Investigating Rock Fall Frequency and Failure Configurations Using Terrestrial Laser Scanner

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Abstract

Terrestrial laser scanner has been used to detect rock falls greater than 0.01 m^3 which have occurred during some years in different rock walls consisting of massive to thin-bedded limestones of the Subalpine Chains and gneiss of the Massif de l'Oisans. For each rock wall, spatial-temporal rock fall frequencies have been determined and the volume-frequency relation has been fitted with a power law. The influence of the geological context on the power law parameters has been studied. These parameters can be used for quantitative assessment of diffuse hazard in rock walls having similar geological and morphodynamic contexts. The geometrical configurations prior to rock fall have also been studied in order to better identify the future rock fall locations. Prone to fall configurations depend on the rock mass internal structure and the wall surface geometry.

Keywords

Rock fall • Frequency • Hazard • Terrestrial laser scanner • Lidar

340.1 Introduction

Quantitative assessment of rockfall hazard in a rock wall must be based on a rockfall inventory, which allows to determine the rockfall frequency as a function of the rockfall volume. Several authors have studied the rockfall frequency from historical inventories including relatively large rockfall volumes (see reviews by Dussauge-Peisser et al. 2002; and Brunetti et al. 2009). Development of teledetection methods such as Terrestrial Laser Scanner (TLS) allows to get more exhaustive inventories covering smaller rockfalls (Lim et al. 2010; Dewez et al. 2013; Abellan et al. 2010; Rabatel et al. 2008; Ravanel et al. 2012). Terrestrial Laser Scanner was used to investigate several cliffs in the French Alps, in different geological contexts. It permitted to have exhaustive inventories of rockfalls occurring on these cliffs, in a volume range depending on the precision of the laser scanning. Thanks to the 3D reconstruction, volume, dimensions, configuration before the fall, and an estimation of failure mechanisms can also be obtained.

340.2 Study Sites and Geological Features

Four sites were studied in the Grenoble area. 3 sites are located in the Subalpine Ranges (Vercors and Chartreuse), one site is located in a metamorphic part of the Massif des Ecrins (Fig. 340.1).

- The Mont Saint Eynard is a 7 km long doubled cliff. The lower cliff is 240 m high, separated from the 120 m high upper cliff by a ledge covered with forest. The investiga-

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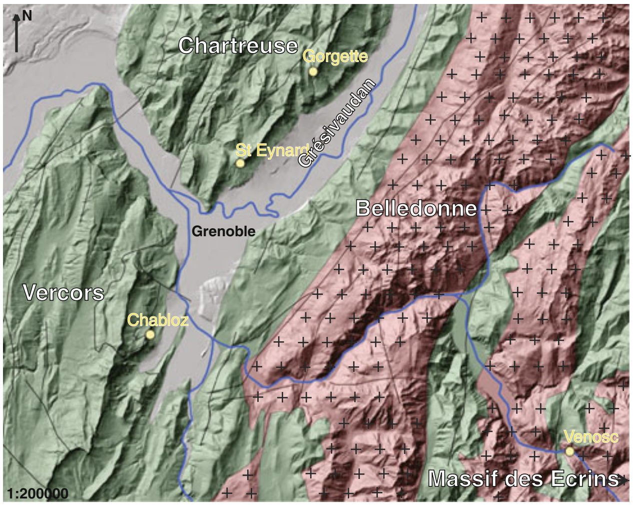

Fig. 340.1 Location of the cliffs investigated (*white circles*). *Green* sedimentary rocks. Red and black cross: metamorphic and magmatic rocks. *Black lines* major faults

tion zone is 750 m long. The lower cliff consists of fractured thin bedded limestones, of the Sequanian stage. The upper cliff consists of massive limestones of the Tithonian stage. This site is located on the oriental edge of the Chartreuse Massif. The cliff (direction N45, facing South-East) belongs to the eastern side of the Sappey syncline (axis direction, N10, dipping North). It is cut by two dextral thrust faults of direction N60–70 (Gidon 1990). The investigation zone is located near the synclinal hinge. Bedding planes are slightly dipping north at this point.

- The Gorgette cliff, facing South-West, is 150 m high, 700 m long. It forms the border of a deep ravine incised by the Gorgette stream. The cliff consists of thin bedded marly limestones of the Valanginian stage (called Fontanil limestones).The Gorgette ravine is located in the oriental part of the Chartreuse Massif. This zone is cut by a normal fault (Gorgette fault), of same direction than the cliff (N–S). This fault is included in a large syncline (Dent de Crolles syncline). Bedding planes are slightly dipping north.
- The Chabloz cliff, facing East, is located on the eastern side of the Vercors Massif. It is 350 m high and 1,500 m long, and consists of massive limestones of Urgonian stage. Bedding planes are dipping west. The investigated zone is 650 m long.
- The Venosc cliff is a 500 m high rockwall, on the border of the Veneon River. It consists of migmatitic gneiss of the Massif des Ecrins. The considered length of rockwall is 1,000 m.

340.3 Rockfall Detection and Spatial Temporal Frequencies

Rockfall detection is obtained by comparison of 2 point clouds of the cliffs acquired in 2009 and 2012 (Guerin et al. 2013). A mesh was built with the point cloud acquired in 2012. This mesh was superposed with the 2009 point clouds, and the positive deviations obtained were considered as rockfalls (Fig. 340.2). Different thresholds were used depending on the precision of the scanning (Guerin et al. 2013). The point clouds defining a fallen compartment were meshed, allowing to calculate the volume of the compartment and to get dimensions and gravity center.

For the 3 cases of Gorgette cliff, lower cliff of St Eynard, and Venosc rockwall the cumulative distribution function of the rockfall volume is well fitted by a power law:

$$N = aV^{-b}$$

where V is the rockfall volume, N the number of rockfalls larger than V, *a* and *b* constants depending on the site. The constant *a* represents the number of rockfalls greater than 1 m^3 and *b* characterizes the distribution of the volumes. N and *a* depend on the size of the cliff and on the length of the observation period. The values obtained for the different sites are given in the Table 340.1.

No fitting has been made for the cliffs where less than 10 rockfalls have been observed, but the parameter *a* has been assessed by the number of rockfalls greater than 1 m^3. To characterize the activity of the different cliffs, we have calculated a spatial-temporal rock fall frequency, which is the number of rockfalls per year and per hm^2:

$$F_{st} = a_{st} V^{-b}$$

The corresponding a_{st} values are given in the Table 340.1. The rock walls can be classified in two classes: (a) Thinly bedded rock walls, which present a_{st} values of about 1 and *b* values of about 0.6; (b) Massive rock walls which present a_{st} values smaller than 0.1 and a *b* value of about 0.4.

Fig. 340.2 Rockfall detection for the Gorgette cliff. The *white spots* correspond to the fallen compartments

Table 340.1 Characteristical values of all sites

Site name	Gorgette	Saint eynard low.	Saint eynard up.	Chabloz	Venosc
Number of events	147	391	3	2	12
Volume range (m3)	0.001−100	0.001−100	0.1−10	1−100	0.1−1000
Average volume (m3)	1.30	1.15	–	–	30.25
Median volume (m3)	0.09	0.13	–	–	7.66
a	16	42	1	2	10
b	0.57	0.71	–	–	0.38
Considered surface (m^2)	51461	129646	77214	104579	365685
ast ($nb/hm^2/yr$)	0.963	1.003	0.040	0.059	0.085

340.4 Failure Configurations and Mechanisms

The 3D reconstructions of the fallen compartments were studied through horizontal and vertical sections of the compartment and the cliff. Each compartment has been approximated by a 6 faces polyhedron closest as possible to the real shape. The faces were described as jointed or not (free). This description gives information about the configuration of the compartment on the wall surface before the fall.

The 3D reconstruction allowed to know the compartment volume and its gravity center. It was then possible to build the half-line wearing the weight vector and starting from the gravity center. Considering that the only moving force is gravity, information on failure mechanism could be obtained (Fig. 340.3b): when the half line intersects a jointed lower face of the compartment, the mechanism was a slide on this lower face; when it intersects a free lower face (overhanging

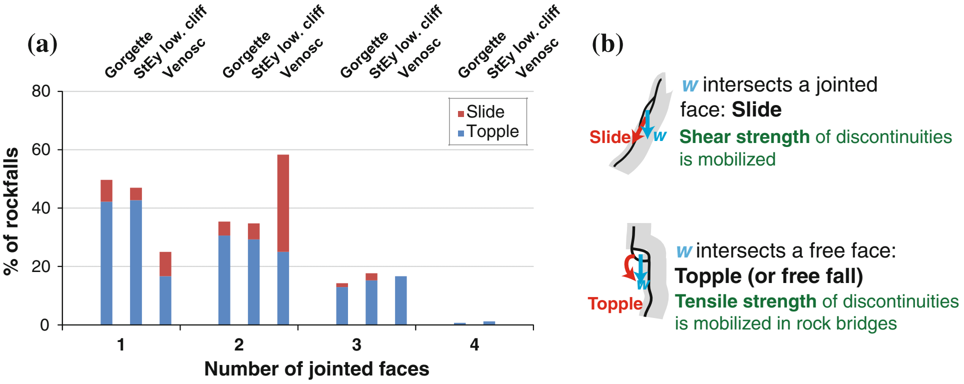

Fig. 340.3 **a** Proportion of compartments as a function of the number of jointed faces and failure mechanisms, for 3 sites. **b** Scheme of the two considered failure mechanisms

Table 340.2 Average dimension ratio of fallen compartments for all sites (length is defined in the cliff direction)

Site name	Gorgette	Saint eynard low.	Saint eynard up.	Chabloz	Venosc
Height/ length	1.00	0.93	0.54	0.75	1.30
Height/ thickness	2.06	1.55	1.50	2.45	2.05

face); a reaction torque is usually needed for the equilibrium of the compartment. When this reaction torque becomes insufficient, the failure occurs with a topple mechanism (or rotational mechanism). Note that when the upper face is jointed and the compartment attached only by a rock bridge in this joint, the failure mechanism is a tension failure, followed in some rare cases by a translational free fall.

The number of jointed faces of each compartment has been studied, and put in relation with the failure mechanism (Fig. 340.3a).

It appears that the two sites of Chartreuse (Gorgette and St Eynard) which have similar geological contexts, present also similar configurations, different from the Venosc site. For these two sites, most of the compartments (more than 80 %) present only 1 or 2 jointed faces. The failure mechanisms were essentially free fall or topple, only a few compartments falling by slide (10–20 %). Typically, one of the jointed faces corresponds to a bedding plane and the other one to a joint having a direction more or less parallel to the cliff.

Venosc site shows different configurations. Most of the compartments (more than 50 %) present 2 jointed faces, and the slides are more important (about 40 %) than for the other sites.

The relation between the three dimensions of the fallen compartments gives information about their global shape (Table 340.2).

For all sites, height of the fallen compartment is 1.5–2.5 times higher than thickness. Fallen compartments are cut superficially, close to the surface.

The Gorgette cliff and the lower cliff of Saint Eynard present a height/length ratio close to 1. External surfaces of fallen compartments seem roughly square. This is consistent with the fact that the distance between crossjoints is close to the bed thickness. Chabloz cliff and the upper cliff of Saint Eynard show height/length ratio of 0.5-0.7. The fallen compartments are longer than higher, following the bedding. The Venosc height/length ratio is superior to 1. The compartments are higher than longer.

340.5 Conclusion

A three-year TLS survey has allowed to estimate the volume-frequency relation for rock walls of several hundreds of meters in length, consisting of thinly bedded limestone. The power laws obtained present exponent values of about 0.6, which are consistent with the value obtained by Hantz et al. (2003) for larger rockfalls occurred in 120 km of limestone cliffs in the Grenoble area. For cliffs consisting of massive rock masses (limestone and gneiss), the number of rockfalls detected in 3 years was not sufficient to give a good idea of the volume-frequency relation. Only the mean number of rockfalls greater than 1 m^3 which occur per year and per hm^2 (a_{st}) has been estimated. It appears that massive rock walls present a_{st} values smaller than 0.1, while thinly bedded rock walls present values of about 1.

TLS survey has also allowed to characterize typical failure configurations and mechanisms: for thinly bedded limestone, most of the rock compartments were linked to the cliff by only 1 or 2 jointed faces, while for gneiss they were linked mostly by 2 jointed faces.

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