribution plots, for example.

Reset View is available in the right-click menu, and the **View** menu.

Show Failed Wedges

The **Show Failed Wedges** option is applicable for Histogram and Scatter plots, and highlights the distribution of failed wedges (i.e. wedges with a safety factor less than 1) on Histogram or Scatter plots.

When **Show Failed Wedges** is toggled on:

- On a Histogram plot, the distribution of failed wedges will be superimposed over the total distribution, and coloured red.
- On a Scatter plot, each data point representing a failed wedge will be coloured red.

The **Show Failed Wedges** option is very useful, because it allows the user to see the relationship between wedge failure, and any given input variable (e.g. Friction Angle) or output variable (e.g. Wedge Weight).

NOTE: on a Safety Factor Histogram, the failed wedges (safety factor less than 1) are ALWAYS highlighted in red. The Show Failed Wedge option is in effect by default, and is not available as a menu option for a Safety Factor Histogram.

Show Failed Wedges is available in the right-click menu, and the **View** menu.

Show Regression Line

The **Show Regression Line** option is only applicable for Scatter plots, and can be used to toggle on or off the display of the best fit linear regression line for a Scatter plot.

Note that the correlation coefficient, and y-intercept and slope (alpha and beta) for the best fit linear regression line, are always listed at the bottom of a Scatter plot, even if the regression line is not displayed.

The **Show Regression Line** option is available in the right-click menu and the **View** menu.

Chart Properties

The **Chart Properties** option allows the user to customize:

Axis ranges

Axis titles

Chart colours

for Histogram, Cumulative, Scatter and Sensitivity plots.

Chart Properties is available in the right click menu and the View menu.

Chart Colours

Whenever you change the chart colours in the **Chart Properties** dialog (Background, Chart Exterior, Chart Interior), these colours will become the default colours of ALL new charts which are generated (ie. Histogram, Cumulative, Scatter and Sensitivity). They will remain the default chart colours each time you start ROCPLANE. If you want to restore the original program default colours, then select the Restore Default Colours button in the Chart Properties dialog. This will restore the original program default colours, for all new charts which are created. It will not change the colours of existing chart views.

Chart in Excel

After creating Histogram, Cumulative, Scatter or Sensitivity plots in ROCPLANE, the **Chart in Excel** option can be used to create the same plot in Microsoft Excel.

To create a chart in Excel:

1. Make sure the chart you wish to export is the active view. If not, click the mouse in the view to make it the active view.
2. Select **Chart in Excel**, which is available in the right-click menu, the **View** menu, and in the toolbar.
3. If you have the Microsoft Excel program on your computer, it will automatically be started. The raw data used to create the chart will be exported to Excel, and a chart will be automatically created. This is all done with a single mouse click!

Also note the following options:

- With the Export Dataset option, any or all data from a Probabilistic Analysis can be copied to the clipboard, saved to a file, or exported to Excel.
- The Copy Data to Clipboard option can be used to copy the raw data for a single graph, to the Windows clipboard.

Zoom and Pan

Zooming and panning of chart views (Histogram, Cumulative, Scatter or Sensitivity plots) can be performed as follows:

Pan

Press the *Shift* key, and press and hold the left mouse button. Move the mouse in any direction to pan the chart in the view.

Zoom Window

Press the *Ctrl* key, and click and drag the left mouse button to draw a window. This will zoom into a specific area of a chart view.

Zoom Mouse

Press the *Alt* key, and press and hold the left mouse button. Move the mouse up or down to zoom the view in or out.

In addition, if the 3D Histogram option is in effect on a Histogram view, the 3D chart can be viewed from any angle, by pressing and holding the left mouse button, and moving it within the view.

Analysis

Project Settings

The **Project Settings** dialog, available in the **Analysis** menu and the toolbar, allows the user to enter a Project Title, select a Unit System, and Analysis Type.

Project Title

The Project Title will appear in the Info Viewer listing and on printouts of the wedge views.

Unit System

The Unit System determines the length and force units used in the input data dialogs and the analysis.

Analysis Type

In ROCPLANE, wedge stability can be assessed using either:

- DETERMINISTIC (safety factor), or
- PROBABILISTIC (probability of failure)

analysis methods.

- In a DETERMINISTIC analysis ROCPLANE computes the factor of safety for a single wedge of known input parameters.
- In a PROBABILISTIC analysis, statistical input data can be entered to account for uncertainty in orientation and other input parameters. This results in a safety factor distribution, from which a probability of failure is calculated.

Note that the Analysis Type can also be selected from the drop-down list in the toolbar.

Compute

The **Compute** option in the toolbar or the **Analysis** menu can be used to re-run a ROCPLANE analysis at any time. **Compute** has exactly the same effect as selecting the **Apply** button on the Input Data dialog. However, note that:

- If your Analysis Type is DETERMINISTIC, **Compute** is not necessary, since you will have already calculated the Safety Factor with the **Apply** button in the Input Data dialog. The Safety Factor will NOT change when you re-compute a model with DETERMINISTIC data.

- If your Analysis Type is PROBABILISTIC, **Compute** (or **Apply**) can be used to re-run your ROCPLANE model with probabilistic Input Data. If the Pseudo-Random Sampling option in the Input Data dialog is NOT selected, analysis results will be different each time you re-run a Probabilistic Analysis. Pseudo-Random Sampling allows users to obtain reproducible results for a Probabilistic analysis. See the Sampling Method topic for details.

In addition to the **Compute** and Apply buttons, a ROCPLANE analysis is also performed each time:

- A file is opened.
- Bolts are added, edited or deleted.

Sensitivity Analysis

The effect of uncertainty in the values of input parameters can be explored using a sensitivity analysis. In sensitivity analysis values of model parameters are varied across a range of likely values and the effect on computed factors of safety observed. This exercise helps identify the parameters that have the most effect on the stability of a sliding block, and can be used to compare the effectiveness of various remedial measures.

Sensitivity plots are plots of factor of safety results against percentage changes in specified model parameters. On sensitivity plots, the gradient of a curve for a parameter indicates the effect that parameter has on the factor of safety of a sliding mass. Steeper rising or falling curves indicate greater influence on the factor of safety.

To generate a sensitivity plot:

1. Select **Analysis → Sensitivity** from the menu, or the "Sensitivity" toolbar button.
2. From the ensuing dialog select the first available checkbox. The input data fields beside the checkbox are activated.
3. From the dropdown list of parameters, select the parameter for which you desire a sensitivity plot.
4. Enter a range within which you would like the parameter to vary. (To assist you in doing so, ROCPLANE automatically displays the mean value of the parameter entered in the Input Data dialog.)
5. If you would like sensitivity plots for other parameters repeat steps 2 to 4. When done selecting parameters, click OK.
6. On a single graph, ROCPLANE will generate the specified sensitivity plot(s).

NOTE:

- A Sensitivity graph is generated by subdividing each variable range (defined by the From and To values in the Sensitivity dialog), into 50 intervals, and calculating the safety factor at each value of the variable between the From and To values. If you right-click on the graph, and select the Markers option, you will see the actual points used to generate the curve(s).

- The Percent Change (on the horizontal axis of a Sensitivity Graph) is the relative difference between the Minimum value of a variable (0 percent) and the Maximum value of a variable (100 percent), according to the From and To ranges you have entered in the Sensitivity dialog.
- You can modify the data in an existing Sensitivity plot, by right-clicking the mouse in the plot, and selecting Update Sensitivity Data

2D Wedge View

A 2D view of the wedge model is available by selecting the **2D View** option from the toolbar or the **Analysis** menu.

This will generate a new view which only displays the 2D wedge model. It is important to remember that the ROCPLANE analysis is a 2D analysis, and that the 3D Wedge View display is for visualization purposes only.

The 2D view can display model lengths and angles, applied and resultant forces, and tables of analysis results and input data. The display can be customized with the Display Options dialog.

NOTE – if you have already generated the 2D Wedge View, and you have multiple views open, you can re-select the **2D View** option at any time, to return to the 2D View. This will NOT generate a new view, but will simply return you to the existing 2D Wedge View.

Info Viewer

The **Info Viewer** option opens a view that displays a convenient summary of model and analysis parameters. The **Info Viewer** can be accessed by selecting **Analysis → Info Viewer** or the "Info Viewer" toolbar button. The information listed in the **Info Viewer** is very useful, and it is recommended that users examine this information, so that they can become familiar with the information available from a ROCPLANE analysis.

The **Info Viewer** listing can be printed. It can also be copied to the clipboard by right-clicking in the view and selecting Copy to Clipboard. Once it is on the clipboard, it can be pasted into a word processor or spreadsheet for inclusion in reports or other documents.

Analysis Results

If your Analysis Type is PROBABILISTIC, the **Info Viewer** lists a summary of Trial, Valid and Failed Wedges. Depending on your input geometry, it is possible for the Probabilistic Sampling of the Input Data to generate invalid wedge geometries.

In general:

Number of Valid Wedges = Number of Trial Wedges – Number of Invalid Wedges

Probability of Failure = Number of Failed Wedges / Number of Valid Wedges

Current Wedge Data

If your Analysis Type is PROBABILISTIC, you will see a Current Wedge Data listing in the Info Viewer. By default, this displays data for the mean wedge (i.e. the wedge based on the mean input data). The Current Wedge Data can also display data for ANY WEDGE generated by the Probabilistic Analysis. See the Viewing Other Wedges topic for details.

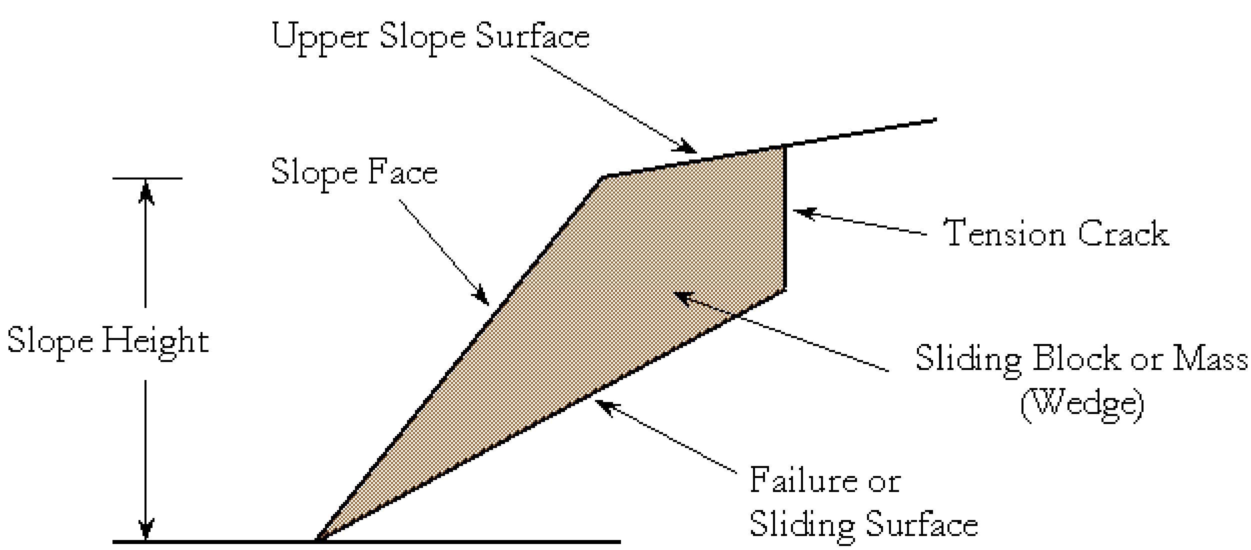
Input Data

Overview of Input Data

ROCPLANE computes the factor of safety for the sliding of a block / wedge formed in a rock slope by:

1. The face of the slope
2. A discontinuity that strikes parallel to the slope and daylights into the slope face
3. The upper ground surface, and
4. A tension crack (optional).

A typical problem geometry is illustrated below.



Typical planar wedge geometry for ROCPLANE analysis.

At an early stage in the solution process, ROCPLANE checks if the geometry of a model is valid, before proceeding to calculate a Safety Factor or Probability of Failure for a sliding block. For more information on the validation of model geometry see the Geometry Validation topic.

To enter model parameters, select the "Input Data" toolbar button or **Analysis → Input Data** from the menu. This opens the Input Data dialog. This dialog allows you to define the following model input parameters:

Slope Angle , Slope Height, Unit Weight

Upper Face Angle , Bench Width Analysis (optional)

Failure Plane Angle , Waviness

Failure Plane Strength

Tension Crack Angle , Location (optional)

Water Pressure

Seismic Coefficient

External Force

Statistical Sampling (Probabilistic Analysis)

Input Data Dialog

Based on the setting of the Analysis Type option, the **Input Data** dialog is configured for either DETERMINISTIC or PROBABILISTIC input.

The **Input Data** dialog in ROCPLANE works a little differently from a regular dialog:

1. It is known as a "roll-up" dialog, since it can be "rolled-up" (minimized) or "rolled-down" again, by selecting the "up" or "down" arrow in the upper right corner of the dialog.
2. You can also minimize / maximize the Input Data dialog, by double-clicking the left mouse button on the title bar of the dialog.
3. It can be left up on the screen while performing other tasks. When not needed, it can be "rolled-up" and dragged out of the way (for example, the top of the screen) with the LEFT mouse button.
4. If multiple files are open, the **Input Data** dialog will always display the data in the active file.
5. The F3 function key can be used as a shortcut to open the Input Data dialog.

You may find these properties of the Input Data dialog useful, for example, when performing parametric analysis, or when working with multiple files.

Slope

Slope Angle

In ROCPLANE there is no restriction on the inclination of the face of the slope; it can exceed 90 degrees (ie. the slope crest can overhang the toe of the slope) but must form a valid wedge or sliding block with the other wedge planes. (See the Geometry Validation topic for more information.)

Slope Height

The Slope Height is the VERTICAL distance from the toe of the slope to the crest (the intersection of the slope face with the upper slope).

Unit Weight

The Unit Weight of the rock mass is used to determine the total weight of the wedge.

Upper Face

Angle

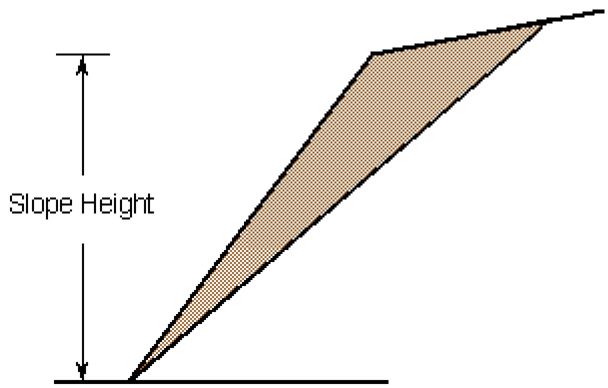
The dip of the upper face of the slope.

Bench Width Analysis

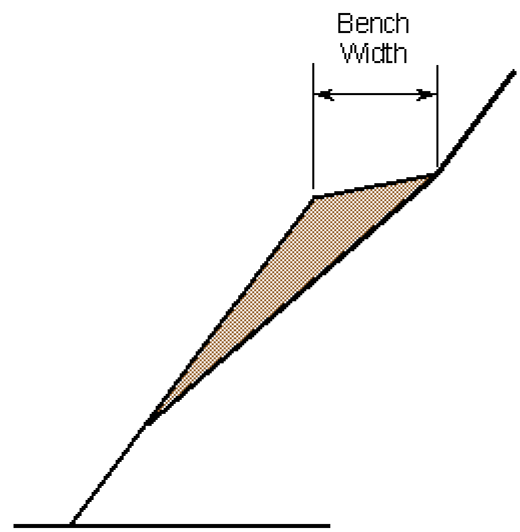
Normally, the wedge size determined by ROCPLANE is based on the Slope Height. However, the user can scale the wedge size according to the width of a bench (Bench Width), by selecting the Bench Width checkbox, and entering a value for the width.

NOTE:

- The Bench Width is defined as the HORIZONTAL distance from the CREST of the slope, to the rearmost wedge vertex, on the Upper Face. This distance is always measured HORIZONTALLY, even if the Upper Face Angle is not horizontal.
- In order to have an effect on the analysis, the Bench Width must define a SMALLER wedge than would be defined by the Slope Height. If the Bench Width value is too large, then the Slope Height will determine the wedge size, as if the Bench Width option were not in use.
- (NOTE: the maximum possible Bench Width, based on the Slope Height, is displayed in the Edit box underneath the Bench Width Analysis checkbox, when the Bench Width Analysis checkbox is not selected).
- If a Tension Crack is defined, the Bench Width cannot define a SMALLER wedge than is defined by the distance of the Tension Crack from the crest. An error message will be displayed in this case.



Sliding block in the analysis of a complete slope. The block is scaled to the height of the slope by assuming that the failure plane passes through the slope toe.



Sliding block in the analysis of a slope bench. The block is scaled to the width of the bench. As such the failure plane does not exit at the slope toe.

Failure Plane

The failure plane is the surface along which sliding of a block or wedge occurs.

Angle

This value refers to the dip of the failure or sliding plane in a model.

Waviness

Waviness is a parameter that can be included in calculations of the shear strength of the failure plane, for any of the strength models used in ROCPLANE. It accounts for the waviness (undulations) of the failure plane surface, observed over distances on the order of 1 m to 10 m. (Ref. 6)

Waviness is specified as the AVERAGE dip of the failure plane, minus the MINIMUM dip of the failure plane. A non-zero waviness angle, will always increase the effective shear strength of the failure plane.

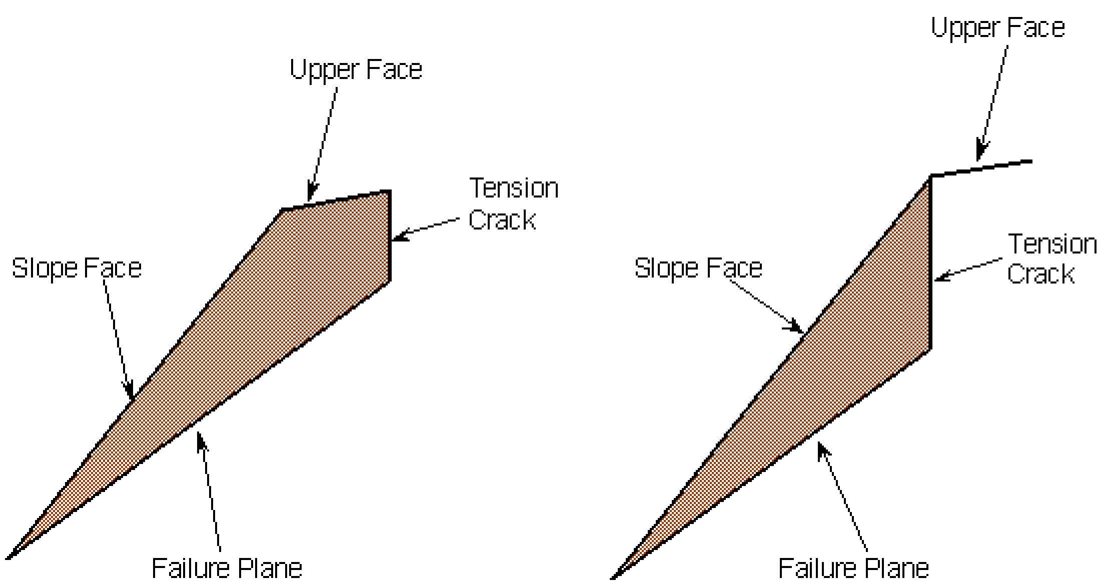
Tension Crack

A Tension Crack is optional in a ROCPLANE analysis. It can be included in a model by selecting the Tension Crack checkbox in the **Input Data** dialog.

When included in a model, a Tension Crack can be specified in one of two ways:

- Minimum Factor of Safety Location – this option gives the location of the critical tension crack that provides the minimum factor of safety for a given model
- Specify Location – this option allows a user to specify a location for a tension crack. The location is specified as a HORIZONTAL distance from the crest of the slope.

ROCPLANE examines how the tension crack intersects with the Failure Plane and Upper Face, and only accepts those cases where the tension crack truncates the wedge in a valid manner (two examples of valid wedge truncation are shown in the figure below). If the tension crack plane does not form an acceptable wedge with the other planes, a warning message will be displayed when you select the Apply button to compute.



Example of valid truncation of wedges

Angle

In addition to vertical tension cracks, ROCPLANE can account for non-vertical tension cracks. You can enter a value into the Angle edit box to specify an angle of inclination of a tension crack from the horizontal. The default value is 90 degrees, the vertical position.

Distance from Crest

This allows a user to specify the HORIZONTAL distance of the Tension Crack from the slope crest, if the Specify Location option is used.

If the Minimum FS Location option is used, then the Distance from Crest edit box is disabled, however, it will display the calculated value of the Minimum FS Location, when the Apply button is selected.

NOTE: the Distance from Crest is always measured horizontally, even if the angle of the Upper Slope Face is not horizontal.

Strength

A critical assumption in planar slope stability analysis involves the shear strength of the sliding surface. There are several models in rock engineering that establish the relationship between the shear strength of a sliding surface and the effective normal stress acting on the plane. ROCPLANE offers the following widely accepted shear strength models:

Mohr-Coulomb

In this model the relationship between the shear strength, τ, of the failure plane and the normal stress, σ_n, acting on the plane is represented by the Mohr-Coulomb equation:

$$\tau = c + \sigma_n \tan \varphi$$

where φ is the friction angle of the failure plane and c is the cohesion.

Barton-Bandis

The Barton-Bandis strength model establishes the shear strength of a failure plane as:

$$\tau = \sigma_n \tan\left[\phi_b + JRC \log_{10}\left(\frac{JCS}{\sigma_n} \right) \right]$$

where ϕ_b is the basic friction angle of the failure surface,

JRC is the joint roughness coefficient, and JCS is the joint wall compressive strength.

Hoek-Brown

This is the original Hoek-Brown strength criterion (Ref. 1) which establishes rock mass strength according to the formula:

$$\sigma_1 = \sigma_3 + \sigma_{ci}\left(m \frac{\sigma_3}{\sigma_{ci}} + s \right)^{1/2}$$

where σ_1 is the major principal stress, σ_3 is the minor principal stress, σ_{ci} is the uniaxial compressive strength of the intact rock, and m and s are material constants for the rock mass.

NOTE: For the Hoek-Brown (and Generalized Hoek-Brown) criteria, the relationship between shear strength and normal stress is derived from the Hoek-Brown equations, which are in terms of principal stresses.

Generalized Hoek-Brown

The Generalized Hoek-Brown criterion establishes strength according to the formula:

$$\sigma_1 = \sigma_3 + \sigma_c\left(m_b \frac{\sigma_3}{\sigma_c} + s \right)^{a}$$

where σ_1 is the major principal stress, σ_3 is the minor principal stress, σ_c is the uniaxial compressive strength of the intact rock, m_b is a material constant for the rock mass, and s and a are constants dependent on the characteristics of the rock mass.

NOTE: if you are using the **Generalized Hoek-Brown** criterion, you can estimate the parameters of the Generalized Hoek-Brown equation, by selecting the **GSI** button in the dialog. This will display a **Parameter Calculator** dialog, which allows you to estimate the equation parameters from values of intact rock constant mi, and GSI (Geological Strength Index). Furthermore, within the **Parameter Calculator** dialog, you may access dialogs for the estimation of mi based on rock type, and the estimation of GSI based on rock structure and surface conditions.

Power Curve

The Power Curve model for shear-strength, τ, of a plane is given by the relationship:

$$\tau = a(\sigma_n)^b + c$$

a, b and c are parameters, typically obtained from a least-squares regression fit to data obtained from small-scale shear tests. σ_n is the normal stress acting on the failure plane. (Ref. 6)

Waviness Angle

Waviness is a parameter that can be included in calculations of the shear strength of the failure plane, for any of the strength models used in ROCPLANE. It accounts for the waviness (undulations) of the failure plane surface, observed over distances on the order of 1 m to 10 m. (Ref. 6) A non-zero waviness angle, will always increase the effective shear strength of the failure plane, regardless of the strength model which is in use. Waviness is specified along with the Failure Plane orientation, rather than with the strength parameters, see the Failure Plane topic for information.

Water Pressure

By default, Water Pressure is NOT applied to a ROCPLANE model. The default analysis therefore assumes a DRY slope.

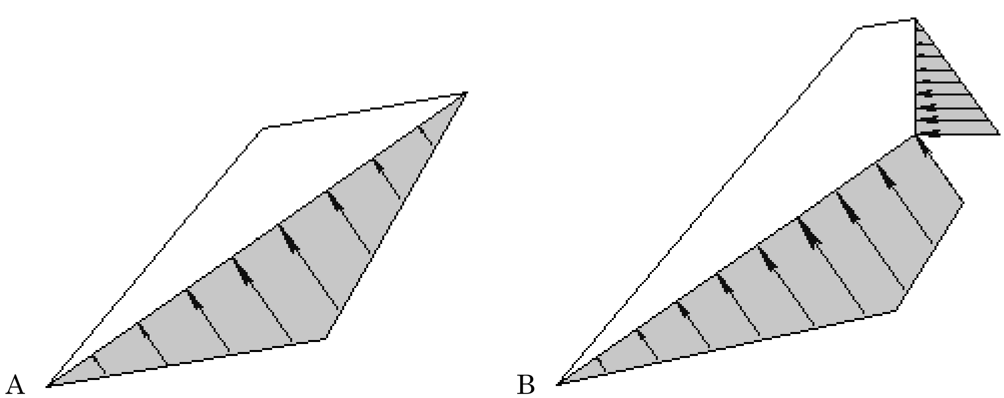
To include Water Pressure in the analysis, select the Water Pressure checkbox in the Input Data dialog. There are four water pressure distribution models available:

- Peak Pressure – Mid Height
- Peak Pressure – Toe
- Peak Pressure – Tension Crack Base
- Custom Pressure

These distributions are illustrated below, for models with and without a tension crack.

Peak Pressure Mid Height

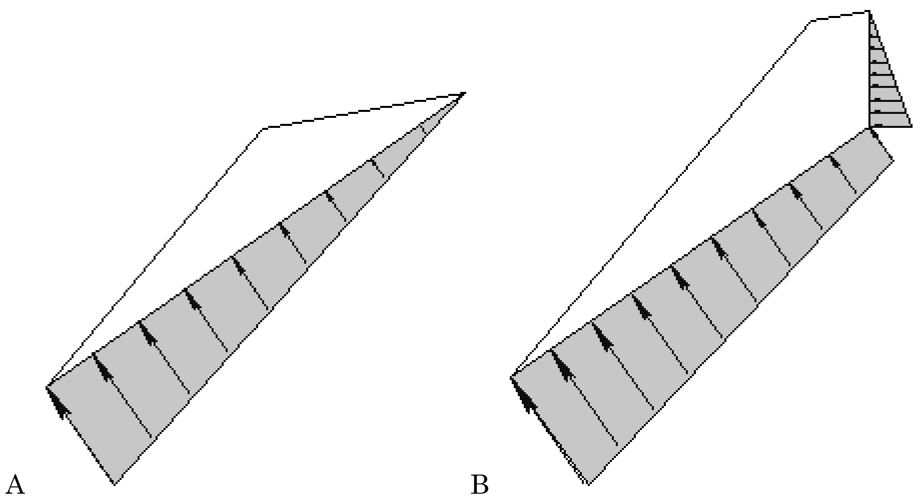
The Peak Pressure Mid Height option assumes that the maximum water pressure occurs at the mid height of the water level in the slope. The pressure is assumed to be zero at the toe of the slope, with linear pressure variation between zero and the maximum pressure.



Peak Pressure Mid Height water pressure option, without tension crack (A) and with tension crack (B).

Peak Pressure Toe

The Peak Pressure Toe option assumes that the maximum water pressure occurs at the toe of the wedge. This is the worst case scenario, since it will result in the maximum hydrostatic force being applied to the wedge. This may occur if drainage at the toe of the slope becomes blocked, for example by freezing of water. The pressure variation is linear from the maximum at the toe, to zero at the top of the water level in the slope.

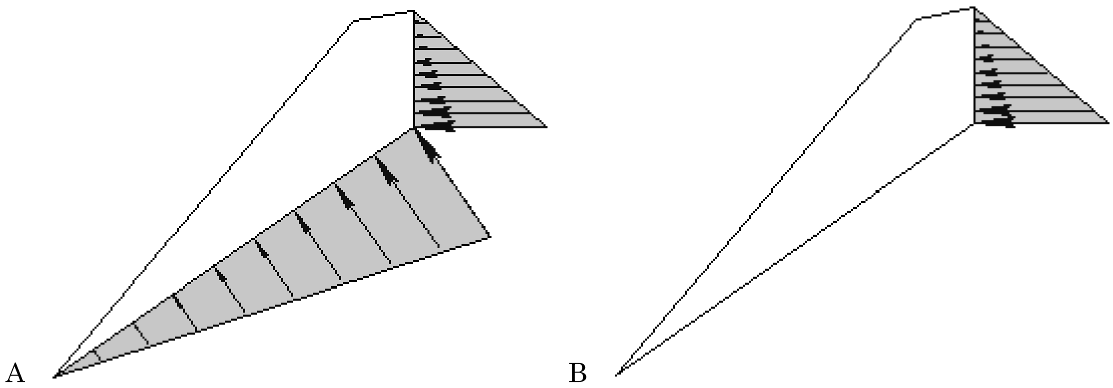


Peak Pressure Toe water pressure option, without tension crack (A) and with tension crack (B).

Peak Pressure Tension Crack Base

The Peak Pressure Tension Crack Base option assumes that the maximum water pressure occurs at the base of the tension crack. This model is only applicable if your model includes a tension crack. The pressure is assumed to be zero at the toe of the slope, with linear pressure variation between zero and the maximum pressure, on both the failure plane and the tension crack.

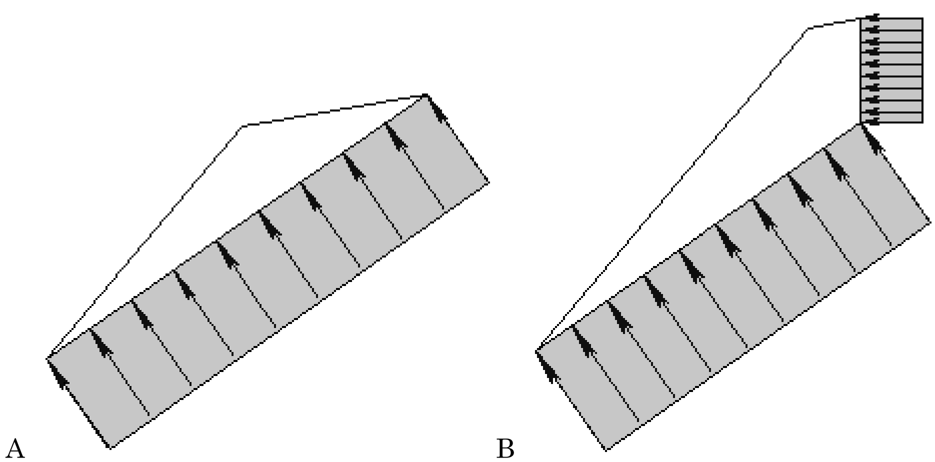
NOTE: with this model, you may choose to turn OFF the water pressure on the failure plane, by selecting the "No Failure Plane Pressure" checkbox. In this case, water pressure will only be applied on the tension crack. This can be used to model the case where the failure plane is impermeable.



Peak Pressure Tension Crack Base option. Pressure on both tension crack and failure plane (A) and pressure on tension crack only (B).

Custom Pressure

The Custom Pressure water pressure option, allows the user to specify the actual (average) water pressure on the failure plane and the tension crack. This is useful if actual water pressure data is available. Remember that these values represent the AVERAGE water pressure on the wedge planes, and that only a single value can be entered for the failure plane, and a single value for the tension crack.



Custom Pressure water pressure option, without tension crack (A) and with tension crack (B).

NOTE: for the Custom Pressure option, the Unit Weight and Percent Filled options are not applicable, since the actual (average) pressure is being entered.

Unit Weight

The Unit Weight option for water pressure allows the user to specify the unit weight of water. The Unit Weight of water is used to calculate the value of Peak Pressure for the following water pressure distribution options:

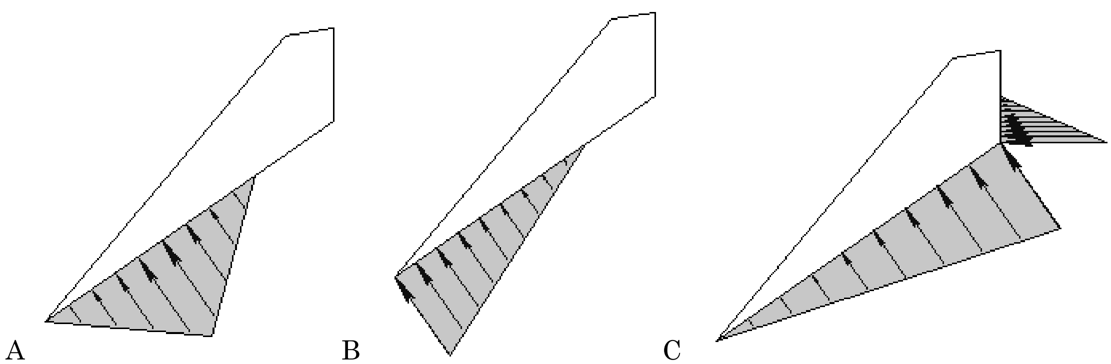
- Peak Pressure Mid Height
- Peak Pressure Toe
- Peak Pressure Tension Crack Base

The Unit Weight option is not applicable for the Custom Pressure option, since the water pressure is entered directly by the user for this option.

Percent Filled

The Percent Filled option allows the user to specify the water level in the slope. Note:

- For the Peak Pressure Mid Height and Peak Pressure Toe options, the Percent Filled is relative to the total height of the wedge (see figures A and B)
- For the Peak Pressure Tension Crack Base option, the Percent Filled TC represents the level of water in the tension crack (see figure C)
- Percent Filled is not applicable for the Custom Pressure option.



Percent Filled = 50% for Peak Pressure Mid Height (A), Peak Pressure Toe (B) and Peak Pressure TC Base (C).

Display of Water Pressure Forces

If Water Pressure has been applied to a model, this will be indicated in the 3D Wedge View, by blue shading of the wedge failure plane and tension crack. If the Percent Filled is less than 100%, the actual water level will be indicated by the level of the blue shading on the wedge planes.

Also, the water forces will be represented on the 3D Wedge model, by blue arrows displayed at the center and directed normal to the Failure Plane and Tension Crack (if present) of the sliding block. These arrows are symbolic and indicate that Water Pressure has been applied. They do NOT indicate the magnitude or method of Water Pressure calculation.

The display of water pressure can be turned on or off, and the default colour can be changed, in the Display Options dialog.

On the 2D Wedge View, the actual water pressure distributions are displayed, as indicated in the above figures.

Seismic Force

Seismic Force can be applied to the wedge by selecting the Seismic checkbox in the **Input Data** dialog, and entering the following data:

Seismic Coefficient

The seismic coefficient is a dimensionless number that defines the seismic acceleration as a fraction of the acceleration due to gravity. Typically the Seismic Coefficient might be around 0.1 to 0.2.

If α = Seismic Coefficient, g = acceleration due to gravity = 9.81 m/s2, and m = mass of the sliding block, then the Seismic Force applied to the block, $F = m \alpha g$.

Direction

By default the Seismic Force will be applied to the wedge in the HORIZONTAL direction.

- However, the user may define the Seismic force at any angle from the horizontal, by selecting the USER DEFINED option for Direction, and entering an Angle.

Display of Seismic Force

If Seismic Force has been applied to a model, the Force will be represented on the model as a yellow arrow at the lowermost wedge vertex on the slope face. The arrow is symbolic and indicates the direction and existence of a Seismic Force. It does NOT indicate the magnitude of the force. The display of this arrow can be turned on or off, and the default arrow colour can be changed, in the Display Options dialog.

Note that the location of the Seismic Force display does NOT indicate the actual location of the force applied in the analysis. As with all other forces in ROCPLANE, a Seismic Force is applied through the centroid of the wedge, during the analysis.

External Force

External Forces (e.g. a structural load on the upper surface of a slope, or the force applied by a waste rock berm to the toe of a slope) can be applied to the sliding block, with the External Forces option in the **Input Data** dialog. To include External Forces in the analysis:

1. Select the Number of External Forces.
2. Enter the Angle (of inclination) and Magnitude of each force.
3. Select the Apply button to run the analysis.

How External Forces are Implemented

In the ROCPLANE analysis, an External Force is exactly equivalent to a rock bolt, using the ACTIVE bolt model. This means that an External Force with the same orientation as a rock bolt, and with a Magnitude equal to the Capacity of the rock bolt, will have exactly the same effect on the Safety Factor, if the bolt model is ACTIVE. See the How Bolts are Implemented topic for more information.

Display of External Forces

If External Forces have been applied to a model, the Forces will be represented on the model, as purple arrows at the center of the wedge face. These arrows are symbolic and indicate the direction and existence of External Forces. They DO NOT indicate the magnitude of the forces. The display of these arrows can be turned on or off, and the default arrow colour can be changed, in the Display Options dialog.

Note that the location of the External Force display does NOT indicate the actual location of the forces applied in the analysis. As with all other forces in ROCPLANE, External Forces are applied through the centroid of the wedge, during the analysis.

Probabilistic Input

Overview of Probabilistic Input

If your Analysis Type is PROBABILISTIC, you will be able to define any or all of the following as random variables, in the **Input Data** dialog:

- Angle of the Failure Plane, Slope Face, Upper Slope Face, and Tension Crack.
- Various parameters of the different shear strength models of the Failure Plane. For example, for the Mohr-Coulomb model Cohesion and Friction Angle can be defined as random variables.
- Percent Filled option for water pressure
- Seismic Coefficient and user-defined Angle

To define a parameter as a random variable, select the desired Statistical Distribution from the dropdown list of distributions for the parameter, and then enter appropriate standard deviation and minimum / maximum values.

Any variable that is NOT assigned a Statistical Distribution is assumed to have a deterministic value (Mean Value) and will thus not be sampled statistically in the analysis.

To carry out a PROBABILISTIC analysis, at least one Input Data variable must be defined as random.

Random Variables

To define a parameter as a random variable in the Probabilistic Input Data dialog, first toggle the Statistical Distribution for that variable from "None" to one of the six possible choices:

- NORMAL
- UNIFORM
- TRIANGULAR
- BETA
- EXPONENTIAL
- LOGNORMAL

Once a statistical distribution has been selected, you will then be able to enter:

- Standard deviation
- Relative minimum and maximum values

NOTE!!!

- The minimum / maximum values are specified in the **Input Data** dialog as RELATIVE quantities (i.e. as distances from the mean), rather than as absolute values.
- EXAMPLE: if the Mean Angle = 45, and the Relative Minimum = 10, then the actual Minimum = 35 degrees.
- All references in the ROCPLANE Help topics to "minimum" and "maximum" values that are not used in the context of the entry of statistical input data, refer to absolute minimums and maximums (i.e. mean – relative minimum and mean + relative maximum), and not to the relative values entered in the Input Data dialog.

Correlation Coefficient (Cohesion and Friction Angle)

In the Probabilistic **Input Data** dialog, the user may define a correlation coefficient between Cohesion and Friction Angle, if the Mohr-Coulomb strength model is used for the Failure Plane.

The correlation coefficient option will only be enabled if:

1. BOTH Cohesion and Friction Angle are defined as random variables (ie. assigned a statistical distribution)
2. Normal or Uniform distributions are defined (will not work for other distribution types).

It is known that Cohesion and Friction Angle are related in a general way, such that materials with low friction angles tend to have high cohesion, and materials with low cohesion tend to have high friction angles. This option allows the user to define the correlation between these two variables.

By default, when the checkbox is NOT selected, Cohesion and Friction Angle are treated as completely independent variables.

In order to see the effect of the correlation coefficient, try the following:

1. Create a file with probabilistic input data.
2. Use Normal or Uniform distributions for Cohesion and Friction Angle.
3. Select the "Correlation coefficient between cohesion and friction angle" checkbox, in the Input Data dialog.
4. Enter a correlation coefficient. (Initially, use the default value of –0.5.)
5. Run the probabilistic analysis.
6. Create a Scatter Plot of Cohesion vs. Friction Angle.

7. Note the correlation coefficient listed at the bottom of the Scatter Plot. It should be approximately equal to the value entered in the Input Data dialog. (It will not in general, be exactly equal to the user-defined correlation coefficient, since the results are still based on random sampling of the input data distributions).
8. Note the appearance of the plots (ie. the degree of scatter between the two variables).
9. Repeat steps 4 to 8, using correlation coefficients of -0.6 to -1.0, in 0.1 increments. Observe the effect on the Scatter Plot. Notice that when the correlation coefficient is equal to –1, the Scatter Plot results in a straight line.

NOTE: the default correlation coefficient of –0.5 is a good typical value to use, if more precise data is not available.

Sampling Method

In the Probabilistic **Input Data** dialog, the user can set the Number of Samples, the statistical Sampling Method (Monte Carlo or Latin Hypercube), and choose Pseudo-Random Sampling, for the ROCPLANE Probabilistic Analysis.

Monte Carlo Method

The "Monte Carlo" sampling technique uses random numbers to generate input data samples consistent with specified probability distributions. Monte Carlo techniques are now commonly applied to a wide variety of problems involving random behaviour, where the passage of time plays no substantive role. As a result, Monte Carlo simulations are generally static rather than dynamic (Ref. 7).

Latin Hypercube Method

The Latin Hypercube sampling technique is a more recent development, which gives comparable results to the Monte Carlo technique but with fewer samples (Refs. 8, 9). The method is based upon "stratified" sampling – a probability distribution is first divided into a number of segments or strata, and then accompanied by random selection within each stratum. Typically, an analysis using 1000 samples obtained by the Latin Hypercube technique will produce comparable results to a Monte Carlo analysis that uses 5000 samples (Ref. 10).

Pseudo-Random Sampling

Pseudo-Random Sampling allows the user to obtain reproducible results from a Probabilistic Analysis. If the Pseudo-Random Sampling checkbox is ON, this means that the SAME "seed" number is always used to generate random numbers for the sampling of the input data distributions. This results in identical sampling of the input data distributions, each time the analysis is run (with the same input parameters). The Probability of Failure, mean Safety Factor, and all other analysis output, will be reproducible. This can be useful for demonstration purposes, the discussion of example problems, etc.

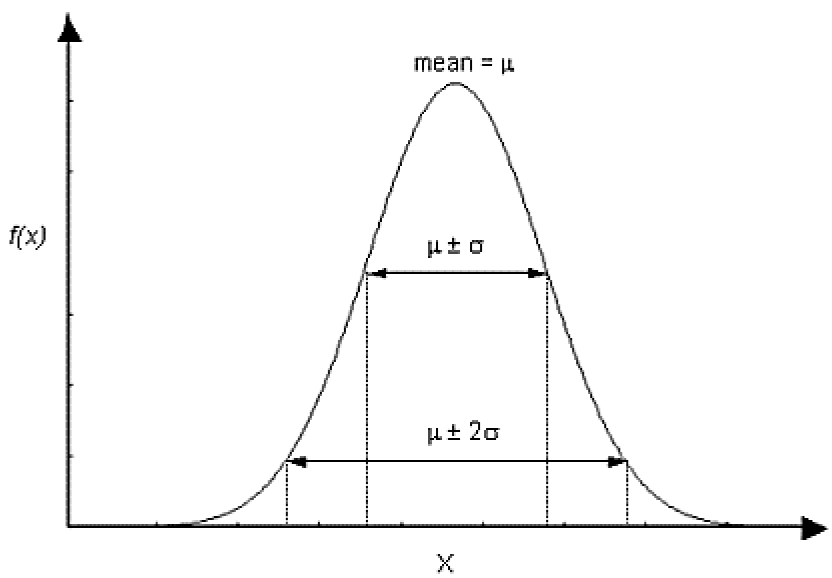
By default, the Pseudo-Random Sampling checkbox is ON.

If you wish to run probabilistic analyses with true Random Sampling, then turn the Pseudo-Random Sampling checkbox OFF. In this case, a DIFFERENT "seed" number is used each time the ROCPLANE Probabilistic analysis is run (ie. each time Compute or Apply is selected). Each analysis will therefore produce different results, and the Probability of Failure and the mean Safety Factor, may vary with each run.

Normal Distribution

The NORMAL (or Gaussian) distribution is the most common probability distribution function (PDF), and is generally used for probabilistic studies in geotechnical engineering. Unless there is good reason to use one of the other five PDFs available in ROCPLANE, it is recommended that the user choose the NORMAL PDF.

For a NORMAL distribution, about 68% of observations should fall within one standard deviation of the mean, and about 95% of observations should fall within two standard deviations of the mean.



Normal probability density function, showing standard deviation ranges.

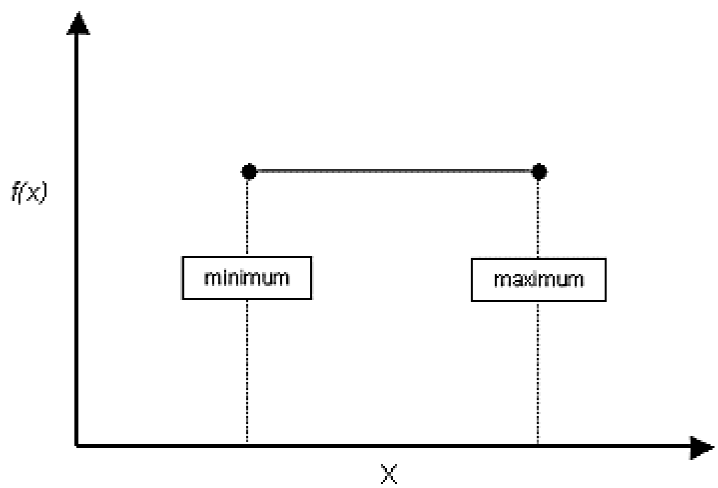
Truncated Normal Distribution

A truncated NORMAL distribution can be defined for a variable by setting the desired minimum and/or maximum values for the variable. For practical purposes, minimum and maximum values that are at least 3 standard deviations away from the mean generate a complete normal distribution. If the minimum / maximum values are less than 3 standard deviations away from the mean, the distribution is visibly truncated.

Uniform Distribution

A UNIFORM distribution can be used to simulate a random variation between two values, where all values in the range are equally probable.

A UNIFORM distribution is entirely specified by the minimum and maximum values. The mean value of a UNIFORM distribution is simply the average of the minimum and maximum values, and cannot be independently specified.

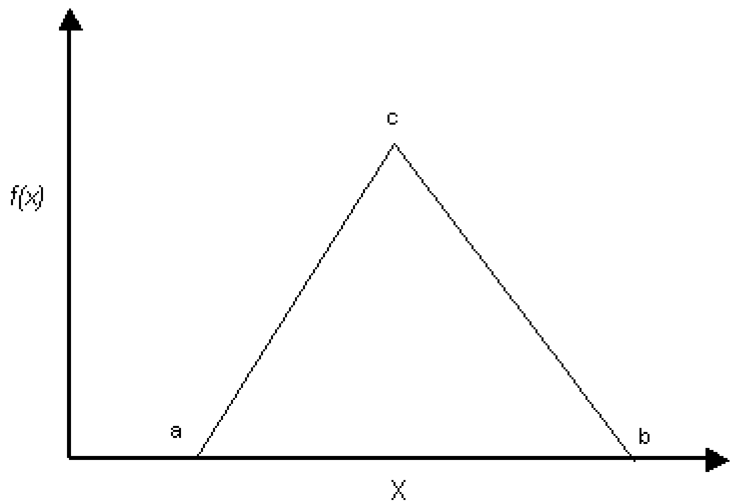


Uniform probability density function.

Triangular Distribution

You may wish to use a TRIANGULAR distribution in some cases, as a rough approximation to a random variable with an unknown distribution.

A TRIANGULAR distribution is specified by its minimum, maximum and mean values. It does not have to be symmetric, and can be skewed either to the left or right by entering a mean value greater than or less than the average of the minimum and maximum values.



Triangular probability density function. Minimum = a, maximum = b, mode = c. For a symmetric distribution, mean = mode.

NOTE:

For a non-symmetric TRIANGULAR distribution, the mean value is not equal to the mode. The mode is the value of the variable at the peak of the TRIANGULAR distribution. The mean of a TRIANGULAR distribution has the following behaviour:

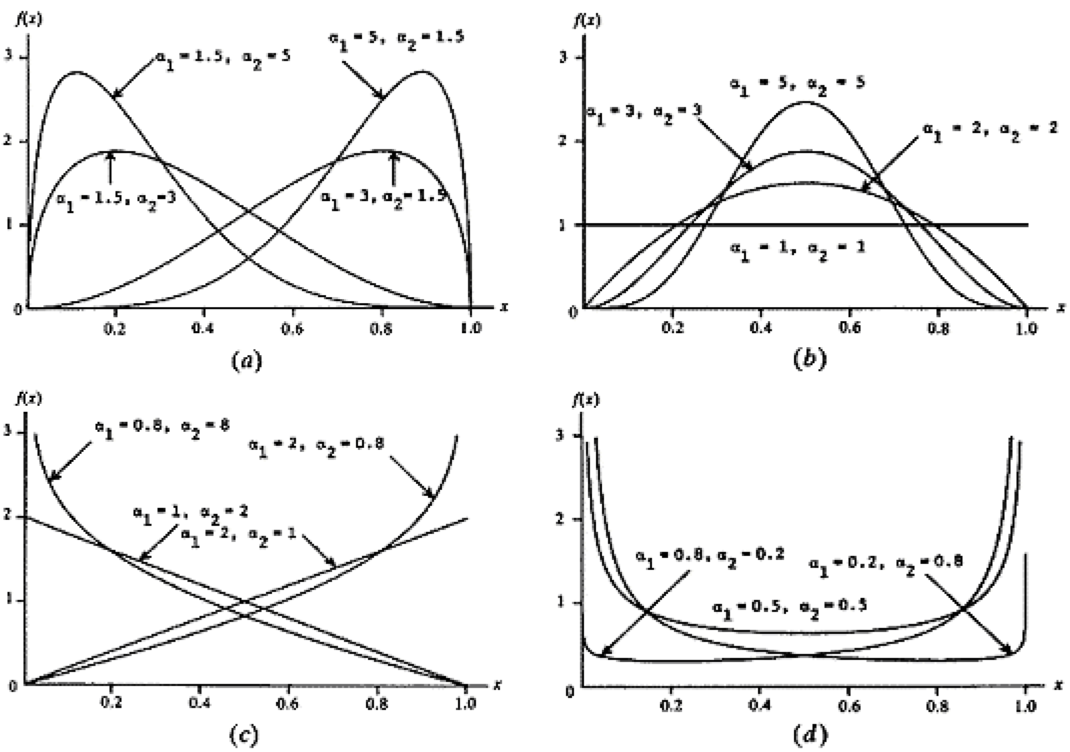
1. In general, the mean of a triangular distribution is always given by:

$$\text{mean} = \frac{\text{minimum} + \text{maximum} + \text{mode}}{3}$$

2. If the distribution is symmetric, then the mean is equal to the mode.
3. For a left triangular distribution, the mode = minimum, and the mean = (2*minimum + maximum) / 3.
4. For a right triangular distribution, the mode = maximum, and the mean = (2*maximum + minimum) / 3.

Beta Distribution

The BETA distribution is a very versatile function, which can be used to model probability density curves of several different shapes, such as those shown below.



Beta ($\alpha 1$, $\alpha 2$) density functions (Ref. 7)

The form of the BETA distribution is determined by the shape parameters $\alpha 1$ and $\alpha 2$. Both $\alpha 1$ and $\alpha 2$ are always positive (greater than 0). The relationship between the shape parameters of the BETA distribution and the ROCPLANE input data is as follows:

$$mean = \frac{\alpha 1}{\alpha 1 + \alpha 2}$$

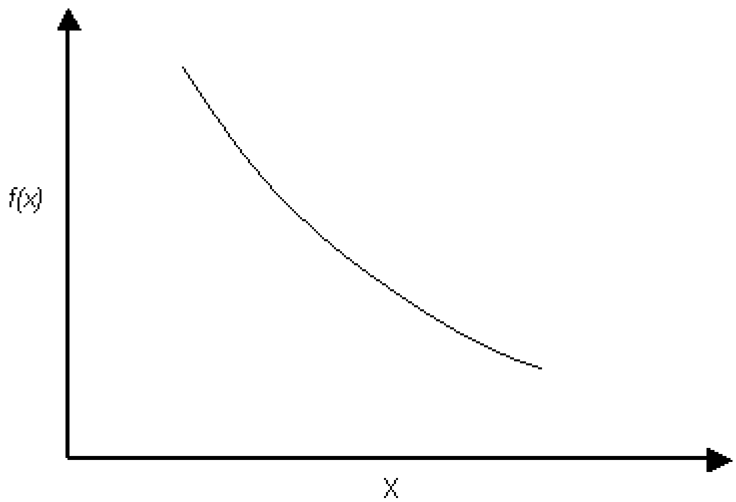
$$\operatorname{var} iance = \frac{\alpha 1 \alpha 2}{(\alpha 1 + \alpha 2)^2 (\alpha 1 + \alpha 2 + 1)}$$

The standard deviation is the positive square root of the variance.

Note that the above equations apply to a beta random variable on [0,1]. To rescale and relocate to obtain a beta random variable on [a, b] of the same shape, use the transformation a + (b–a)X

Exponential Distribution

The EXPONENTIAL probability density function is available in ROCPLANE:



Exponential probability density function.

NOTE:

1. The range of values must always be positive for an EXPONENTIAL distribution. It must therefore not be used for orientation distributions which include negative values (i.e. Dip values less than zero).
2. The mean of an EXPONENTIAL distribution is always equal to its standard deviation. This is a property of the EXPONENTIAL distribution, and cannot be altered by the user.
3. Like the NORMAL distribution, the EXPONENTIAL distribution can be truncated by entering the desired minimum and maximum values (the basic EXPONENTIAL distribution varies from zero to infinity).

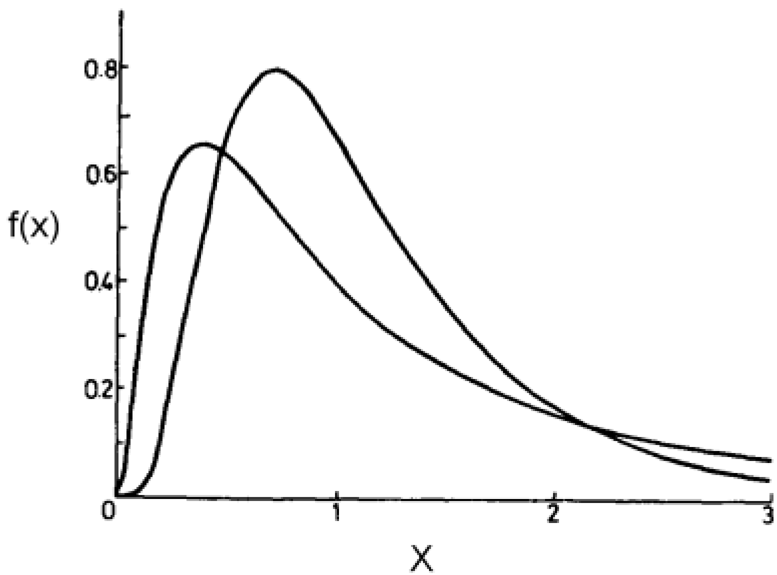
The EXPONENTIAL distribution is sometimes used to define events, such as the occurrence of earthquakes or rockbursts, or quantities such as the length of joints in a rockmass. Of the currently defined statistical variables in ROCPLANE, you may occasionally find it useful for modeling joint cohesion, for example.

Lognormal Distribution

If a random variable has a Lognormal distribution, then its natural logarithm has a Normal distribution. This is the meaning of the term Lognormal.

Like the Exponential distribution, the Lognormal distribution can only be used for variables which are always positive.

A Lognormal distribution can be useful for modeling variables such as cohesion, for example, which may have a large peak in the distribution near zero and then taper off gradually for larger values.



Lognormal probability density functions.

Further Reading

An excellent introduction to probability theory in the context of geotechnical engineering can be found in Chapter 2 of Ref. 10. Probability, reliability and statistical methods in engineering design is covered in Ref. 12

More comprehensive and detailed information can be found in statistics textbooks. For example, Chapter 6 of Ref. 7 provides an excellent guide to the selection of input probability distributions. Ref. 11 provides a summary of over 30 different probability density functions, in a quick-reference format.

Analysis

Running the Analysis

To run a ROCPLANE analysis, select the Apply button in the Input Data dialog, after entering all of your input data.

If the Analysis Type = DETERMINISTIC:

- The Safety Factor will be immediately calculated and displayed in the lower right corner of the dialog, along with the Wedge Weight, Normal Force, Resisting Force and Driving Force.

If the Analysis Type = PROBABILISTIC:

- The Probability of Failure will be calculated and displayed in the toolbar. Detailed statistical results can be viewed with the Plot Histogram, Plot Cumulative and Plot Scatter options in the **Statistics** menu.

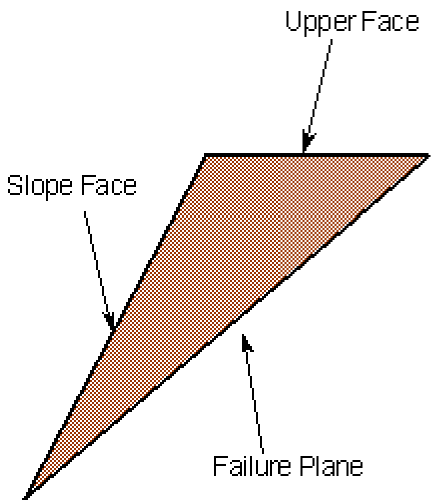
NOTE:

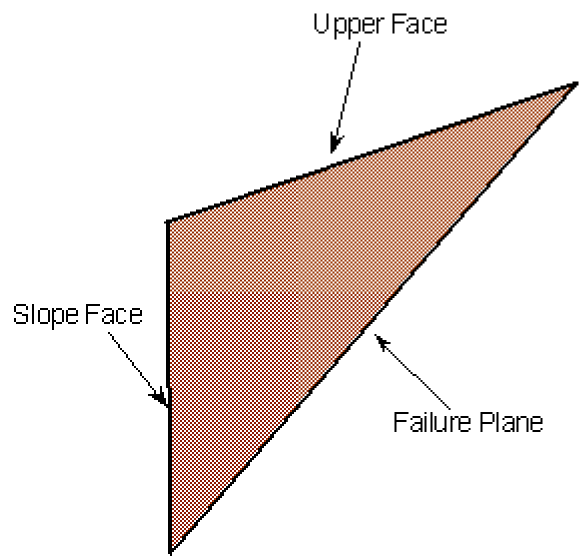
1. The Compute button has exactly the same effect as selecting the Apply button in the Input Data dialog. This can be used for re-running a Probabilistic Analysis if the Input Data dialog is closed. It is not necessary for a Deterministic Analysis, since the Safety Factor will not change when you re-compute.
2. When a file is opened in ROCPLANE, the analysis is automatically carried out, so that the user can immediately view results. Therefore it is only necessary to compute if you are changing the Input Data.
3. The analysis is also run whenever bolts are added or modified.

Geometry Validation

ROCPLANE always checks if the model geometry is valid, before proceeding to calculate a Safety Factor for a given wedge.

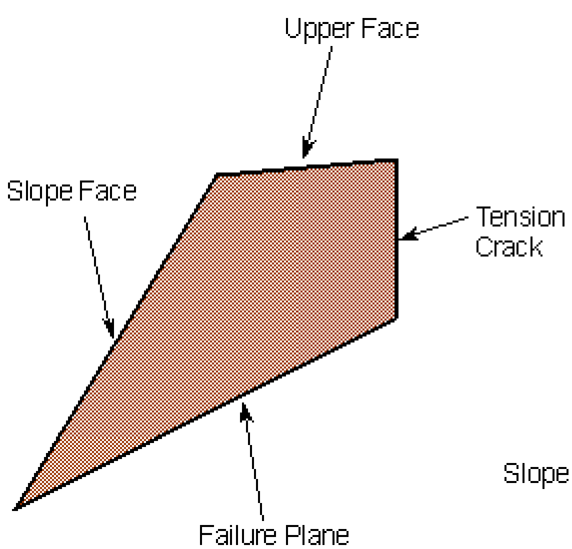
ROCPLANE checks whether the specified Slope Face, Upper Face and Failure Plane form a legitimate sliding block or wedge. (Examples of valid sliding blocks are shown in the figures below.)

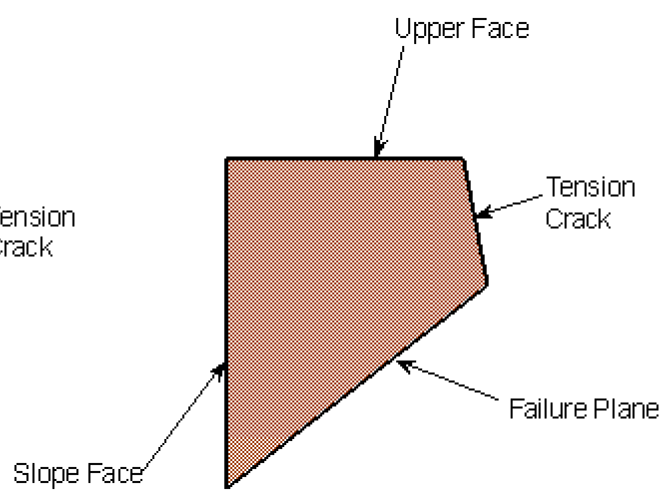




Examples of valid sliding block geometries, when no tension crack is involved.

In addition, ROCPLANE also examines how the tension crack intersects the other planes, accepting only those cases where the tension crack truncates the wedge in a kinematically admissible manner. If a Tension Crack is defined and a Bench Width specified, the Bench Width cannot define a wedge SMALLER than that defined by the distance of the Tension Crack from the crest. An error message will be displayed in this case. Examples of valid sliding block geometries with tension cracks are provided below.





Examples of valid wedge geometries involving tension cracks.

If the Analysis Type = DETERMINISTIC:

- You will receive an error message if there is a problem with your input geometry.

If the Analysis Type = PROBABILISTIC:

- Validation is first performed on the mean Input Data. If the mean orientation data does not form a valid wedge, then the entire Probabilistic Analysis will be aborted, and you will receive an error message. If the mean wedge is valid, but invalid wedges are generated during the statistical sampling, then these results are discarded, but the analysis is allowed to proceed. The Number of Valid Wedges for a Probabilistic Analysis is listed in the Info Viewer option.

Re-Running Probabilistic Analyses

The initial analysis of Input Data is always done as soon as you click the **Apply** button in the **Input Data** dialog.

Later, you may re-run a Probabilistic Analysis by selecting the Compute button in the toolbar. In general, analysis results will be different each time you re-run a Probabilistic Analysis, unless the Pseudo-Random Sampling option is selected in the Input Data dialog. Pseudo-Random Sampling allows the user to obtain reproducible results for a Probabilistic analysis. See the Sampling Method topic for details.

When you re-run a Probabilistic Analysis, all views of the current document will be automatically updated to reflect the current analysis results, including:

- Histograms
- Cumulative Distributions
- Scatter Plots
- Info Viewer

NOTE:

The Wedge view will NOT change when you re-compute, since the default wedge displayed is based on the mean Input Data, which is not affected by re-running the analysis.

References

1. Hoek, E. and Bray, J.W. *Rock Slope Engineering*, Revised 3rd edition, The Institution of Mining and Metallurgy, London, 1981.
2. Hoek, E., 2000, "A slope stability problem in Hong Kong", Practical Rock Engineering, 92-104
3. Sharma, S., Raghuvanshi, T.K. and Anbalagan, R., 1995, "Plane failure analysis of rock slopes", Geotechnical and Geological Engineering , 13, 105-111
4. Froldi, P., 1996, "Some Developments to Hoek & Bray's Formulae for the Assessment of the Stability in Case of Plane Failure", BULLETIN of the International Association of ENGINEERING GEOLOGY, No. 54, 91-95
5. Sharma, S., Raghuvanshi, T. and Sahai, A., 1993, "An Engineering geological appraisal of the Lakhwar Dam, Garhwal Himalaya, India", Engineering Geology, 381-398
6. Miller, S.M., 1988, "Modeling Shear Strength at Low Normal Stresses for Enhanced Rock Slope Engineering", Proc. Of 39th Highway Geology Symp, 346-356
7. Law, A.M. and Kelton, D.W., *Simulation Modeling and Analysis*, 2nd edition, McGraw-Hill, Inc., New York, 1991.
8. Iman, R.L., Davenport, J.M. and Zeigler, D.K. "Latin Hypercube Sampling (a program user's guide)". Technical Report SAND 79-1473. Albuquerque, NM: Sandia Laboratories, 1980.
9. Startzman, R.A. and Wattenbarger, R.A. "An improved computation procedure for risk analysis problems with unusual probability functions". Proc. Symp. Soc. Petrolm Engnrs hydrocarbon economics and evaluation, Dallas, 1985.
10. Hoek, E., Kaiser, P.K. and Bawden, W.F. *Support of Underground Excavations in Hard Rock*, A.A.Balkema, Rotterdam, Brookfield, 1995.
11. Evans, M., Hastings, N. and Peacock, B. *Statistical Distributions*, 2nd edition, John Wiley & Sons, Inc., New York, 1993.
12. Haldar, A. and Mahadevan, S., *Probability, Reliability, and Statistical Methods in Engineering Design*, John Wiley & Sons, Inc., New York, 2000.

Support

Adding a Bolt

Rock bolts are added to a ROCPLANE model with the **Add Bolt** option. This allows the user to evaluate the number, location, length and capacity of bolts necessary to stabilize a planar wedge (i.e. achieve a required Safety Factor or Probability of Failure). To add a rock bolt:

1. Select **Support → Add Bolt** or the "Add Bolt" toolbar button.
2. Move the cursor into the Top or Front orthogonal views.

Notice that the cursor changes to an "arrow / rockbolt" icon.

3. As you move the cursor over the wedge, notice that the "rockbolt" and "arrow" now line up – this indicates that you may add the bolt to the wedge.
4. Click the LEFT mouse button at a point on the wedge where you want the bolt installed.
5. The bolt will initially be installed NORMAL to the face of the wedge on which you clicked (i.e. normal to the Upper or Face slope).
6. The Bolt Properties dialog will appear on the screen, which allows you to modify the bolt orientation and other properties – see the Bolt Properties Dialog topic for details.
7. When the desired bolt properties have been entered, select OK.
8. If you are not happy with the location of the bolt, select Cancel to delete the bolt.

NOTE:

- Bolts CANNOT be added in the Perspective view.

Bolt Properties Dialog

The Bolt Properties dialog, which appears when Adding or Editing Bolts, works as follows:

1. Bolts in ROCPLANE may be defined as either Active or Passive. For information about the Active and Passive bolt models in ROCPLANE see the How Bolts are Implemented topic.
2. If you modify the Capacity or Angle with the "arrow" buttons at the right of the input fields, the Safety Factor is immediately recalculated and displayed in the dialog as the values are being changed. This allows the user to interactively modify the bolt properties, and immediately see the effect on the Safety Factor.
3. Alternatively, values can be typed in to the dialog. In this case, the Safety Factor is NOT automatically re-calculated, the user must select the Apply button to apply typed in values.
4. As the bolt Angle is changed, you will see the orientation of the bolt updated on the screen.

5. Changing the Length of the bolt will be visible on the model, but has NO effect on the Safety Factor, as long as the Anchored Length is greater than zero.
6. The Anchored Length is the bolt length, which passes through the wedge, and is anchored in the slope behind the wedge. Anchored Length is automatically calculated whenever the values of Length or Plunge are changed, and cannot be changed by the user. Anchored Length must be greater than zero, or the bolt will have no effect on the Safety Factor (i.e. its effective capacity will be zero, and it will not be used in the analysis).
7. When the bolt orientation, length and capacity are satisfactory, select OK, and the bolt will be added to the model (if you were Adding Bolts), or saved with the new properties (if you were Editing Bolts).
8. If you are not happy with the location of the bolt, select Cancel, and the bolt will be deleted (if you were Adding Bolts). If you were Editing Bolts, all changes will be cancelled, even if you used the Apply button to apply the changes.

NOTE:

If your Analysis Type is PROBABILISTIC, the Safety Factor is calculated on the mean wedge input data. The Probabilistic Analysis, including the effect of the bolt you just added / edited, will be re-computed when you select OK in the Bolt Properties dialog (Step 7).

Optimize

In the Bolt Properties dialog, the orientation of an individual bolt can be optimized with the Optimize button. The Optimize button automatically determines the bolt orientation (Angle) that provides the maximum safety factor.

Factor of Safety Option

The Factor of Safety option in the Bolt Properties dialog will calculate the bolt Capacity necessary to achieve a specific Factor of Safety. To use this option:

- Select the Factor of Safety option, and enter a desired Factor of Safety (e.g. 2.0)
- Select the Apply button, and the Capacity will be automatically updated with the required capacity necessary to achieve the specified Factor of Safety.
- Note that if the calculated capacity is NEGATIVE, this is not an error; this means that the user has entered a Factor of Safety, which is LESS than the Factor of Safety with NO support. A negative capacity means that the support force is actually applied in the opposite direction from the specified Angle.

NOTE that since the Bolt Properties dialog only applies to individual bolts, you may wish to use the Factor of Safety option as follows:

- Install a single bolt
- Use the Factor of Safety option to determine the total Capacity necessary to stabilize the wedge

- You may then use this value for further design purposes (e.g. to calculate the required number of bolts of a specified capacity). This assumes that all bolts are installed at the same orientation.

Bolts in a Probabilistic Analysis

Bolts should be used with some caution in a Probabilistic Analysis. Since the bolts are added while viewing the mean wedge, the orientations of bolts added on the mean wedge may no longer be optimal in terms of support, to other wedges generated by the Probabilistic Analysis. You should keep this in mind, if you have used the Optimize button to optimize the bolt orientation on the mean wedge.

How Bolts are Implemented

Bolts are implemented in ROCPLANE planar wedge stability analysis as follows:

Capacity and Orientation

1. Bolts affect the Safety Factor through their Capacity and Orientation (Angle).
2. Bolt capacities and orientations are added vectorially, and are included in the Safety Factor calculation as a single, equivalent force passing through the centroid of the wedge. Either the ACTIVE or PASSIVE bolt model will apply (see below).
3. Multiple bolts that have the same orientation can therefore be simulated by a single bolt having the same total capacity.

Length and Location

Bolt Length has NO effect on the Safety Factor in ROCPLANE. As long as a bolt passes through the wedge, (i.e. Anchored Length > 0) the full capacity of the bolt will be applied in the analysis.

1. However, if the Anchored Length of a bolt = 0 (i.e. if it does not pass through the wedge), then the bolt will have NO effect on the model - its effective capacity will be zero.
2. The Location of bolts (on the face of the wedge) has NO effect on Safety Factor, since all forces in the wedge stability analysis are assumed to pass through the centroid of the wedge.
3. The Length, Anchored Length and Location of bolts allow the user to visualize the practical problems of installing the bolts, but DO NOT enter into the Safety Factor calculations.

Bolts vs. External Force

1. A bolt is exactly equivalent to an External Force with the same magnitude and orientation, if the bolt model is ACTIVE (see below).

As a suggested exercise, the user can verify that a bolt using the ACTIVE bolt model, and an equivalent External Force, result in the same Safety Factor, for a given wedge.

2. A bolt, and an External Force with the same magnitude and orientation, will NOT be equivalent, if the bolt model is PASSIVE (see below).

Multiple Bolts

Installation of multiple bolts is useful for visualizing the practical problems of bolt installation, and the necessary bolt lengths and spacing. It is also useful for back-calculating the Safety Factor of an existing wedge support system.

However, since bolts in ROCPLANE simply behave as force vectors passing through the centroid of the wedge, the effect of multiple bolts on the Safety Factor can be simulated by:

- A fewer number of bolts, or even a single bolt, with equivalent capacity and direction, or
- An equivalent External Force (in the case of ACTIVE bolts).

Active and Passive Bolt Models

In general terms, the Factor of Safety is defined as the ratio of the forces resisting motion, to the driving forces. Driving forces include the mass of the wedge accelerated by gravity, seismic forces, and water pressure. Resisting forces arise from the cohesion and frictional strength of the sliding plane (Failure or Discontinuity Plane).

Active Support is included in the ROCPLANE analysis as shown in Equation 1:

$$F = \frac{Resisting Force + T_N \tan \phi}{Driving Force - T_S}$$

Eqn. 1

where T_N is the normal component and T_S is the shear component of the force applied to the rock by the support.

Active Support is assumed to act in such a manner as to DECREASE the DRIVING FORCE in the Factor of Safety calculation. Tensioned cables or rockbolts, which exert a force on the wedge before any movement has taken place, are considered as Active support.

NOTE: External Forces are incorporated in the ROCPLANE analysis in the same manner as Active Support (i.e. according to Eqn. 1).

Passive Support is included in the ROCPLANE analysis as shown in Equation. 2.

$$F = \frac{Resisting\,Force + T_N \tan\phi + T_S}{Driving\,Force}$$

Eqn. 2

By this definition, Passive Support is assumed to INCREASE the RESISTING FORCE provided by shear restraint, in the Factor of Safety equation.

Untensioned dowels or grouted cablebolts, which only develop a resisting force after some movement of the wedge has taken place, are considered as Passive support.

Since the exact sequence of loading and movement in a rock slope is never known in advance, the choice of Active or Passive bolt models is somewhat arbitrary. The user may decide which of the two models is more appropriate for the wedge being analyzed. In general, Passive support will always give a lower Factor of Safety than Active support.

Deleting a Bolt

To delete bolts:

1. Select **Support → Delete Bolt** or the "Delete Bolt" toolbar button.
2. Move the cursor in the Top, Front or Side views.
3. The cursor will change to a small "box".
4. Hover the cursor over a bolt that you wish to delete.
5. The bolt will change colour, to indicate that it is "selected".
6. The properties of the selected bolt will be displayed in the status bar. This may help to identify bolts you wish to delete.
7. Click the LEFT mouse button, and the bolt will be deleted.
8. A new Safety Factor will immediately be calculated.
9. Repeat steps 4 to 7 to continue deleting bolts.
10. Press Escape to exit the **Delete Bolts** option.

To delete ALL bolts at once:

1. While in **Delete Bolts** mode, enter the asterisk (*) character on the keyboard.
2. ALL bolts will be deleted from the model.

NOTE:

Bolts CANNOT be deleted in the Perspective view.

- If your Analysis Type is PROBABILISTIC, the Safety Factor for the mean wedge will be re-calculated each time a bolt is deleted. However, the Probabilistic Analysis will NOT be carried out until you exit the **Delete Bolts** mode.

Editing a Bolt

To edit the properties of an existing bolt:

Select **Support → Edit Bolt** or the "Edit Bolt" toolbar button.

1. Bolts are selected for editing in the same manner as for deleting – see the Delete Bolts topic for details.

Once a bolt has been selected for editing:

You will see the Bolt Properties dialog in the middle of the screen, displaying the properties of the selected bolt.

2. You can modify the properties of the bolt, in the same manner as when you originally added the bolt. See the Bolt Properties Dialog topic for details.
3. When you are finished editing the properties, select OK to save your changes.
4. If you select Cancel, all changes will be cancelled, even if you used the Apply button to apply the changes.

NOTE:

- Bolts can only be edited one at a time in this manner. It is not possible to edit the properties of multiple bolts simultaneously.
- A listing of all currently installed bolts and their properties can be found in the Info Viewer and also in the 2D Wedge View.

Statistics

Plot Histogram

To plot Histograms of results after a Probabilistic Analysis:

1. Select **Statistics → Plot Histogram** or the "Plot Histogram" toolbar button.
2. Select a Data Type from the dropdown list in the dialog.
3. Enter a Number of Intervals. The default is 30, but any value between 1 and 500 can be entered.
4. If the Data Type selected is a results variable calculated in the analysis, a Best Fit Distribution, using the Kolmogorov-Smirnov Goodness of Fit test, can be determined for the variable by selecting the Best Fit checkbox.
5. If the Data Type selected is an Input Data variable, the Input Distribution can be plotted through selection of the Plot Input Distribution checkbox.
6. Select OK.

The Histogram will be generated, and the mean, standard deviation, minimum and maximum values for the data plotted, will be listed at the bottom of the Histogram.

Several options are available in the right-click menu for Histograms, including:

3D Histogram

Input Distribution

Best Fit Distribution

Markers

Show Failed Wedges

Copy Data to Clipboard

Copy View to Clipboard

Chart in Excel

Data Types

After a Probabilistic Analysis, the following data can be plotted on Histogram, Cumulative or Scatter plots:

Calculated Data

Safety Factor

In most cases, the first thing you will want to view is the Safety Factor distribution since it is from this that the Probability of Failure is calculated.

Wedge Weight

The weight of each wedge (per unit thickness of the slope).

Normal Force

The Normal Force refers to the resultant force acting normal to the failure plane.

Driving Force

The driving forces consist of the down-slope component of the weight of the sliding block, forces generated by seismic acceleration, forces due to water pressures acting on various faces of the block, and external forces on the upper slope surface.

Resisting Force

The resisting forces comprise the shear strength of the sliding surface, artificial reinforcement of the slope or other stabilizing external forces, if present.

Failure Plane Length

This refers to the lengths of the failure planes for various sliding block geometries generated in a probabilistic analysis.

Upper Face Length

This refers to the lengths of the upper faces for various sliding block geometries generated in a probabilistic analysis..

Tension Crack Depth

This data type allows users to plot the various tension crack depths generated in a probabilistic analysis.

Wedge Volume

The volume of a wedge in ROCPLANE is numerically equal to its area since the program considers slices of unit thickness only.

Percent Filled

This data type is calculated only in analysis involving water pressures. In analysis involving tension cracks, Percent Filled refers to the water level in the Tension Crack.

Input Data

Input Data Variables

Any Data Types listed after the Calculated Data types (see above), are your Input Data variables (Slope Height, Slope Angle, Upper Face Angle, Bench Width, etc.) to which you assigned Statistical Distributions.

NOTE:

- The Calculated Data types will always be available for plotting.
- At least ONE Input Data variable will always appear in the Data Type list, since at least one Input Data variable must be assigned a Statistical Distribution, before a Probabilistic Analysis can be performed.

Safety Factor Histogram

The Safety Factor Histogram represents the distribution of calculated Safety Factors for all valid planar wedges generated by the Probabilistic Analysis.

Failed wedges (ie. Safety Factor < 1) are highlighted by the red bars at the left of the Histogram.

The Probability of Failure in ROCPLANE is simply the number of Failed Wedges divided by the TOTAL number of VALID wedges generated in the analysis.

- If any wedges have failed, then the Probability of Failure will be > 0.
- If NO wedges have failed, then the Probability of Failure = 0.

Mean Safety Factor

You will notice the mean, standard deviation, min and max values displayed below the histogram.

It should be noted that the **mean** Safety Factor from a Probabilistic Analysis (ie. the average of all of the Safety Factors generated by the Probabilistic Analysis) is not always the same as the Safety Factor of the Mean Wedge (ie. the Safety Factor of the wedge corresponding to the mean Input Data values).

There can be various reasons for this:

1. Monte Carlo sampling does not sample your input data distributions "exactly".
2. Number of samples is small.
3. If invalid wedges are generated by the probabilistic analysis (eg. invalid geometries), this can also lead to differences between the deterministic safety factor and the probabilistic mean safety factor.

NOTE: if you use Latin Hypercube sampling, and a large number of samples eg. (10000), the deterministic and probabilistic mean safety factors should be very nearly equal.

Plot Cumulative

To plot a Cumulative Distribution after a Probabilistic Analysis:

1. Select **Statistics → Plot Cumulative** or the "Plot Cumulative" toolbar button.
2. Select a Data Type.
3. Enter a Number of Intervals. The default is 30, but any value between 1 and 500 can be entered.
4. The display of interval markers may be toggled on or off with the checkbox.
5. Select OK.

The Cumulative Distribution will be generated, and the mean, standard deviation, minimum and maximum values for the data plotted, will be listed at the bottom of the Distribution.

A Cumulative Distribution is, mathematically speaking, the integral of the normalized probability density function. Practically speaking, a point on the cumulative distribution gives us the probability that a random variable will be LESS THAN OR EQUAL TO a specified value.

Simply put, if (X, Y) is a point on the cumulative distribution S-curve, then Y = the probability that the random variable will be <= X.

The data Sampler allows the user to obtain the coordinates of points on the S-curve.

The same Data Types, which can be plotted with Plot Histogram, can also be plotted as Cumulative Distributions – see the Data Type topic for details.

Several options are available in the right-click menu for Cumulative Distributions, including:

Markers

Sampler

Copy Data to Clipboard

Copy View to Clipboard

Chart in Excel

Plot Scatter

To create a Scatter Plot after a Probabilistic Analysis:

1. Select **Statistics → Plot Scatter** or the "Plot Scatter" toolbar button.
2. Select the data you would like to plot on the X-axis and Y-axis.
3. Select OK.

The Scatter Plot will be generated. At the bottom of the Scatter Plot, you will see a listing of the Correlation Coefficient, alpha and beta.

Correlation Coefficient

The Correlation Coefficient indicates the degree of correlation between the two variables plotted. The Correlation Coefficient can vary between -1 and 1. Numbers close to zero indicate a poor correlation, and numbers close to 1 or -1 indicate a strong correlation. Note that a negative correlation coefficient simply means that the slope of the best-fit linear regression line is negative.

Alpha and Beta

Alpha and beta represent the y-intercept and slope, respectively, of the best-fit linear regression line to the scatter plot data. The linear regression line can be displayed on the plot by selecting the Show Regression Line option.

Several options are available in the right-click menu for Scatter Plots, including:

Show Failed Wedges

Show Regression Line

Copy Data to Clipboard

Copy View to Clipboard

Chart in Excel

Viewing Other Wedges Generated by Analysis

The following are useful properties of Histograms and Scatter Plots in ROCPLANE:

- If you double-click the LEFT mouse button anywhere on a Histogram or Scatter plot, the nearest corresponding wedge from the plot, will be displayed in the 3D Wedge View and the 2D Wedge View.

- In addition, all other views of the current document will be updated, to display the results for the "Picked" wedge you have selected. For example, the Info Viewer will be updated to display the results for the selected wedge.

Here is an example:

1. Generate a Safety Factor Histogram.
2. Double-click on the histogram at any desired Safety Factor (for example, Safety Factor = 1).
3. Now look at the 3D Wedge view. A new wedge will be displayed, corresponding to the point (along the X-axis of the Histogram) at which you clicked. This is an actual wedge generated by the Probabilistic analysis.
4. The Safety Factor of this particular wedge will be displayed in the title bar of the Wedge view, and the title bar will now indicate that you are viewing a "Picked" wedge.
5. Look at the Info Viewer. The Current Wedge Data corresponds to the "Picked" wedge you are viewing.
6. In addition to Safety Factor plots the above applies to Histograms or Scatter plots of any Data Type (e.g. Wedge Weight, Input Data variables, etc.).

This feature is meant to give you a general idea of the shape and orientation of wedges corresponding to locations on a Histogram or Scatter plot. For example, on a Safety Factor Histogram, you will probably want to double-click in the "red" Safety Factor region, to get an idea of the wedges that have a Safety Factor < 1.

Resetting the Mean Wedge

To reset all views so that the mean wedge data is displayed, select **Reset Wedge** from the **View** menu. This will re-display the wedge corresponding to the mean Probabilistic Input Data.

Tip

Use the **Tile** option in the Windows menu to tile views, so that you can immediately see the "Picked" wedge data displayed when you double-click on a part of a Histogram or Scatter plot.

Export Dataset

The **Export Dataset** option in the **Statistics** menu allows the user to export raw data from a Probabilistic Analysis, to the clipboard, a file, or to Excel.

Data

All available data from the analysis is initially selected for export (except Wedge Vertex Locations). If you do NOT wish to export a given dataset, clear the corresponding checkbox before exporting. If a dataset is grayed out, this means that no statistical distribution was defined for that dataset. See the Data Type topic for more information about Probabilistic Analysis data.

Copy

Select the Copy button to copy the selected datasets to the Windows clipboard. From the clipboard, the data can be pasted into other applications for further analysis or for reporting purposes.

Save

Select the Save button to save the selected datasets to a file. The Save As dialog will allow you to save the data in one of 3 different text file formats:

- A tab delimited text file (*.txt)
- A comma separated values (CSV) text file (*.csv)
- A space delimited text file (*.prn)

The 3 different formats are all plain ASCII text files, with different methods of delimiting the data in each row of the file.

Excel

Select the Excel button to export the data to Microsoft Excel. If you have the Excel program on your computer, Excel will be automatically launched, and the exported data will appear in a new Excel document.

Tips

Tabs Option

The **Tabs** option in the **Window** menu, will create tabs at the bottom of the ROCPLANE application window, for each view which you currently have open.

If you are working with multiple views or multiple files, then the **Tabs** option can be useful for easily selecting different views, without having to select from the list of views in the Window menu. Views can be left maximized within the ROCPLANE application window, and you can easily select a view by selecting the corresponding tab.

Right-Click Menus

Various options are available in the right-click menus of the following views:

2D Wedge View

Histogram Plot

Cumulative Distribution

Scatter Plot

Sensitivity Plot

Info Viewer

The user will find the right-click menus a useful and timesaving shortcut to many options in ROCPLANE.

NOTE that NO right-click menu is available on the 3D Wedge View, since the right mouse button is used for moving the wedge out of the slope.

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