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Stabilizing a Highway in the Fragile Himalayan Terrain – Case Study of Gulabkoti Landslide

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ABSTRACT

The fragile Himalayan terrain of Uttarakhand (India) faces challenging and tough situations due to landslides, particularly during monsoons. A landslide triggered by a cloudburst resulted in rock-fall at Gulabkoti village, where highly jointed and fractured rocks were present. The paper discusses the destabilizing forces that triggered failure of the fragile hill-slopes. Investigations conducted and remedial measures proposed such as secured drapery system with anchors, retention with reinforced soil system in the valley side and drainage measures are discussed in detail.

Keywords: landslide; geotechnical investigation; rock-fall; water percolation; hill slope stabilization.

1 INTRODUCTION

Landslides are common in the geo-dynamically active domain of the Lesser Himalayan terrain and pose enormous threat / disruption to life and property. The causes include geological, geo-morphological and hydrological factors.

A cloudburst in June 2013 triggered several landslides in the fragile hill slopes of the Lesser Himalayas along the national highway, NH 58 in north India. Of the various landslides occurred along this highway, the paper discusses rock-fall that occurred in the highly jointed and fractured rocks at Gulabkoti.

Destabilizing forces that contributed to slope failure include presence of vertical joints, weak planes, unfavorable dip, improper drainage, seismic forces, etc. The strengthening measures adopted are presented.

Geo-tectonic configuration of the rocks and steep slopes make the area inherently unstable and prone to mass movement. Due to repeated devastation and losses due to natural hazards, the area is inherently vulnerable and fragile. This was aggravated by infrastructure development and lopsided growth.

2.0 SITE CONDITIONS

2.1 Site Location

Gulabkoti village is located in Chamoli district of Uttarakhand state, India. It is 18-km away from Joshimath town. Due to presence of highly jointed and fractured rock, the hill-slopes are prone to rock-fall. The site studied is along NH-58 on the banks of River Alakhnanda.

Fig. 1 presents a satellite image showing the location of the rock fall zone along the highway.

Fig. 1. Location of the rock-fall zone at Gulakoti

2.2 Geology

The Lesser Himalayas lies in a tectonic fore-deep (DMMC, 2014). The Lesser Himalayas are comprised of conglomerates followed by bedded quartzites, slates, phyllites and low-grade schists.

Towards the north of Chamoli, Chinka Formation, Pipalkoti Formation and Gulabkoti Formation are exposed. The Pipalkoti formation forming the core of the Pipalkoti anticline, consists of alternating sequence of slate and dolostone.

In the north, this formation has been thrust upon by the Gulabkoti Formation along Gulabkoti thrust whereas in the south these have been separated from the Chinka Formation by the Birahi Fault (Krishnan, 1986).

The Gulabkoti Formation comprising of quartzites, dolostone and mylonites was thrust upon by the rocks of “Central Crystallines” along the low angle northerly dipping “Main Central Thrust”. The mylonites, occurring in this formation, lie in the “Intra Thrust Zone” and are bounded by the Main Central Thrust in the north and the Salur Thrust in the south.

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2.3 Stratigraphy

As part of the geotechnical investigation, one borehole was drilled and seismic refraction tests were performed along two lines.

Fig. 2 presents a photograph of the geotechnical investigation in progress. The steeply dipping rocks on the hill-side and the rock pieces that have fallen down as a result of the slide is depicted in Fig.2.

Fig. 2. Drilling in progress

Fig. 3 is a photo of the seismic refraction test (SRT) in progress at site. A pictorial summary of the borelog illustrating the core recovery and RQD values is presented on Fig. 4. The geophysical litholog interpreted from one typical SRT is presented on Fig. 5.

Fig. 3. Seismic Refraction test in progress

The rock at the borehole location classifies as quartzite. The quartzite zone is overlain at places by dolomitic limestone followed by siliceous marble.

The quartzites are highly sheared, highly jointed and fractured. Quartz veins and pockets containing mica, kyanite and tourmaline are abundant.

2.3 Rock Joint Mapping

Three joint sets were observed with numerous low persistence joints and fractures. Table 1 shows joint details.

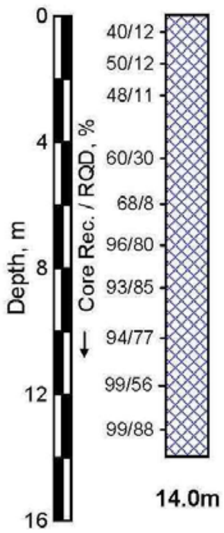

Fig. 4. Borelog

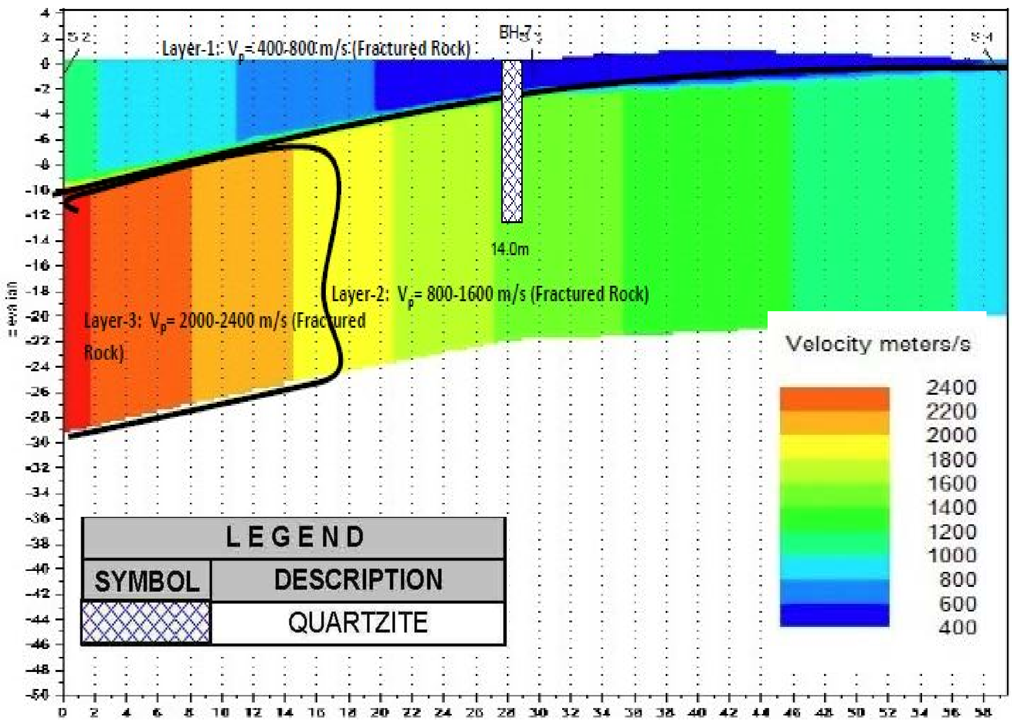

Fig. 5. Geophysical litholog at Gulabkoti

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Table 1. Joint sets from site observation

Sr. No.	Dip Angle	Dip direction	Strike
J1	25	N 225	N 315 - N 135
J2	70	N 280	N 190- N 10
J3	60	N 210	N 300 - N 120
Slope 1	75	N244	N 334 - N 154
Slope 2	56	N270	N 360 – N 180

3 PROBLEM DESCRIPTION

Following are the various destabilizing forces that caused failure.

3.1 Fractured Rock-Mass

The site comprises of heavily jointed rock mass with weak planes along the foliation. At places, tensile force was developed in the rock-mass overhangs due to weight of the overhang. The fractured rock mass is prone to collapse, particularly if water seeps through the joints. Fig. 7 shows the overhanging fractured rock-mass.

Fig. 7. Rock Overhang at Gulabkoti

In addition, there are weak layers, comprising mica, along the foliation plane. The foliation is dipping towards the road (at shallow angle) and kinematically free rock blocks may slide over the weak mica planes towards the road side (refer Fig. 8).

On the top of the slope trees are present. Growth of roots into the joints resulted in widening of joints.

3.2 Water Percolation through Jointed Rock Mass

During rains, water percolates through the joints, generating pore-water pressure which makes the slope more susceptible to rock-fall. Fig. 9 illustrates water seepage through exposed rock-face.

Fig. 8. Foliated rock & blocks of rock below road level

Fig. 9. Water seeping through jointed rock-mass

3.3 Seismic Forces

The area lies in Seismic Zone V as per IS: 1893-2016 and receives heavy rainfall. Hence, seismic force is a major destabilizing force.

Based on analysis of data from 40 earthquakes worldwide, Keefer (1984) suggested that minimum intensity required to trigger rock-fall corresponds to an earthquake magnitude of 4.0 on the Richter scale.

During an earthquake, potentially unstable rock masses will dislodge when the shear resistance of the controlling joint surface(s) is exceeded due to shaking-induced inertial forces. Since seismic loading is cyclic and transient, its magnitude and direction continuously change during the earthquake. Consequently, earthquake induced inertial forces will alternate from stabilizing to destabilizing with respective cycles of motion during an earthquake.

4 ENGINEERING SOLUTION

4.1 Methodology

Between CH 464+400 and CH 464+ 430, the valley side is very steep, nearly vertical. Hence building a retaining wall on valley side was impractical. Therefore, to achieve road width of 12 m, the feasible option was to cut towards hill side.

To achieve the required road with of 12 m, valley side extension was done by providing retaining wall.

4.2 Design Parameters for Analysis

Table 2 presents rock mass properties used for the analysis of rock anchors and slope stability assessment.

Table 2: Properties of Rock Mass

Intact Rock properties	$\gamma = 26$ kN/m^3 E = 40000 MPa $\mu = 0.24$ Tensile Strength = 2.5 MPa $\phi_{peak} = 63°$ $c_{peak} = 5$ kPa $\phi_{residual} = 45°$ $c_{residual} = 5$ kPa
Joint Set 1A c = 4 kPa $\phi = 19.5°$	Inclination -80°, Spacing 4 m, length 15 m, persistence 0.95 Shear Stiffness: 29000 MPa/m Normal Stiffness: 72000 MPa/m
Joint Set 1B c = 4 kPa $\phi = 19.5°$	Inclination -80°, Spacing 4 m, length 6 m, persistence 0.9 Shear Stiffness: 29000 MPa/m Normal Stiffness: 72000 MPa/m

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Joint Set 2 c = 0.02 kPa ϕ = 19.5°	Inclination -7°, Spacing (mean) 1.1 m (max 1.5 m, min 1m, length infinite Shear Stiffness: 25000 MPa/m Normal Stiffness: 12000 MPa/m

4.3 Hill Cutting Ch 464+400 to 464+430

After cutting the hill side between Ch 464+400 and Ch 464+430, rock-fall was arrested with a system of secured drapery i.e with nails and high-resistance mesh.

The system was composed of anchors (steel bars), to stabilize the slope and a mesh which contains the debris or the rock blocks that might move between the anchors. The system, illustrated on Fig. 10 is passive, because both mesh and anchors start to develop resistance if one or more blocks start to move.

The mesh (facing) shall contain the potential unstable blocks that could fall between the nails. These blocks that are supposed to slide along the most critical joint-set shall push against the facing with a force. The mesh was designed to contain deformation (bulging) and consequently reduce the possibility the anchors getting stripped.

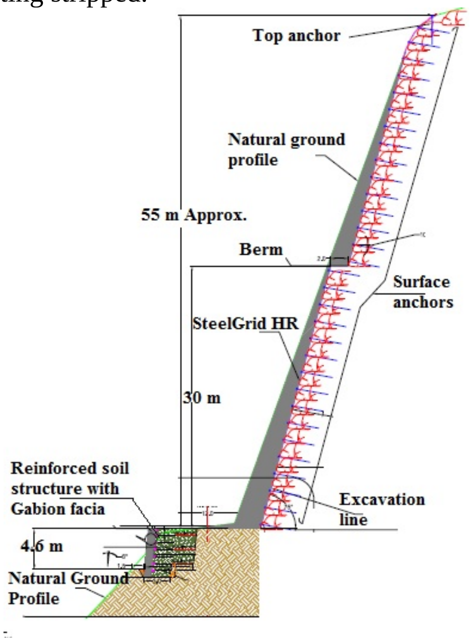

Fig. 9. Typical Cross-Section at 464+400

To channelize the rain water properly and to address the issue of surface water, effective drainage measures were provided (see Fig. 10).

4.4 RE Wall Ch 464+357 to 464+400

For retention of proposed 12-m wide road from CH 464+357 to CH 464+400, reinforced soil wall of maximum height 7.2 m was constructed. Reinforced soil wall was designed for the anticipated traffic and seismic load. Reinforced soil system is advantageous in terms of better uniform pressure distribution at the base of the wall. Differential settlement will be controlled effectively as the system is flexible and monolithic.

Shotcreting was done on the slope surface at drain location. Perforated PVC pipes were provided at locations where sub-surface water is observed, along with provision of basin to absorb falling-water impact. The water from the basin was diverted to the road side drain and discharged to the existing culverts.

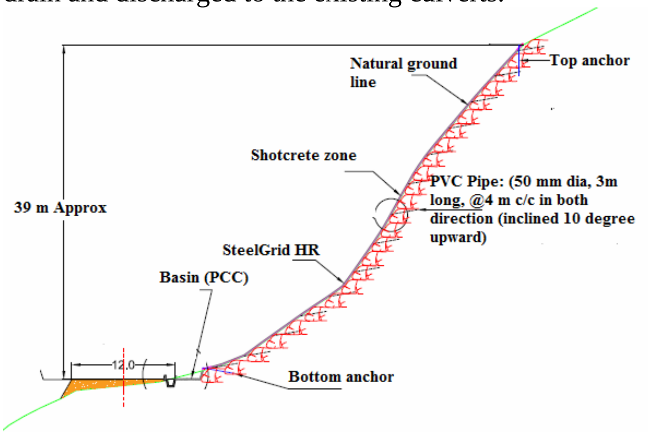

Fig. 10. Typical Cross-Section at CH 464+475 with drainage measures

5 CONCLUDING REMARKS

The geotechnical problems identified along a stretch of highway in the north Indian state of Uttarakhand along the highly fractured and jointed rock slope were:

- Rock-fall of fractured rock mass is prone to collapse, particularly where the rock-mass overhangs towards the road.
- Water percolating into the joints, generating pore water pressure makes the slope more susceptible to rock-fall.
- Seismic activity could cause potentially unstable rock masses to dislodge when the shear resistance of the controlling joint surface(s) is exceeded

Engineering solutions implemented include:

- Hill-side cutting was done between CH 464+400 and 464+430 to obtain road width of 12 m. Rock anchors were installed on the slope and secured using a high strength mesh.
- Effective surface drainage measures were provided.
- Between 464+357 and 464+400, RE wall was provided on the valley side.

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