Slope Stability Analysis of Narayanbagar Landslide on Karnaprayag - Gwaldam Road, Uttarakhand Himalaya

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Abstract

The Narayanbagar landslide located on the left bank of Pinder River, along Karnaprayag - Gwaldam road, Chamoli Uttarakhand is an important landslide, which gets activated almost every year affecting the road traffic. The hill slope is covered by the debris underlain by in situ *rocks. The hill slopes 42^0 towards west, with slide movement occurring along the debris-rock interface, indicating planar debris slide, as it is very common in Himalayan terrain. Systematic Engineering Geological investigations were carried out in order to calculate the factor of safety of this slide and suitable control measures were suggested.*

Introduction

Landslides are one of the major natural disasters in the fragile Himalayan ecosystem and pose serious threat to both life and property. In the recent times, many landslides were caused due to improper planning. The present study deals with Narayanbagar landslide on the left bank of Pinder River, along Karnaprayag - Gwaldam road, Chamoli district, Uttarakhand. Narayanbagar landslide is situated in the middle of Narayanbagar town, along Karnaprayag - Gwaldam road in Chamoli district of Uttarakhand state. The slide occurred initially in 1972 and later got reactivated and extended to present size in 1993. This slide has been a cause of traffic disruption during rainy seasons. Detailed Engineering Geological investigations were carried out to assess the status of stability of the slide. Factor of Safety (F) was calculated along a section across the slope of the slide by limiting equilibrium method under static condition using the method for Talus slide analysis (Anbalagan et al., 2007). The detailed investigations led to know the status of stability of the slide and to arrive at suitable control measures for stabilizing the slope.

Location and accessibility of Narayanbagar landslide

The Narayanbagar landslide is situated at about 30km from Karnaprayag town, in the middle of the small hill town of Narayanbagar, on Karnaprayag - Gwaldam road in Chamoli district. The location of Narayanbagar landslide is shown in Fig 1.

Physiography of slide area

The Narayanbagar landslide is located on a steep, left bank slope of Pinder River which is a tributary of Alaknanda River. Physiographically the slide area is located above the road with a thin cover of debris (Fig 2). The river Pinder, originating from Pindari glacier, flows in a roughly WNW direction close to the toe of the slide. In the landslide zone, the water flow shifts within 40 to 50m wide river course. Close to the toe of Narayanbagar landslide, the Pinder River takes an arcuate turn leading to toe erosion (Fig 2). The landslide is confined to, two minor spurs running roughly in E-W. The landslide extends over a distance of about 100m along the road. The general slope is around 40^0-42^0. The slide scarps are visible as barren patches close to crown area of the slide.

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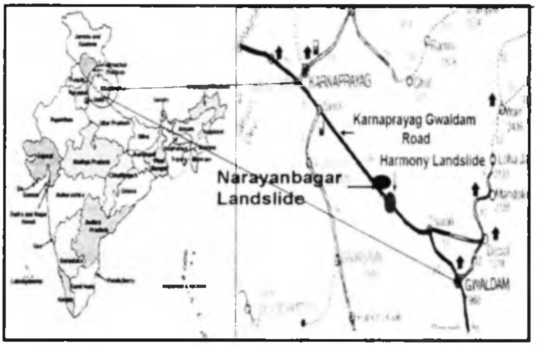

Fig. 1: Location map of Narayanbagar landslide (Not to scale)

Geological setting

The Narayanbagar landslide falls in Higher Himalayas. Regional geology around Narayanbagar was studied by various workers in the past like Gansser (1964), Jain (1971), Valdiya (1980), Jain and Manickavasagam et al. (2002). Medium to low grade metamorphic rocks are exposed in and around the area. Though the Narayanbagar landslide is restricted to loose debris materials, the main rock types exposed below the debris are phyllitic quartzites with minor bands of micaceous schists (Fig 3). In the adjoining area, Munsiari Formation of Almora Group consisting of Granitic Gneiss, Micaceous and Phyllitic Quartzites and of Garhwal Group consisting of massive phyllites is exposed. The debris material was derived due to ancient landslide occurrences. It consists of assorted fragments, ranging from fine grained ones to large rock boulders. The *in-situ* rock is exposed along the boundary of the slide. A geological section (A-A') was prepared in the centre of slide area (Fig 4) which is also used for stability analysis.

landslide

Due to repeated slope movements in the past, the Karnaprayag - Gwaldam road passing through the slide zone is affected, causing traffic disruption especially during rainy seasons. A thin debris cover of about 3m is seen on the entire slope on either side of the road. During rains, the impervious rock

Fig. 2: Panoramic view of Narayanbagar landslide showing toe erosion of slope

surface below the debris causes saturation leading to a temporary phreatic surface within the debris material. The pore pressure exerted by this subsurface water leads to slope failure along the debris bed rock interface leading to planar debris (Talus) slide. This is a typical failure, common in Himalyan terrain. However this type of failure does not find a mention by workers like Hoek and Bray (1981), Wyllie and Mah (2004). As a first step a geological map of the slide area was prepared on 1:1,000 scale with a cross section passing through the centre of landslide (Fig 3 & 4).

Stability analysis of Narayanbagar landslide

To assess the status of stability, the Factor of Safety (F) was calculated along the selected section using limit equilibrium condition under static condition for the possible planar debris failure/ talus slide (Anbalagan et al., 2007). The detailed investigations helped to know the status of stability of this slide and to arrive at suitable control measures for stabilizing the slope. Initially geological mapping of slide zone was done on detailed (1:1,000) scale (Fig 3). A representative geological section was also constructed through the middle of slide area along section lines A-A' (Fig 4). For carrying out stability analysis, it is important to assess

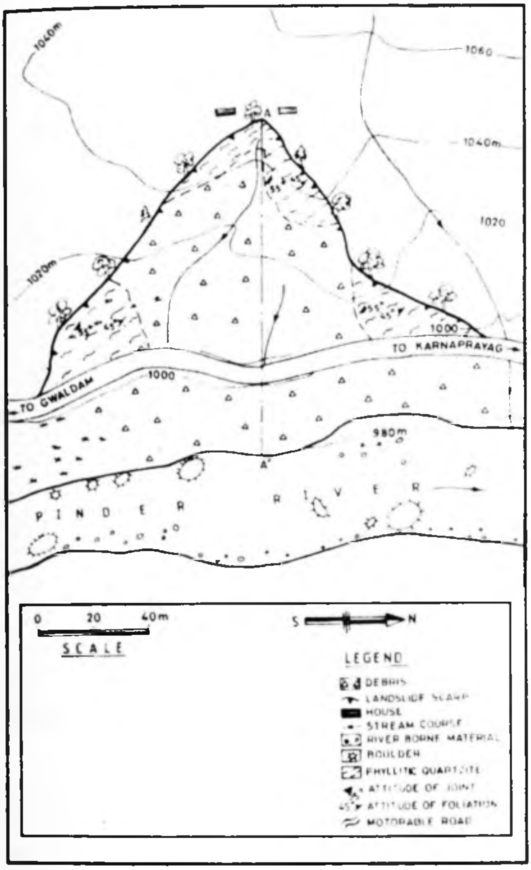

Fig. 3 : Geological Map of Narayanbagar landslide zone.

the shear strength parameters of the slope materials. Three samples were collected from the slide zone at different heights and Direct Shear Test (DST) was conducted in laboratory to estimate their shear strength. The unit weight of slope forming debris (g) was assessed to be 1.8t/m³. The moisture content in all samples was < 5%, indicating dry slope condition. Finally Direct Shear Test was conducted on these representative samples with five different normal loads to get their corresponding shear strength values. The values were plotted in normal stress (ó) – shear stress (ô) axis to obtain representative shear strength parameters. Of the many possible combinations derived from best fit lines of shear test results, a cohesion (C) value of slope forming material was judiciously selected as 1t/m² and a value of friction angle (Ö) as 28°. Status of stability of the given slope is estimated by calculating F (Factor of Safety) following Limiting Equilibrium method under static condition (Coates, 1970). Apart from dry slope condition, status of slope stability is also estimated at saturated condition of 50%.

Calculation of factor of safety (F) of the slope along selected section in static condition

Analysis of talus slide was done by Coates (1970) and the equation of Factor of Safety (F) is given below.

$$F = \frac{C.\sec^2\psi_f/\gamma.Z + \tan\phi\,[1-(1-Z_w/Z).\gamma_w/\gamma]}{\tan\psi_f}$$

The Equation 1 is derived considering the following assumptions.

i) Constant thickness of talus material (Z). In practice, average thickness of non-uniform debris layer is considered.

ii) During long spell of rains, groundwater level starts rising up to a depth Z_w below slope surface.

iii) Surcharge is usually taken into account by increasing Z by equivalent soil cover and decreasing Z_w in the same manner.

Stability analysis of Narayanbagar landslide has been carried out by using the aforesaid equation for calculating F of Talus slide.

Details of input parameters considered for analysis are indicated below.

i) Height of slope = 40m

ii) Average slope angle ($Ø_f$) = 42°

iii) Cohesion of slope forming materials (C) = 1t/m²

iv) Angle of internal friction of slope material (Ö) = 28°

v) Unit weight of slope material (g) = 1.8t/m³

vi) Unit weight of water (g_w) = 1t/m³

vii) Average thickness of talus material (Z) = 3m stability analysis indicates clearly

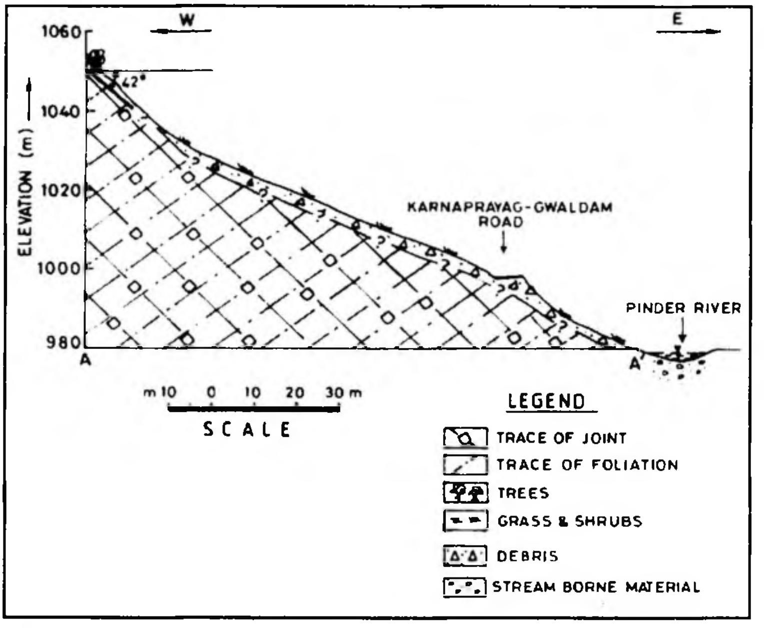

Fig. 4 : Geological section of Narayanbagar landslide (Sec A-A')

that with increasing water saturation, the slope will be more and more unstable.

Discussions on results of stability analysis

The stability analysis was carried out for the Narayanbagar landslide under static condition. The result of stability analysis of Narayanbagar landslide indicates that the F value is 0.98 (about 1.0) under dry condition. On increasing water saturation (50%), the F value gets reduced to 0.8 (Table 1). From the results, it can be inferred that the slope is critically stable under dry conditions. However, during monsoon time, once the slope materials are saturated, it tends to become more and more unstable.

Table 1: 'F' values for Narayanbagar landslide under static condition

Change in 'F' values for different groundwater conditions		
Groundwater condition within Talus material	$Z_w = Z$	$Z_w = 0.5Z$
Corresponding F value	0.98 (= 1)	0.8

Conclusions and Control Measures for Narayanbagar Landslide

The Narayanbagar Landslide is also in a critical state as indicated by stability analysis. However, the material which is sliding down is of the order of few meters (<3m). Every year, at the end of monsoon, the thickness keeps on reducing due to downward movement of the material. In this area, the protection is required mainly in two important locations – i) just at the toe of the slope adjoining Pindar, where there is a heavy river erosion causing instability of slopes and ii) the slope just adjoining the road, where thin debris are present.

Control Measures for preventing toe erosion

Along the left bank of Pinder River, two rows of concrete cubes of the following size may be placed – bottom row 1.5m x 1.5m x 1m (height) and the top row 1m x 1m x 1m. This will help to prevent toe erosion by Pinder River. This will cover up to the high flood level (HFL) of the river. Behind this wall, if required one or two rows of gabion walls shall be constructed to protect the loose slope materials (Fig 5). This will help to stabilize

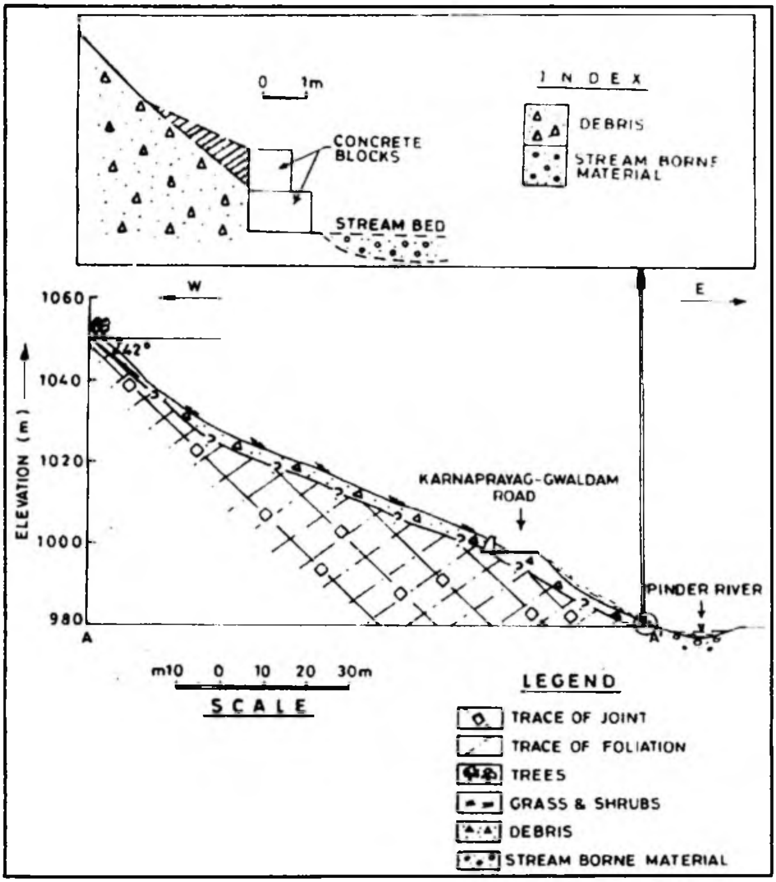

Fig. 5: Control measures suggested for Narayanbagar landslide

the slope up to road level.

Further above the road, because of road cutting, the thickness of the debris might have been reduced considerably. Under this condition, it is advisable to construct a RCC retaining wall founded on the rocks below and extending up to the top of the debris (Fig 5). The wall should have suitable drainage holes in order to prevent any pore pressure buildup at the back side.

In addition, suitable open drains should be provided at the toe of the retaining wall to collect the surface and subsurface seepage water and carry along the gradient and safely away from the slide area. Grass turfing of barren slopes be done to prevent ingress of rain water into slope. Fast growing plants and tree species be planted to provide resistance to surface erosion. The arcuate cracks have to be filled with silty clay or locally available fine grained matrix and compact well.

The results of 'F' values obtained from Eq 1 for different groundwater conditions (Z_w), within Talus material are indicated in Table 1.

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