Landslide and Uplift of River Bed in Tal Valley, Carhwal Himalaya

G.S. MEHROTRA
M.Sc., Ph.D.
Scientist, Central Building Research Institute, Roorkee, India
ARCHANA GUPTA
B.E., M.E.
Research fellow, Central Building Research Institute, Roorkee, India
S. SARKAR
Scientist, M.Sc., M.Tech.
Scientist, Central Building Research Institute, Roorkee, India

SUMMARY In January 1990, a landslide occurred in Tal Valley of Garhwal Himalaya which caused uplift of the river bed by 6-8 m (upto April, 1990). Initially the rate of rise was 2 cm per day which gradually decreased, however, the process is still continued. A detailed geological and geotechnical studies of the area revealed that the slope mass movement was a rotational sliding with slumping triggered by heavy rainfall. The gravitational forces exerting upon highly weathered and sheared material formed a slip surface in the upper part of the slope which is terminating below the river bed. The paper highlights the mechanism of the slide which has been found directly related to the rise of the river bed.

1. INTRODUCTION

Landslides are annual recurring feature experienced in all hill ranges of India and other countries world wide. These are generally the natural events associated with heavy or substantial rainfall, cloud bursts, seismic shocks, river erosion etc.

In January, 1990, a large scale landslide with apparently deceptive movement occurred in the Tal Valley, Garhwal Himalaya, located near Village Bhukundi 15 kms from Chila power house, Hardwar. The most peculiar feature associated with this slide was the uplift (about 8 m) of the river bed (about 250 m long and 30 m wide) in twenty four hours time, after thirty six hours of continuous heavy rainfall. This event had caused enormous fear among the villagers. The slope conditions changed completely with the development of the series of escarpments in the upper part, numerous cracks in the middle portion of the slope and mass destruction of the trees in general on the slope. The river too has changed its course due to the uplift of the bed. In order to ascertain the gravity of the situation, geological, geotechnical & slope stability studies of the slide area were carried out with a view to understand the mechanism of failure and the causative factors of such mysterious movement which got terminated near the river bed due to counter-resistance by the underlying rocks. The paper highlights the findings of the study.

2. DESCRIPTION OF THE SLIDE AREA

The slide area is situated at the left bank of river Tal, 15 kms from Chila Power house, Hardwar. The river is eroding the foot of the hill striking almost in NW-SE direction. The slope area confined between two seasonal drains comprises predominantly of highly weathered rock-mass associated with clayey soil covered mostly by thick vegetation.

At the crown, an escarpment of 20-30 m high and about 300 m long was formed due to the landslide. The escarpment or slip surface is covered with gaugy material and stands at an angle of 50° to 60°. The thin shale bed associated with sandstone in the slip surface has shown the presence of slickenside surfaces at various locations indicating the direction of movement. It was further substantiated by the occurrence of sheared tree roots at the top of the escarpment.

In the middle portion of the slope, the landslide activity has resulted into development of numerous cracks mostly longitudinal or transverse to the slope. The length of the cracks varied from 10 m to 150 m, whereas width varied from few cms to 1 m and depth from 2 to 4 m. Many minor cracks obliquely branching out from the major cracks were also present. During the course of survey, it was observed that the areas lying between the cracks commonly showed several slumped portion clearly indicating subsidence of the slope. Inspite of the fact that the slope was reasonably well vegetated, yet it was marred by tilted and uprooted trees.

3. GEOLOGY OF THE AREA

The main rocks exposed in the slide area are shales and sandstones of Eocene age. Outcrops were found exposed near the slip surface and in the surrounding areas. The shales were generally moderate to highly weathered and fractured in the slide area, associated with exposures of hard and massive sandstones. The rock beds were dipping inside the hill with E-W strike and $20-30^{\circ}$ dip towards south. The sheared rocks with pulverised material indicated the presence of shear zone, the extent of which could not be identified due to lack of continuous exposure of rocks and also due to the thick vegetation on the slope. However, on the basis of some abrupt variation in attitudes of beds the presence of local folding in the area can not be ruled out. Geologically, the area may be considered as weak zone due to the presence of highly fractured and weathered rock mass on the slope.

4. FIELD INVESTIGATIONS AND LANDSLIDE MONITORING

In order to have better understanding of the sliding phenomenon in this region, it was planned to carry out detailed scientific investigations of the area. It involved detailed geological, geomorphological and geotechnical surveying and mapping of the area, monitoring the rise of river bed and displacements in cracks. A contour map alongwith the location of slide boundary and major cracks was prepared (Fig.1).

For the monitoring of the uplift of the river bed, few wooden markers of 90 cm length were installed covering the full stretch of the uplift portion, each going 50 cm below the ground surface. The data of sloping distance, horizontal distance and elevation of these markers were taken using Elec-

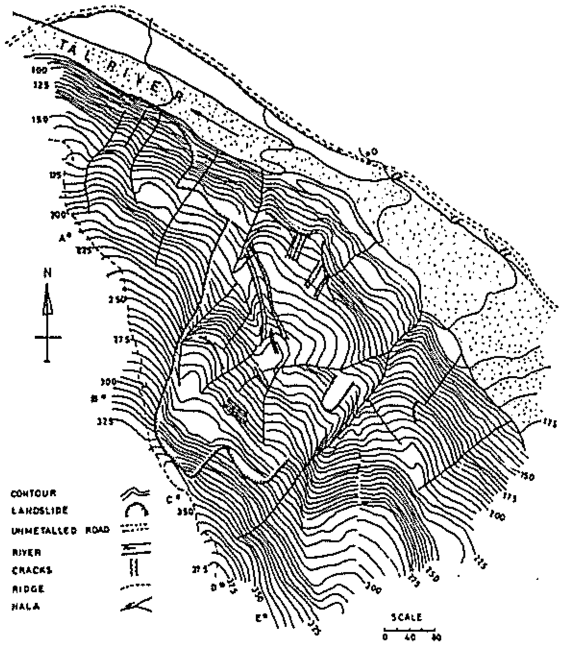

Figure 1 Map of slide area

tronic distance meter, from a fixed bench mark. The observations were taken at different time intervals for assessing the horizontal and vertical displacements. The analysis of the monitoring data clearly exhibits that there was no considerable movement in the horizontal direction, whereas there was significant change in vertical direction. Due to the rise of river bed, most of the markers fixed on the outer profile of the uplift portion got covered with debris and some tilted forward. The angle of tilt varied from 7 to 45 degrees. The rise of different portions of the river bed was found to vary from 0.75 to 2.5 meters in thirty days indicating an average rate of rise of 1.5 cm/day (Fig.2).

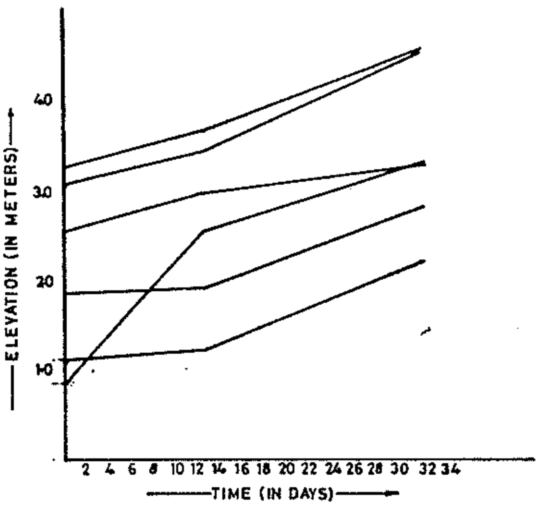

Figure 2 Rise of river bed with time

For the monitoring of movement in cracks, markers (iron bars) were fixed on both the walls of the cracks and the displacements in forward as well as vertical directions were measured from time to time. The analysis of the data obtained for the cracks at different intervals of time have clearly revealed widening of the cracks as well as subsidence of the ground along the cracks. Some of the cracks were found to have widened by 2 cms to 1 m while the subsidence was recorded to vary from 1 to 6 cms. It was observed that there was no relative displacement along the cracks. It is significant to note that during the period of investigations the soil mass close to the slip surface has moved by 20 to 40 cms (in ten days time) indicating the process of subsidence still active in the region.

5. MECHANISM OF THE LANDSLIDE

This is a successive rotational landslide in the weathered rock formation consisting of sandstones interbedded with Shales (Fig.3). Evidence of sliding at the interface of shale and sandstone are prominent & large displacements have been inferred due to presence of slickenside surfaces.

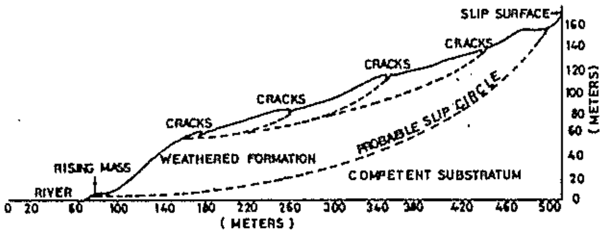

Figure 3 Section showing mechanism of slide

The laboratory testing of the weathered product of the rock formation has shown a low value of cohesion with an average angle of internal friction. The uniaxial compressive strength obtained through point load tests have shown fairly good compressive strength for sandstones, whereas the shales were found to be so soft that even undisturbed sampling was difficult.

It has also been observed that just at the interface of sandstone and shale the particle size of clay material is very fine which indicates that initially because of breakdown of bigger particles proportion of the clay size fraction at the boundary tends to decrease but later on clay fraction records marked increase, as could be expected corresponding to large movements (Mehrotra, 1988). The another important feature is wet conditions of clay surface which indicates high water retaining capacity and obstruction to the water flow causing high pore pressure for sliidng to take place.

6. SLOPE STABILITY ANALYSIS

The main objective of the stability analysis was to evaluate the factor of safety of the hill slope along various sections, compatible with the existing field conditions. The present study area shows the existence of highly weathered and fractured rockmass with soil cover indicating the slip surface to take a circular path. Hence to determine the existing factor of safety, rotational equilibrium analysis has been applied for stability analysis.

A software for circular failure analysis, was developed and run, both for static and dynamic conditions. The program was developed based on Bishop's Simplified Equation (Bishop 1955) with modifications to account for the effects of earthquake forces and pore water pressure. The program also takes into account the effect of tension cracks and water in the tension cracks on the Factory of Safety of the slope. The mathematical equation used is given below :

TABLE I

FACTOR OF SAFETY AT CHILA SLIDE AREA

Seismic Coefficient	0.0, 0.00				0.05, 0.25			
Profile	Pore pressure ratio				Pore pressure ratio			
	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.3
OA	1.209	0.988	0.899	0.776	1.111	0.936	0.823	0.705
OB	1.086	0.912	0.779	0.677	1.002	0.840	0.712	0.612
OC	1.012	0.843	0.715	0.599	1.974	0.775	0.662	0.538
OD	1.004	0.813	0.673	0.547	1.963	0.748	0.612	0.489
OE	1.066	0.863	0.752	0.619	1.992	0.796	0.687	0.558

$$F = \frac{\sum\left[c.b + W(1-\bar{B})\tan(\emptyset)\right]\dfrac{\sec(\alpha)}{1+\tan(\emptyset).\tan(\alpha)/F}}{W + \sum\left[W\sin(\alpha) + \alpha_h W' \cos(\alpha)\right]}$$

where,

- F = Factor of safety of slope
- c = Cohesion of soil
- b = Width of the slice
- W' = Weight of the slice
- W = $(1 + \alpha_v)W'$
- $\bar{B}$ = Pore water pressure/W'
- $\emptyset$ = Angle of internal friction
- α = Angle of the base of slice with horizontal
- α_h = Coefficient of horizontal E.Q. acceleration
- α_v = Coefficient of vertical E.Q. acceleration $=1/2\,\alpha_h$
- VV = Driving moment due to water force/ radius of arc

The input data included the coordinates of the slope profile, depth of hard strata at the toe, cohesion, angle of internal friction, unit weight of soil, unit weight of water, pore pressure ratio and coefficients of horizontal and vertical components of earthquake acceleration.

The analysis was carried out in dry and wet condition with varying amount of pore pressure ratios along five selected sections of the slope. For selection of the sections, change in slope and presence of cracks were taken into cosideration. The depth of hard strata was considered to be 10 metres, as observed from the field investigations. Since the pore water pressure could not be measured in the field, assumed values of pore pressure ratios were considered to evaluate the variation in factor of safety with water saturation. For dynamic analysis of the slope, the values of horizontal and vertical coefficient of earthquake acceleration were taken according to the seismic zones of India (IS:1893-1948). Parameters of soil and seismicity coefficients used in the stability analysis are :

Cohesion of soil	-	250 kN/m^2
Friction angle of soil	-	30^o
Unit weight of the soil	-	17.0 kN/m^3
Unit weight of water	-	10.0 kN/m^3
Pore pressure ratio	-	0.00, 0.1, 0.2 & 0.3
Seismic coefficient :		
Horizontal	-	0.05
Vertical	-	0.025

The existing factor of safety values are tabulated in Table I. The analysis has shown that in dry condition the slope is just stable while with little increment in pore pressure and considering the seismicity, factor of safety for all the sections drop below 1, showing instability.

The existing factor of safety (Table I) along OA, OB & OE ranges from 1.066 to 1.209 without any pore pressure and seismic coefficient and decreased to 0.558 to 0.705 at 0.3 pore pressure & 0.05 seismic coefficient. Whereas along OC and OD, factor of safety ranges from 1.004 to 1.012 without any pore pressure and seismic co-efficient and decreased to 0.489 to 0.538 at 0.3 pore pressure & 0.05 seismic coefficient. Among all the sections, the central portion of the slide area i.e. along OC and OD, has shown the minimum factor of safety indicating unstable zone. This inference is further confirmed by the presence of numerous cracks and signs of subsidence in the central zone.

7. CONCLUSION

The study carried out has established that the uplift of the river bed as well as the development of series of cracks on the slope were caused by the landslide. The manifestation at the crown where slip surface has been developed clearly indicated a shear failure of weathered rockmass. It could be also inferred that the slope movement was initially triggered by gravitational force exerted upon sheared material which have subsequently caused slumping along a slip surface forming an escarpment at the top and terminatig at the toe of the slide.

The evidences produced by the formation of successive layers clearly point towards successive rotational failure of weathered rockmass overlying a hard substrata.

The monitoring data confirming the rise of river bed has led to the conclusion that the area is still rising, though it is not uniform throughout. The river bed material being very loose almost without any cohesion could not resist the stresses which are pushing up the material. The counter resistance of the rocks below the river bed must have been responsible for the uplift. Hence the uplift of the river bed is directly related of the nature of the slide.

The slope stability analysis has shown that the slope appears to be stable with no pore pressure and seismicity. But with marginal rise of water pressure, which is common in this area during monsoon, the slope tends to be highly unstable. The combined effect of seismicity and pore pressure makes the slope highly unstable when the factor of safety drops down to 0.489 from 1.209.

8. ACKNOWLEDGEMENT

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