Determination of Terrain-Specific Restitution Coefficients and Rockfall Hazard Assessment in Urbanized Mountainous Areas of Nepal

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Abstract: The primary aims of this study were to determine the restitution coefficient of the material and to simulate rockfall at the steep slope in Chaku Bazar. Initially, the normal and tangential restitution coefficients were calculated for 10 different rock boulders, varying in shape and composition using the Tracker Video analysis. The computed values for normal and tangential restitution coefficients were then used to simulate rockfall behavior using GeoRock 2D across four different sections, predicting rockfall trajectories and run-out distances. The normal restitution coefficient for vegetated rocky terrain was 0.34, while for solid rock it was 0.73. Likewise, the tangential restitution coefficient was 0.51 for grass-covered areas and 0.82 for rocky surfaces. After determining the restitution coefficients, the calculations revealed a maximum collision energy of 15000 kJ and a maximum bounce height of 30 meters at the bazar area.

Keywords: ***GeoRock 2D, Rockfall, Restitution Coefficient***

Introduction

Rockfall is the natural downward movement of one or more detached blocks with small volumes, characterized by free fall, bouncing, rolling, and sliding (Varnes, 1978) which pose threat to the environment and resulting in loss of life and property (Bunce et al. 1997). These rock blocks can be dislodged through various processes, including natural mechanisms such as freeze-thaw cycles (McCarroll and Pawellek, 1998), seismic events (Abebe et al., 2010), or by human activities such as slope excavation or earth-moving operations (Dorren, 2003).

The impact of the rockfall depends upon the estimation of trajectories, bouncing heights and the kinetic energies of the unstable blocks. These elements are frequently derived through the application of kinematic modeling techniques created using numerical codes like CRSP or RocFall (Pfeiffer and Bowen 1989). The key input parameters influencing the estimated rockfall hazard in computer simulations are the coefficients of restitution. These parameters measure the energy loss that occurs when a block impacts the slope (Sabatakakis et al. 2015). The coefficients of restitution are divided into tangential (Rt) and normal (Rn) components relative to the slope. Two primary methods are used to determine these parameters: direct measurement through experimental tests, both in situ and in the laboratory, and back-analysis of natural or artificially triggered rockfalls (Evans and Hungr 1993). The research focus of the determination of restitution coefficient of the slope material and Rockfall Simulation at Chaku Bazar.

Materials and Methods

This study experimentally evaluates the coefficient of restitution for boulders colliding with rock slopes under different impact conditions, followed by the calculation of their kinetic energy and re-bounce height at four distinct sections of the terrain. The method applied for the study is describe as,

Newton (1686) originally defined the coefficient of restitution (R_C) as the ratio of the rebound velocity to the incident velocity of two colliding particles (or small spheres) along the normal direction. The kinematic definition of the coefficient of restitution, has been generalized and extended to three dimensional collisions by Brach (1991, 1997).

$$R_C = \frac{V_{1n} - V_{2n}}{U_{1n} - U_{2n}}$$

where, V_{1n} & V_{2n} = normal components of rebound velocities, and U_{1n} &U_{2n} = normal component of initial velocities of two colliding bodies. Both normal and tangential component of the restitution coefficient has significant role on the velocities and trajectories of the falling block.

Rockfall simulation

The rockfall simulation in this study was conducted using the CRSP method in GeoRock 2D Software, a widely used tool for rockfall problems. Key input parameters included the restitution coefficient of slope material, slope geometry, and boulder data. The restitution coefficient was derived from field tests and tracker analysis, while the slope geometry was based on contour data defining the cross-sectional profile of the slope. Boulder data, including shape and size, was determined through field measurements and Zingg classification of 100 boulders. The analysis also considered block stability using major discontinuities. The CRSP method applies a rigid body approach, analyzing rock interactions with the slope during contact phases, including slipping and reversal behavior. The terminal impulse calculated from these phases is used to determine outgoing velocities, helping identify critical rockfall events and associated risks.

Result

The in-situ field test where the rockfalls are examined by filming the nature of boulders and evaluates the normal and the tangential coefficient of restitution from different rock samples using video analysis and modelling tool, called Tracker (Figure 1). The values of normal and the tangential coefficient of restitution have been determined for 10 different rock boulders varying on shape and lithology. The tangential coefficient of restitution for the bedrock varies from 0.77 to 0.87 which is in the range of standard values in dolomitic terrain. Similarly, the average normal coefficient for bed rock is 0.73. the average normal and tangential coefficient of restitution for bedrock with vegetation is 0.25 and 0.37 respectively (Table 1).

Table 1, The determined restitution coefficient for rock fall simulations.

Description	Rn	Rt	Roughness
Bed Rock	0.73	0.82	0.5
Bedrock With Vegetation	0.34	0.51	0.5

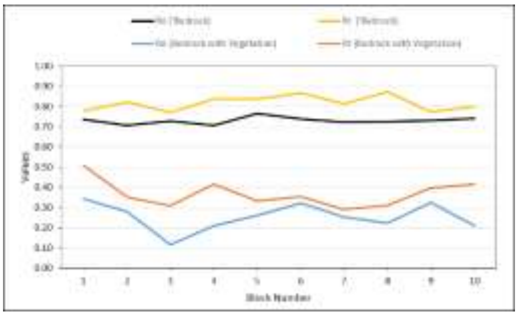

Figure 1, Determined restitution coefficient of the slope material.

The field measurement and discontinuities plot show that the size of the boulder is 2.4 m on average. The Zingg classification of the boulder data shows that the shape of the boulder is Disc Shape. The factor of safety for each block formed by the intersection of discontinuities has found 1.35 for toppling failure, 0.95 for wedge failure and 0.83 for the plane failure. The result shows that there is possibility of the rock slope failure. On varying the shape and size of the block the factor of safety has increased.

The rockfall simulation result shows that the rockfall hazard can be of maximum energy 15000 kJ to the settlement area of Chaku Bazar and Araniko Highway (Table 2). Similarly, the maximum run-out distance will be 160 m. The rebounce height will be 30 as the terrain has very steep which has more than 80°.

Table 2, Section wise rockfall simulation result.

Section	Energy (kJ)	Max. Height (m)	Run out (m)
Section 1	14000	24	140
Section 2	15000	25	160
Section 3	7000	30	160
Section 4	6900	30	160

Conclusion

In this research, rockfall hazard assessment was carried out using field tests and simulations, leading to recommendations for significant stabilization measures. Kinematic analysis indicated a high likelihood of planar failure occurring at rock slope of Chaku Bazar in which factor of safety is less than 1, with notable chances of wedge and toppling failure. The analysis implies that the rock fall is significantly dependent on restitution coefficient and this value should be site specific. The findings highlight the elevated risk, particularly at the toe of the slope, where the highway road is the primary element exposed to danger.

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