rocscience

RocFall3

Rigid Body

Unit Test Verification Manual

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RocFall3 Rigid Body Unit Tests

This document presents several unit tests which have been used as verification problems for RocFall3. Program outputs are compared to analytical results and Rapid Mass Movement Simulation (RAMMS) Rockfall outputs. RocFall3 is a 3D engineering analysis program for assessing rockfall risks in rock slopes, produced by Rocscience Inc. of Toronto, Canada. The purpose of this verification is to confirm that the Rn values, impacts normal to contacts, dynamic friction coefficients, sliding algorithm, and outbound velocities used by the program are working correctly with rigid body methods.

1. Unit Test Set #1: R_n and Impacts Normal to Contacts

The coefficient of normal restitution (R_n) is applied at impact contact points in RocFall3. The R_n ranges from 0 to 1 and serves to dampen the contact incoming normal velocity ($v'_{n, in}$) to result in a smaller contact outgoing normal velocity ($v'_{n, out}$):

$$R_n = \frac{v'_{n,out}}{v'_{n,in}}$$

In a collinear impact, the normal velocity at the rock center-of-mass is the same as the normal velocity at the contact point.

A series of freefall unit tests with collinear impacts were conducted, with rock center-of-mass results tabulated below. Results show that R_n is correctly applied in RocFall3 for various contact types, and the computed rebound heights (h_1 followed by h_2) compare well to the analytical solution:

$$R_n = \sqrt{\frac{h_2}{h_1}}$$

Table 1-1: Freefall of a cube (1 m^3, 2700 kg) from z = 10 m and over a drop distance of 9.5 m; R_n = 0.5; face-face contact.

	Analytical	**RocFall3**	**RAMMS**
Rebound 1 z (m)	2.88	2.87	2.86
Rebound 2 z (m)	1.09	1.09	1.06

Table 1-2: Freefall of rocks with different shapes and contact types; 1 m^3, 2700 kg.

	Octahedron **R_n = 0.3** **Drop distance = 9.09 m** **Vertex-face contact**		**Dodecahedron** **R_n = 0.8** **Drop distance = 9.34 m** **Edge-face contact**	
	Analytical	RocFall3	Analytical	RocFall3
Rebound 1 z (m)	1.73	1.73	6.64	6.63
Rebound 2 z (m)	0.98	0.98	4.49	4.48

Table 1-3: Freefall of an octahedron (1 m3, 2700 kg) from z = 10 m for Rn = 1 and Rn = 0.

	R_n = 1		**R_n = 0**	
	Analytical	RocFall3	Analytical	RocFall3
Rebound 1 z (m)	10	10.00	0	0.00
Rebound 2 z (m)	10	9.98	-	-
Rebound 3 z (m)	10	9.98	-	-

2. Unit Test Set #2: *μ* and Sliding

The dissipation of rock energy during sliding occurs through friction at the contacts. In RocFall3, the dynamic friction coefficient (*μ*) is applied at contact points and acts in the directions opposite to the incoming tangential impulses. The dynamic friction coefficient is a slope material property.

In the case of pure sliding, the work done by friction is equal to the initial translational kinetic energy of the rock. Thus, an analytical solution is available for calculating the sliding distance of a rock with an initial translational velocity.

A series of sliding unit tests were conducted, with rock center-of-mass results tabulated below. The results show that *μ* is applied correctly during rock sliding for various contact types, and the computed sliding distances compare well to the analytical solution.

Table 2-1: Sliding distance of a cube (1 m^3, 2700 kg) with an initial translational velocity of 5 m/s in the direction <1,0,0>; μ = 0.5; face-face contact.

	Analytical	**RocFall3**	**RAMMS**
Sliding Distance (m)	2.55	2.55	2.55

Table 2-2: Sliding distance of a tetrahedron (1 m3, 2700 kg) with an initial translational velocity of 3 m/s in the direction <1,-1,0>; μ = 0.1; edge-face contact.

	Analytical	**RocFall3**
Sliding Distance (m)	4.59	4.59

3. Unit Test Set #3: Freefall with Initial Rotational Velocity

When a rock free falls with an initial rotational velocity, its post-impact translational and rotational velocities could change as a function of R_n and μ (slope properties). In both collinear and eccentric impacts, the solution for the outbound velocities is non-trivial, and no analytical solution is available. For verification, RocFall3 was compared with RAMMS.

In the following example, a cube (1 m^3, 2700 kg) was dropped from z = 10 m with an initial rotational velocity of 45 deg/s. The cube impacted a horizontal slope surface at z = 0 m. For the case of zero friction (μ = 0) and R_n = 0.5, the rock rebounded vertically as no friction was acting to change the translational velocity vector. The rotational velocity changed after eccentric impact. Table 3-1 lists the rock center-of-mass velocities following the first impact.

Table 3-1: Freefall with rotation (μ = 0, Rn = 0.5); velocities after first impact.

	Rotational velocity vector <1,0,0> Edge-face contact			**Rotational velocity vector <1,1,0> Vertex-face contact**	
	RocFall3	RAMMS (R_t = 0)	RAMMS (R_t = 1)	RocFall3	RAMMS (R_t = 1)
x-velocity (m/s)	0.00	0.00	0.00	0.00	0.00
y-velocity (m/s)	0.00	0.00	0.00	0.00	0.00
z-velocity (m/s)	2.40	2.19	2.19	5.43	5.29
x-rotational velocity (rad/s)	20.62	20.90	20.90	8.65	9.15
y-rotational velocity (rad/s)	0.00	0.00	0.00	8.65	9.15
Total Kinetic Energy (kJ)	103.40	104.74	104.74	73.42	75.38