

# *Advanced Tutorial*

Determining Input  
Parameters for a  
RocFall Analysis:

How does each  
parameter affect  
the analysis?

How do you  
choose the  
appropriate  
values?

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# Determining Input Parameters for a RocFall Analysis

The purpose of this document is to answer many of the common questions about input parameters for RocFall. This document offers an explanation of how each parameter affects the analysis, and provides a summary that will assist you in choosing appropriate values.

The input parameters that are dealt with in this document are found in the *Project Settings* and *Material Editor* dialogs in RocFall. The following parameters are dealt with:

- Angular Velocity
- Coefficient of Normal Restitution Scaling
- Slope Roughness
- Friction Angle
- Coefficients of Restitution

## Overall Approach

The calculation engine in RocFall behaves as if the mass of each rock is concentrated in an extremely small circle. Because of this, it is important to keep in mind that any size or shape effects must be accounted for by an approximation of, or adjustments to, other properties.

If you have different sizes or shapes of rocks that are likely to become the “rockfall rocks” you should run a number of simulations (e.g. a run for the round rocks, another run for the rectangular rocks, etc) with the associated changes in parameters. This will allow you to determine the worst case.

Whatever values you choose to use as your parameters, you should adjust them so that the path of the rocks, their energies/velocities, and the location of the rock endpoints, match as close as possible to the rockfall events that have already occurred on site. In the end, you will have to use your engineering judgment to choose the appropriate parameters for your design.

In all cases, it is usually a good idea to see what effect each parameter has by performing a sensitivity analysis on the parameters (e.g. running your model once with *Scale  $R_N$  by Velocity* checked, and once with it unchecked) to see which input parameters have the most effect on your model.

## Additional Resources

1. A detailed explanation of the calculations used by RocFall can be found in the RocFall verification manuals. They describe the theory in detail and show hand calculations beside the results of RocFall. Once you have seen the hand calculations, you will have a good appreciation of what goes on inside RocFall. The verification manuals are installed along with the program. (Available from: RocFall → Help → Manuals → Verification)
2. A good synopsis of rockfall analysis is available in *Analysis of rockfall hazards*, Chapter 9 of Dr. Evert Hoek's Practical Rock Engineering (2000 ed.). Most of the content covers rockfall analysis in general, and is not specific to RocFall. It is available from: <http://www.rocscience.com/hoek/pdf/Chapter 9 of Rock Engineering.pdf>
3. A list of twenty five rockfall-related journal articles and other references can be found at: <http://www.rocscience.com/support/pdf/RF-FAQ3.pdf>

# Angular Velocity

## Summary

In general, it is recommended that the *consider angular velocity* checkbox in the *Project Settings* dialog should be on, as it provides a more realistic simulation of the motion. Initial angular velocity is specified in the *Define Initial Conditions* dialog for the rock seeders. Unless there is a reason to do otherwise, the initial angular velocity for the rocks is often zero.

## Additional Resources

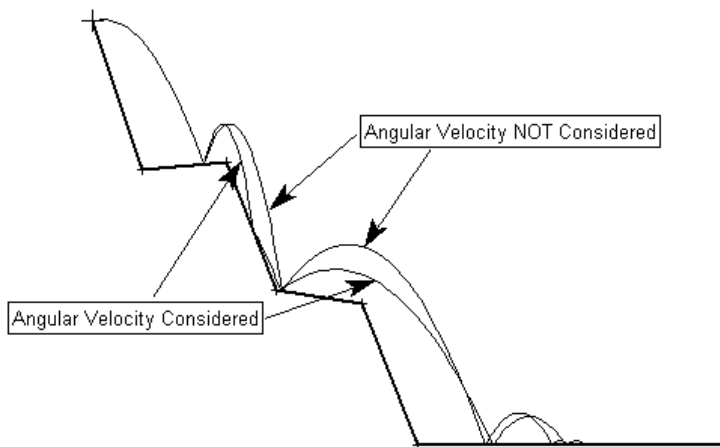
RocFall Angular Velocity verification manual

(Available from: RocFall → Help → Manuals → Verification - Angular Velocity)

## Details

The *consider angular velocity* checkbox in the *Project Settings* dialog controls the use of angular velocity in the calculations. RocFall version 2.0 (and earlier) did not incorporate angular velocity. The checkbox was added so that people opening files from these earlier versions would be able to duplicate their previous results when they opened a file and re-ran the simulation (e.g. if an image had to be re-generated for a report).

An example comparing two RocFall simulations (one considering angular velocity, and one not considering angular velocity) can be found in the Angular Velocity verification manual. Figure A.5.1 of the verification (duplicated here), illustrates the effect of considering angular velocity.



In both cases the initial angular velocity was zero, but in one case the rock was allowed to start rotating, while in the other case, the effect of rotation was ignored. All equations used to calculate the rock paths are worked through using hand calculations in the verification manual.

An important concept to take from reading this verification is that it is not necessarily the initial value of angular velocity that is important, but just the fact that it is considered in the analysis that is most important (i.e. the setting of the *consider angular velocity* checkbox).

You will have to use your engineering judgment to pick the exact value that is applicable to your situation, but in general, the initial value for angular velocity is fairly small and is often zero (the idea being, that most rocks start with not much movement, but during their travel down the slope can start rotating quite quickly). The vast majority of models that we have seen have the initial angular velocity set to zero.

When you are running your models, you can see if entering a non-zero initial angular velocity changes your results much (i.e. this would be a comparison of the rock starting off spinning, or not spinning). It is usually a good idea to verify that it does not change the results very much.

# Coefficient of Normal Restitution Scaling

## Summary

The concept behind scaling the normal coefficient of restitution by velocity is the idea that  $R_N$  is not independent of velocity.

- For simulations with higher velocity rocks, a typical approach is to turn on the scaling by velocity, use the default value, and adjust the coefficients of restitution, and the slope roughness to get realistic rock paths.
- For simulations with lower velocity rocks, experiment with the setting checked and unchecked, to see which setting gives more realistic rock paths.

## Details

For example, at low speeds you might expect a rock to bounce on grass, whereas at higher speeds you might expect the rock to imbed further into the ground before rebounding, or to start to break. In these cases the effective value of  $R_N$  should be less at higher velocities, and this is what the equation is trying to capture.

$$R_N(\text{scaled}) = R_N * \text{scaling factor}$$

$$\text{scaling factor} = \frac{1}{1 + \left(\frac{V_{ROCK}}{K}\right)^2}$$

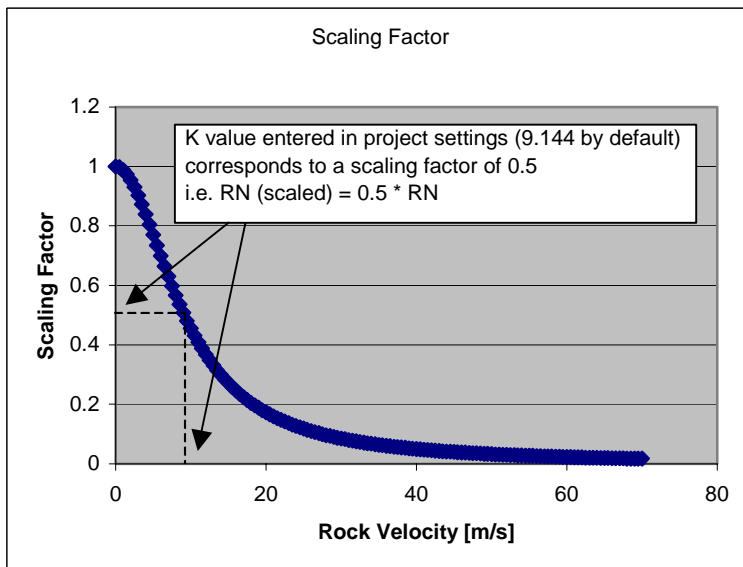
$K$  = velocity at which scaling factor = 0.5

$V_{ROCK}$  = Velocity of the rock, immediately before impact, measured normal to the surface.

The source of the equation used for scaling  $R_N$  by velocity comes from the paper:

Pfeiffer, T.J., and Bowen, T.D.,(1989) Computer Simulation of Rockfalls. Bulletin of the Association of Engineering Geologists Vol. XXVI, No. 1, 1989 p 135-146.

The justification (from the paper) for the factor is the following: "This factor represents a transition from nearly elastic conditions at low velocities to highly inelastic conditions caused by increased fracturing of the rock and cratering of the slope surface at higher impact velocities".



The default value of the constant  $K$  (9.144 m/s) is the metric equivalent of 30 ft/s, which was empirically derived, and is briefly explained in the paper.

If you evaluate this equation in a spreadsheet, for a range of velocities, you will generate the chart shown to the left.

As can be seen in the chart, the scaling factor becomes more significant as the rock velocity increases. For this reason, the settings you use are less important for rockfall simulations where the rocks are moving relatively slowly, and more important for faster

moving rocks. The definition of "fast" and "slow" is somewhat subjective, and a judgement has to be made as to how far from the peak of the curve (in the chart) your rock velocities are.

Scaling by mass works in an analogous manner, although it is a much less popular choice. Scaling by velocity AND mass simultaneously is not recommended, as too much energy is lost in each impact, and generally results in unrealistic rock paths.

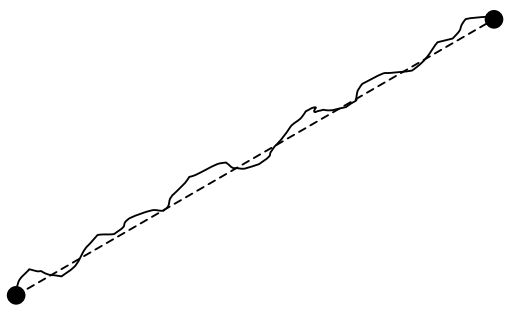
# Slope Roughness

## Summary

Typical values of slope roughness, from users of RocFall, are usually quite small. Common values for the standard deviation of slope roughness are 0, 2, 3 or 5 degrees. Of the files that have been sent to Rocscience, we have not seen any values that are larger than 5.

## Details

Slope Roughness is used to model local variations in geometry, on a scale that is measured between the vertices you have entered as the slope geometry. Consider the image on the left as a



representation of slope roughness in RocFall. The two black circles at the ends are vertices that were entered as the slope geometry. The dashed line in the image represents the line segment between the two vertices. The wavy line is a representation of how the line segment will act for the purpose of calculating how the rocks will reflect off of the segment. The inclination of the wavy line, at any point, is determined by sampling a normal distribution. The mean of the distribution is equal to the original slope segment inclination, and the standard deviation is entered in the *Material Editor*. The

most probable inclination of the wavy line is equal to the inclination of the original slope segment, and inclinations more and more different than this, are less and less probable.

Slope roughness is represented by a normal distribution. The standard deviation is entered in the material properties dialog. The mean value is calculated directly from the slope geometry (which is why it is not necessary to enter this value in the dialog). If a standard deviation of zero is entered, the segment will behave as the original straight-line segment would. As the standard deviation is increased the curves in the diagram will get more pronounced, the rocks are more likely to bounce in directions increasingly different from the angle of the slope segment, and the rocks paths will look more “unpredictable” or “unusual”.

Slope roughness is best explained by way of an example:

Just before a bouncing rock impacts a slope segment, the slope of the segment is calculated from the geometry (e.g. 15 degrees from horizontal) and the slope roughness is determined from the material specified for the segment (e.g. standard deviation of 2 degrees). From these parameters a normal distribution is created with a mean of 15 and a standard deviation of 2. This normal distribution is sampled (e.g. 16.2 degrees) and this value is used for the impact calculations. i.e. the rock acts as if it impacted a segment with an inclination of 16.2 degrees from the horizontal.

You should select the standard deviation such that most cases are covered (e.g. if your slope varies locally from 13 to 17 degrees you could specify a standard deviation such that most of the samples from this distribution fall within this range). You can use the following statistical properties to help you choose a good value:

Recall that for a large number of samples from a normal distribution:

- 68.27% of samples fall within 1 standard deviation of the mean.
- 95.44% of samples fall within 2 standard deviations of the mean.
- 99.74% of samples fall within 3 standard deviations of the mean.

The appropriate roughness value depends not only on the materials, but also on the size of the “rockfall rocks” compared to the surface. For example: Imagine a uniform, flat, layer of gravel. For a rock with a radius of 1m that bounces on this layer of gravel, the surface would be unlikely to change the direction of the rocks - so the roughness value would be quite small. For a rock with a radius of 20mm the surface would be very likely to change the direction of the rock, so the roughness value would be higher.

# Friction Angle

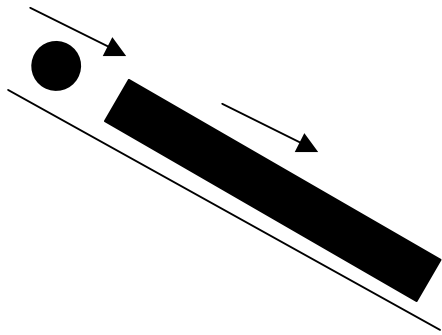
## Summary

The friction angle is chosen based on the particle shape and the mode of movement. The value you should enter for the friction angle is the inclination of the segment such that a rock tossed onto this segment would continue to move downslope. In general, lower values are more conservative (i.e. the rocks will tend to move further downslope, and provide the “worst case” scenario).

## Details

The “friction angle” as it used in RocFall, is the critical angle of your slope segments for the purpose of the rocks moving downslope. If the slope segment is inclined more than this angle, the rocks will move downslope, if it is inclined less than this, they will come to rest on the segment (assuming they don’t reach the end of the segment before stopping).

When choosing values for the friction angle (as with the slope roughness) it is important to keep in mind that the rocks are reduced to a single point for the purposes of the analysis, and that any size or shape effects must be accounted for by an approximation of other properties.



For example: Picture a segment of your slope and a typical rock. Given the same material on the slope, and the same material making up the rocks, the “friction angle” you enter will be different depending on whether the rocks are all spherical “baseball” shaped rocks, or if they are flat slabs. If your rocks are long flat slabs, then the mode of movement will be sliding, and the value you enter will be higher (much closer to a

“standard” friction angle, as could be determined by a tilt test). If your rocks are all spherical, then the mode of movement will tend to be rolling, rather than sliding, and the value you enter will be much lower (close to zero). If your rocks are somewhere between these two extremes (the most common situation) the value will also be somewhere between these two values, in proportion to the shape.

Because this approach already contains a lot of simplifications, it was decided that the same value would be used for both the case of static (from rest) and dynamic (while moving) friction.

There are two additional options available in the *Project Settings* dialog that affect the friction angle:

1. The option “*Set friction angle to zero (rolling)*” provides a quick way to test the “worst case”, as this setting provides essentially no resistance to motion, and usually results in the rocks traveling the furthest distance downslope.
2. The option “*Calculate friction angle from  $R_T$* ” provides a method of defining the “friction angle” in terms of the coefficient of tangential restitution.

$$\text{friction angle} = \frac{(1 - R_T)}{R_T}$$

Note: equation gives friction angle in radians, which is then converted to degrees

This option has the advantage of correlating the friction angle and the coefficient of tangential restitution, and reducing the required number of parameters, if the friction angle is difficult to determine. The disadvantage of this option is that the coefficient of tangential restitution can be more difficult to estimate than the friction angle.

# Coefficients of Restitution

## Summary

The selection of the proper coefficients of restitution is important, because the outcome is often quite sensitive to the value used. If unsure of what values to use, begin with the material in the coefficient of restitution table that most closely matches your site, and then adjust the coefficients until the rock paths / energies / velocities / rock-endpoints are as close as possible to your observations of past rockfall events.

## The Rocscience Coefficients of Restitution Table

The "Rocscience Coefficient of Restitution Table" is available by pressing the *Help* button in the material editor (*RocFall->Slope->Materials->Coefficient of Restitution*). This table is the extent of the data that is available from Rocscience. You can review some of the references about rockfalls or search the Internet for more values, but values are generally difficult to find. Unfortunately coefficients of restitution are not always easy to determine, and the analysis can be sensitive to the value you choose.

## Origin of Coefficients of Restitution listed in RocFall

The default set of materials listed in RocFall, were taken from the paper:  
*Hoek, Evert. "Unpublished notes" NSERC Industrial Research Professor of Rock Engineering, Department of Civil Engineering, University of Toronto.*

The table of coefficients of restitution was generated by looking through the RocFall references, and from responses from other users of RocFall. The description listed for the materials, is the only description that is available. In many cases, it would be much better to have more detailed descriptions (even photographs) but, unfortunately, that is not typically available.

## Back Calculation of Coefficients of Restitution

Coefficients of restitution are often determined from back calculation of known rock paths and rock endpoints. If you have observations of past rockfall events (knowing the starting point, the endpoint, and the path of the rock) you can use these to help calibrate your model.

Once you have these "known" rock paths and endpoints, you can pick a value from the coefficient of restitution table (pick the value that best describes your site - so you have a decent starting point), and then adjust the coefficients of restitution in the program until the rock paths in the program are similar to the observed rock paths.

Depending on your situation, you may also be able to go out to your site and send some rocks down the slope, and use these to further calibrate your model.

## Standard Deviations

The coefficients of restitution in RocFall are normally distributed. Since the mean values of coefficients of restitution are rarely well known, selecting the standard deviations are even more difficult. For this reason it is often useful to recall the statistical properties of a normal distribution (refer to the Slope Roughness section of this document for the values).

## Possible Trends in the Coefficient of Restitution Data

As a general rule, harder materials will have higher coefficients of restitution than softer materials, and as a general rule, as the normal coefficient of restitution increases so will the tangential coefficient of restitution. Unfortunately, there is little data available, and as can be seen from looking at the coefficient of restitution table, it is difficult to draw anything but broad conclusions from the data. For example, there are a lot of data points where the same value of  $R_N$  (eg.  $\sim 0.4$ ) is paired with a wide range of  $R_T$  (eg. 0.56 to 0.85).

## Conclusion

When choosing the values of certain parameters (eg. friction angle, slope roughness) it is important to keep in mind that the rocks are reduced to a single point for the purposes of the analysis, and that any size or shape effects must be accounted for by an approximation of other properties.

Whatever values you choose to use as your parameters, you should adjust them so that the path of the rocks, their energies/velocities, and the location of the rock endpoint, match as close as possible to the rockfall events that have already occurred on site.

We hope this document was helpful to you. If you have any suggestions, comments, or questions, please feel free to send feedback to [software@rocscience.com](mailto:software@rocscience.com)

We would be especially appreciative if you can contribute to the coefficient of restitution table. If you can do so, please send us the values you have used, and as much supporting information as possible (eg. RocFall files, photographs, site descriptions, reports, etc).