



RocFall3

Barrier Analysis

Verification Manual

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RocFall3 Barrier Analysis Verification Examples

This document presents examples used to verify the accuracy of the barrier analysis feature in RocFall3. RocFall3 is a 3D rockfall simulation program for assessing rockfall risks in rock slopes, produced by Rocscience Inc. of Toronto, Canada. The purpose of this verification is to compare program outputs to analytical solutions to ensure RocFall3 barrier results are accurate for both lumped mass and rigid body methods.

1. Example #1: Percentile calculation check

This example is based on the Tutorial 3 model geometry. Using 200 lump mass rocks and a barrier height of 0.5 m, the rock impact heights were evaluated. The impact height results for “graph along barriers” using 1 bin were compared to the bounce height cumulative frequency plot generated from “graph barriers”. The same results are expected because a bounce height and an impact height are equivalent on a vertical barrier.

Table 1.1 – Comparison of “Graph Along Barriers” and “Graph Barriers”

Percentile	Graph Along Barriers (1 bin) – Impact Height (m)	Graph Barriers (cumulative frequency plot with 100 bins) – Bounce Height (m)
50	0.323	0.323
95	0.365	0.365
100 (max)	0.395	0.397

2. Example #2: Percentile calculation check

Expanding on Example #1, to check percentile calculations in the individual bins of “graph along barriers”, Example #2 compares two models: 1) the first model uses the exact barrier from Example #1 and “graph along barrier” with 2 bins (Bin 1 and Bin 2); 2) the second model has the single barrier from Example 1 replaced with 2 barriers of equal length and analyzed with “graph barriers” for each barrier (Barrier 1 and Barrier 2). Results are tabulated below. The small percent differences observed are due to the interpolation of percentiles.

Table 2.1 – Comparison of Impact Height (m) in Bin 1 from “Graph along barriers” vs. Impact Height for Barrier 1 from “Graph barriers”

Percentile	Graph Along Barriers (Bin 1)	Graph Barriers (corresponding Barrier 1 to Bin 1)	% difference
50	0.320	0.322	0.621
95	0.360	0.363	0.830
100 (max)	0.395	0.395	0.000

Table 2.2 – Comparison of Impact Height (m) in Bin 2 from “Graph along barriers” vs. Impact Height for Barrier 2 from “Graph barriers”

Percentile	Graph Along Barriers (Bin2)	Graph Barriers (corresponding Barrier 2 to Bin 2)	% difference
50	0.324	0.323	0.309
95	0.369	0.371	0.541
100 (max)	0.394	0.394	0.000

Table 2.3 – Comparison of translational kinetic energies (kJ) in Bin 1 from “Graph along barriers” vs. Barrier 1 from “Graph barriers”

Percentile	Graph Along Barriers (Bin 1)	Graph Barriers (Barrier 1 corresponding to Bin 1)
50	197	197
95	235	235
100 (max)	256	256

Table 2.4 – Comparison of translational kinetic energies (kJ) in Bin 2 from “Graph along barriers” vs. Barrier 2 from “Graph barriers”

Percentile	Graph Along Barriers (Bin 2)	Graph Barriers (Barrier 2 corresponding to Bin 2)
50	24	24
95	233	233
100 (max)	242	242

3. Example #3: Percentiles calculation check for a small number of rocks

When generating percentiles for a small number of rocks, linear interpolation is used to obtain any in-between percentile values. For this example, 10 rocks are traversing down a slope that has a slope material with a normal distribution for the normal and tangential restitutions. All 10 rocks impacted the barrier. Results for the rock total kinetic energy is tabulated below.

Table 3.1 – Comparison of Total Kinetic Energy (kJ) between “Graph Along Barriers” (1 bin) and “Graph Barriers” (500 bins cumulative frequency) for a small number of rocks

Percentile	Graph Along Barriers	Graph Barriers	% difference
50	3.001	3.006	0.166
95	4.111	4.114	0.073
100	4.319	4.319	0.000

The following sample calculation is for the 95th percentile calculated using linear interpolation. Given 10 rocks, impact values are available for every 10th percentile up to the 100th percentile (or maximum value). The 95th percentile is calculated as the average of the 90th percentile (3.908 kJ) and the 100th percentile (4.319 kJ or the max value).

$$95^{\text{th}} \text{ percentile} = 3.908 \text{ kJ} + (0.95 - 0.9) * (4.319 \text{ kJ} - 3.908 \text{ kJ}) / (1 - 0.9) = 4.114 \text{ kJ}$$

or

$$95^{\text{th}} \text{ percentile} = (3.908 \text{ kJ} + 4.319 \text{ kJ}) / 2 = 4.114 \text{ kJ}$$

Note that a source of error is the bin size for the cumulative frequency plot.

Also note that for bins with only one rock, no linear interpolation is done. The value of any percentile for that bin is reported as equal to the single value in that bin.

4. Example #4: Bounce Height vs. Impact Height

To understand the difference between bounce height and impact height, a simple unit test was done for a single lump mass rock dropped from a height of 5 m onto a flat plane at $z = 0$ m. The rock had an initial rotational velocity of 90 deg/s. On impact at (0,0), the rock incurred a horizontal velocity and then impacted onto an adjacent barrier. The barrier was vertically inclined in the first case (normal to slope surface) and 30 degrees inclined from vertical in the second case (Figure 4-1).

Table 4.1 – Impact height and bounce height on barriers at different inclinations.

Barrier Inclination (deg)	Impact z	Impact Height above slope (m)	Barrier Bounce height (m)	Barrier Impact height (m)
0 (vertical)	0.39	0.39	0.39	0.39
30 deg	0.24	0.24	0.238	0.275

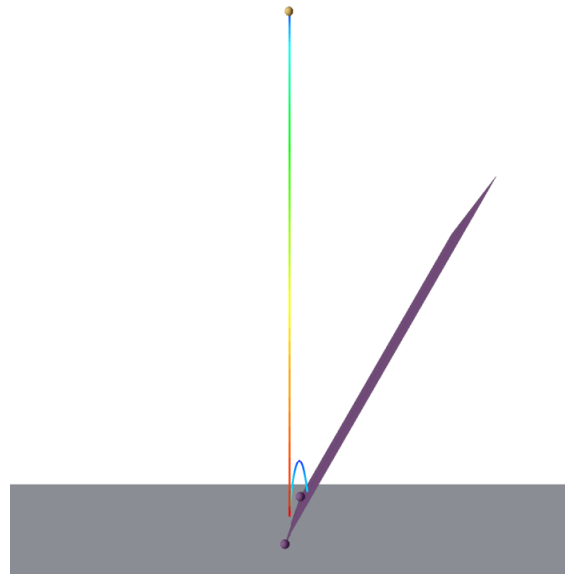


Figure 4-1: Barrier Inclined at 30 degrees.

Hand calculation of impact height for the barrier inclined at 30 degrees:

$$0.238 \text{ m} / \cos(30 \text{ deg}) = 0.275 \text{ m}$$

Therefore,

Impact height = length along the barrier from the ground to the point of impact

Bounce height = height of point of impact on the barrier from the ground surface directly below

5. Example #5: Number of hits and passes

This model contains 20 rigid body rocks and one barrier with a height of 2 m. The initial mean velocity of the rocks is 5 m/s trending east (90 degrees) (Example 5a).

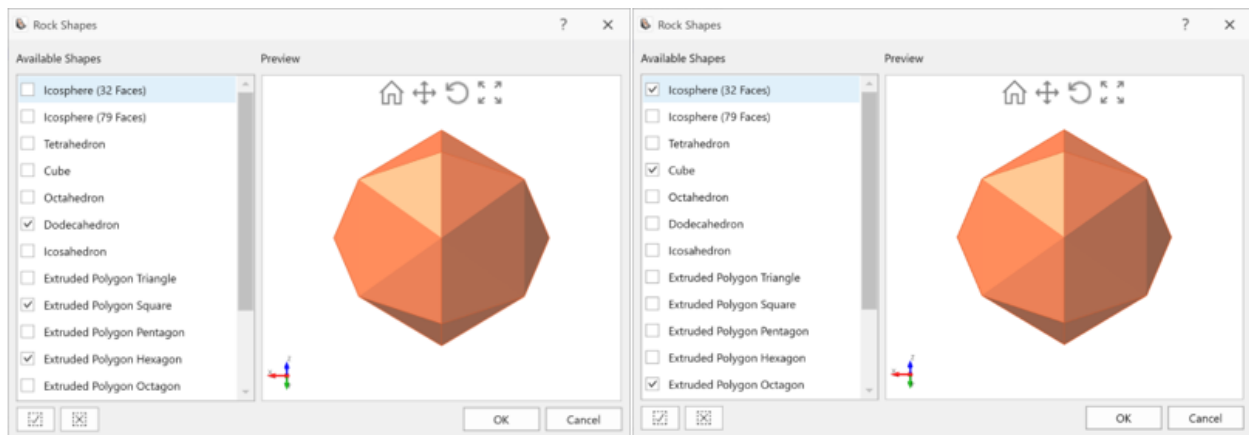


Figure 5-1: Groups 1 and 2 shapes (left and right, respectively)

The rock information table and the report generator both report 14 hits on the barrier. This is verified from the modeler view, as shown below.

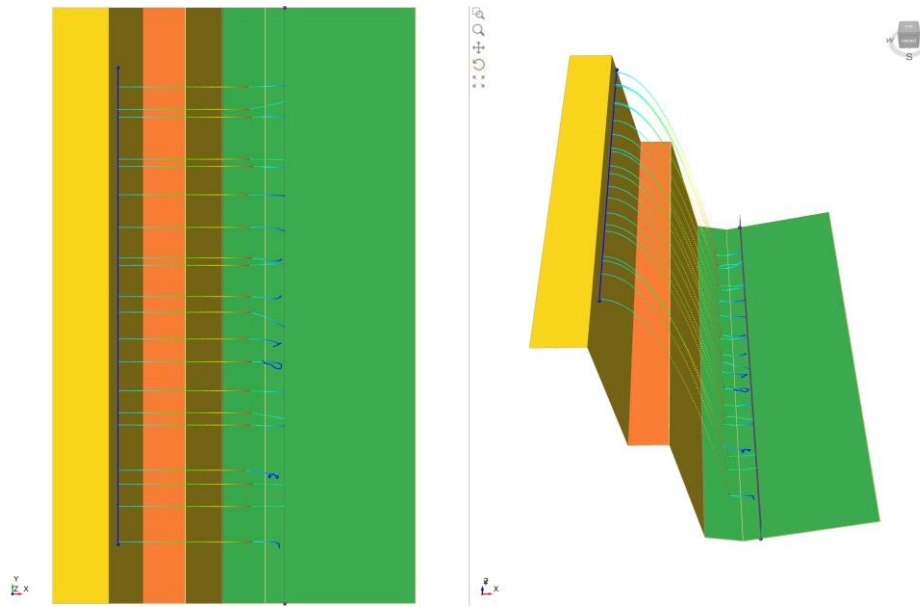


Figure 5-2: Modeler view showing 14 hits on the barrier

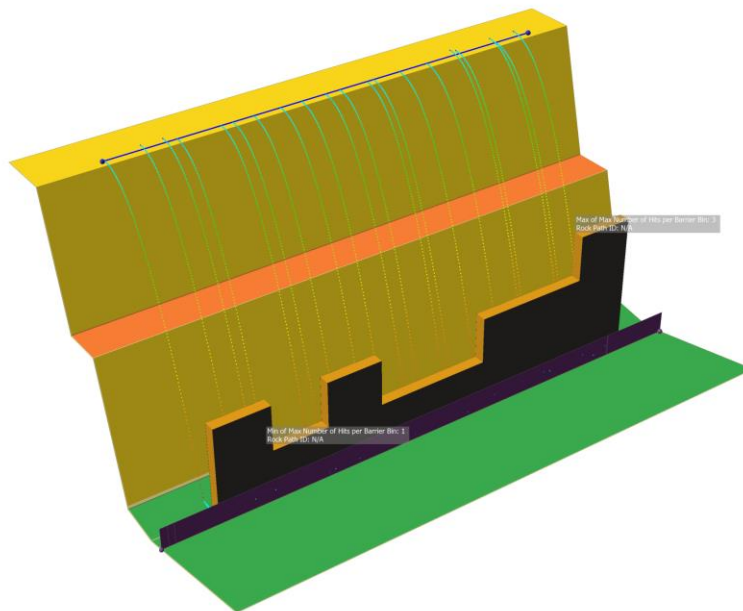


Figure 5-3: Modeler view with 3D barrier plot showing the correct number of hits for 10 bins

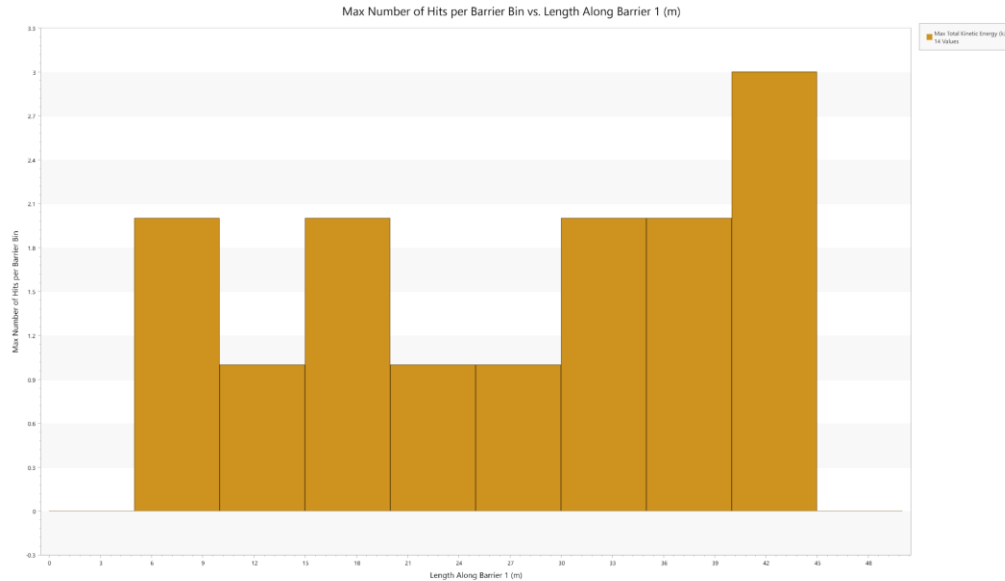


Figure 5-4: 2D barrier plot (“graph along barrier”) showing the correct distribution of hits along the barrier length (consistent with 3D plots in Figure 5-3)

For this same example, shorten the barrier height to 0.5 m such that some rocks would pass over the barrier (Example 5b). As the barrier has infinite capacity, any rock that passes over the barrier represents cases where the rock centre-of-mass has exceeded the barrier height. A total of 9 rocks passed over the barrier, and they are distributed correctly as shown in Figures 5.5 and 5.6.

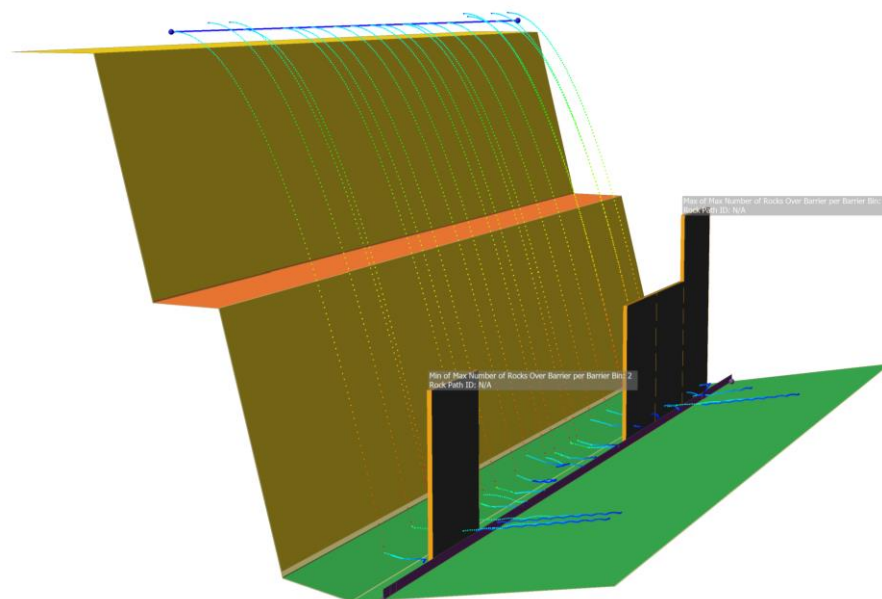


Figure 5-5: Modeler view of the number of rocks passing over the barrier

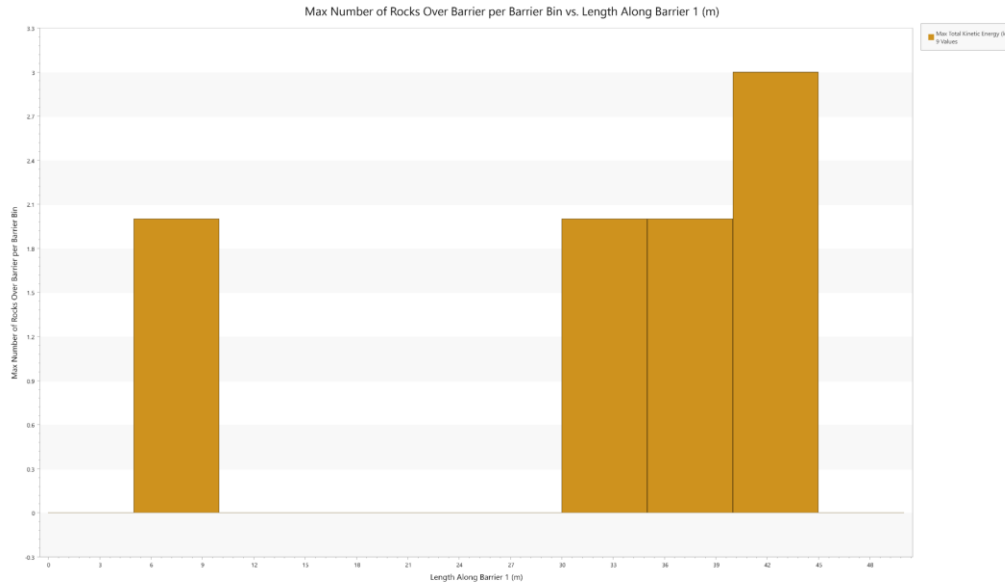


Figure 5-6: 2D Barrier plot of the number of rocks passing over the barrier, corresponding with Figure 5-5

6. Example #6: Impact Angle and Impact Angle (abs)

The impact angle is defined as the angle at which the rock hits the barrier relative to the normal of the barrier. It is calculated using the instantaneous velocity of the rock when it hits the barrier and the normal of the barrier. The impact angle is always acute, regardless of the side of the barrier that the rock is hitting. Rocks that trend towards the slope and the barrier base on impact have positive impact angles, while rocks that trend away from the slope and the barrier base have negative impact angles.

The Impact Angle (abs) is the same as the Impact Angle except all values are positive (absolute).

This verification model contains 3 rocks dropping from an initial height of 5 m and an initial velocity of 2 m/s towards a vertical barrier of height 3.5 m. The first rock is 1.8 m away from the barrier, the second rock is 2.3 m away, and the third rock is 2.8 m away. The first rock hits the barrier before slope impact, while the second and third rocks bounce on the slope surface before hitting the barrier.

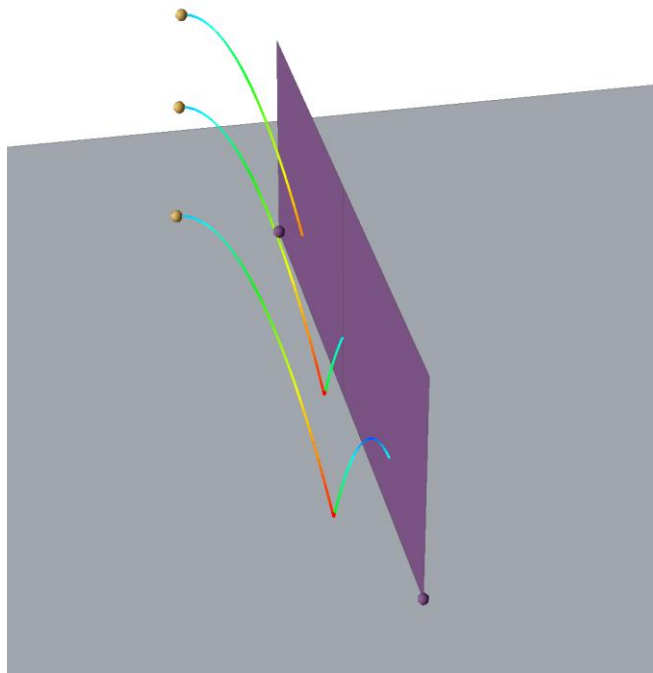


Figure 6-1: Rocks impacting barrier at three different impact angles

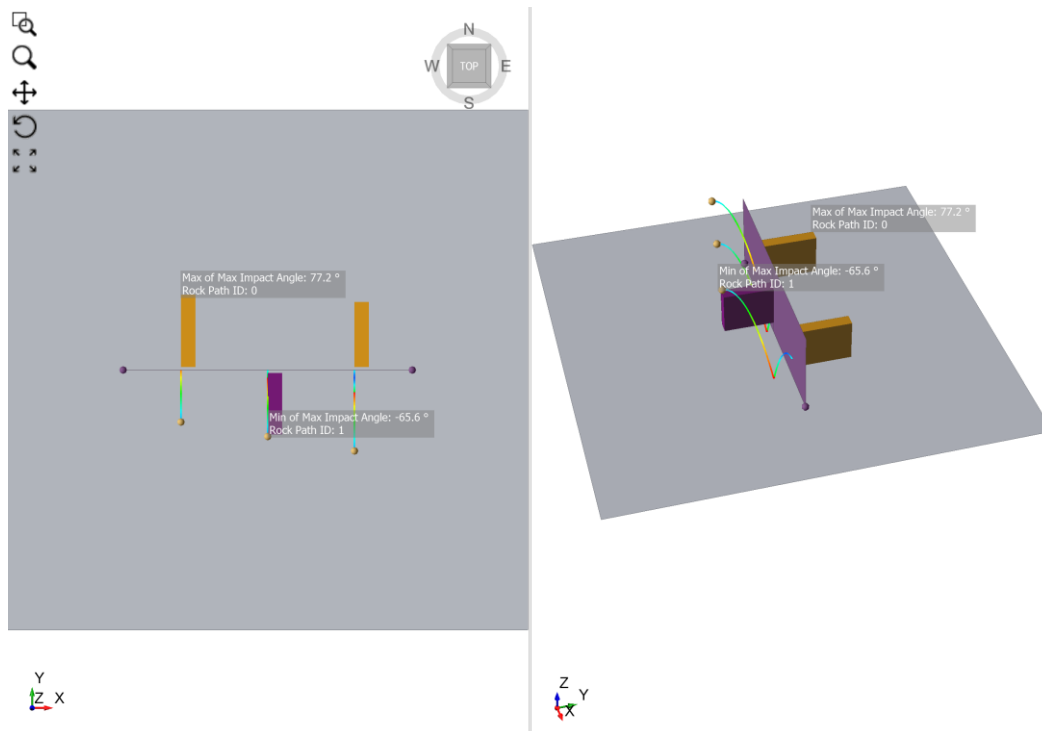


Figure 6-2: Impact angles plotted in 3D. Negative angles are shown in purple and positive angles are shown in orange.

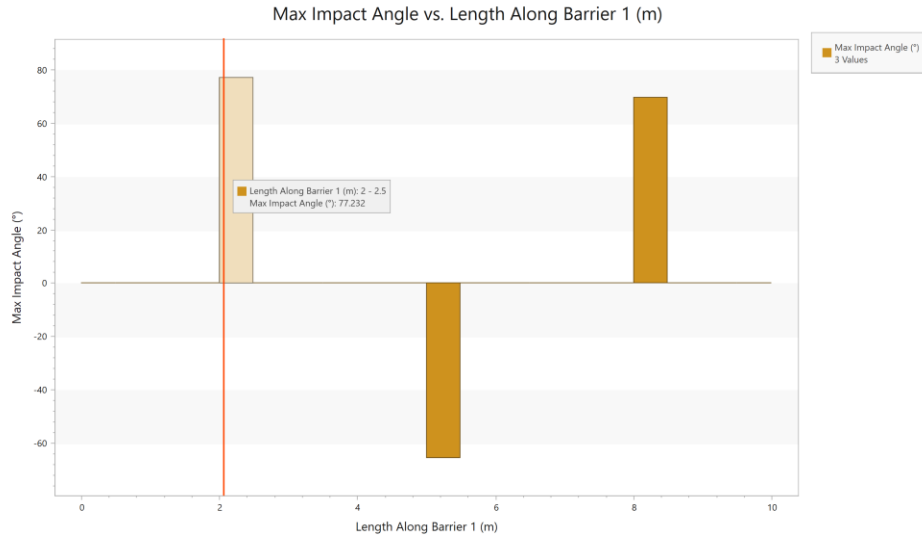


Figure 6-3: Graph Along Barriers plot for the barrier in Figure 6-2

Given that gravity is -9.80665 m/s^2 , both the normal and tangential restitutions are 0.5, and no initial rotational velocity is considered, we can calculate the expected impact angle given the initial conditions above and the trajectory velocities provided from “Export All Results”.

Table 6.1 – Comparison of Impact Angles (degrees)

Rock	Hand calculated	Graph Along Barriers
1	77.232	77.232
2	-65.576	-65.574
3	69.687	69.687

Hand calculation formula:

$$\text{Impact angle} = \arctan(V_z / V_y) * 180 \text{ degrees} / \pi$$

Rock 1:

$$\text{Impact angle} = \arctan(-8.826 \text{ m/s} / 2 \text{ m/s}) * 180 \text{ degrees} / \pi = -77.232 \text{ degrees} = +77.232 \text{ degrees (rock trends towards the slope)}$$

Rock 2:

$$\text{Impact angle} = \arctan(2.202 \text{ m/s} / 1 \text{ m/s}) * 180 \text{ degrees} / \pi = 65.576 \text{ degrees} = -65.576 \text{ degrees (rock trends away from the slope)}$$

Rock 3:

$$\text{Impact angle} = \arctan(-2.701 \text{ m/s} / 1 \text{ m/s}) * 180 \text{ degrees} / \pi = -69.687 \text{ degrees} = +69.687 \text{ degrees (rock trends towards the slope)}$$

7. Example #7: Height over Barrier

The height over barrier is defined as the vertical distance from the top of the barrier to the rock as it passes over the barrier. To show this, we use a flat slope with two barriers (3.5 m tall) and two rocks (Figure 7-1). Barrier 1 is vertical while Barrier 2 is inclined at 20 deg from vertical. Both rocks start 1.75 m away from Barrier 1 and have a starting velocity of 1 m/s towards the barrier. However, one rock starts at a height of 5 m while the other starts at a height of 4 m.

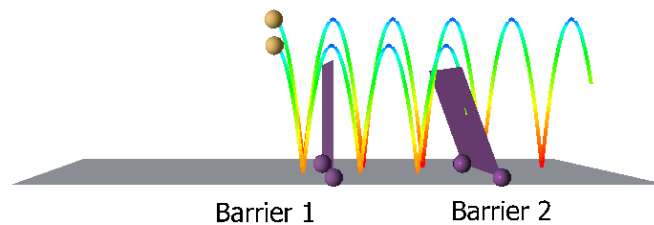


Figure 7-1: Rocks bouncing over two barriers

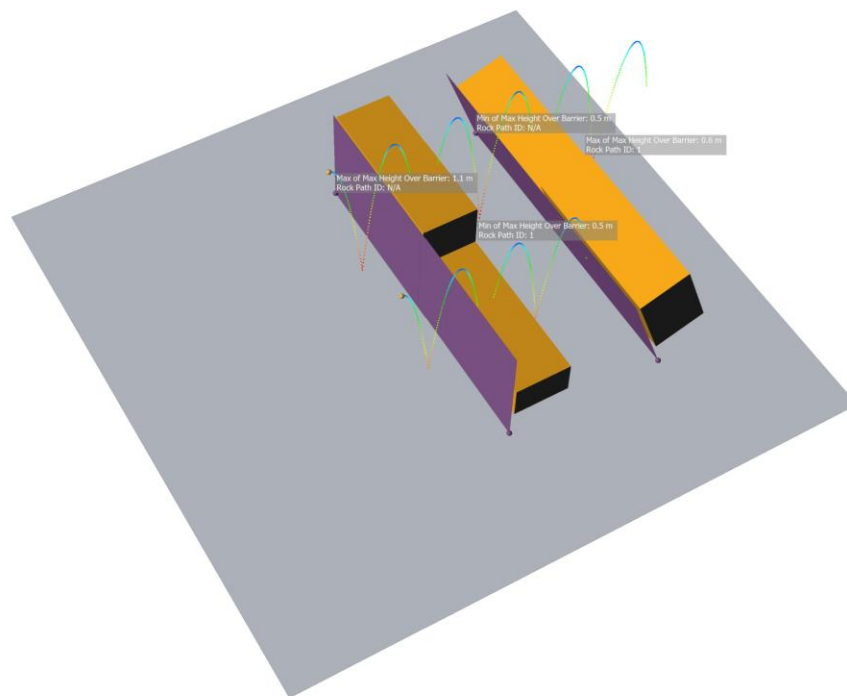


Figure 7-2: 3D plot showing that the rock with starting height of 5 m has a greater max height over barrier 1 than the rock starting from a height of 4 m.

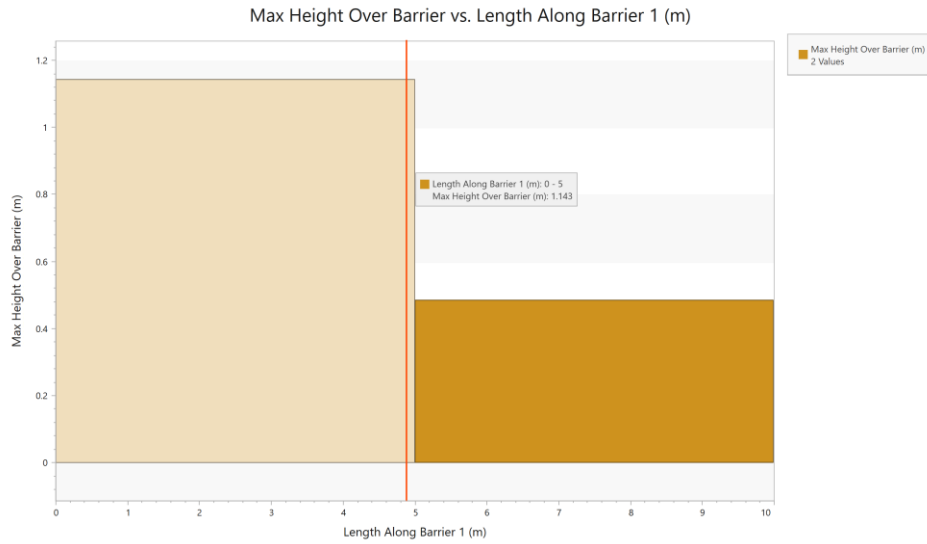


Figure 7-3: Max height over barrier along length of Barrier 1

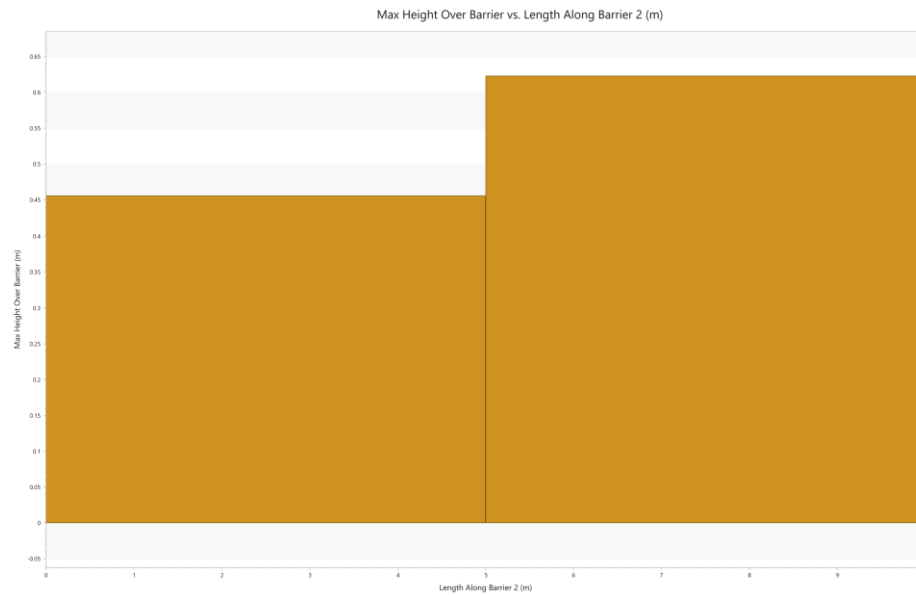


Figure 7-4: Max height over barrier along length of Barrier 2

Given that the slope is at $z = 5$ m, we can calculate the expected height over barrier using the rock's z -value when the y -value is closest to 5 m and 10 m (barriers 1 and 2 locations), provided from "Export All Results".

Table 7.1 – Verification of Reported Height Over Barrier (m)

Rock	Barrier	Hand calculation	Reported from Graph Along Barriers	% Difference
1 (left)	1	1.169	1.143	2.249
2 (right)	1	0.486	0.484	0.412
1 (left)	2	0.437	0.456	4.255
2 (right)	2	0.628	0.623	0.799

Hand calculation formula:

Height over barrier = Rock z-value – slope z-value – barrier inclined height

For Barrier 1, barrier (inclined) height = 3.5 m

For Barrier 2, barrier (inclined) height = $3.5\cos(20 \text{ deg}) = 3.289 \text{ m}$

Rock 1: Height over barrier 1 = $9.669 \text{ m} - 5 \text{ m} - 3.5 \text{ m} = 1.169 \text{ m}$

Rock 2: Height over barrier 1 = $8.986 \text{ m} - 5 \text{ m} - 3.5 \text{ m} = 0.486 \text{ m}$

Rock1: Height over barrier 2 = $8.726 \text{ m} - 5 \text{ m} - 3.289 \text{ m} = 0.437 \text{ m}$

Rock 2: Height over barrier 2 = $8.917 \text{ m} - 5 \text{ m} - 3.289 \text{ m} = 0.628 \text{ m}$

A source of error is “Export All Results” does not provide the rock position at exactly the barrier positions because of the time step size adopted in reporting.