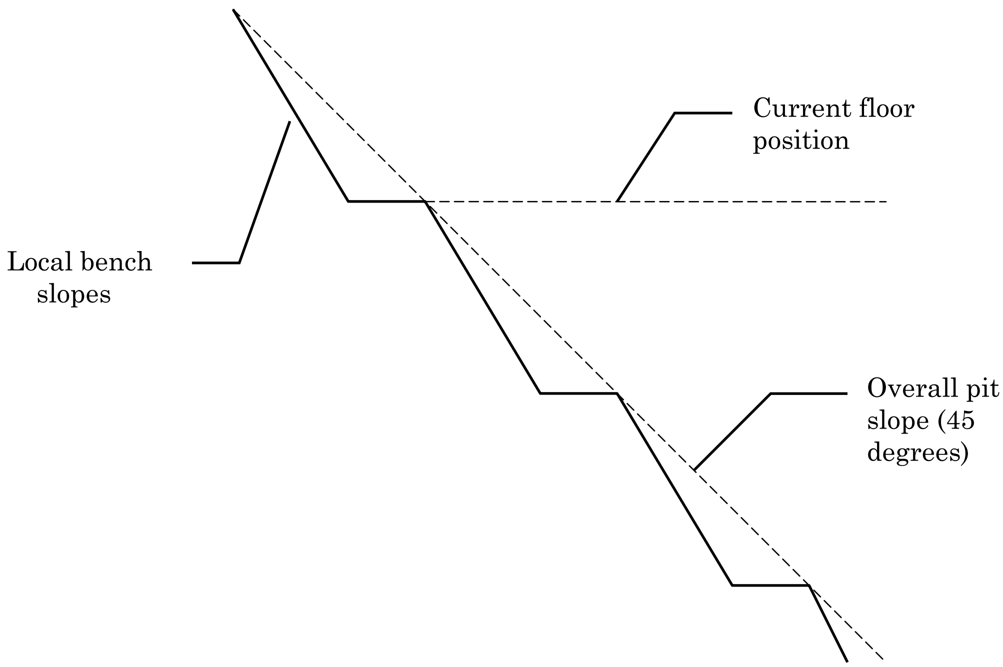
Toppling, Planar Sliding, Wedge Sliding

This tutorial demonstrates how to perform stability analyses (toppling, planar sliding, wedge sliding) using the Kinematic Analysis option in *Dips*.

The tutorial uses the example file **Examppit.dips6**. The data has been collected by a geologist working on a single rock face above the first bench in a young open pit mine.



The rock face above the current floor of the existing pit has a dip of 45 degrees and a dip direction of 135 degrees. The current plan is to extend the pit down at an overall angle of 45 degrees. This will require a steepening of the local bench slopes, as indicated in the figure above.

The local benches are to be separated by an up-dip distance of 16m. The bench roadways are 4m wide.

Examppit.dip File

Navigate to the Examples folder in your *Dips* installation folder.

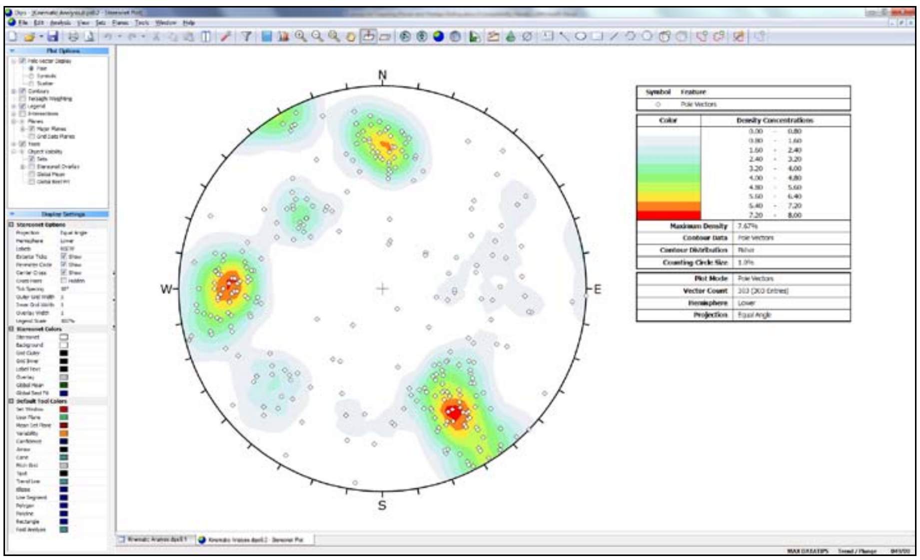
Select: File → Recent Folders → Examples Folder

Open the **Examppit.dips6** file. Save this example file with a new file name so that we do not modify the original file.

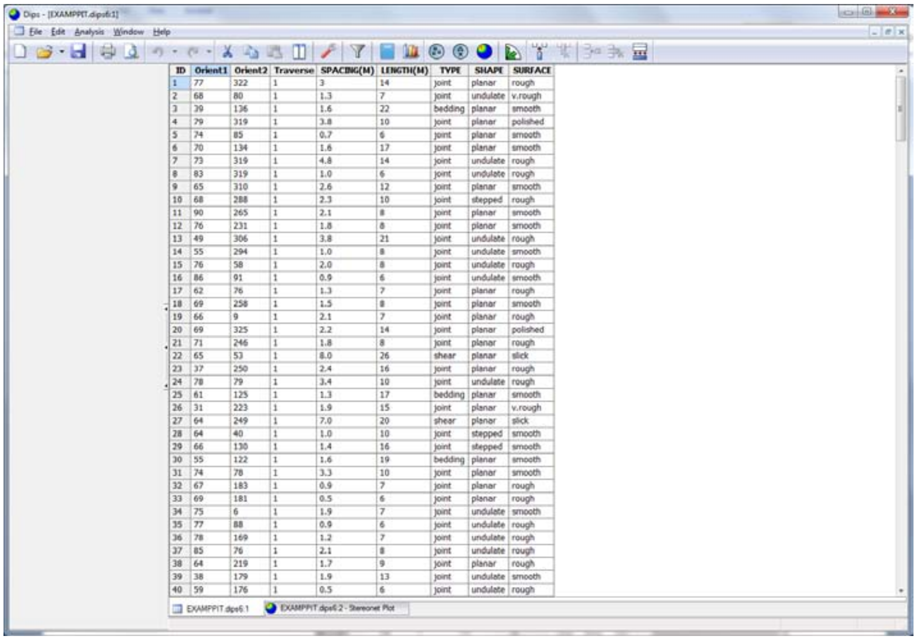
Select: File → Save As

Enter the file name **Kinematic Analysis.dips6** and save the file.

You should see the stereonet plot view shown in the following figure. If this file has been previously opened and saved, the screen may show a different view or plot, since *Dips* saves the most recent view state when a file is saved. If you do not see the plot below, then use the sidebar plot options to view pole vectors and contours on the stereonet.



Switch to the grid view of the input data using the tabs at the lower left of the view.



ID	Orient1	Orient2	Traverse	SPACING(M)	LENGTH(M)	TYPE	SHAPE	SURFACE
1	77	322	1	3	14	joint	planar	rough
2	68	80	1	1.3	7	joint	undulate	v.rough
3	39	136	1	1.6	22	bedding	planar	smooth
4	79	319	1	3.8	10	joint	planar	polished
5	74	85	1	0.7	6	joint	planar	smooth
6	70	134	1	1.6	17	joint	planar	smooth
7	73	319	1	4.8	14	joint	undulate	rough
8	83	319	1	1.0	6	joint	undulate	rough
9	65	310	1	2.6	12	joint	planar	smooth
10	68	288	1	2.3	10	joint	stepped	rough
11	90	265	1	2.1	8	joint	planar	smooth
12	76	231	1	1.8	8	joint	planar	smooth
13	49	306	1	3.8	21	joint	undulate	rough
14	55	294	1	1.0	8	joint	undulate	smooth
15	76	58	1	2.0	8	joint	undulate	rough
16	86	91	1	0.9	6	joint	undulate	smooth
17	62	76	1	1.3	7	joint	planar	rough
18	69	258	1	1.5	8	joint	planar	smooth
19	66	9	1	2.1	7	joint	planar	rough
20	69	325	1	2.2	14	joint	planar	polished
21	71	246	1	1.8	8	joint	planar	rough
22	65	53	1	8.0	26	shear	planar	slick
23	37	250	1	2.4	16	joint	planar	rough
24	78	79	1	3.4	10	joint	undulate	rough
25	61	125	1	1.3	17	bedding	planar	smooth
26	31	223	1	1.9	15	joint	planar	v.rough
27	64	249	1	7.0	20	shear	planar	slick
28	64	40	1	1.0	10	joint	stepped	smooth
29	66	130	1	1.4	16	joint	stepped	smooth
30	55	122	1	1.6	19	bedding	planar	smooth
31	74	78	1	3.3	10	joint	planar	smooth
32	67	183	1	0.9	7	joint	planar	rough
33	69	181	1	0.5	6	joint	planar	rough
34	75	6	1	1.9	7	joint	undulate	smooth
35	77	88	1	0.9	6	joint	undulate	rough
36	78	169	1	1.2	7	joint	undulate	rough
37	85	76	1	2.1	8	joint	undulate	rough
38	64	219	1	1.7	9	joint	planar	rough
39	38	179	1	1.9	13	joint	undulate	smooth
40	59	176	1	0.5	6	joint	undulate	rough

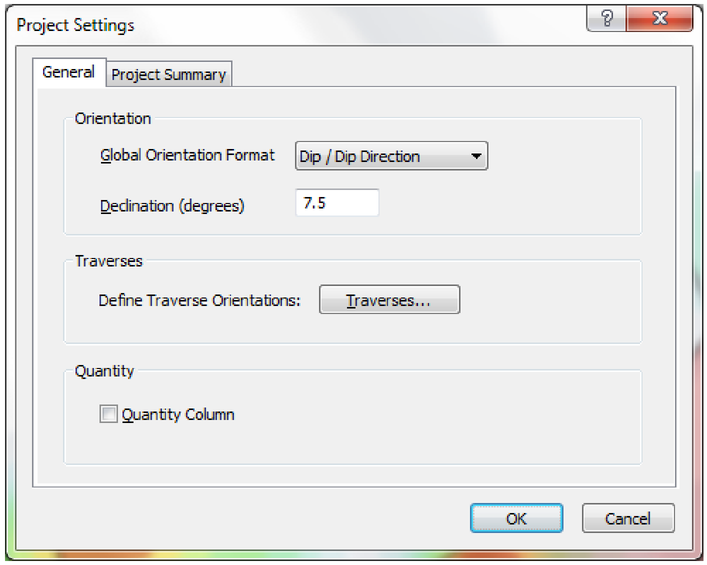
The **Examppit.dips6** file contains 303 rows, and the following columns:

- The two mandatory Orientation Columns
- A Traverse Column
- 5 Extra Columns (spacing, length, type, shape, surface)

Let's examine the Project Settings information for this file.

Project Settings

Select: Analysis → Project Settings

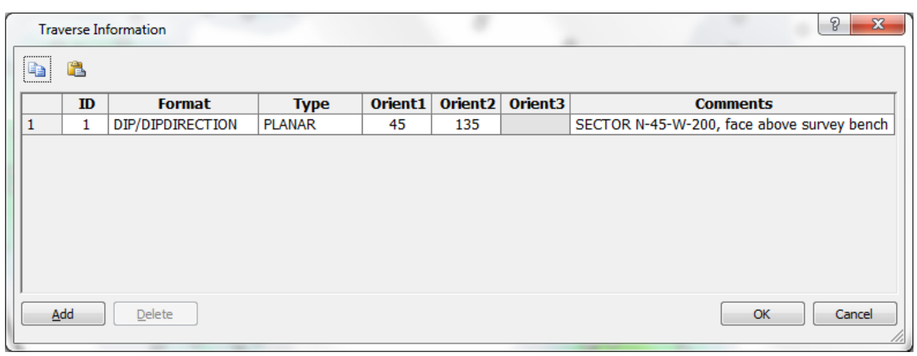


Note the following:

- the Global Orientation Format is DIP/DIPDIRECTION
- The Declination is 7.5 degrees, indicating that 7.5 degrees will be added to the dip direction of the data, to correct for magnetic declination
- The Quantity Column is NOT used in this file, so each row of the file represents an individual measurement.

Traverses

Let's inspect the Traverse Information. You can select the Traverses button in the Project Settings dialog (the Traverses dialog is also available directly in the Analysis menu).



As you can see in the Traverse Information dialog, this file uses only a single traverse:

- The Traverse is a PLANAR traverse, with a Dip of 45 degrees and a Dip Direction of 135 degrees (i.e. the face above the survey bench, as you can read in the Traverse Comment).

- Note that the Traverse Orientation Format is the same as the Global Orientation Format (DIP/DIPDIRECTION), as we would expect for a file with only a single traverse defined.

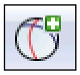
Select Cancel in the Traverse Information dialog.

Select Cancel in the Project Settings dialog.

Switch back to the stereonet plot view. Before we proceed with the kinematic analysis, we will add the slope plane to the view, create a symbolic plot, define sets for the main data clusters and estimate the friction angle from the joint surface condition.

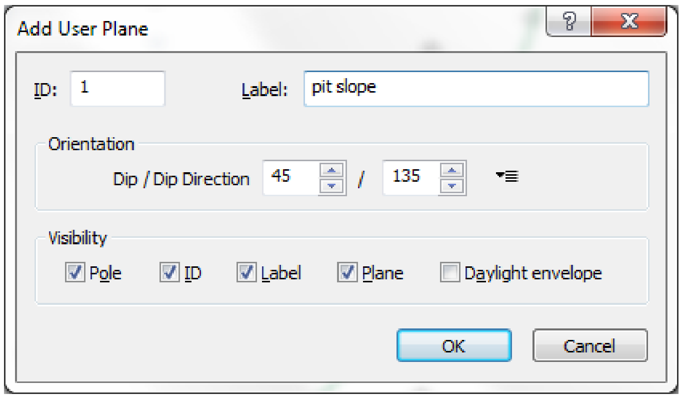
Add Plane

Let's add the slope plane to the stereonet.

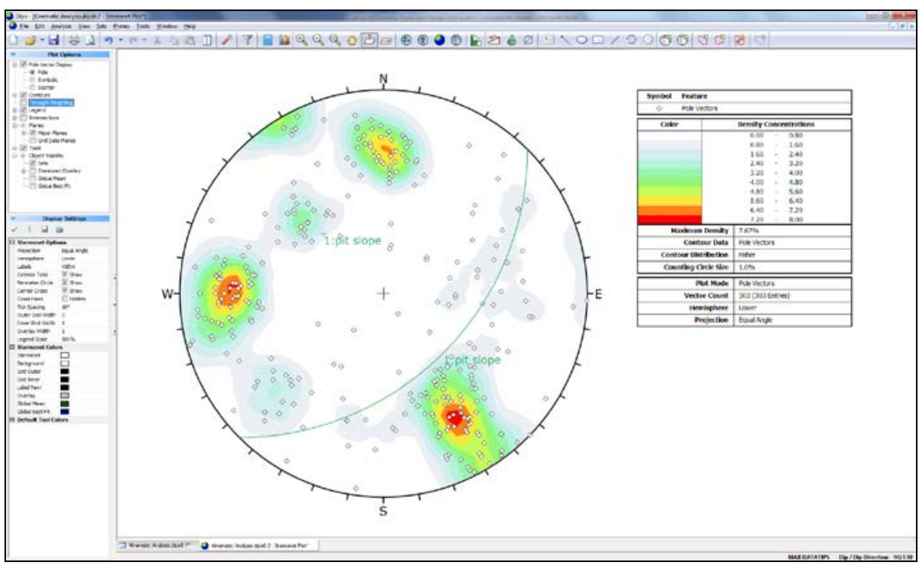


Select: Planes → Add Plane

Click the mouse anywhere in the stereonet. In the Add Plane dialog enter the coordinates 45 / 135 (dip/dipdirection) and the label Pit Slope. Note: if the Orientation input format is not Dip / Dip Direction, click on the button at the right of the orientation input boxes and change the convention to Dip/DipDirection.



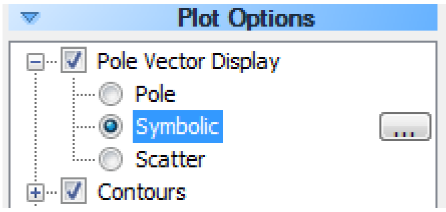
Select OK. You should see the pit slope plane as shown below.



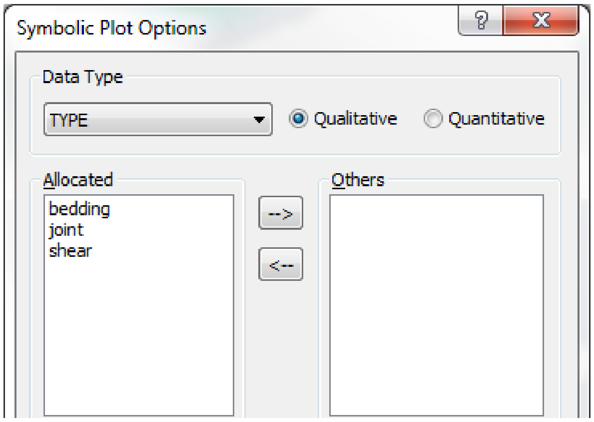
Symbolic Pole Plot

Feature attribute analysis can be carried out on a Pole Plot with the Symbolic Plot option. Let's create a Symbolic Pole Plot based on the discontinuity type (i.e. the data in the TYPE column).

In the sidebar plot options, select Pole Vector Display > Symbolic and select the small button which appears at the right.



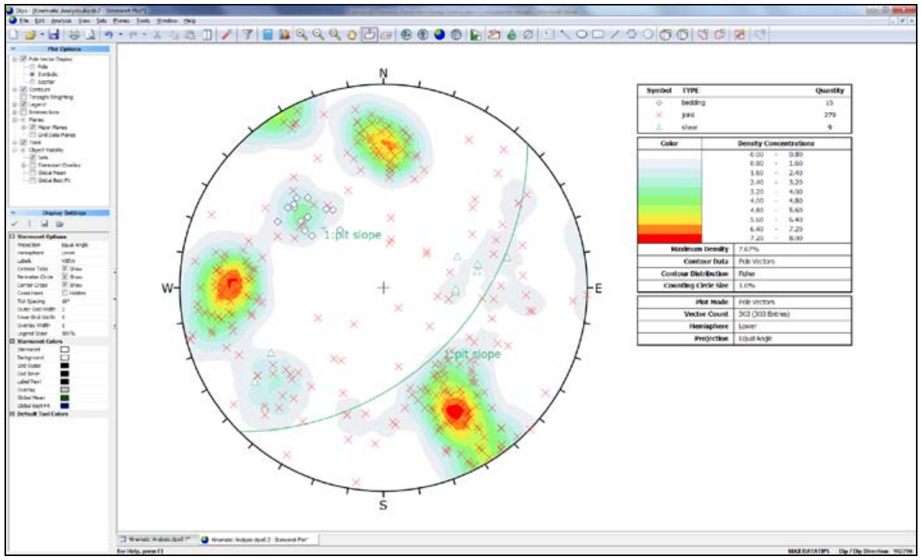
You will see the Symbolic Plot dialog. Change the Data Type = TYPE. The data in the TYPE column is Qualitative which is the default selection, so just select OK to generate the Symbolic Plot.



Look closely at the data clustering and the data TYPE. Most of the features are joints as indicated in the legend. Note the clustering of bedding features and the two clusters of shear features. These may behave very differently from similarly oriented joints or extension fractures, and should be considered separately.

Although the Shears are not numerous enough to be represented in the contours (the number of mapped shears is small), they may have a dominating influence on stability due to low friction angles and inherent persistence. It is always important to look beyond mere orientations and densities when analyzing structural data.

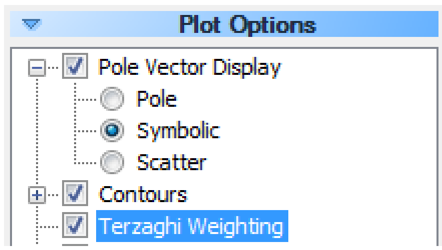
Observe the clustering of ***joint***, ***bedding*** and ***shear*** *features on a Symbolic Pole Plot.*



Contour Plot

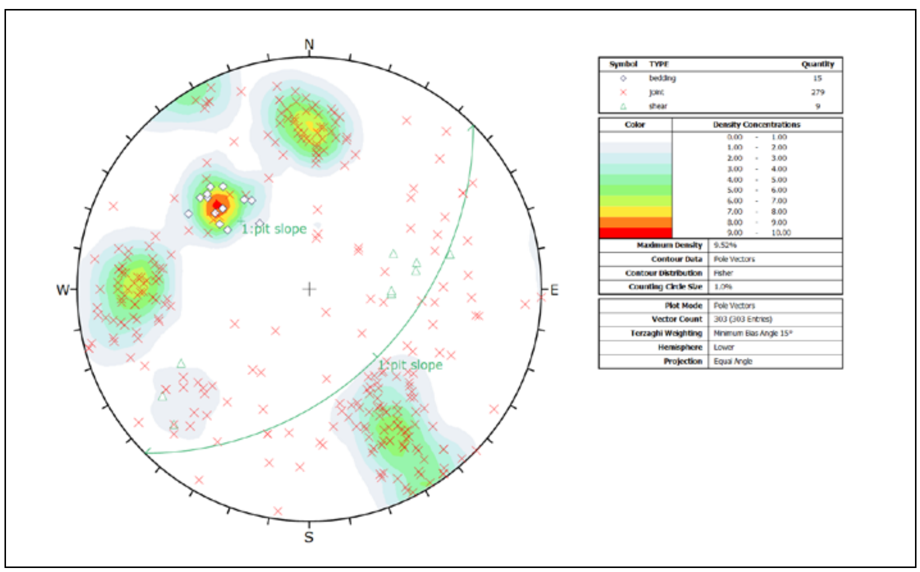
Let’s examine the data contours. A useful rule of thumb is that any cluster with a maximum concentration of greater than 6% is very significant. 4-6% represents a marginally significant cluster. Less than 4% should be regarded with suspicion unless the overall quantity of data is very high (several hundreds of poles). Rock mechanics texts give more rigorous rules for statistical analysis of data.

Now apply the Terzaghi Weighting to the data, to account for bias correction due to data collection on the (planar) traverse. Select the Terzaghi Weighting checkbox in the sidebar plot options.



Observe the change in adjusted concentration for the set nearly parallel to the mapping face (the “bedding plane” joint set).

Observe the effect of ***bias correction*** *on the bedding plane joint set in particular.*



Terzaghi Weighting applied to data contours

See the *Dips* Help system for more information about the Terzaghi Weighting procedure used in *Dips*.

To restore the original unweighted plot turn off the Terzaghi Weighting checkbox in the sidebar plot options.

Creating Sets

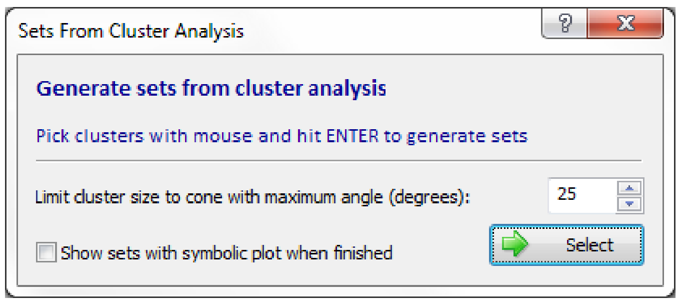
Let's use the **Sets from Cluster Analysis** option to delineate the joint contours and create four Sets from the four major data concentrations on the stereonet.

Select: Sets → Sets from Cluster Analysis

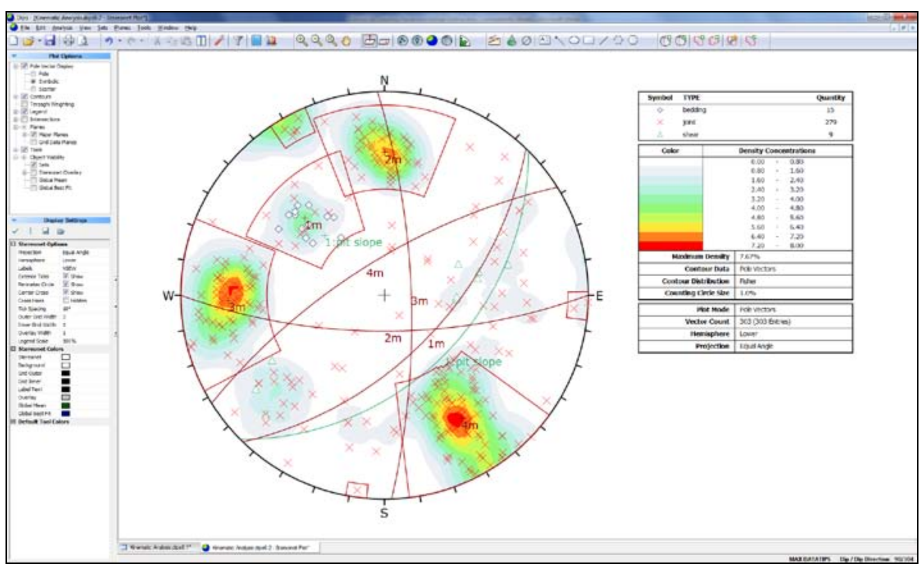
(Note: see Tutorial 03 for instructions on how to create Sets. Also see the *Dips* Help system for detailed information.)

1. In the Sets from Cluster Analysis dialog, enter 25 degrees as the maximum cone angle.

2. Press the Select button, and use the mouse to click on the approximate center of the four main data clusters on the stereonet.



3. Right-click and select Done. You should see the Set Windows shown below.



Turn off the display of the mean joint set planes and the pit slope by clearing the Planes > Major Planes checkbox in the sidebar plot options.

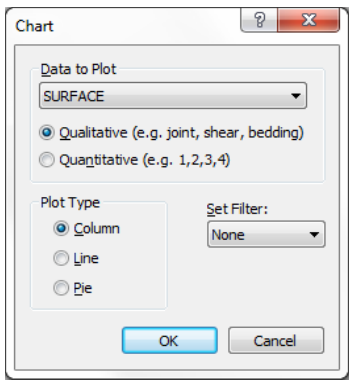
Estimating Friction Angle

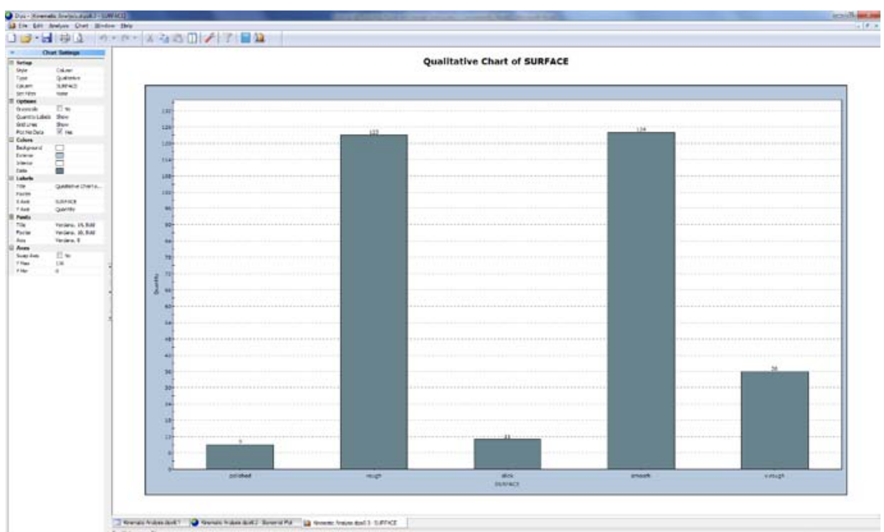
For stability analysis it will be necessary to assume a value for friction angle on the joint surfaces.

For the purpose of estimating a friction angle, we will create a Chart of the data in the SURFACE column of the **Examppit.dip** file.

Select: Analysis → Chart

In the Chart dialog, select Data to Plot = SURFACE. Select OK, and the Chart will be created.





From the chart, the surfaces are about 50 percent rough (considering both “rough” and “v.rough” features) and 50 percent smooth, so we will assume an average friction angle of 30 degrees for all features. Note: this process can be refined by using the Set Filter (in the Chart dialog) and examining the joint roughness of individual sets. This is left as an optional exercise. Close the Chart view and we will return to the stereonet.

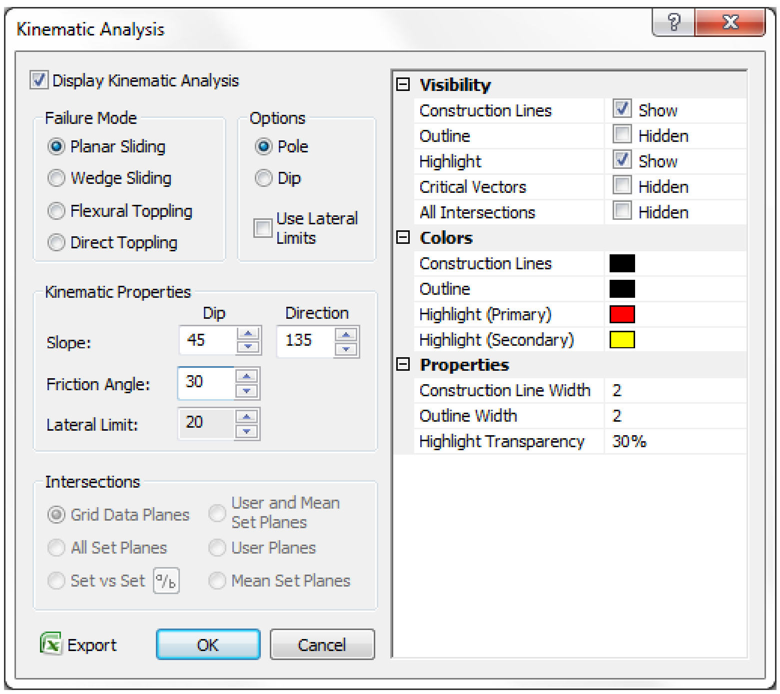
Planar Sliding

We will now proceed with the analysis of 3 potential failure modes of interest – planar sliding, wedge sliding and toppling. Select the Kinematic Analysis option from the Analysis menu.

Select: Analysis → Kinematic Analysis

In the Kinematic Analysis dialog:

1. Select the **Display Kinematic Analysis** checkbox.
2. Select the **Planar Sliding** Failure Mode.
3. Turn off the **Use Lateral Limits** checkbox.
4. Enter the Slope Dip = 45 and Dip Direction = 135.
5. Enter Friction Angle = 30 degrees.
6. Select OK.



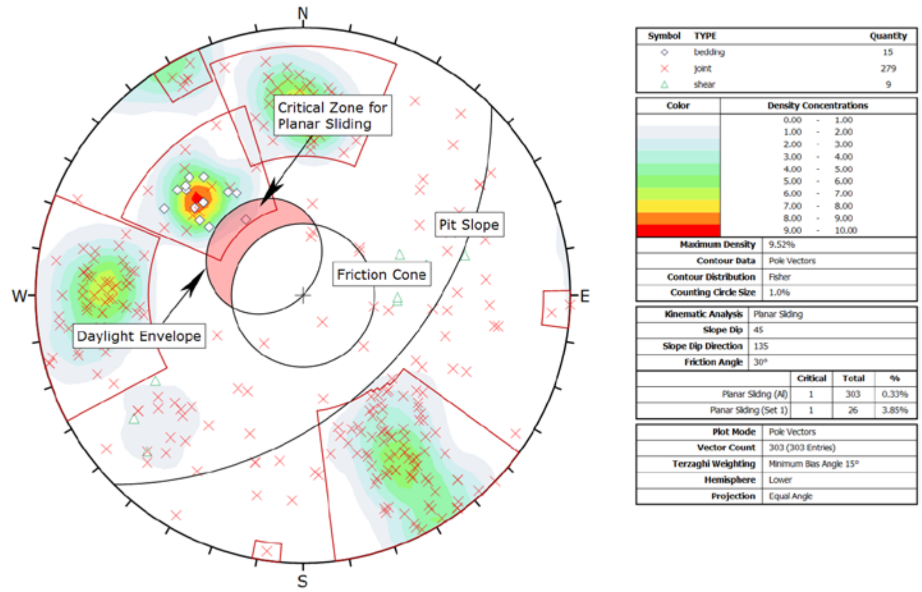
You should see the kinematic analysis overlay for planar sliding as shown below. The key elements of planar sliding using pole vectors are:

1. **Slope plane and daylight envelope**

2. **Pole friction cone (angle measured from center of stereonet)**

3. **Lateral limits (optional)**

These are discussed below. Note: the text labels in the figure were manually added using the Add Text option in the Tools menu.



Slope Plane

The great circle of the slope plane is displayed and labeled Pit Slope on the above figure with orientation 45/135 Dip/DipDirection. Note: the slope plane is automatically displayed by the kinematic analysis. The slope plane that we added earlier using the Add Plane option is now hidden.

Daylight Envelope

The Daylight Envelope corresponding to the slope plane is required for a planar sliding kinematic analysis as shown in the above figure. A Daylight Envelope allows us to test for kinematics (i.e. a rock slab must have somewhere to slide into – free space). Any pole falling within this envelope is kinematically free to slide if frictionally unstable.

Friction Cone

A pole friction cone of 30 degrees is displayed. Any pole falling outside of this cone represents a plane which could slide if kinematically possible.

NOTE: when considering pole vectors, the friction cone angle is measured from the CENTER of the stereonet.

Critical Zone for Planar Sliding

The crescent shaped zone formed by the Daylight Envelope and the pole friction circle encloses the region of planar sliding. Any poles in this region represent planes which can and will slide, i.e., the critical zone for planar failure is defined by poles which are:

- OUTSIDE of the pole friction circle and
- INSIDE the daylight envelope

This region is automatically highlighted for planar sliding analysis as shown in the above figure. The highlight colour and other display options can be customized in the Kinematic Analysis dialog.

Legend

A summary of the planar sliding kinematic analysis results is displayed in the Legend.

Kinematic Analysis	Planar Sliding		
Slope Dip	45		
Slope Dip Direction	135		
Friction Angle	30°		
	Critical	**Total**	**%**
Planar Sliding (All)	1	303	0.33%
Planar Sliding (Set 1)	1	26	3.85%

In this case only a single pole is contained within the critical planar sliding zone. The Legend provides results as a percentage of all poles in the file (1/303), and as a percentage of poles for individual sets (1/26 for Set number 1).

In either case, you can see that the probability of planar sliding is very low for this combination of slope orientation and friction angle.

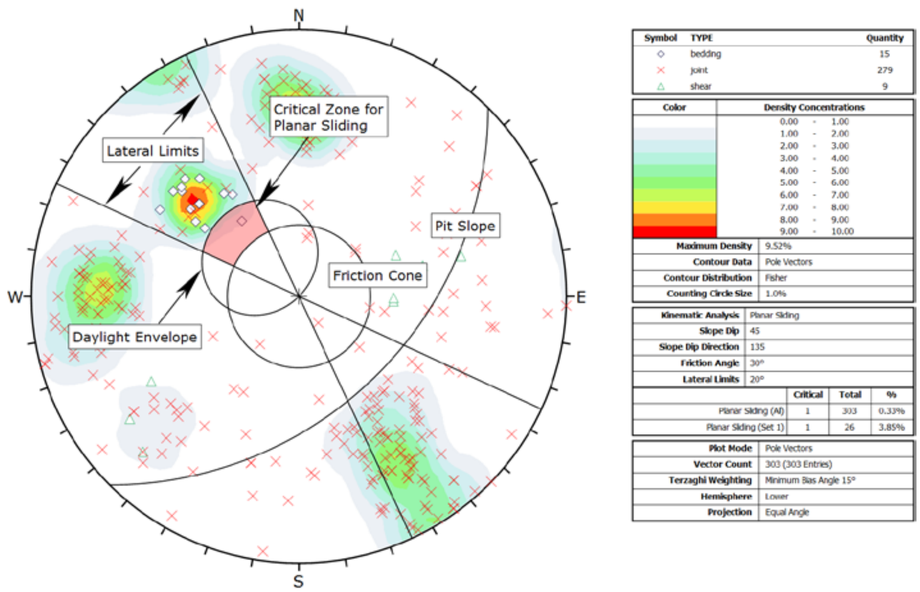
Lateral Limits

The planar sliding analysis described above considers the entire daylight envelope as a kinematically valid sliding zone.

In practice it has been observed that planar sliding (and toppling) tends to occur when the dip direction of planes is within a certain angular range of the slope dip direction. Typically a range of plus/minus 20 or 30 degrees is considered, and poles outside of this range represent a low risk.

To add lateral limits to the kinematic analysis, return to the Kinematic Analysis dialog and turn on the Use Lateral Limits checkbox. Or alternatively, select the **Planar Sliding** option from the sidebar (instead of **Planar Sliding (No Limits)**).

Since the stereonet is getting a bit cluttered, turn off the display of Set Windows (select Object Visibility > Sets from the sidebar plot options and turn off the checkbox). You should see the following.



The lateral limits are simply two straight lines which define an angular range measured from the dip direction of the slope. In this case we have used the default value of plus/minus 20 degrees.

For this example, the addition of lateral limits does not change the results, since only a single pole is in the critical planar sliding zone. However this depends on your file, and the inclusion of lateral limits could significantly change results if there are many poles inside the daylight envelope.

Planar Sliding Release Planes

An important assumption regarding “pure” planar sliding is that release planes are assumed to exist (e.g. lateral joints, tension cracks or other mechanism) which allow a planar sliding failure to occur.

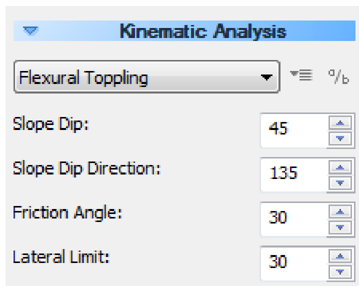
Such release planes are not explicitly modeled in the planar sliding kinematic analysis but you should be aware that some release mechanism must exist to allow a block sliding on one plane to be removed from the slope. Planar sliding can be considered a special case of wedge sliding where sliding takes place on only one plane, and other planes act as release planes.

Flexural Toppling

Now let's examine the Flexural Toppling failure mode.

1. Select the **Flexural Toppling** kinematic analysis option in the sidebar or the Kinematic Analysis dialog.

2. Enter Lateral Limits = 30 degrees.



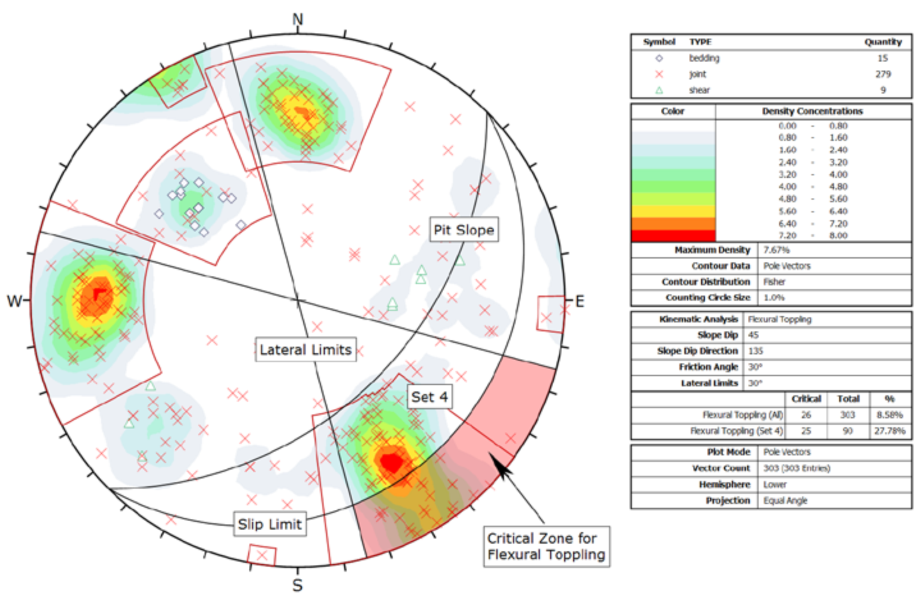
Also do the following:

1. If you added any text or arrows, delete them.

2. Re-display the Set Windows (select Object Visibility > Sets in the sidebar plot options).

3. Remove the Terzaghi weighting (clear the Terzaghi weighting checkbox in the sidebar plot options). This will highlight the data contours for Set 4.

You should see the kinematic analysis overlay for flexural toppling as shown below.



The key elements of flexural toppling analysis using pole vectors are:

1. **Slope plane**
2. **Slip limit plane (based on slope angle and friction angle)**
3. **Lateral limits**

These are discussed below. Any poles that plot within the critical zone for flexural toppling represent a toppling risk. This analysis is based on the flexural toppling analysis described by Goodman (Ref.1).

Slope Plane

The great circle of the slope plane is displayed, and labeled Pit Slope with orientation 45/135 Dip/DipDirection.

Slip Limit

Planes cannot topple if they cannot slide with respect to one another. Goodman (Ref. 1) states that for slip to occur, the bedding normal must be inclined less steeply than a line inclined at an angle equivalent to the friction angle above the slope.

This results in a "slip limit" plane which defines the critical zone for flexural toppling. The Dip angle of the slip limit plane is derived from the PIT SLOPE ANGLE – FRICTION ANGLE = 45 – 30 = 15 degrees. The DIP DIRECTION of the slip limit plane is equal to that of the face (135 degrees).

Lateral Limits

The Lateral Limits for flexural toppling have the same purpose as described for planar sliding. They define the lateral extents of the critical zone with respect to the dip direction of the slope. For this example we have increased the limits from 20 degrees (used in the planar sliding example) to 30 degrees as suggested by Goodman.

Critical Zone for Flexural Toppling

The critical zone for flexural toppling is the highlighted region between the slip limit plane, stereonet perimeter and the lateral limits. Any poles in this region represent a risk of flexural toppling. Remember that a near horizontal pole represents a near vertical plane.

Legend

A summary of the flexural toppling results is displayed in the Legend.

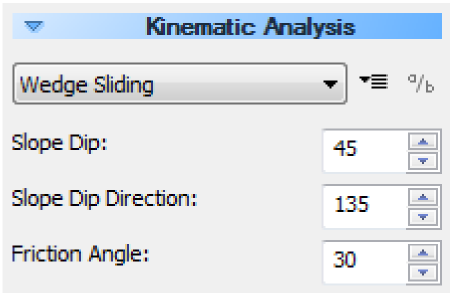
Kinematic Analysis	Flexural Toppling			
Slope Dip	45			
Slope Dip Direction	135			
Friction Angle	30°			
Lateral Limits	30°			
		Critical	**Total**	**%**
Flexural Toppling (All)		26	303	8.58%
Flexural Toppling (Set 4)		25	90	27.78%

In this case there is a significant risk of flexural toppling. The Legend provides results as a percentage of all poles in the file (26/303), and as a percentage of poles for individual sets (25/90 for Set number 4). For set number 4 the toppling probability is nearly 30 percent.

Wedge Sliding

From the Planar Sliding kinematic analysis, it has been shown that a sliding failure along any single joint plane is unlikely. However, multiple joints can form wedges which can slide along the line of intersection between two planes.

Select the **Wedge Sliding** kinematic analysis option in the sidebar or the Kinematic Analysis dialog.



Also do the following:

1. If you added any text or arrows, delete them.
2. Turn off the display of Set Windows (select Object Visibility > Sets in the sidebar plot options).
3. Turn off the display of pole vectors (select the Pole Vector Display checkbox in the sidebar).
4. Turn on the display of Intersection Contours (select Contours > Intersection in the sidebar).

You should see the kinematic analysis overlay for wedge sliding as shown below. The key elements of wedge sliding analysis are:

1. **Slope Plane**
2. **Plane friction cone (angle measured from perimeter of stereonet)**
3. **Intersection plotting**

The primary critical zone for wedge sliding is the crescent shaped area INSIDE the plane friction cone and OUTSIDE the slope plane. Any intersection points that plot within this zone represent wedges which are able to slide.

Intersections

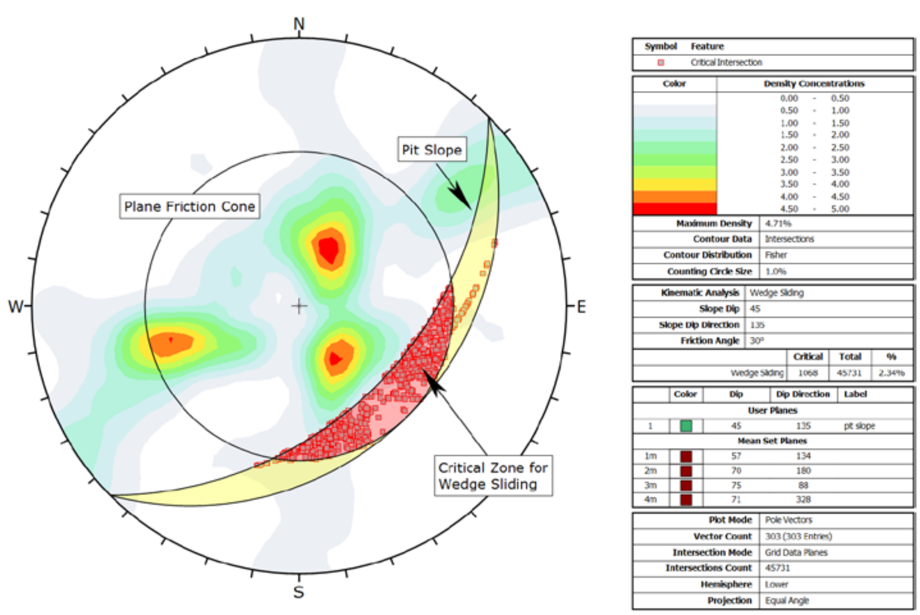
The points that you see plotted for the wedge sliding analysis are intersection points. Each point represents the intersection of two joint planes. By default, all planes in the file are considered (i.e. each plane in the file is intersected with every other plane in the file, to determine the intersection points). The intersection points represent the actual trend/plunge of the line of intersection of two joint planes. By default only the critical intersections are displayed.

There are several options available for the display of intersections:

- All planes in the file can be intersected with each other (Grid Data Planes option)
- Intersection contours can be displayed (based on the intersection of all planes) as shown below.
- Major plane intersections can be plotted (i.e. mean set planes and/or user-defined planes).

Intersection Contours

An immediate indication that wedge sliding is not an issue for this slope orientation, are the intersection contours. You can see that the main concentrations of intersections are all well outside the critical zone for wedge sliding.



Slope Plane

The pit slope plane defines the daylighting condition for intersections. Any intersection point which plots outside the pit slope great circle satisifies the daylighting condition.

Friction Cone

For wedge sliding, it is important to remember that the friction cone (30 degrees) is measured from the EQUATOR of the stereonet, and NOT FROM THE CENTER, because we are dealing with an actual sliding surface or line. (When we are dealing with poles the friction cone is measured from the center of the stereonet).

Critical Zone for Wedge Sliding

The primary critical zone for wedge sliding is the crescent shaped area INSIDE the plane friction cone and OUTSIDE the slope plane (highlighted in red in the above figure). Intersections which plot in this zone represent wedges which satisfy frictional and kinematic conditions for sliding.

However wedges do not necessarily slide along the line of intersection of two joint planes. Wedges can slide on a single joint plane, if one plane has a more favourable direction for sliding than the line of intersection. In this case, the second joint plane acts as a release plane rather than a sliding plane. This can occur in either the primary or the secondary critical region.

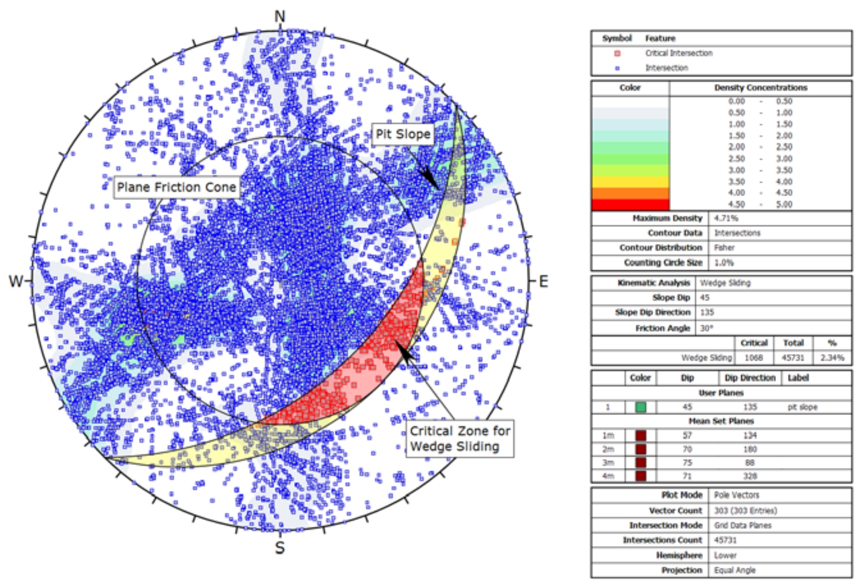
The secondary critical zone (highlighted in yellow in the above figure) is the area between the slope plane and a plane (great circle) inclined at the friction angle. Critical intersections which plot in these zones always represent wedges which slide on one joint plane. In this region, the intersections are actually inclined at LESS THAN the friction angle, but sliding can take place on a single joint plane which has a dip vector greater than the friction angle.

Legend

A summary of the wedge sliding results is displayed in the Legend.

Kinematic Analysis	Wedge Sliding		
Slope Dip	45		
Slope Dip Direction	135		
Friction Angle	30°		
	Critical	**Total**	**%**
Wedge Sliding	1068	45731	2.34%

For this example, the percentage of critical intersections compared to the total number is actually very low (about 2 percent) so wedge sliding is not a great concern for this slope orientation.



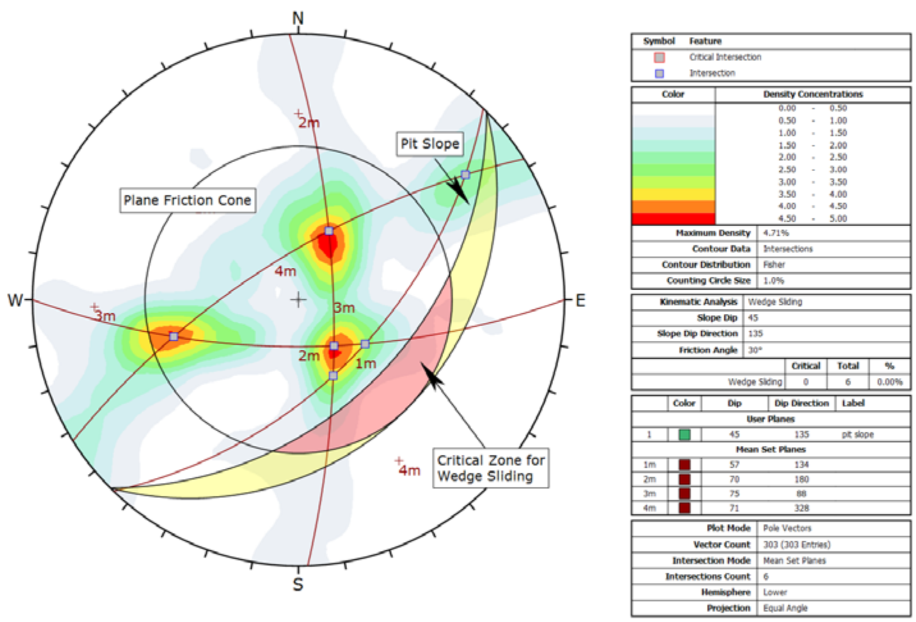
To view all intersections, select the **Show All Intersections** checkbox in the Kinematic Analysis options in the sidebar. This will give you a better feel for the relatively small number of critical intersections compared to the total number, as shown in the above figure.

Mean Set Plane Intersections

Let's demonstrate one more possibility for assessing the risk of wedge sliding. We will view the intersections of the mean planes (from the four sets we created earlier in this tutorial).

1. In the sidebar plot options, select Intersections > Mean Set Planes
2. Display the mean set planes (select Planes > Major Planes > Mean Set Planes).

The plot should look as follows.



Notice that the four mean set planes intersect each other to form six intersection points. Notice that these intersections correspond with the maximum concentrations of the intersection contours, as we would expect.

Since none of the mean set plane intersections are within the critical wedge sliding zone, again we can conclude that wedge sliding is not an issue for this slope orientation. Note that the Legend indicates zero critical intersections out of a total of 6 mean set plane intersections.

Toggle the Terzaghi weighting checkbox to see the effect of applying bias correction to the mean set planes. The effect in this case is small.

Discrete Structures

Finally, for wedge sliding you should analyze the shear zones mentioned earlier. If these shears occur in proximity to one another they may interact to create local instability.

Perform an analysis similar to the one above using discrete combinations of shear planes.

- Use the Add Plane option to add planes corresponding to the shear features.

- TIP: while using Add Plane, the Pole Snap option (available in the right-click menu) can be used to snap to the exact orientations of the shear poles.

Determine whether the shears will interact with any of the mean joint set orientations to create an unstable wedge. Using the procedure described above, the stability of discrete combinations of shear planes, or of shear planes with the mean joint orientations, may be analyzed. In the sidebar plot options, select Intersections > User Planes (or Intersections > User and Mean Set Planes).

You should find that the risk of wedge failure along the shear planes is low, for this pit slope configuration.

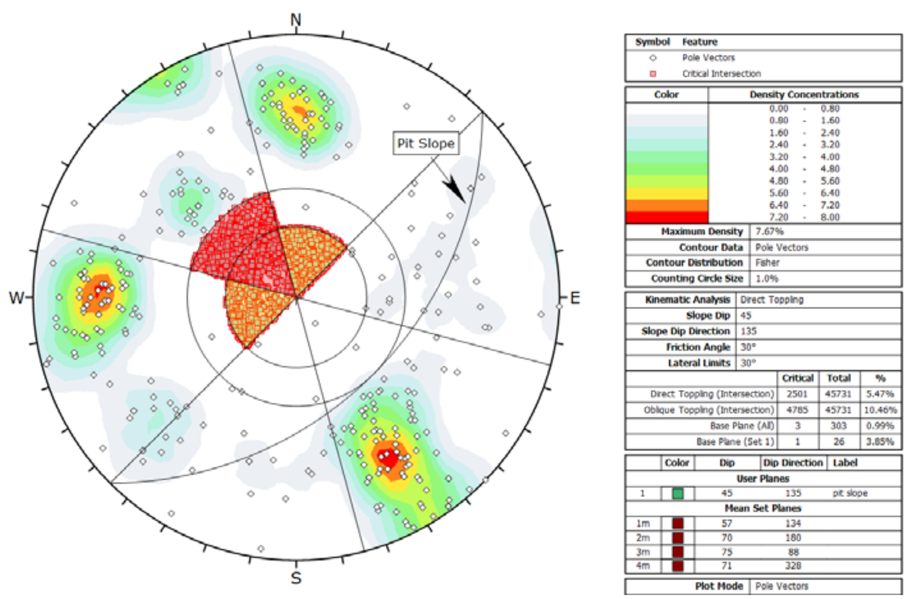
Direct Toppling

There is one more kinematic analysis failure mode that we have not yet discussed – Direct Toppling.

Direct Toppling involves a different set of assumptions in comparison to Flexural Toppling. The two primary features of Direct Toppling are:

- Two joint sets intersect to form intersection lines dipping into the slope which can form discrete blocks.
- A third joint set of near horizontal planes act as release planes (or sliding planes) for the discrete blocks.

Direct Toppling analysis is somewhat more complicated than the other analysis modes and is based on the method described in Hudson and Harrison (Ref. 2). This is left as an optional exercise to experiment with, for more information see the *Dips* help system.



Info Viewer

Although the Legend displays a summary of kinematic analysis results for the currently selected method, the **Info Viewer** provides a detailed summary of kinematic results for ALL failure modes.

As soon as kinematic analysis is enabled, *Dips* automatically carries out the analysis behind the scenes, for all failure modes, for the current input parameters (slope orientation, friction angle, lateral limits) and this information is available at all times in the Info Viewer. This is useful for carrying out sensitivity analysis as discussed below.

Select: Analysis → Info Viewer

Go to the Info Viewer to see the format of the kinematic analysis results. For further details see the *Dips* help system.

Sensitivity Analysis

The Kinematic Analysis option in *Dips* makes it easy to perform sensitivity analysis, by varying the main input parameters (slope angle, slope dip direction, friction angle) and plotting the results for each failure mode. As noted above, results for all failure modes are always available in the Info Viewer.

Increased Local Pit Slope

Repeat these analyses for steeper local slopes. If the overall slope is to be maintained at 45 degrees (see the first page of this tutorial), the local bench slope will have to be increased to accommodate the roadways. What is the critical local slope?

Other Pit Orientations

Examine the stability of other pit slope orientations.

Assume that the joint sets are consistent throughout the mine property, and perform the analyses described in this tutorial using 45 degree increments of dip direction around the pit wall.

Assume that the joint sets are consistent throughout the mine property. Are there any slope orientations that are more unstable than others? Examine slope dip directions in 45 degree increments around the pit wall.

HINT:

- You can import *Dips* plots into AutoCAD using the Copy Metafile option in the Edit menu. This will copy a metafile of the current view to the clipboard, which can then be pasted into AutoCAD.
- Pole or Contour plots showing mean planes and the selected pit slope orientation can be imported into a plan of the pit and placed in their appropriate orientations for quick reference.

Summary

Kinematic analysis of rock slope failure modes using stereonets is an extremely useful and easy to understand analysis tool which allows you to quickly evaluate potential failure modes. However keep in mind the following.

- The analyses presented here are just a starting point for more detailed analysis and should always be accompanied by a more thorough field analysis in cases where a risk of failure is indicated.
- Real slopes may exhibit more than one failure mode. It is rare to see pure examples of these failure modes, particularly with the toppling analysis, which may exhibit complex behaviours involving sliding, toppling, rotating etc.
- Even if a kinematic analysis indicates risk of failure, this does not necessarily mean that failure will occur, since factors other than kinematics and friction angle may work to increase stability (e.g. joint cohesion, joint persistence etc).
- It is important to look beyond statistical results (e.g. mean set plane orientations) and consider major discrete structures such as shear zones which may have a dominant effect on stability due to low friction angles and inherent persistence.
- More detailed analysis including safety factor calculation can be carried out with the Rocscience programs *Swedge* (wedge analysis) and *RocPlane* (planar analysis).

References

1. Goodman, R.E. 1980. Introduction to Rock Mechanics (Chapter 8), Toronto: John Wiley, pp 254-287.
2. Hudson, J.A. and Harrison, J.P. 1997. Engineering Rock Mechanics – An Introduction to the Principles, Pergamon Press.