AN ALTERNATIVE METHOD FOR CHECKING THE KINEMATIC ADMISSIBILITY OF WEDGES

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INTRODUCTION

Failure mechanisms for rock slopes are conveniently assessed by means of stereographic projections of the defect data and the slope geometry. Methods are available for planar, wedge and toppling failures as described in Markland [1], Hoek & Bray [2], Goodman [3] and Rocscience [4]. The methods commonly used for planes and wedges require different constructions for the two failure mechanisms and the wedge method is restricted to consideration of mean defect orientations only. The method described in this note does not suffer from the above disadvantages.

This note uses a defect data set generated by the *JTDist* utility in *Dips.* Five sets have been generated with a standard deviation of 5° together with random defects. Figure 1 shows the contour plot of the defects together with a pit slope of 60/300 (dip/direction). The rock defects have a friction angle of 25°.

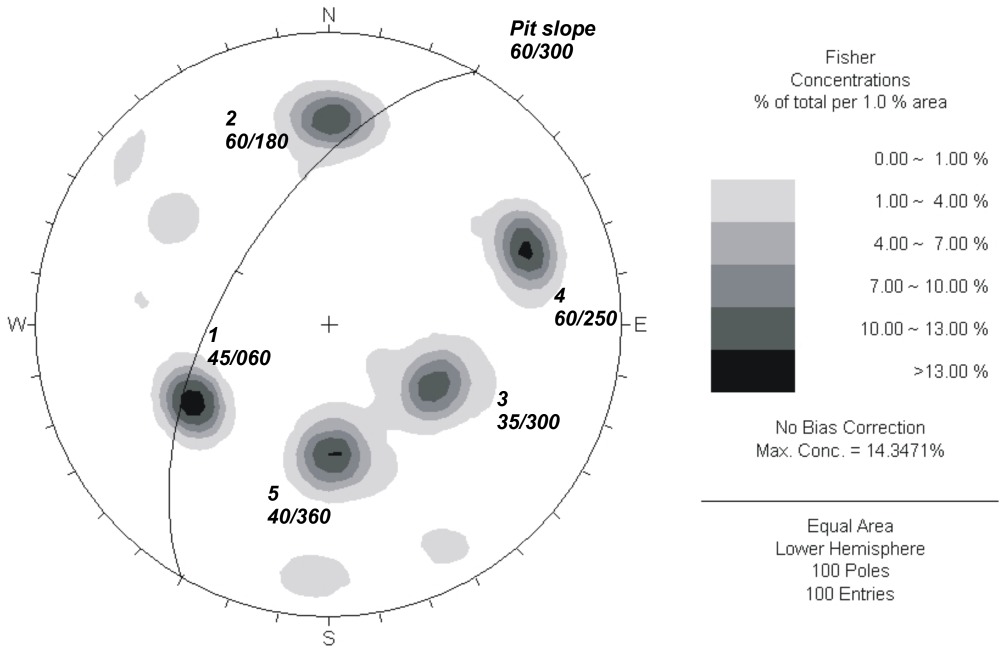


Figure 1: Defect data set generated by JTDist

1 Markland JT. *A useful technique for estimating the stability of rock slopes when the rigid wedge sliding type of failure is expected.* Imperial College Rock Mechanics Research Report No 19, 1972

2 Hoek E, Bray JW. *Rock Slope Engineering.* Institution of Mining and Metallurgy, London, 3rd Edition, 1981

3 Goodman RE, Bray JW. *Toppling of rock slopes.* Proceedings Special Conference on Rock Engineering for Foundations and Slopes, Boulder, Colorado, 1976

4 Rocscience. *Dips User's Guide.* Toronto, 2001

EXISTING METHODS FOR CHECKING KINEMATIC ADMISSIBILITY OF PLANES AND WEDGES

The *Dips* manual provides detailed information on the construction of the daylight envelopes and friction cones needed for checking planar and wedge failures. The latest version of *Dips* (version 5.1) includes the useful facility of being able to save Drawing Tools (such as *friction cones* and *daylight envelopes*) along with the *Dips* file. These automatically appear on the stereonet the next time the *Dips* file is opened.

Planar sliding

The check for planar sliding uses a *daylight envelope* and a *friction cone*. Any pole falling within the *daylight envelope* represents a plane which is kinematically free to slide if frictionally unstable. The pole friction cone is measured from the centre of the net. Any pole falling outside the *friction cone* represents a plane which could slide if kinematically possible. Any poles within the crescent shaped zone formed by the *daylight envelope* and the *friction cone* represent planes which are kinematically admissible and frictionally unstable.

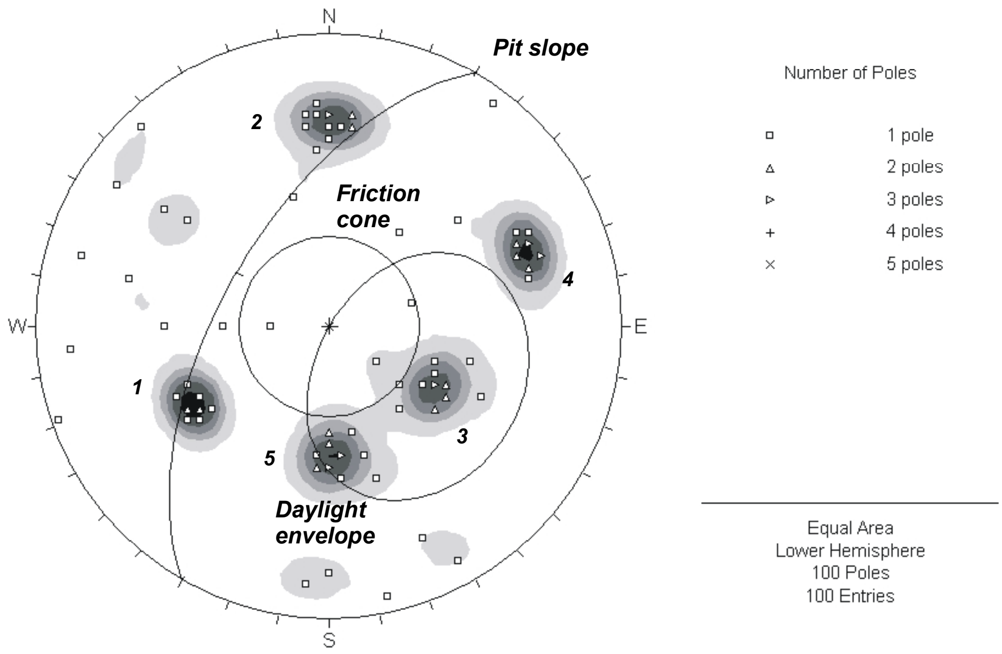


Figure 2: Kinematic check for planar failures

Figure 2 shows that almost all of defect set 3 and most of set 5 lie within the region for planar sliding and the slope will have a significant problem with planar failures on these sets.

Wedge failures

The analysis for wedge failures is different to that for planes:

- Major planes representing the mean concentrations for each set are used instead of poles
- The plane friction cone angle is measured from the perimeter (equator) of the stereonet instead of the centre
- The wedge sliding zone is that defined by the friction cone and the great circle of the pit slope

The stereoplot in Figure 3 shows a Major Planes Plot for the mean planes for each defect set, the great circle for the pit slope and the plane friction cone. Plane intersections are shown as black dots on this plot. The zone outside the pit slope but enclosed by the friction cone represents the zone of wedge (intersection) sliding. Any plane intersections which fall within this zone will be unstable. Intersections between planes 3, 4 and 5 and 2, 3 lie in the wedge sliding zone and wedge sliding failures will be significant for this slope geometry.

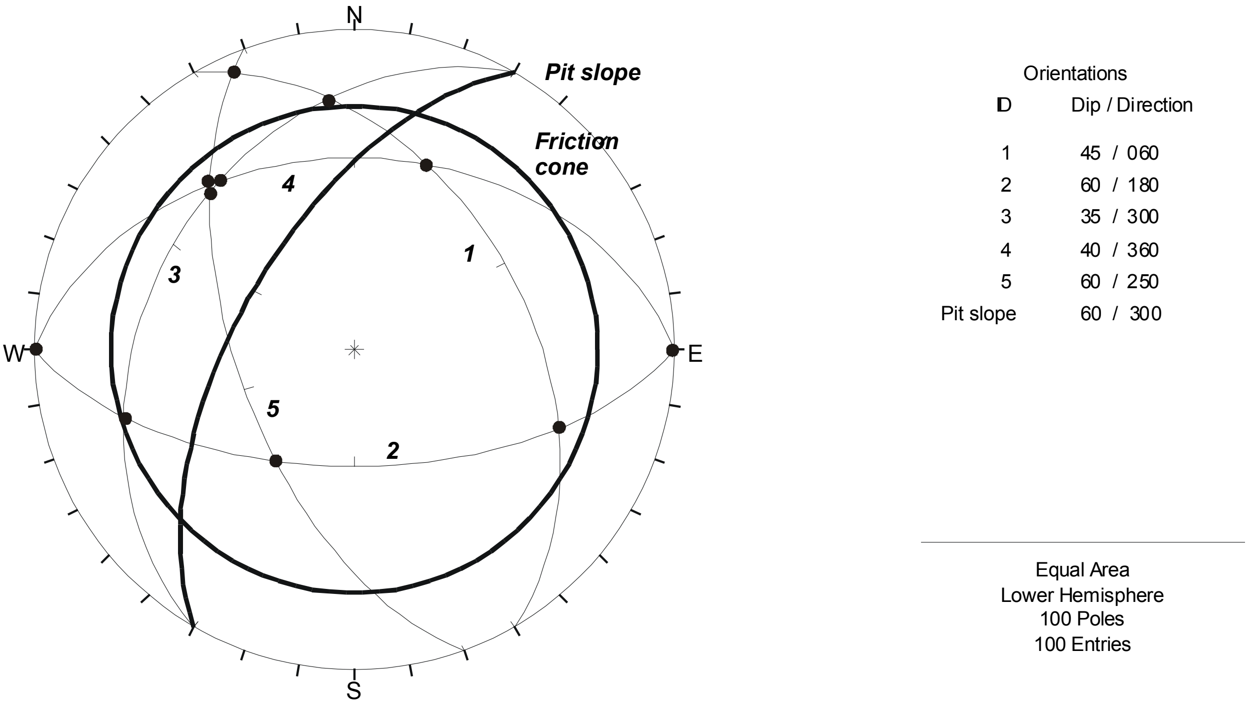
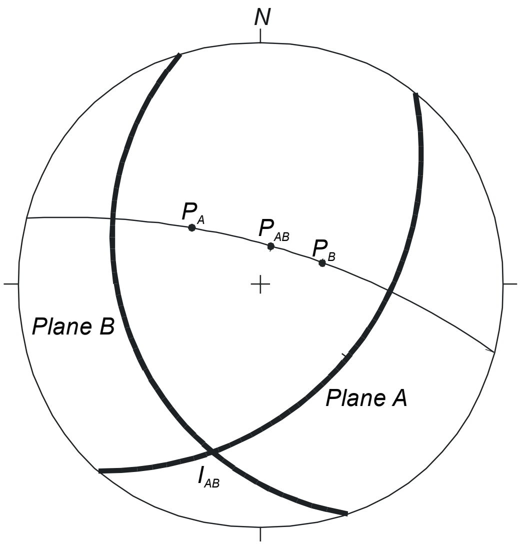


Figure 3: Kinematic check for wedge failures

ALTERNATIVE METHOD FOR CHECKING KINEMATIC ADMISSIBILITY OF WEDGES

The method of using great circles to define the lines of intersections of planes is tedious for large data sets and requires different kinematic and frictional criteria compared with those for planes. A simpler technique is to use the 'pole' to the line of intersection rather than the line of intersection itself [5] (as shown in Figure 4). In stereographic projections, a pole is the point at which the sphere is pierced by the radial line normal to a plane. The 'pole' to the line of intersection (P_{AB}) is the dip/direction of the great circle that passes through the poles of the two planes (P_A, P_B) – the line of intersection (I_{AB}) being normal to this great circle. For the purposes of this note, the pole to the line of intersection defined in Figure 4 is termed a wedge pole to distinguish it from the plane poles.



P_A, P_B *Poles to Planes A and B*
I_{AB} *Line of intersection between Plane A and Plane B*
P_{AB} *Wedge pole or 'pole' to line of intersection*

Figure 4: Definition of wedge pole

5 Richards L, Atherton D. *Stability of slopes in rock.* In Bell FG (Ed). *Ground Engineers Reference Book.* Butterworths, London, 1987

The trend and plunge of the line of intersection between two planes can be calculated from the orientation of the two planes as described in the following equations from Priest [6]. If the trend and plunge of the normals to planes 1 and 2 are α_l / β_l and α_m / β_m, respectively, then the direction cosines for the two normals are:

$$l_x = \cos\alpha_l \cos\beta_l \qquad m_x = \cos\alpha_m \cos\beta_m$$
$$l_y = \sin\alpha_l \cos\beta_l \qquad m_y = \sin\alpha_m \cos\beta_m$$
$$l_z = \sin\beta_l \qquad m_z = \sin\beta_m$$

where x, y, z represent the right hand coordinate system north (x), east (y) and down (z).

The Cartesian components of the line of intersection are given by the vector product as follows:

$$i_x = l_y\, m_z - l_z\, m_y$$
$$i_y = l_z\, m_x - l_x\, m_z$$
$$i_z = l_x\, m_y - l_y\, m_x$$

The trend and plunge α_i / β_i of the line of intersection can be calculated as follows:

$$\alpha_1 = \arctan\left(\frac{i_y}{i_x}\right) + Q$$

$$\beta_i = \arctan\left(\frac{i_z}{\sqrt{i_x^2 + i_y^2}}\right)$$

An alternative form of the above equation which avoids problems of division by 0 is:

$$\beta_i = \arcsin\left(\frac{i_z}{\sqrt{i_x^2 + i_y^2 + i_z^2}}\right)$$

The parameter *Q* is an angle in degrees that ensures α_i lies in the correct quadrant and in the range 0 to 360°.

Values of quadrant parameter Q		
i_x	i_y	Q
≥ 0	≥ 0	0
< 0	≥ 0	180°
< 0	< 0	180°
≥ 0	< 0	360°

If the trend/plunge data for the lines of intersection are used in *Dips* as though these were the dipdirection/dip of planes, the program will plot the wedge poles. Figure 5 shows the wedge poles of the mean planes of each of the defect sets.

For *n* planes, there are *n(n-1)/2* possible wedges. However, combinations of planes with the same orientation do not count and the effective number of wedges may be slightly smaller than the above value. An Excel spreadsheet has been used to calculate all the possible lines of intersection for the defects in Figure 1. This is not a particularly effective method since the spreadsheet calculations are quite slow for high defect numbers.

Figure 6 shows the wedge poles formed from all the defects in Figure 1. These have been contoured and the pit slope, daylight envelope and friction cone drawn as before. The wedge pole concentrations can be related to the combination of particular defects by comparison with Figure 5. Figure 6 shows that the following wedges lie within the unstable zone

- virtually all the wedges formed by combinations of defects 3 and 4, 3 and 5, and 4 and 5
- about half the wedges formed by defects 2 and 3.

[6] Priest SD. *Discontinuity analysis for rock engineering.* Chapman & Hall, London, 1993

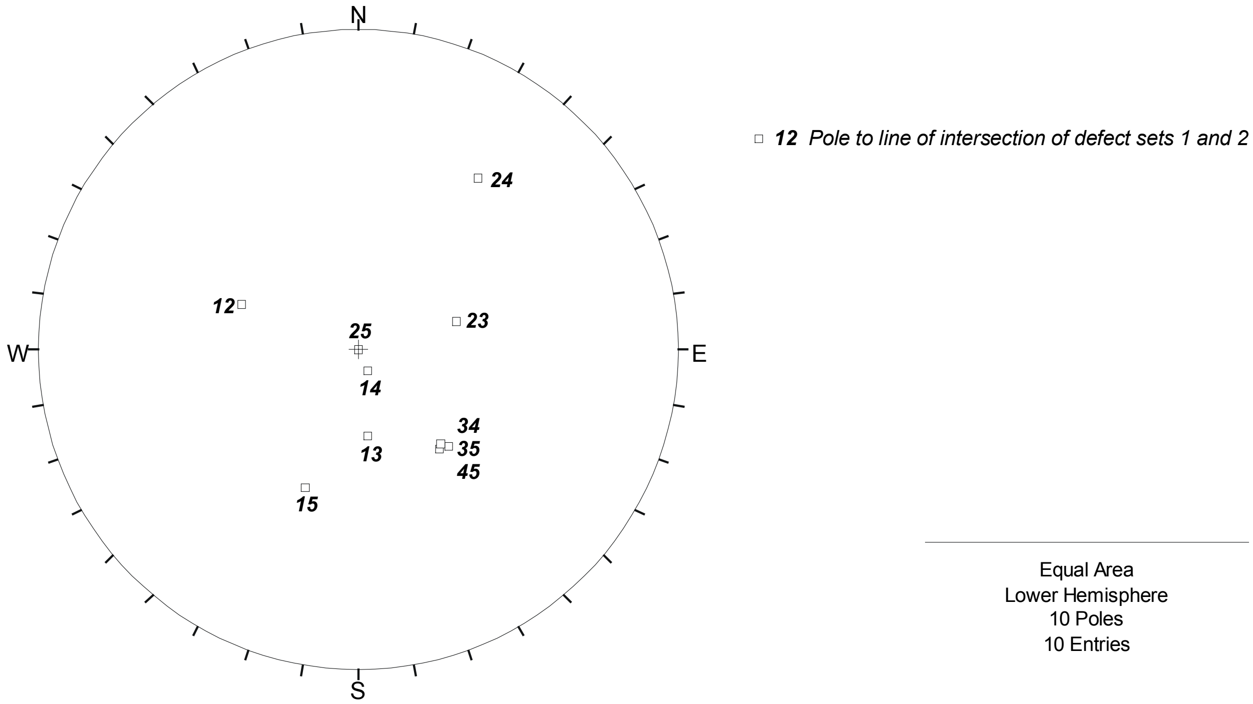


Figure 5: Wedge poles formed by mean defect planes

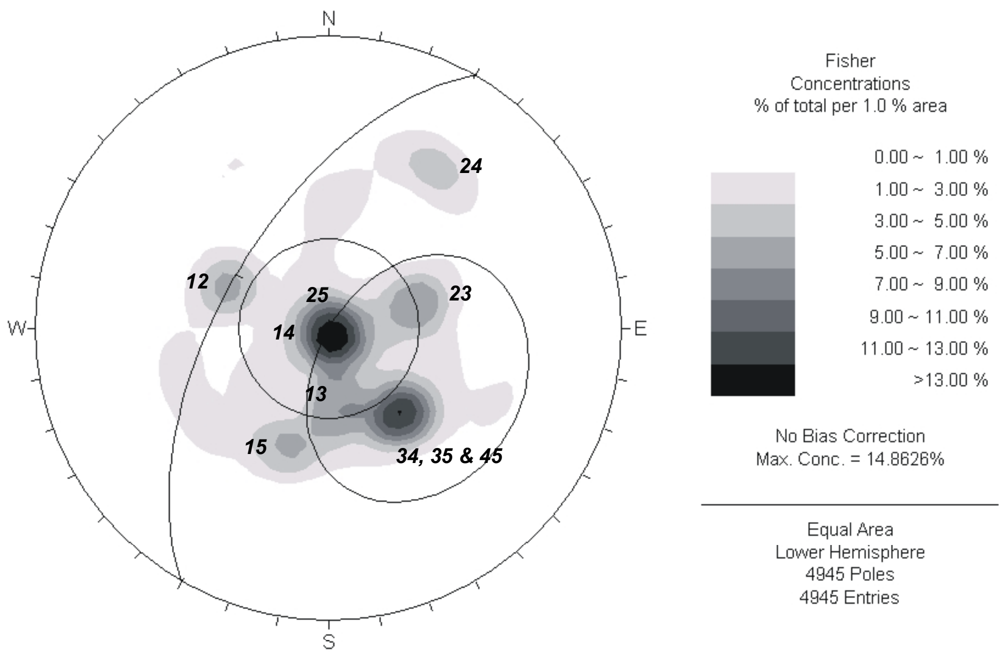


Figure 6: Wedge poles formed by combinations of all defect planes

CONCLUSIONS

This note outlines a method of identifying wedges by using wedge poles rather than the lines of intersection. This allows the kinematic check to be carried out using the same constructions as for planes. This process also allows the proportion of unstable wedges to be calculated rather than considering the mean planes only.

The method presently uses a spreadsheet to do the calculations but this would more conveniently be done as part of future versions of *Dips.* The counting of planes and wedges within the friction cone and daylight envelope would also be a useful feature in *Dips.*

ACKNOWLEDGEMENT

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