 https://doi.org/10.31705/BPRM.v4(1).2024.18

Ensuring Quarry Safety: Integrating Rockfall Barriers and Bench-Slope Engineering for Effective Protection

A single rock piece or several rock boulders getting detached and displaced from their initial position followed by free falling, sliding, bouncing, rolling, and deposition creates a rockfall incident [1]. Rockfalls are characterized by a greater destructive potential, owing to higher mobility and energy [2]. Recent instances including the Great Orme rockfall, in North Wales, UK (2023), Yosemite National Park rockfall in California, USA (2022), and the Glacier National Park incident in Montana, USA (2019) highlight their catastrophic nature. They not only interrupt the daily essentialities such as travel and transportation but also cause property damage as well as loss of life [3], [4], [5] (Figure 1). A rockfall is triggered by a natural or an anthropogenic alteration of the forces acting on a rock mass under stable conditions. Natural processes include weathering, earthquakes, formation of discontinuities, plant roots penetrating the rocks, rainfall, freeze-thaw cycles, and long-term deformations in the rock mass. Also, there is a significant contribution of human interventions such as slope cutting, blasting, heavy vehicle, and machinery operations to rock movements [1], [2]. Due to the prevalence of such activities, quarries rank top among the sites that are susceptible to frequent rockfall hazards [6], [7].

Given the critical nature of this issue, constant efforts have been made to devise an effective solution, incorporating expertise in geo-technology and engineering. There are two distinct engineering approaches, respectively, to prevent and mitigate rockfall as detailed in Figure 2. Most often, a combination of those two techniques is adopted in many quarry sites to enhance effectiveness [2].

Rockfall barriers as a preventive measure, can be of different forms, such as concrete barriers, steel barriers, earthen barriers, flexible barriers, structural walls, anchored hanging meshes, restraining nets, and attenuators, etc. [2], [8]. They have different energy absorption capacities, with the cost varying accordingly. Therefore, the choice of a suitable barrier depends on both the energy of falling rocks and the economic feasibility, especially with regard to industrial applications such as quarrying. Slope stabilization techniques, such as removing loose rock, rock nailing, and using

Figure 1 : A) Great Orme rockfall, in North Wales, UK (2023), B) Yosemite National Park rockfall in California, USA (2022), and C) Glacier National Park incident in Montana, USA (2019) (Sources: [3], [4], [5])

anchored wire meshes, can also complement the effectiveness of rockfall barriers [9].

Modifications in rock slope design focusing on catch-bench width control are also identified as viable rockfall hazard mitigation strategies for many quarries [8]. An addition of a safety berm to the edge of a catch bench not only improves its retention capacity but also offers additional protection to the mining vehicles, clearing the accumulated rock fragments [10]. Benching is a common practice in quarries to protect the machinery and workers on lower benches from the rockfalls initiated at upper levels. The minimal berm width required for this can be mathematically computed for a known bench

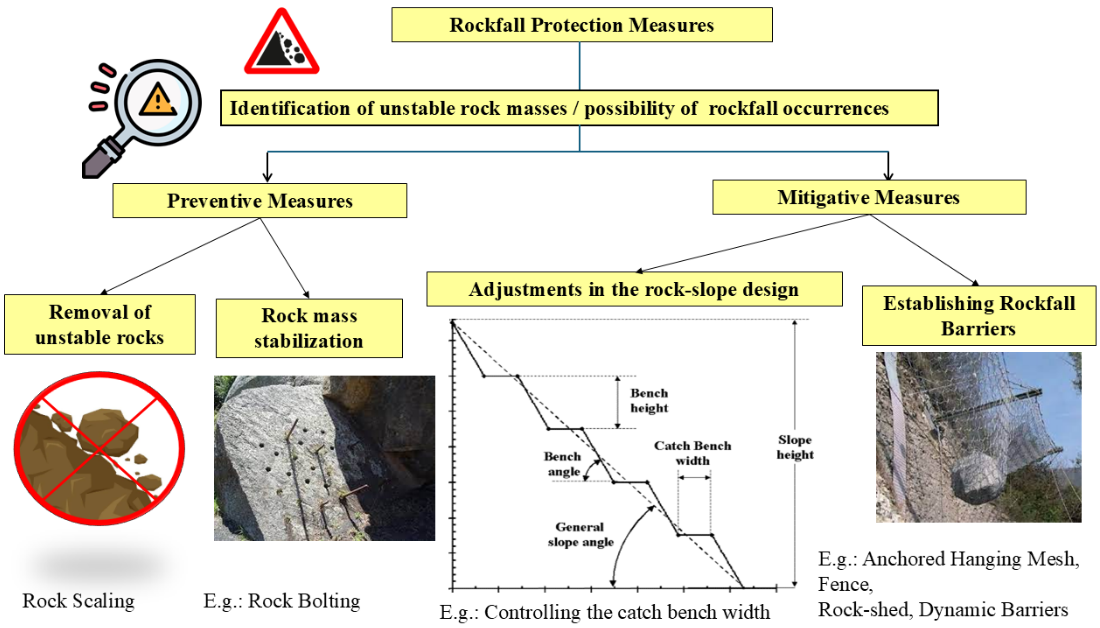

Figure 2 : Rockfall Protection Measures (Sources: [2], [8])

height [9], [11]. Similarly, double benching, which involves increasing the bench height without reducing the berm width, will help to steepen the overall slope angle in quarries and open-pit mining, thereby improving production. In addition, retaining the wide berms ensures unaltered safety levels while preventing blasting damage [9].

A range of parameters needs to be accounted for when developing an effective rockfall protection system. These include the location of potential rock launching points and runout areas, impact zones, slope height, slope angle, vegetation cover, soil and rock types, surface roughness, and other features demarcating the topographic profile. Therefore, a detailed site survey is needed as a preliminary step in formulating a barrier design [2]. Analysis of the rockfall trajectories, together with velocity, kinetic energy, and bounce height of the descending rocks, is pivotal for both structural adjustment in the rock slope and the introduction of a barrier. These parameters can be predicted using software-aided modeling and empirical methods. They become governing factors in determining the variables such as the type, strength, height, and position of the barrier, as well as the catch bench height, width, and angle [8].

An accurate rockfall model should incorporate all four types of motions (free-fall, rolling, bouncing, and sliding) experienced by a falling rock block. The available rockfall models are two-typed: the rigorous model which factors both rock shape and volume, and the lumped-mass model which disregards these parameters, assuming that the entire rock mass is concentrated at its center. Owing to the lack of realistic data on rock shape and volume, the lumped-mass model has gained popularity over the rigorous model. RocFall is a statistical analysis program employing the lumped-mass model to generate 2D rockfall paths and to compute the velocity, rebound energy, and fall-path endpoints, which are the governing factors of safety [8]. At present, state-of-the-art software, for example, RAMMS allows for 3D rockfall modeling in which rock shape and all forms of motion are considered, facilitating the computation of fall paths over 3D terrain [9].

Rockfall events obviously lead to economic losses, if not prevented or mitigated. Nevertheless, the economic and technological feasibility of any rockfall protective measure should be properly assessed, especially when proposing such remedies to developing countries [12]. For any such protective strategy to be economically viable, its cost should not exceed the total value of additional material recovered and savings in operational expenses [9].

Notably, rockfall protective systems developed by integrating barrier installation and bench-slope design modifications can increase the profitability in mining and quarrying industries, while proving to be more effective than the standalone approaches. For instance, berm width can be substantially reduced through the installation of catch fences on berms, retaining the same safety level provided by the wider berms. With this strategic measure, the overall slope angle can be made steeper, yielding higher production, without compromising safety [9].

The prevalent occurrence of rockfall hazards in quarries inflicting considerable damage demands an effective engineering solution. With this regard, the installation of rockfall barriers and adjustments of the bench slope configurations emerge as two distinct viable solutions. Developing a suitable protective system necessitates considering a range of parameters, which can be achieved via software-aided modeling, together with empirical methods. Also, it has been proven that rockfall protection systems created by incorporating both barrier installation and slope design alterations are more economically viable and functionally effective.

References:

[1] A. Binal and M. Ercano⎕lu, “Assessment of rockfall potential in the Kula (Manisa, Turkey) Geopark Region,” Environ Earth Sci, vol. 61, no. 7, pp. 1361–1373, Oct. 2010, doi: 10.1007/s12665-010-0454-1.

[2] A. Polat, I. Keskin, and I. Denizli, “Preventing and analysis of falling rocks: A case of Sarica village (Gürün, Turkey),” J Geol Soc India, vol. 88, no. 6, pp. 763–772, Dec. 2016, doi: 10.1007/s12594-016-0544-0.

[3] F. Karimi and L. James, “Falling rocks kill a teen and injure 4 others at Glacier National Park,” CNN. Accessed: Mar. 03, 2024. [Online]. Available: https://www.cnn.com/2019/08/14/us/glacier-national-park-fatal-rockfall/index.html

[4] A. Forgrave, “Great Orme rockfall 'disrupts' filming of major new ITV drama in Llandudno,” North Wales Live. Accessed: Mar. 03, 2024. [Online]. Available: https://www.dailypost.co.uk/news/north-wales-news/great-orme-rockfall-disrupts-filming-27349292

[5] CBS News, “Update: San Jose couple killed by falling rocks in Yosemite National Park - CBS San Francisco,” CBS News. Accessed: Mar. 03, 2024. [Online]. Available: https://www.cbsnews.com/sanfrancisco/news/two-killed-tuesday-falling-rock-yosemite/

[6] A. Pedrazzini, T. Oppikofer, M. Jaboyedoff, M. Güell i Pons, R. Chantry, and E. Stampfli, Assessment of rockslide and rockfall problems in an active quarry: case study of the Arvel quarry (Western Switzerland). 2010, p. 596.

[7] D. Peila, M. Patrucco, and M. Falanesca, “Quantification and Management of Rockfall Risk in Opencast Quarrying Activities,” Environmental and Engineering Geoscience, vol. 17, no. 1, pp. 39–51, Feb. 2011, doi: 10.2113/gseegeosci.17.1.39.

[8] L. R. Alejano, B. Pons, F. G. Bastante, E. Alonso, and H. W. Stockhausen, “Slope geometry design as a means for controlling rockfalls in quarries,” International Journal of Rock Mechanics and Mining Sciences, vol. 44, no. 6, pp. 903–921, Sep. 2007, doi: 10.1016/j.ijrmms.2007.02.001.

[9] R. Luis and H. Salzmann, “Rockfall mitigation measures in open pit mines. Case study quarry wall stabilisation and protection works at Mandai,” 2018.

[10] D. R. Wijesinghe and G. You, “Optimization of the catch bench design using a genetic algorithm,” International Journal of Mining Science and Technology, vol. 26, no. 6, pp. 1011–1016, Nov. 2016, doi: 10.1016/j.ijmst.2016.09.008.

[11] A. M. Ritchie, “Evaluation of Rockfall and Its Control,” Washington State Highway Commission, Highway Research Record, United States, vol. 17, pp. 13–28, 1963.

[12] A. Volkwein et al., “Rockfall characterisation and structural protection – a review,” Nat. Hazards Earth Syst. Sci., vol. 11, no. 9, pp. 2617–2651, Sep. 2011, doi: 10.5194/nhess-11-2617-2011.

Article by

Chamila Nanayakkara, Anjula Dassanayake, Patabendige Chaminda

Department of Earth Resources Engineering, Faculty of Engineering, University of Moratuwa, Sri Lanka