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SLOPE INSTABILITY AND RISK ASSESSMENT OF AN UNSTABLE SLOPE AT AGRAKHAL, UTTARAKHAND

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ABSTRACT: Slope instability problems at Agrakhal on Rishikesh-Uttarkashi-Gangotri National Highway of Uttarakhand State has induced distress in many houses situated on the slope. Geological and geotechnical investigations were carried out to assess the slope instability and risk assessment. Topographic survey of the slope was carried out and a contour map was prepared for topographic analysis. Geologically the rocks present in the area are highly weathered phyllites. The outward dipping discontinuity in the rocks favour slope instability. From the field investigation it is inferred that continuous water flow in a drain and water seepage at various locations are the main contributing factors for the instability. Soil samples were collected and tested in the laboratory for their geotechnical engineering properties. The paper presents the details of site investigation and slope stability analysis and risk assessment.

1 INTRODUCTION

The Rishikesh-Uttarkashi-Gangotri National Highway in the state of Uttarakhand has many unstable slopes and landslides. These landslides always threat human lives and properties, which include buildings, bridges, power transmission line etc. The Varunavat landslide of 2003 at Uttarkashi is an example (Sarkar et al., 2003). One such unstable slope near Agrakhal (40 km from Rishikesh) on way to Uttarkashi is causing continuous road subsidence and affected several houses situated on down hill slopes (Fig. 1). The guest house of Garhwal Mandal Vikas Nigam constructed by Uttaranchal Tourism has been damaged due to slope instability and is presently abandoned. There are several houses which have developed multiple cracks and are at risk. It was felt that the existing slope conditions must be studied in details because of associated potential risk. The paper presents the investigations carried out in the field and in the laboratory to assess the slope instability. Paper also highlights the major findings of the study with respect to the possible instability and the associated risk in case of a major event.

Figure 1. Study area in Google image

2 SLOPE INSTABILITY AND GEOLOGY

Slope instability of the area is indicated by the road subsidence at upper level and by the distress observed in the houses situated on down hill slope. There are several cracks in many houses situated on the slope (Fig. 2). It is informed by the house owners that these cracks get widened during rains. Water seepage was noticed on the walls of the houses during rain.

Figure 2 Road subsidence & damaged houses

A small slope failure was also noticed along joint plane. The slided debris is mostly fragmented rock pieces with soil (Fig. 3).

Figure 3. A small landslide on down hill slope

The geological data was collected to prepare the geological map of the area. Rocks present in the area are 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 (Fig. 4). The soil cover on the slope is about 2-5 m thick. There are three major drains on the slope. The houses situated on either side of the central drain have shown sign of distress. From the field investigation it is inferred that continuous water flow in the central drain is contributing slope instability in the area. The sub-surface water seepage particularly during rains is causing slow failure at few locations resulting in development of cracks in houses.

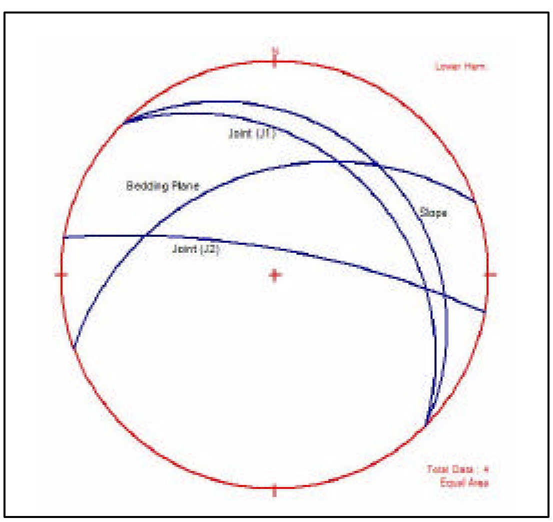

Figure 4. Stereographic analysis of structural data

3 TOPOGRAPHIC ANALYSIS

Topographic survey of the slope was carried out and a contour map was prepared on 1:1,000 scale with 2 meter contour interval (Fig. 5). The contours were digitized and a Digital Elevation Model (DEM) was generated in using Arc GIS (Fig. 6). A slope map was also derived from the DEM to see the distribution of slope amounts in the area. Several slope profiles were prepared from the DEM which were used for slope stability analysis.

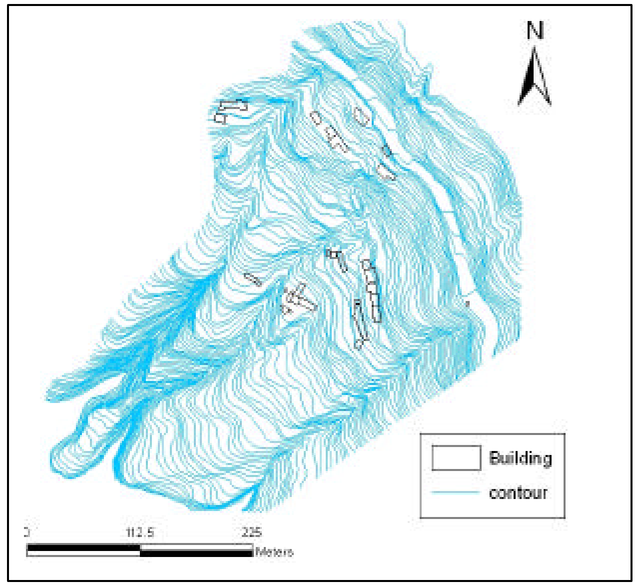

Figure 5. Contour map of the slope

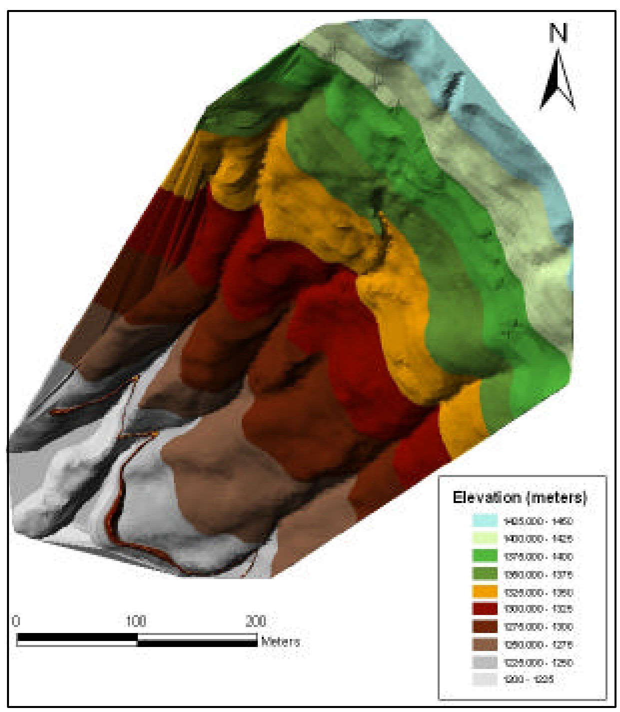

Figure 6. DEM of the slope

4 GEOTECHNICAL INVESTIGATION

Soil samples were collected from different horizons of the slope. These samples were tested in the laboratory for their geotechnical engineering properties such as grain size, proctor density, direct shear etc. The following are the results of some of the laboratory tests:

Grain Size: Gravel 34%, Sand 35%, Silt 29%, Clay 2%
O.M. C. 18%
Proctor density: 1.74 gm/cc
Cohesion: 0.02 -0.11 Kg/cm^2
Friction angle: 40 - 46^0

Results of few shear tests are shown in the Figure7.

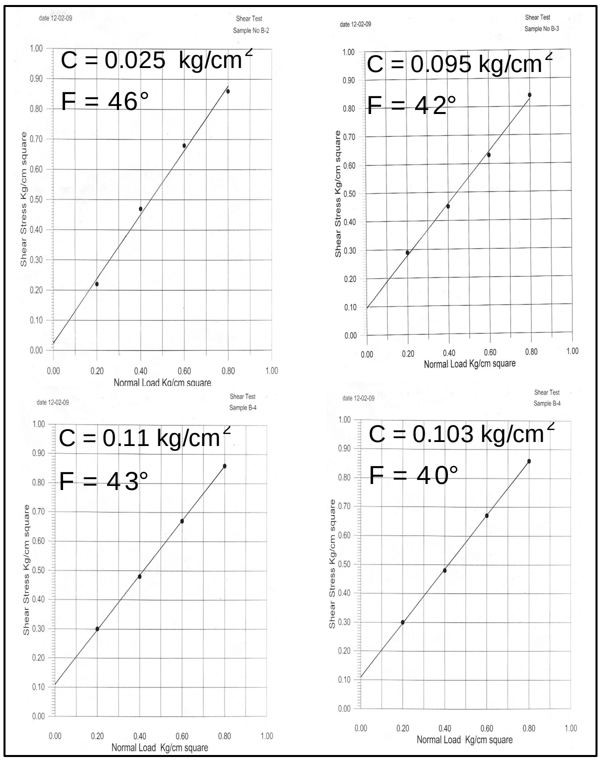

Figure 7. Shear test results

5 STABILITY ANALYSIS

Primary objective of the stability analysis of slope is to evaluate the factor of safety under static and dynamic load. The slope under consideration was also analysed under static and seismic condition because the state of Uttarakhnad falls in the highly seismic zone. Moreover the slope is inhabited by the local villagers and most of the houses developed cracks over a period of time.

The failure of slope mostly takes place due to the action of (1) Gravity force, (2) Seepage force (3) Rise of pore pressure within the body of the slope mass and (4) Seismic force.

5.1 Limit Equilibrium Analysis

Conventionally Limit Equilibrium analysis is carried out to determine the global factor of safety of the slope. The slope is considered to be stable if the factor of safety is more than unity. In this case the seismic force is not considered.

5.2 Inputs for the Stability Analysis

Two types of inputs are required for carrying out the slope stability analysis. These are the geometrical inputs which are obtained from the profile of the slope under consideration and the other input is the geotechnical input comprising of the friction and cohesion of the slope material. The engineering parameters considered for the analysis are taken from the laboratory evaluated values.

5.3 Seismic Stability Analysis

Due to past experience of seismicity in the region it was felt that seismic stability analysis of the slope should be carried out. Seismic stability analysis of slope considers the effect of earthquake forces while computing the displacement of the slope. The work of Newmark (1965) for computing the displacement of the slope instead of computing global factor of safety was brought to the common application by Sarma (1975), Makdisi and Seed (1977), Chang et al (1984) and Lin et al (1986). Vonthun and haris (1981) computed the displacement of a rockfill dam when subjected to an earthquake load utilising this concept. Ghosh and Haupt (1989) computed the seismic stability of rock wedge combining the concept of Newmark and the conventional limit equilibrium method.

Time – Acceleration history along with the geometry of the slope and the engineering parameters of the slope material evaluated in the laboratory was used as input parameter. Permanent displacement of the slope was computed under the action of the seismic force. Since the slope is found to have seepage even during the lean season and flowing water condition during rainy season the strength parameters evaluated under saturated condition was used for stability analysis.

Slope was analysed both under static and seismic loading condition. While under static loading condition global factor of safety was determined, under seismic loading displacement of the slope was computed. The results of the stability analysis is given in Table 1.

Table 1. Results of stability analysis

Condition of analysis	F.S Under Lt. Equilibrium Analysis	Displacement under seismic analysis
Dry slope under static load	1.43	-
Saturated slope under static load	1.19	-
Dry slope under seismic load	-	3 – 4 cm
Saturated slope under seismic load	-	93cm

6 RISK ASSESSMENTS

Factor of safety computed from stability analysis shows that the slope is unstable under saturated condition. There are many houses situated on the slope which have already shown distress. Some houses have been cracked so much that the occupants perforce have to vacate the house (Fig. 8).

Figure 8. A major crack in one of the houses

From the present investigation it has been inferred that the multiple cracks developed in the houses are continuously widening. Cracks are being monitored periodically. Though some of the houses have been vacated and the GMVN guest house has been abandoned, there are many houses where peoples are still leaving. This is because they have their agricultural land on this slope. Except agricultural land and few houses there is no other infrastructures which could be assessed under economic loss due to any future event. Since there is not much ground movement observed on the slope, the risk is not very high. However, the people living there should be educated properly so that they can monitor the cracks and other indications of instability and alert themselves before any major event.

7 CONCLUSIONS

The unstable slope was investigated in detail for its stability and risk assessment. The main conclusions are given below:

I. The geological investigation has indicated presence of highly fractured and weathered phyllitic rocks, which allows easy seepage of underground water. The structural data also shows presence of unfavourable discontinuity plane.

II. Geotechnical investigation has shown high fine content (Silt + Clay 31%). This can be attributed to particle break down due to movement of the slope.

III. As observed in the field the prime cause of instability is the perennial underground water seepage.

IV. Stability analysis shows that the slope in dry condition is stable but in reality during rainy season the slope gets saturated and as expected the factor of safety gets reduced. But even then this situation does not lead to a catastrophic failure. However when subjected to seismicity the dry slope undergoes displacement of the order of 3 – 4 cm. When seismicity and saturation of the slope gets coupled catastrophic failure takes place. Due to very large displacement. Slope being situated in the hilly state of Uttarakhand such a combination of forces can not be ruled out.

V. The associated risk in the area is few houses with their inhabitants. Though the area at present does not show any indications of disaster but to be more specific about the degree of distress, few cracks in the houses are being monitored through instrumentation. Further studies are being carried out to suggest adequate remedial measures to stabilize the slope and protect the houses.

8. RERENCES

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