Runout distances and the fractal rock blocks size distribution in avalanches: DEM analysis

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Abstract

Long runout distances developed by rock avalanches are an important parameter used for the design of the safe location of civil engineering structures. Fragmentation takes place during the initiation and movement of rock avalanches, and causes the rocks to shatter into a mixture of rock blocks with a fractal size distribution. Very few numerical studies has been conducted to date analysing how a fractal block size distribution influences the mobility of rock avalanches and their associated long runout distances. In this study, the mobility characteristics of poly-dispersed rock blocks that have a fractal size distribution were investigated using DEM. Simulated mixtures of the rock blocks having different fractal size distributions were placed in a container. The container was lifted and the long runout distance of the mixture was measured with respect to the original position of the container. It was determined that the long runout distance of the mixtures was directly related to their fractal block size distribution values. That is, the larger the long runout distance of the mixture, the larger was the fractal size distribution value of the mixture of rock blocks tested. Thus, the fractal size distribution in dry mixtures of rock blocks forming part of avalanches seems to have a large influence on their mobility and in their associated long runout distances.

1 INTRODUCTION

Granular flows in the form of dry rock avalanches are widespread in nature and are among the most impressive, powerful and destructive phenomena with respect to their capacity to modify the natural landscape and devastate engineering structures. An important feature of these flows is their extremely high mobility on slopes of very small inclinations. Among the many explanations for the high mobility of rock avalanches are the following (Legros, 2002):

(1) Air cushion theory. It is suggested that a sheet of rock slide debris slides on a cushion of air, trapped when the slide is catapulted into an air trajectory by a ramp.

(2) Fluidization by trapped air. A similar air entrapped process is thought to cause a full or partial fluidization of the debris by means of upward flow of air.

(3) Fluidization by vapor. It has been demonstrated that rock avalanche movement expends sufficient energy to vaporize pore water. The pressure induced in the granular material by this vaporized water aids its mobility.

(4) Rock melting. It has been found that specimens of molten rock near the sliding surface of a rockslide in Switzerland. Frictional heat can be produced in exceptionally thick slide masses to melt igneous rock which in turn causes a corresponding reduction of the friction angle in experiments.

(5) Fluidization by dust dispersion. It has been proposed that during a rock avalanche dense dispersion of rock dust acts as pore fluid among the larger clasts.

(6) Acoustic fluidization. Vibrations produced on the sliding surface by rapid movement over uneven ground could reduce the friction angle of the granular debris. Direct shear tests of sand conducted on a vibrating table have shown that such a phenomenon does exist.

(7) Lubrication by liquefied saturated soil. The high mobility of the Elm Slide was explained by the effects of mud, entrained by the rockslide from loose valley deposits, liquefied under the weight of the debris.

(8) Fragmentation and spreading. Studies of rock avalanches have indicated that the component material is pervasively fragmented with rock fragments of different sizes immersed in a matrix constituted of finely comminuted rock granules.

From field measurements, Crosta et al. (2007) have determined that the rock blocks size distribution in various rockslide deposits is fractal in nature (Fig. 1) (Table 1).

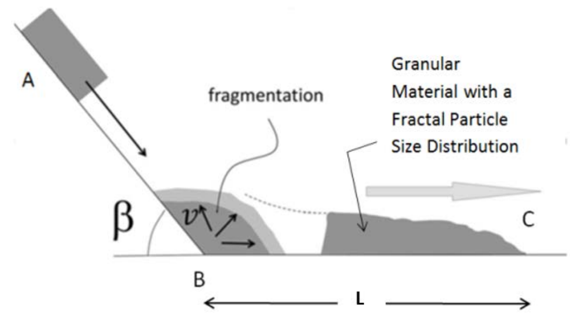

Figure 1. Long runout distance, L, of rock dep osits forming part of rock avalanches.

Table 1 Fractal dimension of the mixture of rock blocks forming part of rock avalances (Crosta, et al., 2007)

Location	Lithology	Fractal Dimension, D
Flims, Switzerland	limestone	1.90 – 2.95
Campo di Giove, Italy	limestone	2.65 – 2.72
Coal dumps, Canada	Coal	2.62 – 2.89
Mount St. Helens, United States	volcanic	3.00 – 3.50
Thurwieser, Italy	dolostone	2.65 – 2.86
Mt. Cook, New Zealand	sandstone	2.73
Val Pola gabbro, Italy	diorite	2.20 – 3.10

An analysis of Table 1 indicates that the size distribution of the rock blocks in the rock avalanches analyzed by Crosta et al. (2007) is fractal in nature. The fractal dimension, D , of the rock blocks size distribution of the deposits forming part of rock avalanches varied in value between 1.90 and 3.50. According to Tyler (1990) a particle size distribution with D = 0, reflects a distribution composed solely of particles of equal diameter; a D between 0 and 3 reflects a particle size distribution with a greater number of larger grains; while a D > 3 reflects a particle size distribution dominated by smaller grains. Thus, the different values of D reported in Table 1 seems to indicate different levels of fragmentation in the material forming part of rock avalanches. In this study, the effect of the fractal rock block size distribution on the value of the long runout distance, L, developed by rock avalanches will be investigated (Fig. 1).

2.0 NUMERICAL ANALYSIS OF THE RUNOUT DISTANCES OF MIXTURES WITH A FRACTAL ROCK BLOCK SIZE DISTRIBUTION

2.1 Preparation of samples with a fractal rock block size distribution

For the preparation of granular samples with a fractal rock block size distribution (frbsd), the method outlined by Palmer and Sanderson (1991) and Hooke and Iverson (1995) will be used. According to these researchers, the following relationship applies to a granular mixture with a frbsd:

$$N(r) = N_0\left[\frac{r}{r_0}\right]^{-D} \quad (1)$$

where N(r) is the number of rock blocks of radius r, N_0 is the number of rock blocks of a reference size r_0, and D is the fractal dimension of the rock blocks size distribution. Thus, one can start with certain selected values of N_0, r_0 , r and D and obtain the value of the number of rock blocks, N(r) , of size r. In the numerical simulations, six different sized rock blocks (assumed circular) are used to represent small (radii of 0.20 and 0.40 m), medium (radii of 0.60 and 0.80 m) and large (radii of 1.00 and 1.20 m) ones, respectively. In order to obtain different samples with different D (1.00, 1.50, 2.50 and 3.50), Eq. (1) was used. The double log plot of number of particles N(r) against particle radius r is given in Table 2 and Fig. 2.

Table 2 Characteristics of granular mixtures with different fractal dimensions

Rock block radius (m)	Number of rock blocks in mixtures with different D values			
	D=1.0	D=1.5	D=2.5	D=3.5
0.20	850	1650	4920	9800
0.40	425	583	869	860
0.60	284	318	315	210
0.80	213	206	154	74
1.00	170	148	88	35
1.20	142	112	55	19
Total Area (m^2)	2245.23	2244.72	2245.10	2244.85

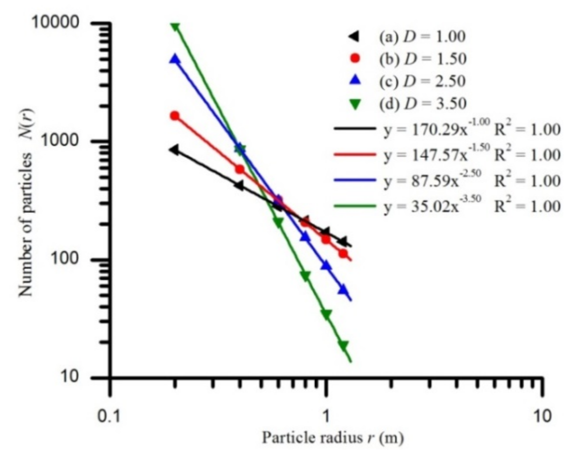

Figure 2. Particle (rock blocks) size distribution versus number of particles (rock blocks) in mixtures with different fractal dimensions

2.2 Set up of the DEM model

Table 2 and Fig.2 shows the distribution of rock blocks in four samples of granular mixtures with different fractal dimension D, which are simulated by a two-dimensional discrete element method code PFC^{2D} (Itasca, 2002). Rock blocks are treated as disks of unite thickness in the simulations. Different sized rock blocks are randomly generated in a rectangular container and the number is specified according to Table 2. The container shown in Fig. 3 is L_o = 40.0 m in width, and H_o = 80.0 m in height and is constructed of elastic walls with the same normal and tangential stiffness as those of the particles (10^{10} N/m). The particle density is 2500 kg/m^3.

The friction coefficient between particles is set to 0.60, whereas the walls are frictionless. These numerical parameters are chosen from pertinent references (Langlois et al., 2015) in order to acquire reasonable results.

Finally, the gravity (9.81 m/s^2) is applied to settle the particles. Fig. 3 shows the numerical samples with different fractal dimension *D* at rest. Blue, red and yellow particles (rock blocks) in the figure represent small, medium and large ones, respectively. For every sample, the total mass of the particles is the same.

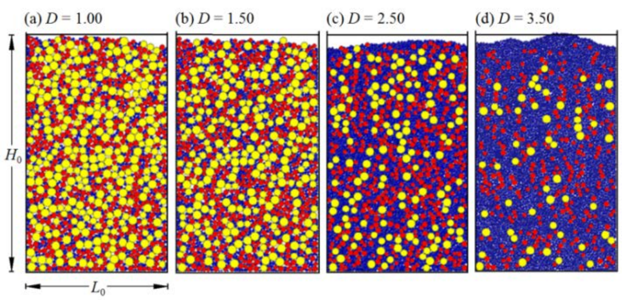

Figure 3. Numerical mixtures with different fractal dimension values

2.2 The long runout distance using numerical model

After the particle mixtures completely fill the container, they are allowed to spread by lifting the lateral walls of the container at a velocity of 5 cm/sec. After spreading, the long runout distance, L, is determined as shown in Figs. 4 and 5 in function of the fractal dimensión of the mixtures. The distance L is

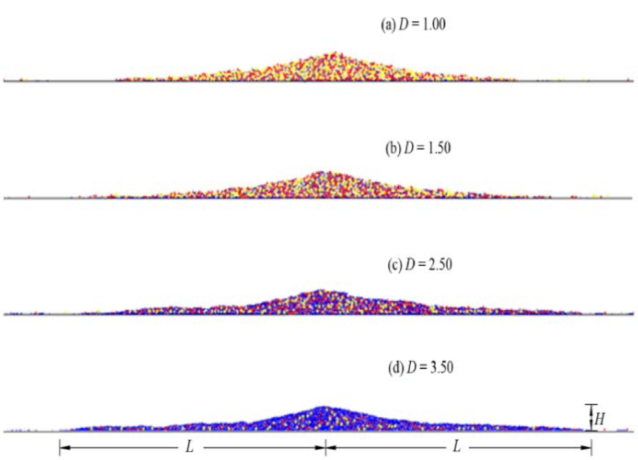

Figure 4. Long runout distance, L, developed by the simulated rock block mixtures.

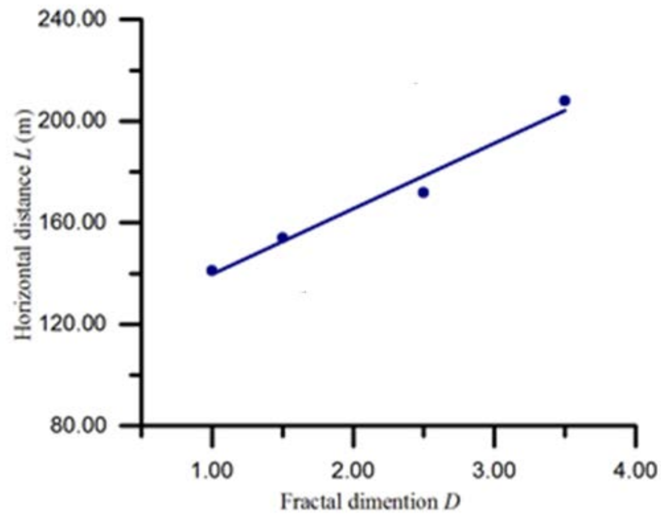

Figure 5. The long runout distance, L, or rock avalanches in function of the fractal size distribution, D, of the rock blocks in the avalanches (R^2=0.98).

measured from the location of the center of the container to the point in which the simulated rock blocks are still in contact (Fig. 4)

An analysis of Figures 4 and 5 indicates that the long runout distance, L, obtained by the mixtures depended upon the value of the fractal dimension, D, of the size distribution of the rock blocks. That is, the higher is D the larger is L. Thus, the fractal dimension,D, of the size distribution of the rock blocks in rock avalanches seems to have a large influence in their long runout distance. The sufficiently large range of D (between 1.00 and 3.50) was chosen in this study in order to evaluate the effect of D on the long runout distance, L.

3 EXPLANATION FOR THE LONG RUNOUT DISTANCE, L, AS A FUNCTION OF THE FRACTAL DIMENSION D.

A DEM study of flows of granular materials made of two different size particles indicated that the smaller size particles improved the rotation of the particles in the mixture (Linares-Guerrero, et al, 2007) [Fig. 6(a)]. This improved rotation translates into an improved mobility of the binary granular mixtures. Laboratory experiments on the flow of binary granular materials on horizontal surfaces conducted by Chick and Vallejo (2005) and Phillips et al. 2006 [Fig.6(a)], arrived at the same conclusion. The same improved mobility seems to occur in the flow of granular mixtures with a fractal particle size distribution on horizontal surfaces [Figs. 4 and 6(b)]. The presence of a great number of smaller grain size particles in the mixtures [D > 3, Table 2, and Figs. 4 and 6(b)] seems to contribute to the rotation (mobility) of the particles and not to the shearing friction between them during the movement of the particles on horizontal surface (Fig. 4). The presence of a large number of the smaller grain size particles in the granular mixtures seems to cause an increase in their rotation (mobility) that seems to be translated on the long runout distance (L) of the mixtures.

In a previous study by the authors of the present manuscript (Lai et al., 2017), it was determined that the spreading of granular materials with a fractal particle size distribution on a horizontal surface was the result of a boundary layer developed at the interface. In this boundary layer the particles experience high levels of velocity and high shearing stress levels. These high velocities and high shearing stress levels were responsible for the high levels of spreading. Also, these high levels of spreading were directly related to the values of the fractal dimension of the particle size distribution. In the present study, the high levels of spreading of granular materials are analyzed using the decrease in frictional resistance that takes place in the granular mixtures as a result of an improved rotation that is facilitated in the granular mixtures by the presence of the smaller size particles (Fig. 6)

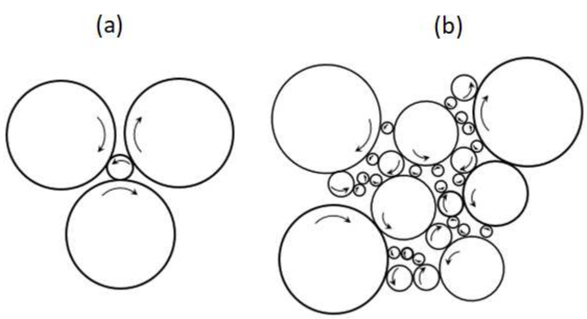

Figure 6. (a) Full rotation of particles in binary granular Mixtures; (b) complete rotation between particles in a mixture with a fractal particle size distribution (this is an original figure developed by the authors of the present manuscript).

Also, it should be noted that the rotation of the granular materials is improved if they are spheres. In real rock avalanches this is not the case since the particles resemble polygons.

4 CONCLUSIONS

In this study, the mobility characteristics of poly-dispersed rock blocks that have a fractal size distribution were investigated using DEM. Simulated mixtures of the rock blocks having different fractal size distributions were placed in a container. The container was lifted and the long runout distance of the mixture on a horizontal surface was measured with respect to the original position of the container. It was determined that:

(1) The long runout distance of the mixtures was directly related to their fractal block size distribution values. That is, the larger the long runout distance of the mixture, the larger was the fractal size distribution value of the mixture of rock blocks tested. Thus, the fractal size distribution in dry mixtures of rock blocks forming part of avalanches seems to have a large influence on their long runout distances.

(2) The mobility of the granular mixtures was improved by the presence of a large number of smaller size particles in the mixture. The presence of these smaller size particles promoted the rotation of the particles and thus the mobility of the mixtures.

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