Comparison of methods for estimating volume of failed wedges

William Gibson and Justine Paul

Abstract

In open pit mines, bench and berm design plays a critical role in minimising kinematic failures and reducing and controlling rockfalls. Where kinematic failure mechanisms and rockfall risk—rather than rock mass failure—are the dominant controlling factors for slope failure, benches and berms must be designed according to the specific requirements of different rock types and pit sectors, which in turn impacts inter-ramp and overall slope angles. It is therefore critical to design benches and berms as accurately as possible, and determining appropriate berm widths (also known as spill or catch berms) is a key factor. Berms must be wide enough to contain any material falling from the bench faces above, so when designing a berm it is essential to identify potentially unstable wedges and to calculate the likely volume of failed material.

Introduction

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In 2006, Gibson proposed a method for calculating the required catch berm width from the wedge failure volumes for a given bench and berm geometry (Gibson et al, 2006). These methods have subsequently been utilised in Rocscience, SWedge software. Gibson proposed two equations; the first assumes that the failed material is distributed on the berm in a symmetric conical shape (Figure 1), while the second assumes that the failed material is distributed on the catch berm in the form of a pyramid (Figure 2). The expected berm width corresponds to the lower of the two values calculated.

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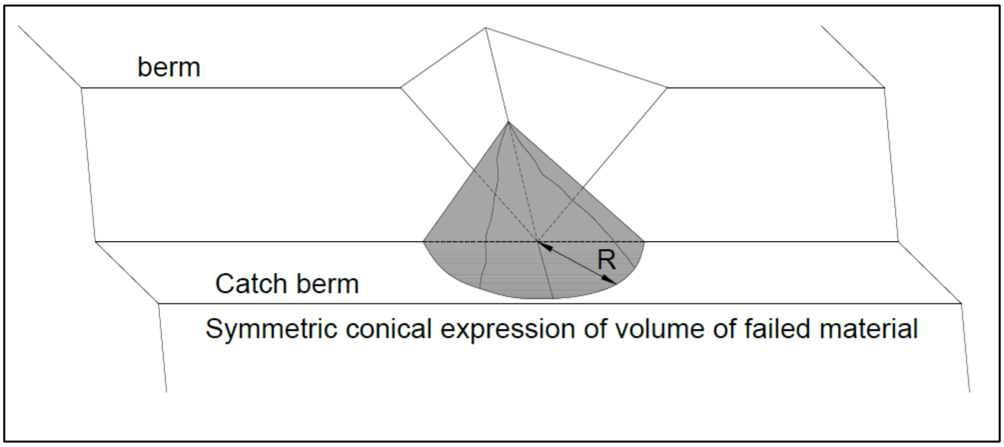

Figure 1. Symmetric conical distribution of failed material on a catch berm

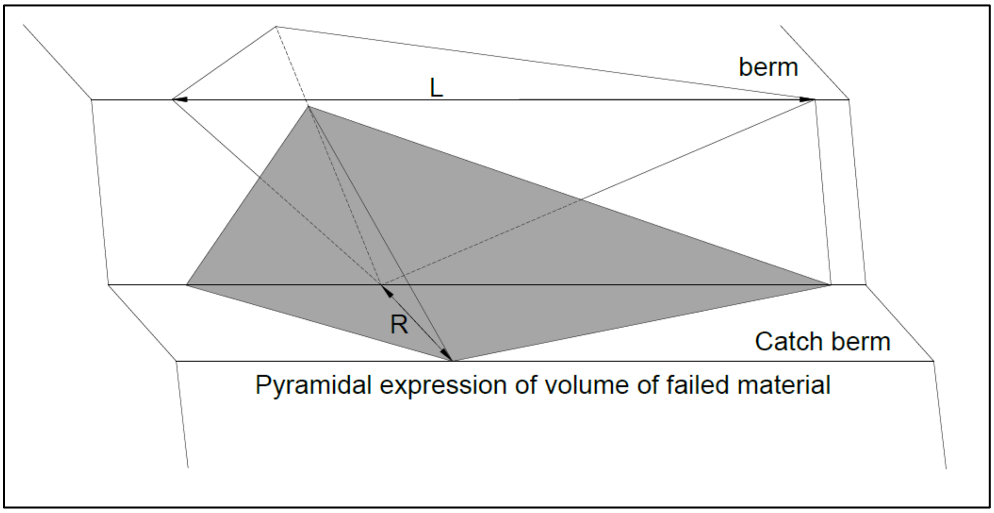

Figure 2. Pyramidal distribution of failed material on a catch berm

The two equations for determination of R is expressed as follows:

For conical shape:

$$R = \sqrt[3]{\frac{6KV}{\pi} \times \frac{\tan\alpha - \tan\phi}{\tan\phi \cdot \tan\alpha}}$$

For pyramidal shape:

$$R = \sqrt{\frac{6KV}{L} \times \frac{\tan\alpha - \tan\phi}{\tan\phi \cdot \tan\alpha}}$$

Where:

K = swelling factor

V= volume of the wedge

L = length of the wedge (see Figure 2)

□ = bench face angle

□= angle of repose of failed material.

Where R is greater than the catch berm width, the failed material will not be contained by the berm and will spill onto the berm below.

The first equation, which assumed a conical shape, does not take the geometry, width or symmetry of the wedge into account. It tends to overestimate the catch berm widths required to contain failed material of wedges where L significantly exceeds R.

The second equation takes the shape of the wedge into account and assumes that the failed material is distributed on the catch berm in the form of a pyramid with L=length R=maximum spill width (see Figure 2).

The second equation also tends to overestimate the required catch berm where L is relatively small. The lesser of the two R values calculated for a particular wedge geometry is therefore deemed to be the most realistic.

Both equations were developed using a common sense approach by taking the shape of the wedge and the possible shape of the material retained on the berm into consideration. Due to the limitations described for each method, the lesser of the two R values calculated for a particular wedge geometry is deemed to be the most realistic and is adopted as the required berm width.

The results of the equations have now been compared with the results obtained using Frac_Rock, a computer program recently developed by SRK. The program calculates the stability of wedges of any shape and volume, and in the case of unstable wedges, Frac_Rock calculates the end position of the failed material, taking swelling into account.

Several wedge geometries have been defined (from different joint orientations and dimensions) and analysed; the results in terms of required berm width (indicated by R) were compared with the two equations developed by Gibson.

Figure 3 shows examples of wedge geometries that were analysed for wedge lengths of 8m, 12m and 20m. Figure 4 illustrates the location and shape of the failed materials.

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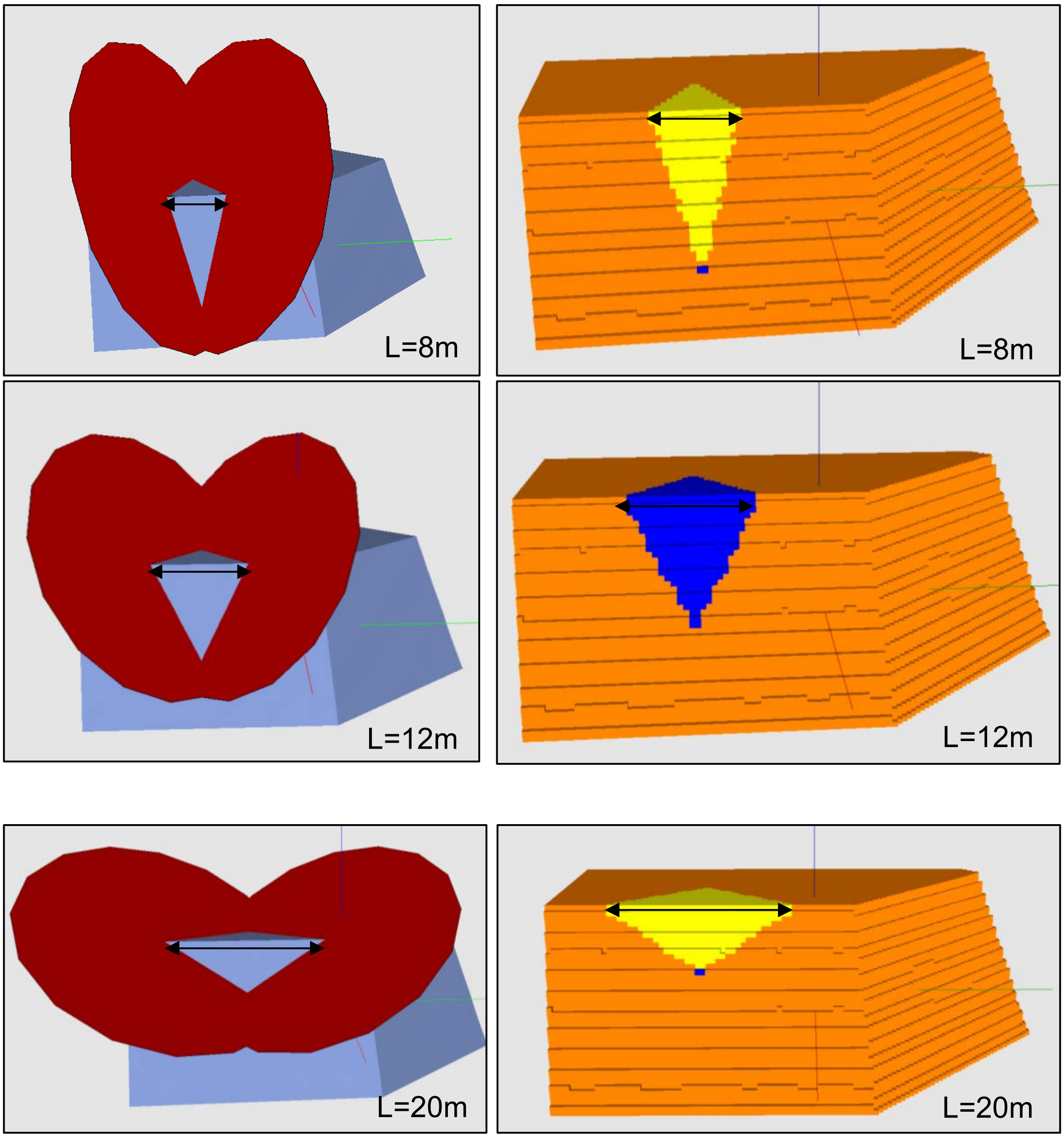

Figure 3. Examples of wedge geometries analysed using Frac_Rock

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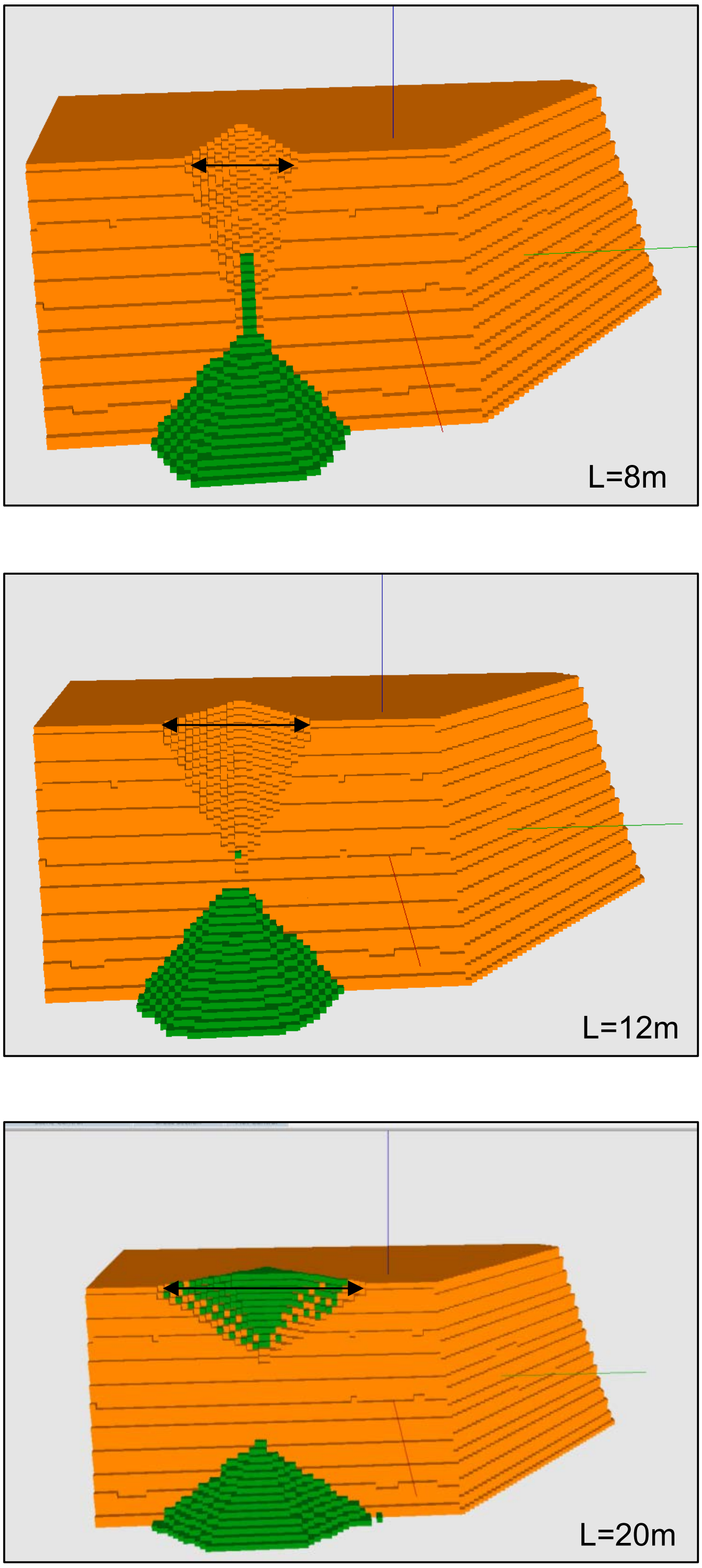

Figure 4. Location and shape of failed materials from different wedges (Frac_Rock)

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Frac_Rock gives the shape and volume of the failed material as numerous individual failed cells that can be exported as csv file format into other software packages. The R value of the wedge can then be measured with a simple measuring tool as illustrated in Figure 5.

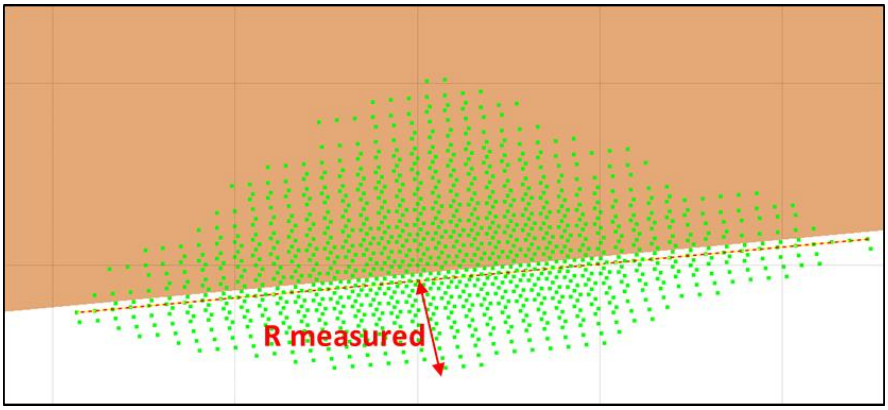

Figure 5: Illustration of the measurement of radius R

Figure 6 shows the comparison of the radius (R) obtained (measured) using the Frac_Rock program and the radius calculated using the equations developed by Gibson, 2006.

The lengths of the wedges analysed were 4m, 8m, 12m, 16m, 20m and 24m. A bench face angle of 75° and a 45° angle of repose were used.

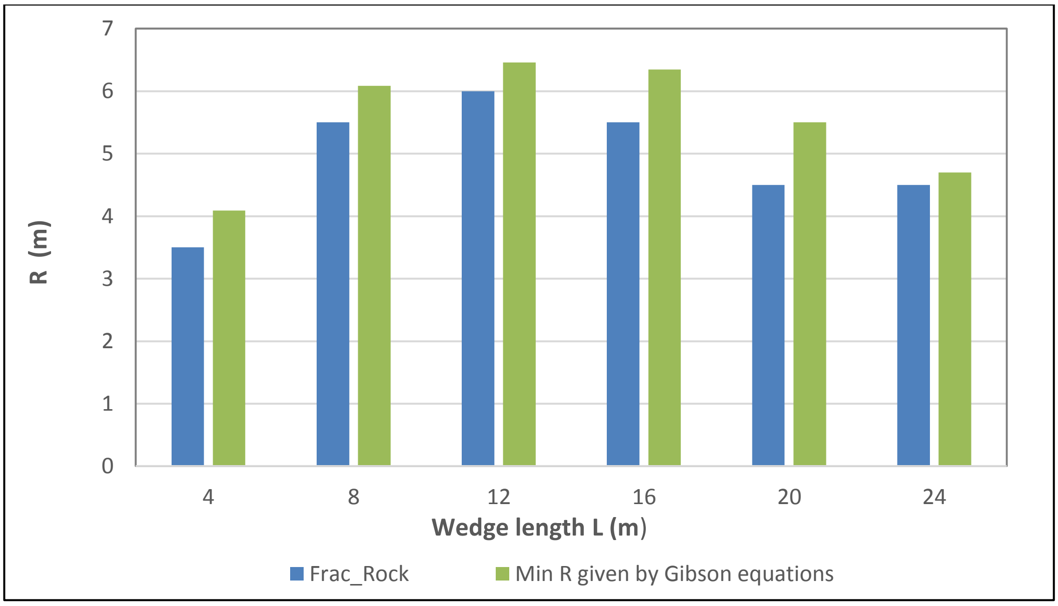

Figure 6. Comparison between radius obtained in Frac_Rock and radius calculated from equations

It can be seen that, compared with the results obtained using Frac_Rock, the Gibson equations tend to overestimate the minimum berm width required by 10% to 20%. They remain a useful tool for rapid estimation of the catch berm width required, however the more accurate Frac_Rock method serves to

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remove the indicated degree of conservatism and allows for more accurate bench/ berm designs to be achieved with regards to wedge failure. This may allow for steepening of inter-ramp or overall slope angles in some cases.

For more complex situation where there is interaction of wedges (Figure 7) the equations start losing applicability and numerical modelling is required to assess the spill volume and location.

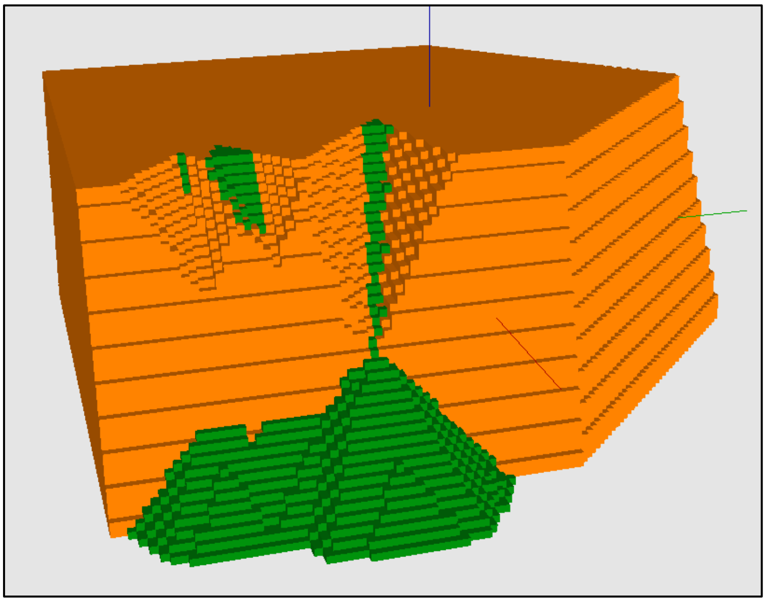

Figure 7. Interaction of multiple wedges

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References

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Rocscience, SWedge Manual. *Persistence and Bench Design*.