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Slope Stability Assessment and Monitoring of a Vulnerable Site on Rishikesh-Uttarkashi Highway, India

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Abstract Landslides are frequently occurring phenomenon in the Himalayas, in the Northern part of India. There were many landslide disasters in the recent past which have taken lives and caused extensive damage to property and public utility services. It is an imperative task to assess the slope instability and evaluate the risk where lives and property are at danger. A vulnerable slope on Rishikesh-Uttarkashi road having few houses, which are under distress, was studied for slope stability assessment. The slope instability was evident by road subsidence and development of cracks in few houses. A comprehensive geological and geotechnical investigation was carried out along with slope movement monitoring. The paper describes the findings of the study.

Keywords Landslide, Himalaya, movement, monitoring

Introduction

In recent years, a number of major disasters have made the global community aware of the immense losses of human lives and property. Although an individual slope failure is, in general, not so spectacular or devastating as an earthquake, a volcanic eruption or a flood, yet, being much more frequent and wide spread over the years, landslides have caused considerable loss of property and life. In many countries, economic losses due to landslides are great and apparently are growing as development expands into unstable hill areas under the pressure of expanding populations. Hence assessment of landslide hazard and risk is an imperative task in the area of disaster management.

The occurrence of landslides is a common phenomenon in the Himalaya which is a conspicuous landscape in the northern part of the Indian subcontinent. The Himalaya presents rock types, tectonic zones, topographic reliefs and slopes of diverse nature. The structurally deformed rocks have been subjected to severe erosion by toe cutting action of rivers and streams. All these adverse characteristics contribute in making the terrain susceptible to landslide occurrence (Sarkar et al 2005). A large number of slope failures have affected the main highways in the Himalaya, which are important routes for pilgrims (Sarkar et al, 2005). Many landslides along these highways are triggered during the monsoon season. These landslides always threat human lives and properties, which include buildings, bridges, power transmission line etc. One such unstable slope on Rishikesh-Uttarkashi road near Agrakhal is causing road subsidence and affecting several houses situated on down hill slopes (Fig. 1). The present study was undertaken to assess the slope instability and monitor the slope movement. The paper presents the results of slope monitoring and the investigations carried out.

Figure 1 Study area

Geology and slope instability

Slope instability in the area is evident by road subsidence and development of cracks in the houses situated on the downhill slope (Fig.2). Water seepage on the walls was noticed during the rains. There is a small slope failure

Figure 2 Indications of slope instability manifested by cracks in houses, road subsidence & slope failure

along the discontinuity plane. It was told by the residents of the houses that cracks on the walls get widened every year. All these field observation have indicated that the slope is presently unstable.

Topographic analysis was carried out using a contour map (1:1000 scale with 2m contour interval) and DEM was generated in GIS (Fig.3). A slope map showing the slope distribution of the area was derived from the DEM. Rocks present in the area are shale and Phyllites, which are highly weathered, fractured and thinly bedded. The rock beds dip 50° towards NW and there are two major joint sets, out of which one joint dipping towards NE is outward dipping favouring slope instability. The soil cover on the slope is varying from 5 to 10 m. There are three major drains on the slope. From the field investigation it is inferred that the unconsolidated overburden material lying above the soft geological strata is contributing slope instability in the area.

The topography of the slope and the slope material, which comprise mainly of gravels and sand, indicate that the area is probably a very old slide zone. Field investigation has shown that the sub-surface water flow during heavy rains is causing subsidence at various locations resulting into development of cracks in the houses. Resstivity survey has also indicated weatherd and saturated soil at a depth of about 9 m. Hence the causes of slope instability can be listed as follows:

- Topography and soil cover indicates presence of a old slide.
- The geological investigation has indicated presence of fractured & weathered rocks, underlying loose overburden material allowing easy seepage of water.
- The structural data shows presence of unfavourable discontinuity.
- The rain water in the catchment area percolating underground and developing pore pressure.

Geotechnical investigation

Laboratory investigation of soil samples was conducted. The soil comprises of gravel 34%, sand 35%, silt 29% and clay 2%. The cohesion varies between 0.02 -0.11 Kg/cm^2 and friction angle varies between 40° - 46°. The slope geometry obtained from the DEM and the friction and cohesion values were used for carrying out the slope stability analysis. Factor of safety obtained from stability analysis using the Slope/W software (Fig.4) under static condition shows that the slope is stable under dry condition (Factor of safety 1.4) which drops down to 1.19 under partially saturated condition. Dynamic slope stability analysis was also carried out considering the seismic effects and the displacement was found to be only 3-4 cm under dry condition but under saturated condition displacement was quite significant (Ghosh et al 2010).

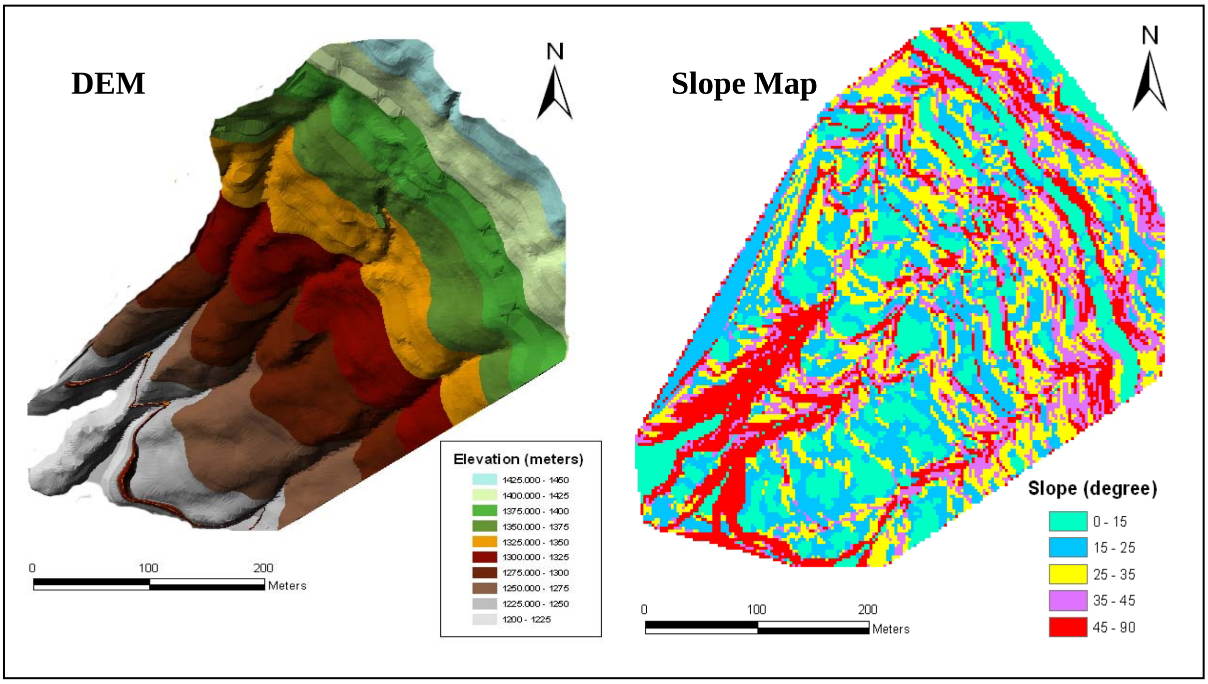


Figure 3. DEM and slope map of the area

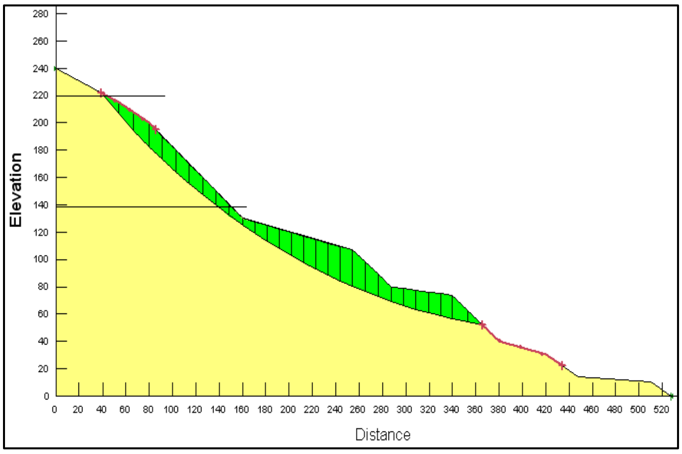


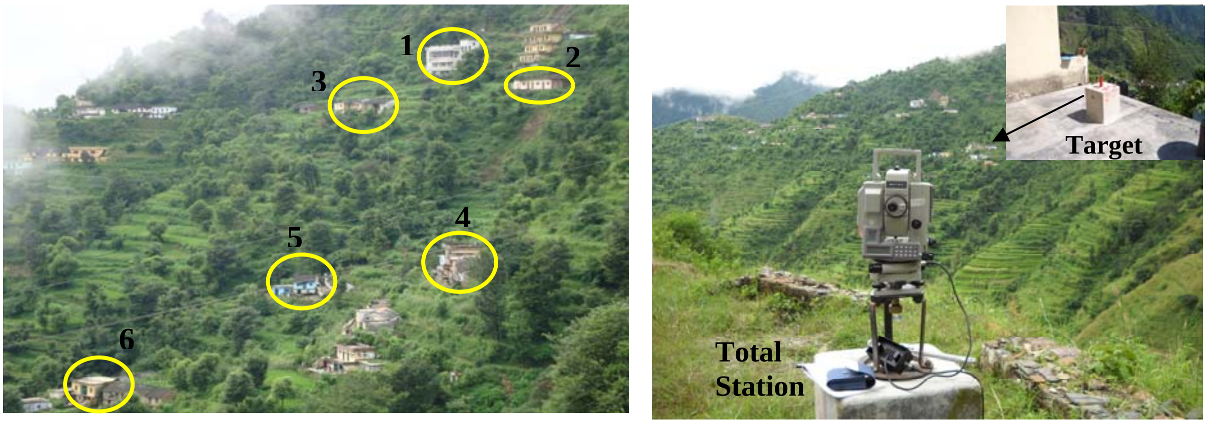
Figure 4 Slope profile and probable slip surface

Monitoring scheme

There are six houses on the slope which have shown distress manifested by development of cracks on the walls and floor subsidence. A monitoring scheme was planned to monitor the horizontal and vertical movements of these houses using Total station from a far distance outside the unstable zone. The Total station is an electronic theodolite integrated with an electronic distance meter (EDM) to obtain sloping, horizontal and vertical distances from the instrument to a particular point. Electronic Distance Measurement technology uses a ground-based, high-precision survey instrument that emits infra red wave to measure the time the wave travels from the instrument to a reflector prism installed on the moving object.

The accuracy of this type of surveying technique is high (mm accuracy), yielding much better basic surface movement data than the extensometers or inclinometers (Petley et al, 2004). However, movements associated with rotations of the objects upon which the targets are located may result into erroneous data. But even with these shortcomings, the datasets are excellent and allow a very high level of understanding of surface movements as commented by Petley et al. (2004). The advantages and disadvantages associated with total station systems was commented by Savvaidis (2003). The main advantage of using total station instruments is that they provide three dimensional coordinate information of the points measured. The disadvantage is the requirement to have an unobstructed line-of-sight between the instrument and the targeting prism.

In the present study fixed points were installed as observation points on roof top of the six houses. A stable zone based on field observation was identified at a distance of 800 m from the unstable slope. The reference point was made at this location from where all the observation points could be seen without any hindrance (Fig. 5). At the time of taking observation the total station was fixed on this reference points and the data were collected from the six observation points located on the selected houses. The movement data were collected for the period August 2009 to June 2011. The horizontal and vertical movements of the observation points were calculated from the periodic monitoring data.



(a) (b)

Figure 5 Houses being monitored (a) and position of Total Station and target (b)

Monitoring of movement

The movement data is shown in the Fig 6. An automatic rain gauge was installed at the site to collect rainfall data. The monthly rainfall data is shown in the “Fig.7”. The rainfall data shows that in the monsoon period of 2009, the maximum rainfall was only 232 mm in the month of September. While in the year 2010 there was a heavy rainfall during July to September and rainfall of 950 mm was recorded for the month of July only.

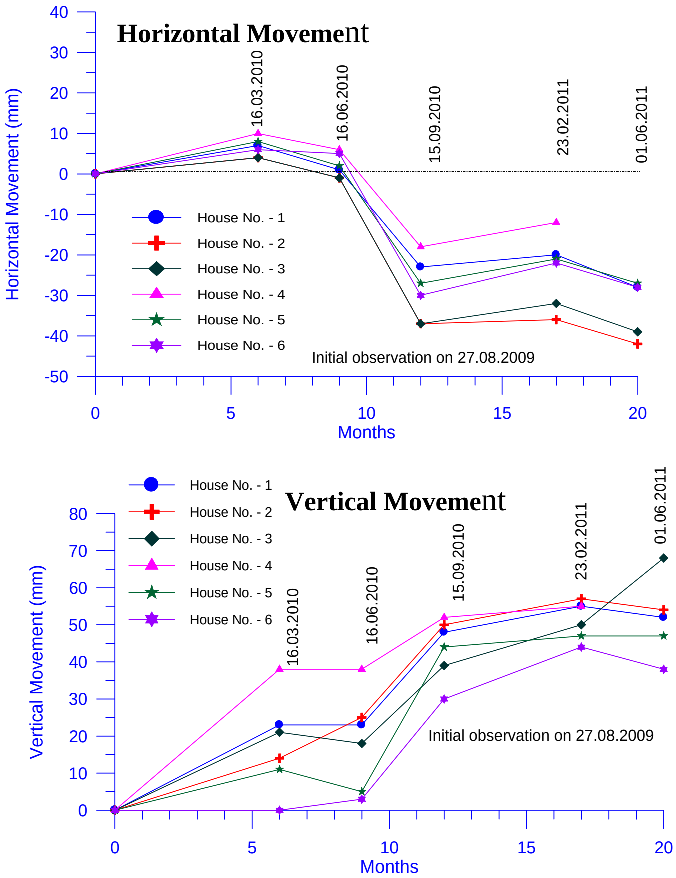


Figure 6 Horizontal and vertical movements

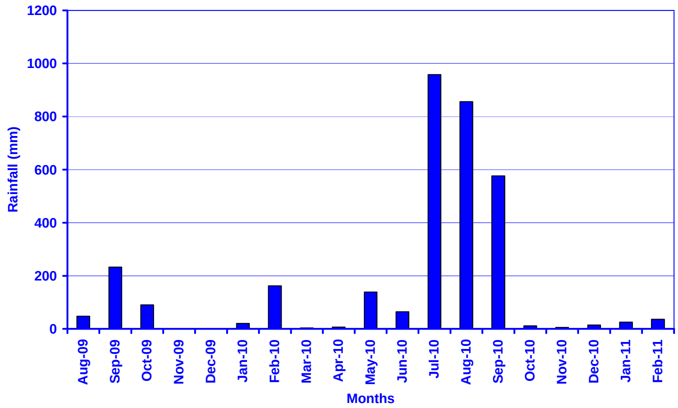


Figure 7 Monthly rainfall data

The observation points of the six houses show varied vertical and horizontal movements. In case of vertical movement, the house no 4 shows a vertical movement of 40 mm from August 2009 to March 2010 while the house no 6 shows negligible vertical movement during that period. There is no considerable movement during March 2010 to June 2010. A considerable movement varying from 15 mm to 35 mm is shown by all the houses during June 2010 to September 2010. The movement data when compared with the rainfall data (Fig. 7), it was found that the sudden increase of vertical movement during June to September 2010 can be well explained by the heavy rainfall during that period. During September 2010 to February 2011 there is not much movement. However, it can be inferred from the figure that all the houses have shown movements of a similar trend.

When considering the horizontal movement the total maximum movement of 40 mm during the total monitoring period is shown by the house no 2. The house no 4 has shown the least horizontal movement of 18 mm. In this case also maximum movement was observed during the heavy rainfall period of June 2010 to September 2010. Hence, the movement monitoring data of the last two years has shown a cumulative vertical movement of 38-68 mm and cumulative horizontal movement of 20 to 40 mm. The monitoring study is being continued to assess the vulnerability of these houses against the slope instability.

Conclusions

A potential unstable slope was studied to determine the degree of instability in terms of factor of safety and the slope movement. Stability analysis has shown that the slope in dry condition is stable but under seismic and saturated condition this may suffer large displacement leading to landslide. There are few houses which have shown distress manifested by development of cracks and subsidence. Topography and soil cover indicates presence of an old slide zone and the geological discontinuity shows presence of unfavourable rock mass structure. However the prime cause for the distress in the houses is the sub-surface water seepage. The movement of the slope is being monitored by monitoring the vertical and horizontal movements of bench marks installed on the houses. This has shown vertical movement of 38-68 mm and horizontal movement of 27 to 39 mm for different houses for the period of about 2 years.

The risk elements in the area are few houses and the highway which are vulnerable to sliding activity. Few control measures such as surface drainage and retaining walls have been suggested to arrest the further damage to the houses. The area at present does not indicate a major landslide event to occur however, it can not be ruled out in case of heavy precipitation accompanied by seismic shocks.

Acknowledgments

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