Geotechnical Investigation across a Failed Hill Slope in Uttarakhand – A Case Study

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ABSTRACT: A landslide triggered by a cloudburst in 2013 had blocked a major highway in Uttarakhand. The paper presents details of the geotechnical and geophysical investigations done to evaluate the failure and to develop remedial measures. Seismic refraction test has been effectively used to characterize the landslide and assess the extent of the loose disturbed zone. The probable causes of failure and remedial measures are discussed.

Keywords: *geotechnical investigation; seismic refraction test; slope failure; landslide assessment*

1. Introduction

Fragility of terrain is often reflected in the form of disasters in the hilly state of Uttarakhand. Geotectonic configuration of the rocks and the high relative relief make the area inherently unstable and vulnerable to mass movement. The hilly terrain is faced with the dilemma of maintaining balance between environmental protection and infrastructure development.

The cloudburst in June 2013 triggered several landslides along the Rudraprayag-Badrinath road section of NH-58. The paper presents a case study of one such landslide along the highway on the bank of River Alaknanda.

Detailed geotechnical investigation including borehole and seismic refraction tests were used to characterize the landslide and to assess the lateral and vertical extent of the failure. The results were used to develop engineering solution to mitigate the distress and to ensure safety of the highway.

2. Generalized Site Conditions

2.1 Geological Setting

Geologically, the area belongs to the Lesser Himalayas and lies in a tectonic fore-deep. It is sandwiched between North Almora Thrust and Main Central Thrust (DMMC, 2014). The rocks of the Lesser Himalayas belong to the Central Crystalline Group.

The rocks comprise gneisses and quartzites which are extremely deformed during ductile regime to form different types of myolinites, myolinitic gneisses, schists, amphibolites, etc. The gneisses and quartzites are sheared and give rise to sericite-schists, sillimanite bearing mica-schists.

The area has a highly rugged topography characterized by moderate to steep slopes that are intervened by narrow valleys. Presence of overburden soils and fractured / laminated weak-rocks makes the area prone to landslides during heavy rains.

2.2 Site Conditions

The rock mass in the area has unfavorable dip towards the valley side. In a 100-150 m stretch, the gabion wall on the down-hill side of the highway, showed extensive distress. The overburden of boulders and soil had slid down, probably due to buildup of water pressure behind the gabion wall during heavy rains. Drainage is usually the main culprit in most landslides; the same can be observed here. A photograph showing the site condition is presented on Fig. 1.

Fig. 1 View of Hill slope showing landslide and movement of soil and gabion wall

The landslide location is towards the valley side of the highway. The high velocity and current of the Alaknanda River continuously erodes the toe of slope towards the valley side. This worsens the overall stability of the area inducing conditions favorable for slide. The Main Central Thrust passes through the area in the vicinity that makes the region seismically active.

2.3 Stratigraphy

Geotechnical investigation has been carried out to evaluate the stratigraphy of the area. The investigation included two boreholes and seismic refraction tests along two lines. A photograph of the borehole drilling in progress is illustrated on Fig. 2.

Fig. 2 Borehole drilling in progress

An overburden of boulders (colluvial deposit) is encountered to about 14-16 m depth underlain by quartz-mica-schist. The overburden is mostly landslide material. Typical borehole data is presented on Fig. 3.

2.4 Geophysical Profile

Seismic refraction test was done along the road alignment to characterize the ground conditions, evaluate the geophysical litholog and to make an assessment of the extent of the landslide.

The survey was done along two lines. The geophysical litholog encountered along one line is illustrated on Fig. 4. It indicates a three-layered geological model. A slide-zone of overburden with boulders was clearly identified which can be correlated very well with the borehole data.

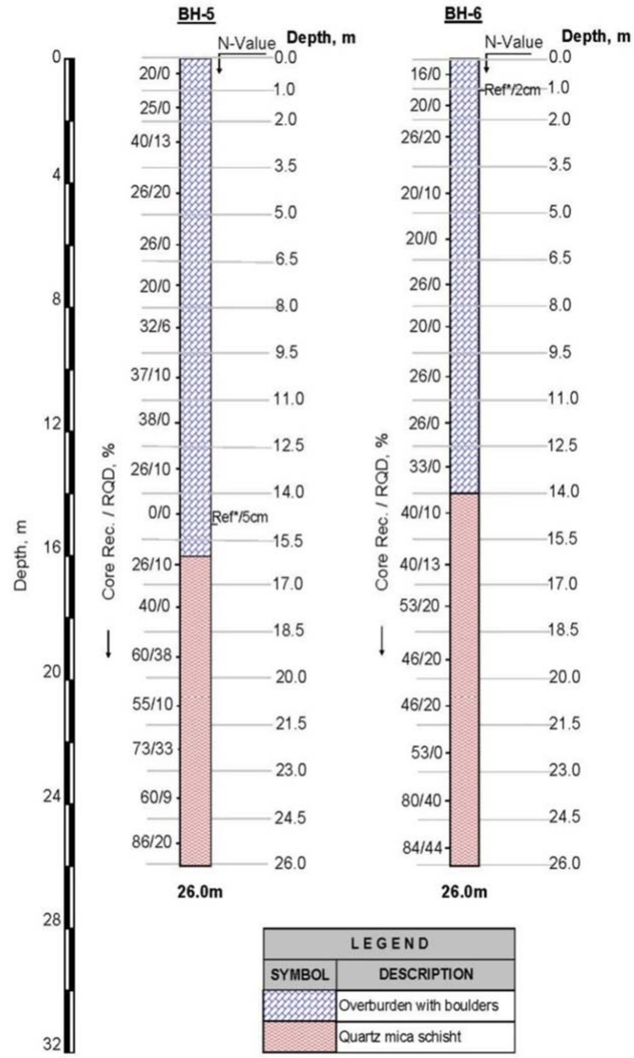

Fig. 3 Summary of borehole profiles

It may be seen that the Layer 1 consisting of overburden soils with boulders is the slide-material in disturbed condition. The boreholes also indicate the presence of the overburden to 14-16 m depth. Fractured rock / hard rock met below the slide zone is the underlying stable zone.

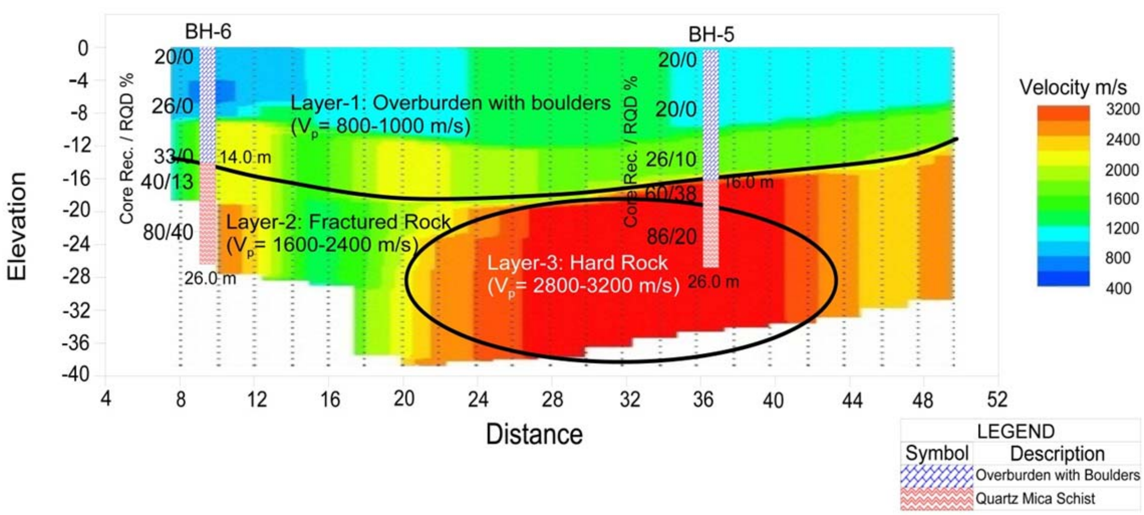

Fig. 4 Seismic sectional profile along the landslide

3. Engineering Assessment

The site consists of rockmass units dipping unfavorably towards the valley side. A sketch showing the unfavorable dip and the failure zone is illustrated schematically in the geological section on Fig. 5.

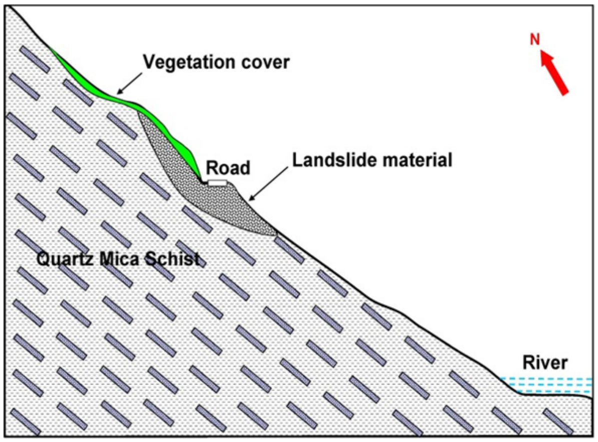

Fig. 5Schematic sketch illustrating the rock mass dip

The unfavorable dip of the rock combined with the build-up of pore water pressure behind the gabion wall and erosion of the river bank toe during heavy rains resulted in increased instability of the area.

Improper drainage and movement of the rock mass along the weak planes are the major reasons of deflection of the gabion wall towards valley side. Erosion of the slope due to heavy rainfall resulted in movement of overburden soil along the valley slope.

A photograph showing the displaced gabion wall is presented on Fig. 6.

Fig. 6 Displaced Gabion wall

A culvert at the slide location (see Fig. 7) adjoining the gabion wall got choked, resulting in accumulation of water behind the wall. As a consequence, pore-water pressure built up behind the wall which probably is the triggering factor of failure. Erosion of the strata below the gabion wall resulted in differential settlement which led to tilting of wall.

Fig. 7Damaged Culvert at the valley side

Distress was also observed at the toe adjacent to the river. The loose accumulated alluvium at the river bank toe gets further eroded in the rainy season (see Fig. 8).

Fig. 8 Eroded River Bank

As per the authors' assessment, the existing gabion wall on the valley side was inadequate to retain the loads.

4. Remedial Measures

Remedial measures adopted to stabilize the area and to limit possibility of further movement on the valley-side slope are briefly mentioned below.

4.1 Drainage

The drainage on the hill-side and valley-side was improved to channelize the water flow effectively and to minimize further buildup of pore-water pressure. This includes a series of culverts, catch-water drains and chute drains.

4.2 Reinforced Soil Wall

A new reinforced soil wall has been proposed in place of existing gabion wall towards valley side. This reinforced wall is designed for the anticipated traffic, seismic forces and lateral earth pressure. The reinforced soil system is advantageous because of a better and uniform pressure distribution at the base of the wall.

4.3 Apron for Toe Protection

A gabion wall connecting the gabion mattress has been proposed at the river toe. Gabion wall protects the exposed toe and reduces the erosion at that location while the gabion mattress protects the wall against scour as well as from flowing debris.

5. Concluding Remarks

The study illustrates the use of seismic refraction tests in characterizing the ground conditions in landslide zones. A proper geotechnical investigation including deep boreholes and geophysical testing in conjunction with a geological evaluation can effectively evaluate the landslide, its extent and severity of the problem. The assessment can then be used to work out an engineering solution for long term stability of the distressed area.

6. Acknowledgement

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References

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