

STABILITY ANALYSIS OF CUT SLOPES ALONG THE BANKS OF RIVER SUTLEJ, LUHRI, HIMACHAL PRADESH, INDIA

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Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here].

Abstract:

The vulnerable cut slopes along the banks of river Sutlej, Luhri, H.P., India were studied for instability. The studied slopes were classified based on RMR and Q System for support design. Stability analysis being an integral part of geotechnical engineering, therefore, finite element analysis was used to know the stress-strain history of the studied slope. Rockfall analysis was later carried on the cut slope based on the result obtained from FEM. Several parameters like bounce height, translational velocity, kinetic energy and falling trajectory were deduced from this analysis. These parameters are essential for designing the support system to stabilize the slopes and minimize the risk of damage to lives and infrastructures.

Keywords: Slope stability; Finite Element Method; Rockfall; Cut slope; Luhri

Introduction

Landslides are an important discipline which need to be focused, particularly in Himalayas being an active seismo-tectonic belt suffering from recurrent slope failures throughout the year. The 2013 episodic loss in infrastructures and human lives in Kedarnath is an example of lack of utilization of sufficient geotechnical or engineering geological investigations in such areas. It has been shown that rainfall and earthquakes acts as the promoters of landslides throughout the world, but a detailed study correlating such catastrophic events lacks in scientific world. Keefer (1984) has collected data from landslides triggered by earthquakes all around the world and presented several correlations [1]. Unfortunately, India lacks such kind of studies on a professional level. Tremendous amount of study has been done in terms of slope failures triggered by heavy precipitation in India. Water has the effect of saturating the geo-material to an extent that it reduces the shear strength of the material, responsible for holding the material in place. Increase in pore water pressure acts in opposite direction of the resisting forces, thereby, decreasing the overall effective stresses acting to stabilize the slopes. But not enough examples can be cited where remediation measure have been suggested for such kind of failures.

Most of the landslides are a result of fragile stress conditions created by anthropogenic activities in the mountainous areas along the cut slopes. Increasing population and shifting of large population towards hilly areas has put tremendous pressure on the local stress equilibrium of a particular area. Therefore, it has become imperative to conduct detailed geological and geotechnical investigation before construction of any civil structure.

Several researchers in the past have used various methods for stability analysis in India [2-8]. While the routine practice suggests that, stills the conventional methods are being used for stability analysis of cut slopes and other rock engineering problems. These method, although good for highly fractured or homogenous rock mass, may not do justice to a rock having any structural control, like unfavorable joint orientation [9-10]. Therefore, in this study, finite element method is used for stability analysis followed by rockfall analysis for the design of support systems and minimizing the risk of damage.

Study Area

The study area is a part of seismo-tectonically active Lower Himalayas which holds within, tremendous amount of energy capable of emanating earthquakes at recurrent interval. Lurhi is located 120Km north of Shimla, towards Rampur (Fig. 1). The main source of drainage in this area is river Sutlej. Along the banks of the river, highly vulnerable cut slopes are exposed which are responsible for periodic slope failure casing loss of infrastructures and disruption of transportation facilities [11- 12]. The problem becomes more critical as the area receives intense rainfall during the monsoonal months, from July to October. The geology of the area is also very complex where in; augen gneisses are the most common occurrences, belonging to Kullu formation along with patches of schist, quartzite and dolomite of Larji formation [13]. Irrespective of geology, there are several tectonic joints which have dissected the rocks and reduced their strength appreciably. The bedding joints are highly persistent in comparison to other joint sets and their spatial orientation with respect to slope face is such that a number of wedges are formed. Joints in gneisses are widely spaced whereas; they are thinly spaced in schist, quartzites and dolomites.



Fig.1 Location and accessibility map of the study area (courtesy: mapsofindia.com.)

Rock Mass Rating (RMR)

Rock Mass Rating (RMR) is a type of geomechanical classification used for the classifying rocks [14]. This classification is broadly used when not much detailed information about the rock mass, its stress and hydrological characteristics are known.

Six different parameters are used for the determination of RMR. These parameters are Uniaxial Compressive strength of rock material (UCS), Rock Quality Designation (RQD), Spacing of discontinuities, Condition of discontinuities, Ground water condition, Orientation of discontinuities. Accordingly, depending upon the calculated value of the RMR, the rock mass is classified. Depending upon the values of RMR, different classes have been assigned (Table 1).

TABLE I. RMR values for different class

Rock Mass Class	<i>Class I</i>	<i>Class II</i>	<i>Class III</i>	<i>Class IV</i>	<i>Class V</i>
RMR value	81-100	61-80	41-60	21- 40	<20

NICHOLSON AND BIENIAWSKI (1990) HAVE GIVEN NONLINEAR DEFORMATION MODULUS BASED ON RMR [15]. HAMIDI ET AL., (2010) HAVE EXPERIMENTED ON THE PERFORMANCE PREDICTION OF HARD ROCK TBM USING RMR SYSTEM [16]. HOEK AND DIEDERICKS (2006) HAVE SUGGESTED A RELATIONSHIP FOR THE ESTIMATION OF MODULUS OF DEFORMATION ON THE BASIS OF CLASSIFICATION SCHEMES SUCH AS RMR [17]. RMR FOR FEW LOCATIONS IN THE STUDY AREA HAVE BEEN SHOWN IN TABLE 2.

TABLE II. Quantification of different parameters used for the estimation of RMR

Location	<i>UCS</i>	<i>RQD</i>	<i>Discontinuity Spacing</i>	<i>Condition of Discontinuity Surface</i>	<i>Groundwater Condition</i>	<i>RMR Basic</i>
L-1	12	17	15	14	12	70
L-2	12	15	15	13	12	67
L-3	7	8	8	11	4	38
L-4	7	13	8	14	7	49

Q System

The Q-system also known as rock tunneling quality was originally developed for classification of rock masses and underground structures [18]. It is an important tool for evaluating the need for support in tunnels, slopes and rock caverns. Barton et al., (1974) proposed three important parameters like relative block size (RQD/J_n), inter-block shear strength, active stresses (J_w/SRF) for the quantification of 'Q' which is calculated as

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

The Q system has wide application in estimation of several tunneling parameters like unsupported span, design of support, p wave velocity etc. Q-system has its best application in jointed rock masses where instability is caused by block falls but the user should be aware of the limitations associated with it [19-20].

Stability Analysis

Stability analysis is a tool to assess the stability of any slope by a term known as factor of safety. A jointed rock mass is full of heterogeneities and therefore, modelling such system requires incorporation of material model which can incorporate non linearity, complex boundary conditions and in-situ stress conditions. Development in the field of rock engineering has made it possible to analyze any complex problem with ease and without any priori assumptions as in the case of conventional methods like limit equilibrium methods (LEM).

Finite Element Method (FEM) is an excellent alternative to traditional limit equilibrium method, involvins method of slices, which are in use for decades and are essentially unchanged. The FEM is a mathematical model which works through discretization technique in which it uses mesh generation process to divide the complex geometry into smaller components of simple elements. The geometry of the discrete elementis defined bynode points and these node points are characterized by finite number of degree of freedom [21].

There are several advantages of FEM over traditional methods which make it reliable for use in rock engineering problems. Firstly, location and shape of slip surface is a not a prerequisite, multiple failure surfaces can be obtained, both stress and strain (kinematics) are satisfied in contrary to LEM and finally it shows the effect of stress redistribution and progressive failure after initiation of failure [22].

FEM was therefore adopted for this analysis. A highly jointed gneissic rock mass of about 50 m height is encountered while moving upstream of Luhri town. The susceptibility of the slope to failure has led to the stability analysis of this area. Material properties were determined in the laboratory from the samples collected during field investigation (Table 3).

TABLE III. Intact material properties obtained from samples in the laboratory

Parameters	<i>Unit</i>	<i>Value</i>
Cohesion	MPa	2
Angle of Internal Friction	o	38
Elastic Modulus	GPa	30
Poisson's Ratio	-	0.21
Unit Weight	MN/m ³	0.026

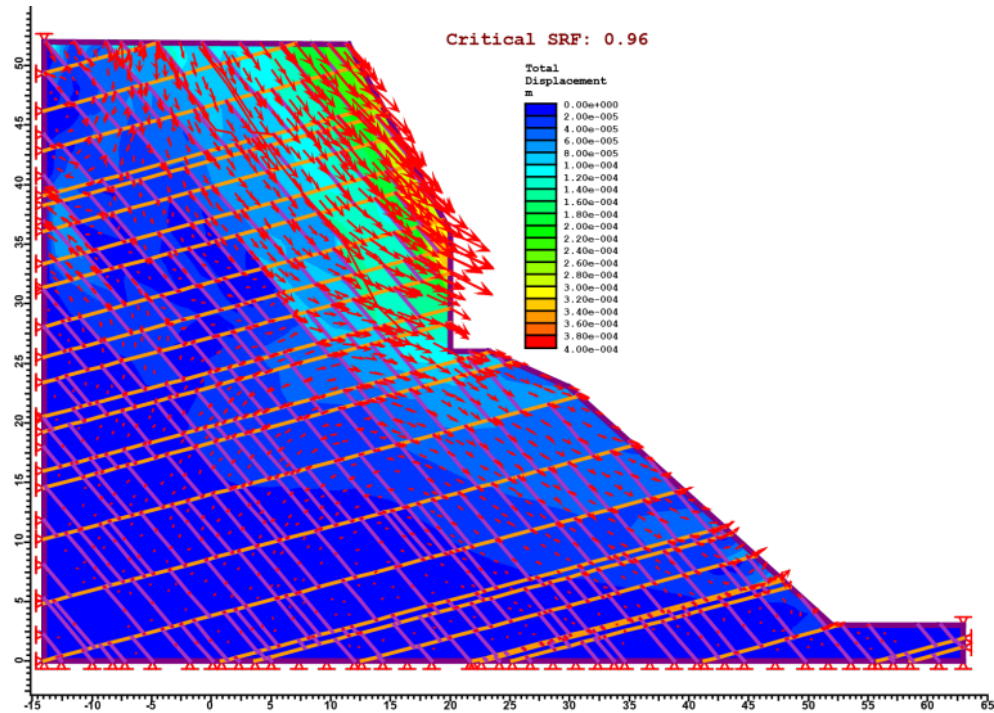


Figure 1 FEM analysis of a cut slope in highly jointed gneissic rock, Luhri, H.P

The result of FEM shows that the entire exposed cut slope is vulnerable to failure. The orientation of bedding joints and daylighting joints are such that several wedges are formed along the slope which act as a major cause of failure. The contours of displacement vectors show distress at around 10m inside the slope while the maximum displacement is observed near the slope face (Fig. 2). The magnitude of displacement is very less to cause a large scale failure and therefore, small blocks get detached from time to time.

Rockfall

Rock fall is considered as one of the most aggressive hazard in high hill regions. In Luhri, Himachal Pradesh, rock fall is very conspicuous along the banks of river Sutlej. The area mainly comprises of weak and weathered metamorphic rocks which occur at a nearly vertical slopes along national highways. The rocks are highly jointed and sheared at places which lead to frequent problems related to toppling and wedge failures (Fig. 3).

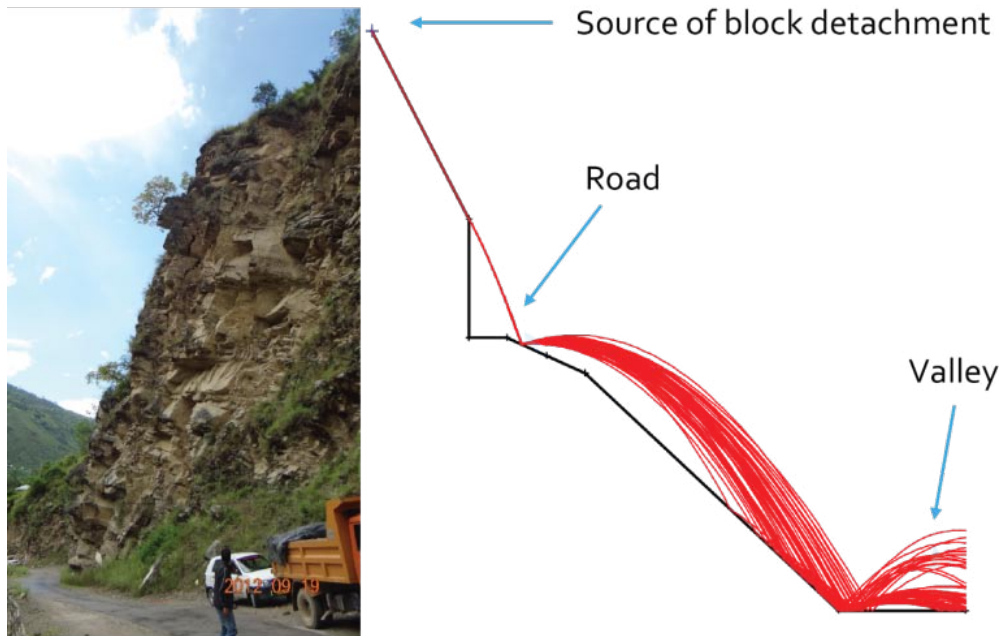


Figure 2 Exposed gneisses as a result of cut slope along the right bank of river Sutlej

Rockfall occur when the unsupported rock mass gets detached from the cliff face and falls down under the influence of gravity [23-25]. According to Chen and Huang (1994), a rockfall is an abrupt movement of independent blocks or complexes of uninterrupted rocks detached from steep slopes [26]. Failure mainly occurs due to the presence of discontinuities within the rock mass. The detachment of the rock mass can be triggered by physical, seismic or other anthropogenic activities [27]. Rockfall motion is mainly dependent on parameters like geometry of the slope, height, slope inclination and surface irregularities and predominantly on the shape of the blocks (Ritchie 1963). For rock blocks with same mass, the rounded blocks travel maximum distance down the slope followed by square blocks [28 & 29].

Results and Discussion

Stability analysis was done by initially characterizing the rock mass in terms of the commonly used classification techniques like RMR and Q system. The result shows that out of the total area of 13km, ~44% falls in fair category, 8% in good and 48% in poor category as per RMR approach while Q system shows that 48% lies in fair category and only 16% falls in poor category, while 31% comes under good category rocks (Fig. 4).

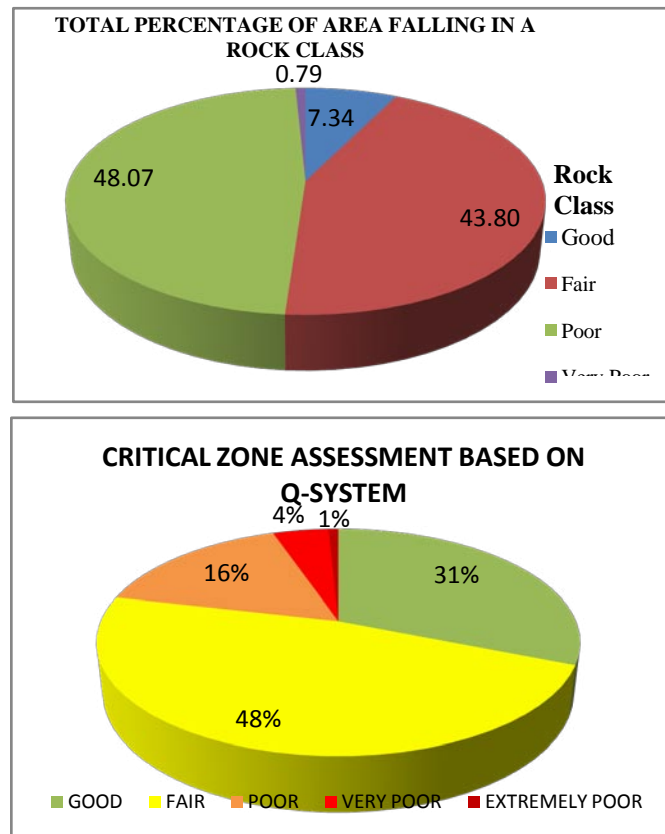


Figure 3 Rock class identification based on RMR and Q system, Luhri, H.P.

This variation is seen due to the application of different parameters and rating scheme employed for the estimation of each parameter used in the respective classifications. It is very difficult to adopt a particular classification for cut slopes and because of wide variation both of these classification may not be the best method for rock slopes.

The results of FEM analysis shows that the safety factor, a value obtained from the ratio of shear strength to available shear stress along the potential sliding plane, is 0.96. This means that slope is a state of in-equilibrium and that failure is highly probable. The affected area according to the analysis is around 10m below the slope face. The failure condition is mainly due to the daylighting joints and bedding joint, acting as release surface.

Rockfall analysis on the other hand shows that the maximum bounce height achieved for this condition reaches up to more than 12m for a 50kg block which keeps

on decreasing as the blocks encounters the slope face (Fig. 5). The behaviour of falling body during the interaction with slope face is governed by the surface geometry and mechanical characteristics of the falling body and slope surface [30].

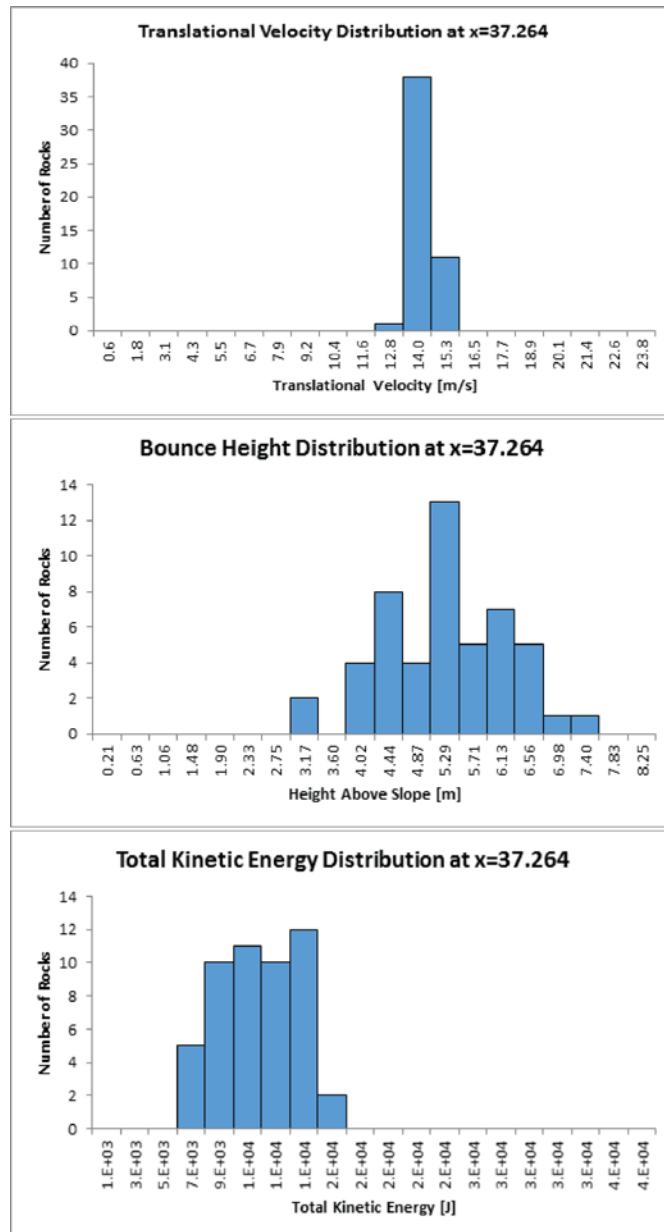


Figure 4 Translational velocity, bounce height and kinetic energy obtained from rockfall analysis

Since the slope face is near vertical after a certain height, motion of the falling body starts from sliding leading to free fall where slope face becomes vertical finally striking the national highway. The translational velocity reaches in excess of maximum of 15m/s which is not very high given the fall height and impact of the falling body itself is very less. The total kinetic energy reaches up to 20kJ which is sufficient to cause damage to infrastructures and claim lives of travelers and local inhabitants.

Conclusion

The vulnerable cut slopes along the banks of river Sutlej were studied in detail for their instability. Initially, a detailed field survey was conducted to gauge the in-situ condition of the rock mass. Widely used classification techniques like RMR and Q system were used in the study for classifying the rock of the study area. Later on, stability analysis was done using FEM. The results show that the cut slope is in state of in-equilibrium and possibility of failure, although of small magnitude, cannot be neglected. Rockfall analysis was done to assess the bounce height, translational velocity and kinetic energy of the falling body. Trajectory of the falling blocks was also deduced from rockfall analysis. The detached blocks after sliding suffers free fall on the roadways directly due to vertical slope and kinetic energy attained by the blocks reach 20kJ for only 50kg block.. All these parameters will be required by engineers to design rockfall catch fences and other support systems for stabilizing the slopes.

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