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# Development of a 3D rockfall simulation model for point cloud topography

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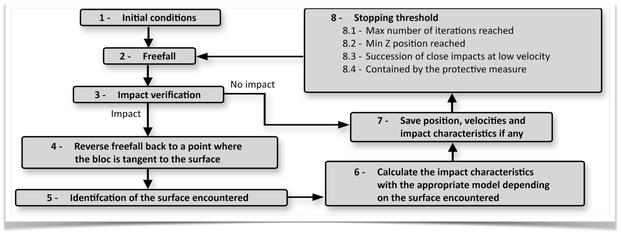
## Introduction

Rockfall simulations are generally used, for example, as input data to generate rockfall susceptibility map, to evaluate the reach probability of an infrastructure or to define input parameter values for mitigation designs. During the simulations, the lateral and vertical deviations of the particle and the change of velocity happening during the impacts have to be evaluated. Numerous factors control rockfall paths and velocities, like the particle's and terrain's shapes and compositions. Some models, especially the ones using discrete element methods, can consider a lot of physical factors. However, a compromise often has to be done between the time needed to produce a sufficient amount of 2D or 3D rockfall trajectories and the level of complexity of the model. In this poster, the current version of our rockfall model in development is detailed.

## Impact detection algorithm

1. The particle is positioned to its initial location near the terrain surface;
2. The particle is free falling for a distance slightly less than its diameter;
3. An impact is detected if ground or infrastructure's points are inside the particle;
4. to 6. We go back in time until the particle is tangent to the surface and changes in velocities due to the impact are evaluated;
7. The new velocities and position of the particle are saved;
8. If stopping thresholds are not met, the process starts back at step 2.




## Impact model

Wyllie (2014a, b) analyzed rockfall data coming from sites of different morphologies and geologies and suggested that the normal restitution coefficient ($R_N$) varies hyperbolically with the incident angle of the particles with the ground surface at impact ($\theta_i$). He developed impact equations which account for this. We adapted them for use in our simulation model with point cloud topography.

### List of variables

| | | | | | |
|---|---|---|---|---|---|
| $t$ | Time | s | $d$ | Diameter of the particle | m |
| $X$ | Position of the particle in 3D space | m | $k_{cube}$ | Radius of gyration or gyradius of the particle | m |
| $\vec{v}$ | Translational velocity of the particle | m/s | $R_N$ | Normal coefficient of restitution | - |
| $\vec{a}$ | Acceleration of the particle | m/s$^2$ | $R_T$ | Tangential coefficient of restitution | - |
| $\overrightarrow{F_D}$ | Drag force due to air resistance | N | $\theta_i$ | Incident impact angle with the ground | ° |
| $\rho$ | Air mass density (~1.2 kg/m$^3$) | kg/m$^3$ | $\mu$ | Randomly generated values normaly distributed around a mean value | - |
| $C_D$ | Drag coefficient of the particle (~0.9) | - | $\sigma$ | Standard deviation of the normal distribution of $\mu$ | - |
| $A$ | Cross sectional aera of the particle | m$^2$ | $v_i$ | Initial translational velocity (just before an impact) | m/s |
| $\overrightarrow{a_D}$ | Acceleration due to drag opposed to the particle motion | m/s$^2$ | $v_f$ | Final translational velocity (right after an impact) | m/s |
| $g$ | Gravitational acceleration (~9.81 m/s$^2$) | m/s$^2$ | $\omega_i$ | Initial angular velocity | Turn/s |
| $r$ | Mean radius of the particle | m | $\omega_f$ | Final angular velocity | Turn/s |

### Balistic / free fall phase

Position:

$$X_t = X_{t0} + \overrightarrow{v_{t0}}t + \frac{1}{2}\overrightarrow{a_t}t^2$$

Translational velocity:

$$\overrightarrow{v_t} = \frac{dX_t}{dt} = \overrightarrow{v_{t0}} + \overrightarrow{a_t}t$$

Acceleration:

$$\overrightarrow{a_t} = \frac{d\overrightarrow{v_t}}{dt}$$

Rayleigh drag equation:

$$\overrightarrow{F_{Dt}} = \frac{1}{2}\rho\overrightarrow{v_t}^2 C_D A$$

$$\overrightarrow{a_{Dt}} = \frac{\overrightarrow{F_{Dt}}}{m}$$

Acceleration components :

$$\overrightarrow{a_t} = \begin{bmatrix} a_{xt} \\ a_{yt} \\ a_{zt} \end{bmatrix} = \begin{bmatrix} \pm a_{xDt} \\ \pm a_{yDt} \\ \pm a_{zDt} - g \end{bmatrix}$$

With the signs of $\overrightarrow{a_{Dt}}$ opposed to the ones of $\overrightarrow{v_t}$.

### Restitution coefficients

Normal restitution coefficient:

$$R_N = min\{\,2;\ 10(\theta_i - 4)^{\mu_N} + 0.08\,\}$$

$$mean\{\mu_N\} = -1.08 \ \ \& \ \ \sigma_N = 0.15\left(1 - \frac{\theta_i}{100}\right)$$

Tangential restitution coefficient:

$$R_T = min\{\,1;\ |\mu_T|\,\}$$

$$mean\{\mu_T\} = 0.69 \ \ \& \ \ \sigma_T = 0.13$$

### The changes in velocities at impact

Particle's spherical shape mean radius:

$$r = rayon\ moyen = \frac{(d_x + d_y + d_z)}{6}$$

Particle's radius of gyration:

$$k_{cube} = \frac{2r}{\sqrt{6}}$$

Normal velocity after impact:

$$v_{fN} = -v_{iN} \cdot R_N$$

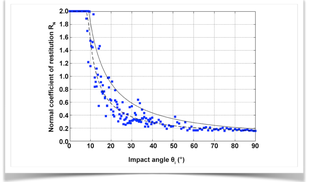
Tangential velocity after impact:

$$v_{fT} = \left[v_{iT} - \frac{v_{iT} + r \cdot \omega_i}{1 + {r^2}/{k^2}}\right] \cdot R_T$$

Angular velocity after impact:

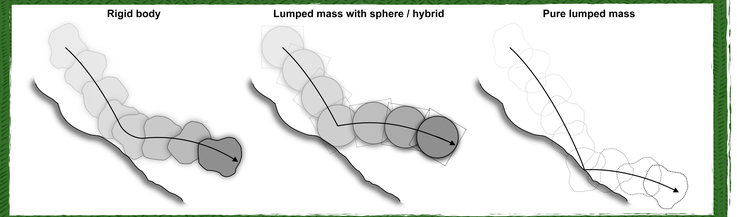
$$\omega_f = \omega_i - \frac{r \cdot (v_{iT} + r \cdot \omega_i)}{k^2 \cdot \left(1 + {r^2}/{k^2}\right)}$$

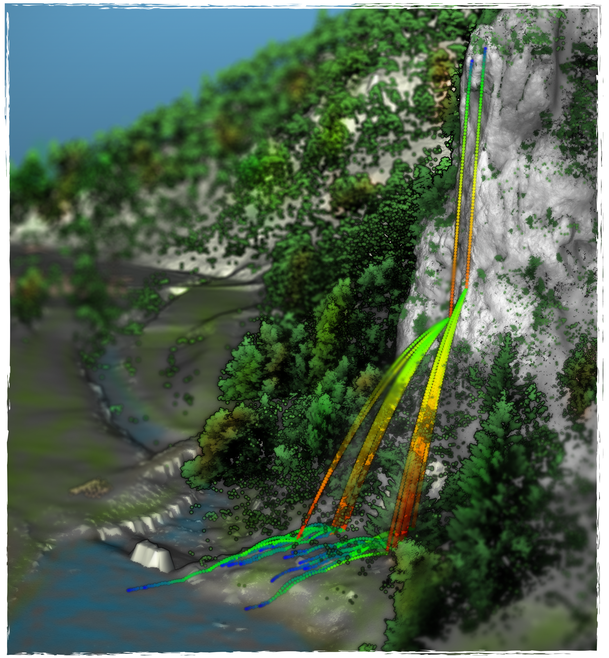
As an $R_N$ superior to one involves a velocity input, it was decided that the gain in energy would be transferred from the tangential to the normal velocities. We arbitrarily fixed this transfer to a maximum corresponding to 20% of the tangential velocity, because more transfer would induce a relationship between the incident angle and the tangential coefficient of restitution.




## Particle's size and shape

For now, the particle's shape is simplified to a sphere which can vary in size and a cubical shape is used to compute the 3D rotational inertia. This has the avantage of speeding up the calculation so a high number of rockfalls can be obtained for probabilistic risk analysis. Also, because the size of the particle is considered and a very detailed terrain can be used with point cloud, effect of walls, ditch or natural topographic depressions can be simulated.



## Conclusion

Some main advantages of the proposed 3D rockfall simulation model using point clouds are: 1) overhanging slopes are represented and can be identified as sources; 2) Bias liked with gridded/rasterized elevation data are eliminated; 3) The reach probability, energy and incident angle of impacts against protective measures or infrastructures can be identified.

## References

Wyllie, D. C. (2014a). Calibration of rock fall modeling parameters. International Journal of Rock Mechanics and Mining Sciences, 67, 170–180.

Wyllie, D. C. (2014b). Rock fall engineering: development and calibration of an improved model for analysis of rock fall hazards on highways and railways. The University of British Columbia.