EVALUATION OF ROCK FALL ANALYSIS AND SUITABLE PROTECTION MEASURES IN SIDDHABABA SECTION ALONG SIDDHARTHA HIGHWAY

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Abstract**—Rock falls are major hazard in mountain areas that causes tremendous damage to life and property especially along highways. The Siddhababa section of Siddhartha Highway is one of the highly rock fall prone area among many of the highway sections in Nepal. Due to rock fall a significant number of accidents have occurred along Siddhartha highway. Highly steep slope geometry, discontinuities in bedding, weathering effects is the main causes of rock fall. It is essential to study the area vulnerable to rock fall and to propose mitigation measures. This paper describes about the analysis of rock fall using Geo rock 2D, a computer simulation program based on CRSP (Colorado rock fall simulation programme) model. Rock fall simulation was performed in six selected profiles by varying different shape and size of the rock boulders. Rock fall barrier was used as mitigation measure. Probabilistic analysis was used to analyze the suitable location for the positioning of a rock fall barrier. Barriers in 7m height with capacities ranging from 2000 KJ to 3000 KJ are suggested as protective measures.**

Keywords—Rock fall, Geo rock2D, Rock fall barrier

I. INTRODUCTION

Rock falls are the most common phenomenon on steep natural or cut slopes in mountainous countries like Nepal. It involves downward and outward movement of rocks by means of some combination of sliding, rolling, bouncing or free fall under the action of gravity (1).The Siddhartha highway in Siddhababa area is one of the highly rock fall prone area. In past few years, many people lost their life in this area due to rock fall during travelling. Rock fall not only blockaded the highway repeatedly in the past but also resulted in several deaths and injuries to many people. This research in intended to carry out rock fall simulation using Geo rock 2D by varying shape and size of rock boulders and to locate the suitable position of rock fall barrier as mitigation measures.

A. Study Area

The Study area lies in Palpa district of Province No 5, Nepal, near the Butwal city. The study area lies along the Siddhartha Highway. About 2.3 km stretch of the road Chidiyakhola- Dhovan road section is taken as study area. Geographically, the section is located between 83°46’90”E to 83°46’57”E longitude and 27°72’19” N to 27°73’67” N latitude.

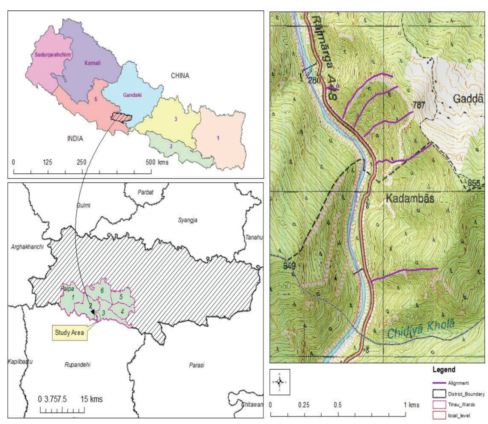

Fig. 1. Location map of the study area

B. Rock fall Problem

Due to the existence of sufficiently fissured rock mass, steep slopes angle ranges from 70 degree to 88 degree, discontinuities, physical and chemical weathering of rocks, produces the unstable rock blocks. Presence of alternative bedding of soft mudstone and hard sandstone is also a major problem as mudstone quickly and easily erodes by gully or rain fall due to which overlaid sandstone looses support causing large block fall into highway. Pore water pressure, heavy rainfall vibration due to traffic and earthquakes are also important triggering factors causing rock fall.

Fig. 2. Alternative bedding of sand stone and mudstone

C. Factors affectiong the rock fall

Once rock fall has been initiated, its behavior is influenced chiefly by the slope geometry, material and surface cover and the rock geometry and material properties. (2)

Some of the influencing factors to rock fall are as follow:

- Slope geometry: height, inclination, surface roughness, lateral variability, bench configuration.
- Slope material properties: slope, coefficient of restitutions, Normal (Rn) and Tangential (Rt)
- Rock geometry: size and shape
- Rock material properties: durability, mass, type
- Seismic effects
- Others factors: vegetation, talus buildups, catchment geometry.

D. Rockfall Simulation

Rock fall simulation are done using computer modeling programs. Rock fall modeling aims to define, for a specified “design block”, the fall path, the maximum run out distance, the envelope of trajectories and the velocity and energy distribution along them (3). The rock fall modeling programs can be categorized in two different methods to model the rock fall; lumped mass or rigid body. According to (4):

Lumped mass: This method considers the falling block as a point, dimensionless, with a predefined mass. This method only considers the normal and tangential velocities, not rotational.

Rigid body: This method defines the shape, dimensions and considers all motions.

GeoRock is software made by geostru for the 2D simulation of rockfalls using Lumped Mass model and rigid body based CRSP (Colorado Rock fall simulation) model.

CRSP(Colorado Rock fall Simulation Program) is developed by Pfeiffer and Bowen in 1989 with the purpose of modeling the falling motion of boulders having the shape of spheres, cylinders or disc. Geo rock 2D is the software developed by GeoStru for determining the trajectories of a boulder in free fall from a rock slope. Due to the large variation in site condition, geometry, initial condition, material on the slope, location, mass, size and shape of rock that fall the accurate prediction of rock fall is practically impossible. Using Geo rock 2D the analysis of rock fall simulations has proven to be an effective and acceptable method for dealing with these difficulties.

Geo rock 2D gives information about the energy, velocity, height of the parabola at any point of a rock fall trajectory of the rock boulder.

E. Review related to the study area

Siddhababa section of Siddhartha Highway is hazardous and needs structural countermeasures and Structural countermeasure as rock fall barriers, rock netting and rockshed, and assisted with rock bolting were proposed based on simulation studies and analysis of the rock fall scenario in RocscienceRocfall® program. (5)

Research entitled “Hazard Rating and Event Tree Analysis for Assessing Rockfall Risks along Siddhartha Highway in Siddhababa Area, Nepal”. Was carried out and classified the different section of the highway based on the final scores of the Rock fall Hazard Rating System. Event tree analysis was used to assess the risk reduction obtained from various preventive measures to be used. (6)

II. METHODOLOGY

A. Desk Study

The objective of the desk study is to develop the preliminary concept of the study area about the nature of the slope, settlement, stream and catchment boundaries. The available literature collected for the studies were used together with the geological and topographic maps of available scale. A large number of the published reports, journals and papers regarding the rock fall analysis were studied and reviewed well.

B. Data Collection/Field Visit/Surveys

Field work was carried out to collect the primary data related to the rock fall. The following procedures were carried out.

- Field Study: Possible rock fall sites were identified by questionnaire with locals, literature review and reconnaissance survey.
- Data collection of attitude of joints for Kinematic analysis
- Total Station Survey of selected sites to define topographic profile of the rock slope.
- Measurement of shape and size of rock fall boulders in the highly rock fall area

Fig.3. Measurement of size of boulders

C. Kinematic Analysis

Kinematic analysis is a method used to analyze the potential for the rock slope failures (plane, wedge, toppling failures), that occur due to the presence of unfavorably oriented discontinuities.
Using stereographic projection technique kinematic analysis was performed DIPS6 developed by Roc science. Joint sets and their corresponding mean orientations were identified. On a stereo net, the possibility of planar sliding, wedge sliding and toppling was evaluated, based on kinematic and friction angle considerations. Preliminary kinematic analysis allowed selecting potential failure plane orientations.

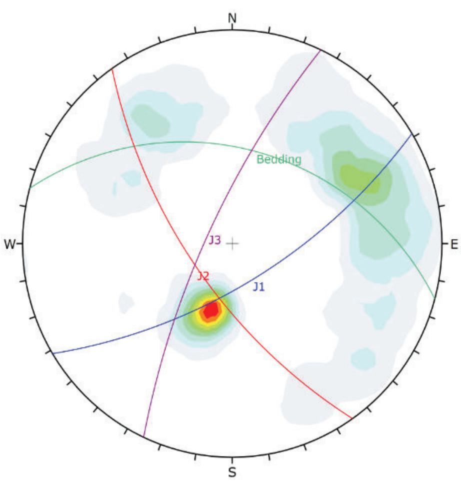

Fig.4. Stereographic Projection for major discontinuities

D. Rock fall Simulation

A. Preparation of Topographic Profile

First of all, topographic profile of the slope should be defined. The profiles were selected according to following factors:
i. The site with high hazard zone (from previous work)
ii. The site with maximum rock fall event observed during field.
iii. The places with most rock fall event in the past (from Historical data).
Total station survey was carried out in six different rock fall slopes profiles to record horizontal directions, vertical directions to define a slope contour for rock fall simulation. Six profiles were generated and used in rock fall simulation

B. Preparation of Boulder data

The boulders measured in the field were analyzed as the program enables spherical, cylindrical or disc shape for boulder.
During rock fall simulation shape and size of boulders were taken as parametric variation. Seven boulders different sizes and different shapes (cylinder, disc, sphere) were used for each slope profiles during rock fall simulation.

Table 1: Boulder Size used in rock fall simulation

S. n	Volume (m^3)	Mass (kg)
1	0.1	230
2	0.2	460
3	0.4	920
4	0.6	1380
5	0.8	1840
6	1	2300
7	1.3	2990

C. Computation Method

CRSP (Colorado rock fall simulation programme) model was used as during simulation as it takes into account the shape and size of the boulder, boulders having the shape of spheres, cylinders or discs.
The simulation was carried out with GeoRock2D which is a software made by GeoStru for the 2D simulation of rock falls using the C.R.S.P. model. Hence from the rock fall simulation, it is possible to

prepare the following different types of graphs which help in the further interpretation and the analysis.

- Energy histogram
- Energy distribution
- Trajectory height
- Velocity charts

2D Rock fall simulation was conducted assuming hundred numbers of trajectories of a boulder. The profile consists of two lithological units: exposed sandstone and mudstone. Total six profiles were drawn and numerical simulations were done for each profile to analyze the change in the maximum velocity at which the block falls, the maximum run-out distance it covers measured along the horizontal direction the maximum height it gains, during each fall and the maximum pre-impact energy it gains.

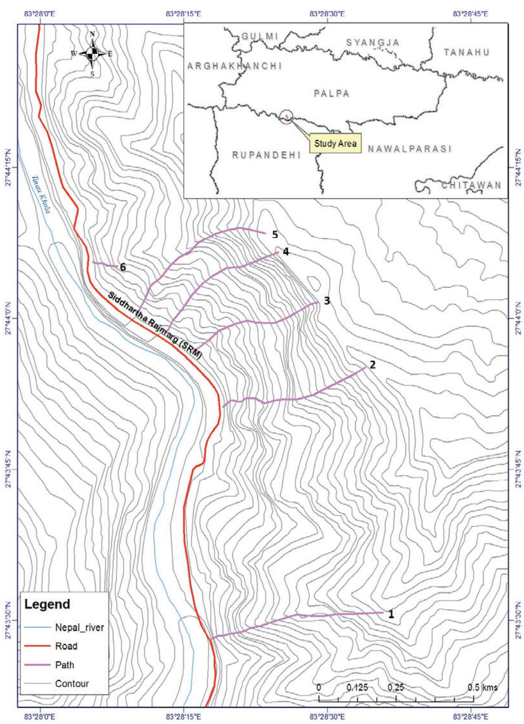

Fig. 5. Showing six selected profiles used in rock fall simulation

Fig. 6. Showing first profile in location prepared in geo rock 2D

D. Data Analysis and Interpretation

All the data and information obtained during desk study, fieldwork and computer works were then refined and analyzed. The graphical representations of the results were analyzed. The kinematic analyses of joints were carried out using DIPS 6.0 software. The rock fall simulation was done using the Software GeoRock2D. Finally all the resultant data were analyzed.

III. RESULTS AND DISCUSSION

A. Kinematic Analysis

Discontinuity measurements were collected in the field and plotted stereographic projection using Dips 6.0 .The stereo plot of discontinuities from the rock fall had shown three major discontinuities including the bedding plane. During kinematic analysis we were able to identify the probability of wedge sliding 30.65%, 15% of planar sliding and 10.94% of direct toppling. All types of failures were observed in the field in which wedge failure is more prominent.

B. Rock fall Simulation

Rock fall simulation was done in Geo rock 2D using CRSP model for six different profiles. Chidiyakhola - Dobhan section of Siddhartha Highway was selected to simulate rock fall for providing mitigation measures. The site was highly affected by rock fall as the road is damaged by the falling rocks making huge economic as well as human life losses. Here at first, rock fall simulation was done for all six profiles without barrier system. From this simulation the section with low energy and bouncing height was Determined and simulation was repeated with required barrier system locating on the section to mitigate the rock fall hazard on the impact zone. During the simulation shape and size of boulders were used as parametric variation.

Fig. 7. Showing Rock fall simulation on first profile without barrier system

After the rock fall simulation in each profile by varying shape and size of the boulders various data (velocity, run out distance and pre impact energy) were collected respectively. Graphs were plotted between different volumes of the boulders each having different shapes and the outcomes from rock fall simulation.

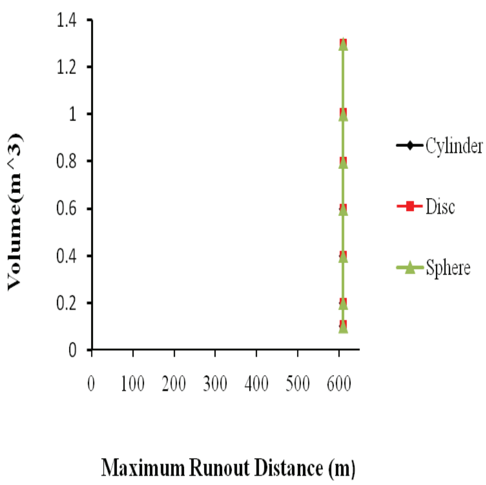

Fig. 8. Maximum Run out distance travelled by boulders on first profile

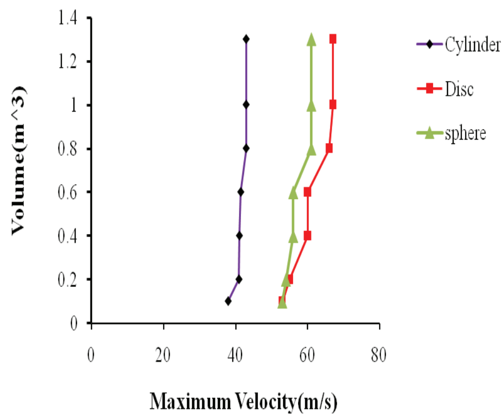

Fig.9. Maximum velocity travelled by boulders on first profile

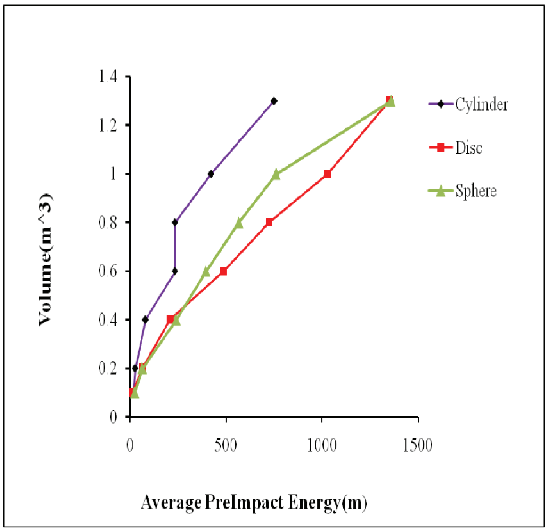

Fig.10. Average Pre Impact Energy gained by boulders on first profile

(Fig 8) shows that the distance travelled by all the boulders is same, irrespective of shape and size of the boulders.

The maximum velocity and the volume of the curve (Fig 9) show that the velocity gained by the disc shape boulders is greater than the maximum velocity gained by the spheres and cylinder. Up to $0.8m^3$ maximum velocities slightly increase for disc and spheres and after that volume remain constant but for cylinders as the volume increases maximum velocity of the boulders remains almost constant.

(Fig 10) show that maximum Pre-impact energy and gained by the boulders is minimum for cylinders and maximum for disc.

The study of the effects of rock sizes and shapes enables engineers to predict the possible trajectories of the rock. Thus, a safe zone can be designed accordingly with respect to the sizes and shapes of rocks on the cliff. This safe zone can avoid unnecessary fatalities and damage. (7)

IV. Barrier Input

For suitable mitigation measures systems, TRUMER Schutzbauten Rock protection flexible barrier systems are used which are tested in accordance with ETAG27. (8) TRUMER offers a wide range of tested systems that differ in the maximum energy level and approved heights. Fixed rotations systems, as well as systems with retaining ropes were available. Observing the energy distribution, bouncing height and velocity of the entire trajectory barriers were proposed as per site topography conditions. The choice to provide effective mitigation measures is flexible barrier net at the required location provided by simulation.

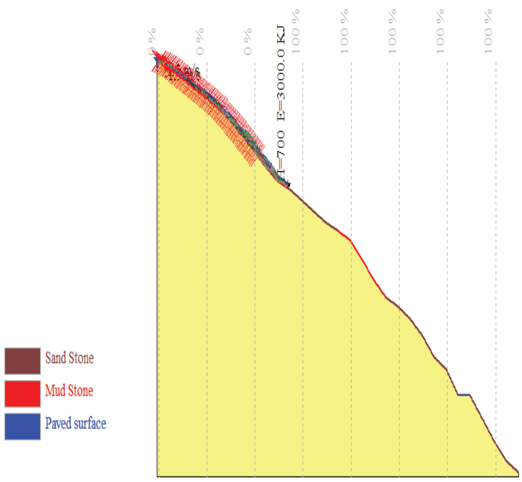

Fig.11**.** Showing the rock fall simulation on first profile with a barrier system

Observing the energy distribution, and bouncing height and velocity of all the trajectory and the site topography, a barrier of 3000KJ energy of height 7m inclined at an angle of 60° is proposed for first profile. Similarly Barriers were suggested in each profile after simulation, and Rock fall barriers were effective to stop 100 % of boulders.

V. Conclusion

This study was intended to simulate rock fall on the highway section between chidiya khola and dhovan which is found to be a critical site for rock fall hazard and to provide mitigation measures.

Computer simulation was carried out in six different profiles using geo rock 2D software; shape and size are used as parametric variation. The output of the rock fall is bounce height, total kinetic energy, velocity used to evaluate mitigation measure for rock fall. From rock fall analysis of 100 different rock fall trajectories, it is found that rock fall property vary with the profile of the slope and size and shape of the boulder. The area within the risk of rock fall and requires rock fall protection measure is provided by flexible barriers in the simulation.

The flexible barrier is placed at slope where the kinetic energy and bouncing height of each trajectories are minimum is able to stop the falling rock block.

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