Rockfall simulation and identification their sources locations along Massive external crystalline in Alps zone using LiDAR and Panorama Images: Case of La Grave, France

Tiggi Choanji, Li Fei, Charlotte Wolff, Chunwei Sun, Marc-Henri Derron, Michel Jaboyedoff
Risk Group, ISTE, University of Lausanne, Geopolis – Quartier Mouline, Lausanne, Switzerland

Frack Bourrier
Université Grenoble-Alpes, INRAE, ETNA, Grenoble, France

Romain Gaucher
Service Ingénierie, Département des Hautes-Alpes, Gap, Provence-Alpes-Côte d'Azur, France

Kan Jean Kouamé
CURAT, Côte d'Ivoire, Bd. De l'Université, Université Félix HOUPHOUËT-BOIGNY d'Abidjan Cocody (Côte d'Ivoire)

ABSTRACT: Rockfall hazards are fundamental problems for roadway safety in hilly areas. Monitoring rockfall activity along the 17 km long road from Chambon to La Grave is necessary to assess frequency, return period, and magnitude of rockfall events. According to historical inventory, more than 15 rockfall occurred between 1999 and 2020. Therefore, annual LiDAR measurements, with a point density of 40 to 189 points/m^2, and more than 10'000 images from high-resolution cameras are used for detecting and evaluating rockfalls. Based on comparisons between 2020 and 2021, three rockfall sources totalling 200 m^3 have been identified. Rock stability is assessed by analysing topography to identify potential rockfall sources using slope angle distribution (SAD) analysis and overhanging slopes from point clouds. Then, the trajectory from each identified source was simulated and verified using historical rockfall data. Thus, this combination of techniques better identifies and predicts deposited rockfall and impacts on infrastructures.

Keywords: Rockfall, LiDAR, Alpes, Rock stability.

1 INTRODUCTION

Slope movement processes like rockfalls (Varnes 1978) are common in mountainous areas, height rock walls have the capacity to generate large rockfalls that are developing talus at their toe on which the blocks rebound, fragmented and slide, stopping or not on it. Consequently, rockfall hazards can be high on these talus slopes. The risks for persons on roads and in houses that are built on these talus or located below these cliffs can be high (Volkwein et al. 2011).

Road access to La Grave is one road that connects Grenoble to Briançon in France. Along the side of the road is a cliff with a high slope, including several scree slopes. This area is constantly monitored for hazards as multiple hazards happened. So, this paper presents a case study to assess the sources of rockfalls and a statistical modelling of rockfall trajectories and an assessment of potentially impacted areas and infrastructures.

1.1 Geological setting

The study area is located in the western Alps, in a zone made up essentially of crystalline basement (external massifs) with its autochthonous (in place) and parautochthonous (slightly displaced) Mesozoic and Tertiary covers (Ramsay 1963). This area is separated by a great thrust plane, called the frontal Pennine thrust, a significant dislocation on which the internal zone has moved a proven minimum distance of forty kilometres over the external zone.

The external crystalline massifs are predominantly composed of metamorphic gneiss, migmatites, granites, amphibolites, and sedimentary rocks from the Variscan period, which occurred around 300 million years ago (Mercier et al. 2023). Furthermore, the research site exhibits a variety of geological formations, including amphibolite gneiss, aplite, granite, biotite gneisses, micaschist, and some sections are overlaid with scree or avalanches (BRGM 2005). In addition, on top of the biotite gneisses in the crystalline massif region, dolomites and dark clay deposits, along with minor extensive faults. The observed structural characteristics indicate a distinct staircase fault pattern, oriented in a North-South direction (Gidon 2020).

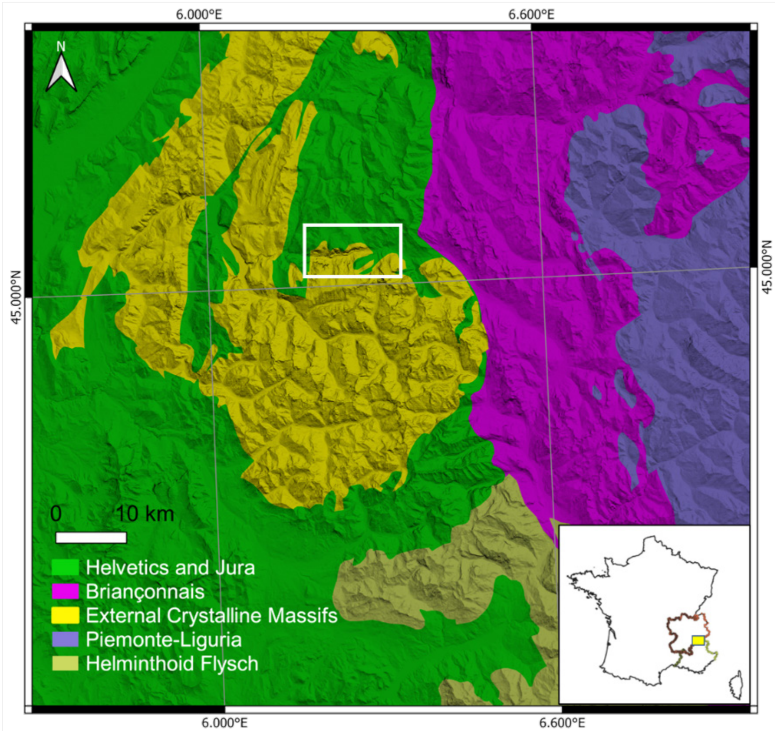

Figure 1. Simplified geological map of Western Alps which comprises External Crystalline Massif (white box) (modified from (Bonnet et al. 2022)).

The structural setting in this area was influenced by two significant tectonic stages: Jurassic extension followed by subsequent crushing and shearing after the Nummulitic period (Gidon 2001). Both the basement and the cover layers exhibit decollement structures. The Pelvoux massif comprises the Combeynot, La Meije, and Plateau components, which were thrust by basement faults, leading to the separation of the eastern and western parts of the Grandes Rousses massif. In addition, its resulting of hanging wall reverse faults that dominated structure in the area (Beach 1981).

2 METHODOLOGY

Methods used to pinpoint the source of rock fall include Slope Angle Distribution (SAD) analysis based on 1 m resolution DEM data (Jaboyedoff & Labiouse 2011; Loye et al. 2009). The SAD express a range of slope angle values characteristic of a given morphology and rock type. The SAD can therefore be decomposed into several Gaussian slope angle frequency distributions (Strahler 1950) that are characteristic of a specific morphological unit (Jaboyedoff & Labiouse 2011; Loye et al. 2009). While, overhang position analysis is defined based on LiDAR data using slope identification above 90^o on cloud points which could be identified as negative normal using open software StnParabel (Noël et al. 2021).

The rockfall simulation was carried out by preparing three-dimensional point cloud data from LiDAR at an equal distance between each point cloud (including trees and infrastructures). After that, an impact detection algorithm was used in conjunction with a rolling friction rebound model (Noël et al. 2021) because most of the simulated area was covered with mostly vegetated rock scree. The trajectory simulations were carried out with 1 m^3 block from identified rockfall sources.

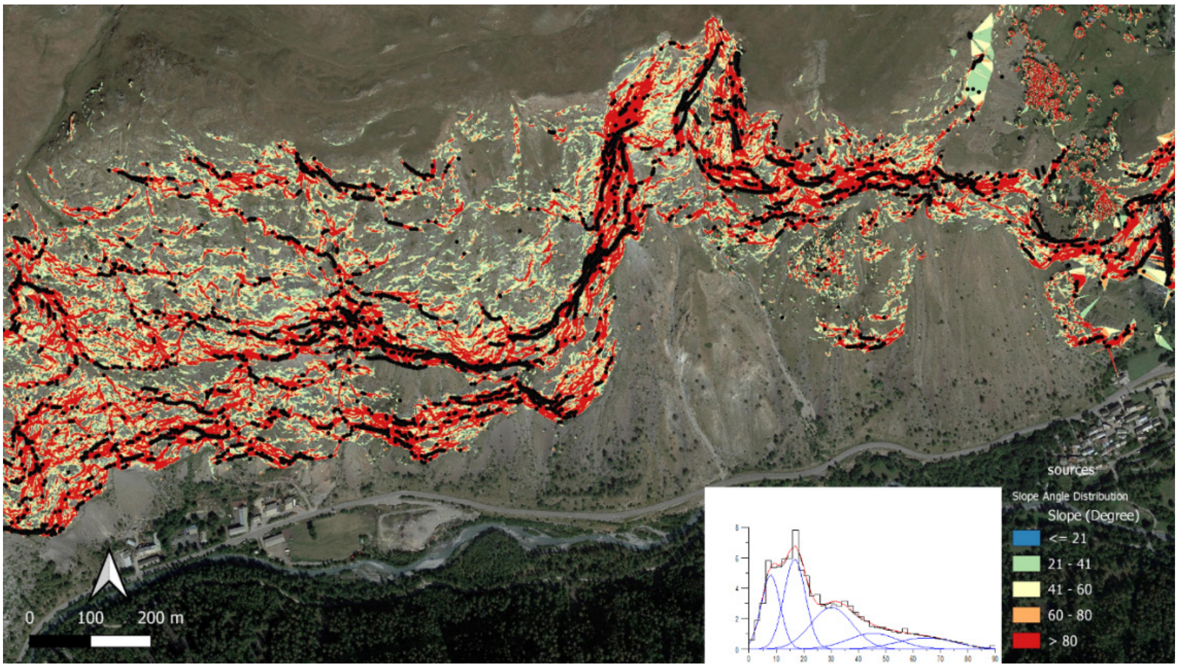

Figure 2. Slope angle distribution for steep slopes overlain by rockfall scar identification (black dot) and Gaussian distribution graph showing five threshold angles.

3 RESULT

From the slope angle distribution results, five thresholds were obtained based on grid of the 1 x 1 m DEM data used ranging from 11^0, 22^0, 41^0, and 55^0, which were then overlaid with slopes overhangs identification from point cloud to obtain around 3813 location points that are potential rockfall source areas scattered along the hill slope.

One hundred blocks were simulated for each sources cell of the DEM. The results are of two types: rockfall deposits and rockfall impacts. According to these preliminary simulation results, 62% of the blocks are deposited on the scree slope, 17% on the road, and 2% in the river. The remaining 18% did not move or stop near the source of the rockfall. The impact of rockfall on infrastructure was 91% on the road, 2% on the power line, and 7% on the buildings (Figure 3). The simulation results also provided 3D positions of the sources and the ratios of the trajectories simulated from them that are reaching infrastructures mostly dominated in two areas (the middle and the eastern zone of the study area), as shown in Figure 4.

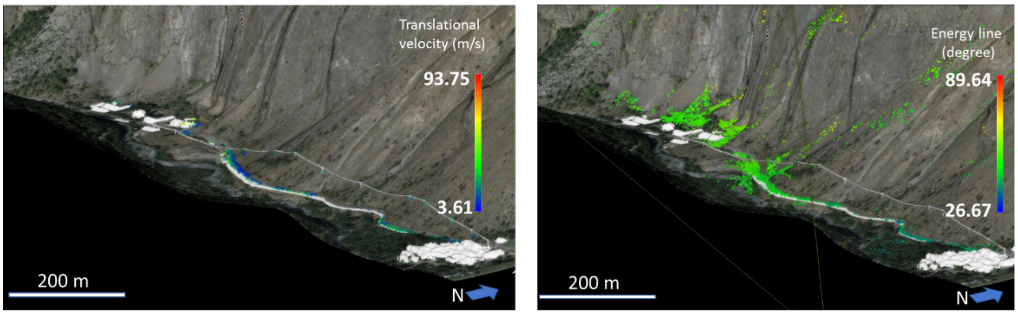

Figure 3. 3D point location of points which reach infrastructures (left) based on rolling friction rebound model simulation with the value of velocity (left) and energy line (right).

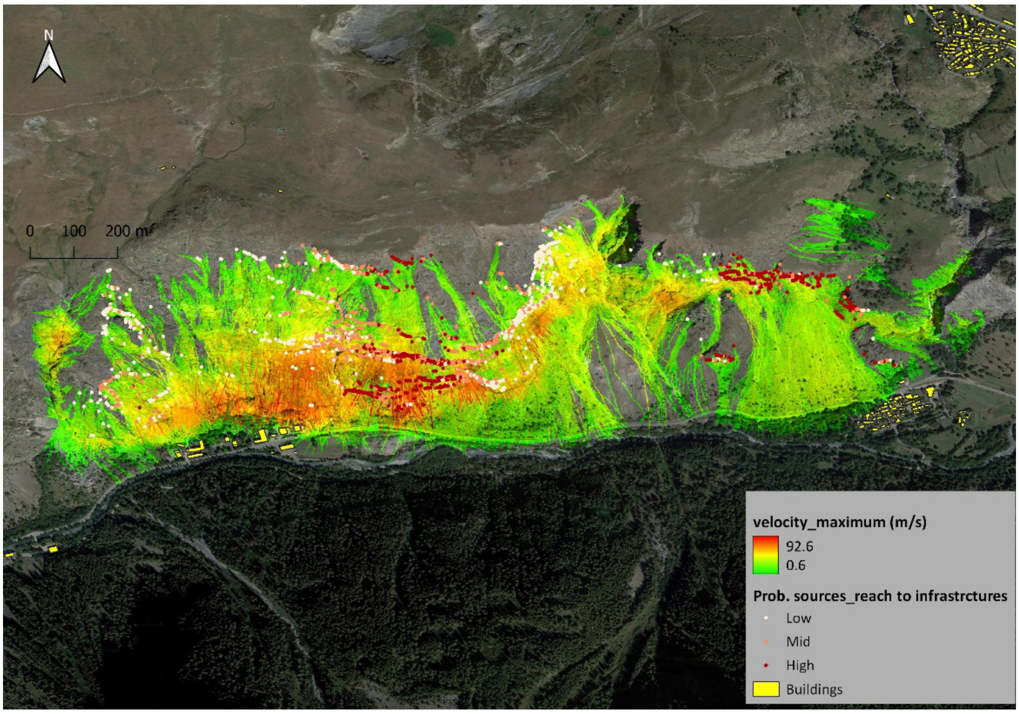

Figure 4. Trajectography simulation of each rockfall with velocity maximum and ratio probability source reach to the infrastructures.

4 CONCLUSION

Therefore, the combined method of determining the source of rockfall using a combination of SAD analysis and overhang slope from the point cloud can provide convincing simulation results to determine the potential rockfall that can hit infrastructure and identify which area can be prioritised area for treatment in the future. The results must now be verified and calibrated with the existing inventory and the observed impacts on the road.

ACKNOWLEDGEMENTS

Thank you to Département des Hautes-Alpes, Gap, Provence-Alpes-Côte d'Azur, France, for providing historical data. Also, the Indonesia Endowment Fund for Education (LPDP) with grant number 201905220214428. Furthermore, all teams help with the manuscript.

REFERENCES

Beach, A. 1981. Thrust structures in the eastern Dauphinois Zone (French Alps), north of the Pelvoux Massif. *Journal of Structural Geology*, *3*(3), pp. 299–308. DOI: 10.1016/0191-8141(81)90026-2

Bonnet, G., Chopin, C., Locatelli, M., Kylander-Clark, A. R. C., & Hacker, B. R. 2022. Protracted Subduction of the European Hyperextended Margin Revealed by Rutile U-Pb Geochronology Across the Dora-Maira Massif (Western Alps). *Tectonics*, *41*(4), pp. 1–31. DOI: 10.1029/2021TC007170

BRGM. 2005. *Cartes géologiques vectorisées et harmonisées à 1/50 000*. BRGM. https://www.geocatalogue.fr/Detail.do?fileIdentifier=94636790-8615-11dc-9e02-0050568151b7

Gidon, M. 2001. Les massifs cristallins externes des Alpes occidentales françaises sont-ils charriés ? *Géologie Alpine*, *77*, pp. 23–38. http://geologie-alpine.ujf-grenoble.fr/articles/GA_2001__77__23_0.pdf

Gidon, M. 2020. *En Paris - plateau et revers oriental*. http://www.geol-alp.com/h_oisans/_lieux/romanche/enparisE.html

Jaboyedoff, M., & Labiouse, V. 2011. Technical Note: Preliminary estimation of rockfall runout zones. *Natural Hazards and Earth System Sciences*, *11*(3), pp. 819–828. DOI: 10.5194/nhess-11-819-2011

Loye, A., Jaboyedoff, M., & Pedrazzini, A. 2009. Identification of potential rockfall source areas at a regional scale using a DEM-based geomorphometric analysis. *Natural Hazards and Earth System Sciences*, *9*(5), pp. 1643–1653. DOI: 10.5194/nhess-9-1643-2009

Mercier, A., Leloup, P. H., Courrioux, G., Caritg, S., Lopez, S., Grandjean, P., Passot, S., & Kalifi, A. 2023. Large thrusting and late faulting shape the Aiguilles Rouges crystalline massif (Western Alps), structural implications. *Tectonophysics*, *847*(December 2022), pp. 229691. DOI: 10.1016/j.tecto.2022.229691

Noël, F., Cloutier, C., Jaboyedoff, M., & Locat, J. 2021. Impact-Detection Algorithm That Uses Point Clouds as Topographic Inputs for 3D Rockfall Simulations. *Geosciences*, *11*(5), pp. 188. DOI: 10.3390/geosciences11050188

Ramsay, J. G. 1963. Stratigraphy, structure and metamorphism in the western Alps. *Proceedings of the Geologists' Association*, *74*(3), pp. 357–391. DOI: 10.1016/S0016-7878(63)80028-0

Strahler, A. N. 1950. Equilibrium theory of erosional slopes approached by frequency distribution analysis; Part II. *American Journal of Science*, *248*(11), pp. 800–814. DOI: 10.2475/AJS.248.11.800

Varnes, D. 1978. Slope movement types and processes. *TRB*, *176*, pp. 11–33.

Volkwein, A., Schellenberg, K., Labiouse, V., Agliardi, F., Berger, F., Bourrier, F., Dorren, L. K. A., Gerber, W., & Jaboyedoff, M. 2011. Rockfall characterisation and structural protection - A review. *Natural Hazards and Earth System Science*, *11*(9), pp. 2617–2651. DOI: 10.5194/nhess-11-2617-2011