Geotechnical evaluation of Harmony landslide on Karnaprayag–Gwaldam Road, Uttarakhand Himalaya

R. Anbalagan*, Atul Kohli and D. Chakraborty
Department of Earth Sciences, Indian Institute of Technology, Roorkee 247 667, India

Landslides constitute one of the major natural disasters in the fragile ecosystem of the Himalaya. Due to landslides, the Himalayan region faces major problems of geoenvironmental imbalance and poses threats to life and property. In 1986, a major landslide occurred near Harmony village on left bank of Pinder river, along Karnaprayag–Gwaldam Road, Chamoli District, Uttarakhand. This landslide is reactivated almost every year causing disruption of traffic along this important hill route and creating recurrent economic loss to the state exchequer. In view of the importance of the Harmony landslide, detailed investigations incorporating relevant engineering geological and geotechnical parameters were carried out in order to find suitable control measures.

Keywords: Circular failure charts, geoenvironmental imbalance, harmony landslide, factor of safety.

In the hilly terrains, the slopes appear to be stable, though they are constantly subjected to natural processes of instabilities such as weathering and erosion. The fragile Himalayan ecosystem, which is characterized by weak rocks, various types of geological discontinuities and unfavourable hydrogeological conditions, is more prone to frequent slope failures, especially along the roads. During the past few decades, the processes of natural instabilities have been accentuated due to accelerated anthropogenic activities. Such anthropogenic activities include road and building construction, terracing for agriculture, deforestation and other such activities. If located in zones of high annual precipitation and/or seismic activity, such slopes become highly susceptible to landslides. The study area, namely Harmony landslide is located near Harmony village along the Karnaprayag–Gwaldam Road (District Chamoli, Uttarakhand). This hill road is strategically important as it is the only route in the upper hills connecting Garhwal and Kumaun physiographic divisions of Uttarakhand (Figure 1). During times of emergency, this road acts as a communication link between military cantonments located at Gauchar (Garhwal) and Gwaldam as well as Pithoragarh (Kumaun). Detailed engineering geological investigations incorporating relevant geotechnical parameters were carried out in order to assess the status of stability of the slope and to design suitable control measures. This landslide has been identified as a circular type of failure. The slide occurred initially in 1986 as a small slope failure above the road. Since then, it gets reactivated almost every year during rains, with proportionate increase in its size. Presently, the entire slope above and below the road up to Pinder river is affected by landslide activity. This has resulted in the sinking of the road stretch of about 450 m length. One can see traces of past roads (at least three in number) below the present one due to repeated sinking process.

Location of study area

The study area, i.e. Harmony landslide falls in the Survey of India (SOI) toposheet No. 53 J/8 and is situated at about 30 km from Karnaprayag (Figure 1). Karnaprayag is a town of religious significance, where the Pindar river joins the Alaknanda river.

The Karnaprayag–Gwaldam Road joins the Delhi–Sri Badrinath Road (NH-58) at Karnaprayag, which is located about 200 km from Rishikesh. Gwaldam is a picturesque hill town nestling in the woods and its salubrious climate attracts many tourists. This town is also connected to Delhi via Kathgodam. The tourist traffic to Badrinath via Gwaldam is also sizeable during the pilgrimage season.

Physiography of slide area

The Harmony landslide is located on a fairly steep slope adjoining Pinder river on its left bank. The village Malla Harmony (elevation 1638 m) is located close to the slide zone. The Pinder after originating from the Pindari glacier, flows from north to south up to Dhaura and then takes a sharp turn towards WNW and joins the Alaknanda at Karnaprayag. The Pinder generally flows through a deep V-shaped valley in its entire course, except at certain locations where the valley is wider due to the presence of older river terraces.
This perennial river with high run-off, steep river-bed gradient and tight V-shaped valley (between 50° and 60°) indicates a young stage of regional geomorphological development. In the slide area, the Pinder flows in a roughly WNW direction close to the toe of the slide on the left bank. Near the slide area, the river has a wide course of more than 50 m, within which the water course keeps shifting from one end of the bank to the other. Close to the toe of the landslide, the river takes an arcuate turn leading to toe erosion (Figure 2).

The landslide is confined to an arcuate depression between two minor spurs running roughly in the E-W direction. The slide extends over a distance of about 450 m along the road level. The general slope is of the order of about 35°–40°, while it becomes comparatively steeper (55°–60°) just above the road and (55°–65°) close to the ridge top. However, the slope below the road level is of the order of 40°–45°. The slide scars are visible as barren patches close to the crown area of the slide. Two streamlets flowing eastwards border the slide area on its flanks. The one flowing on the upstream side has a clear course of flow with water flowing down up to the Pinder river. However, the other shows a breach in its course, with part of water flowing into the slide zone.

**Geological setting of the area**

The Harmony landslide falls in the Garhwal Lesser Himalaya. Regional geology around the Harmony landslide was studied by various workers in the past.

Garhwal Lesser Himalaya is comprised of medium to low grade metamorphic rocks, which occur as nappes/klippen over metamorphosed to unmetamorphosed sedimentary sequence. Though the landslide is mainly restricted to loose debris materials, the adjoining areas are constituted of Chamoli Formation comprising phyllites, quartzitic phyllites, phyllitic quartzites and massive quartzites of Proterozoic age (Figure 3). The debris material seen on the slope was derived due to ancient landslide activities from higher levels. As such, it consists of assorted materials ranging from clay to big boulders. On the surface, debris consisting of rock blocks of varying size embedded within a matrix of fine soil (clay to silt size fraction) is observed. The in situ rock exposures, though not visible on the surface, are present at deeper levels. Three geological cross-sections have been drawn across the slide area (Figure 4 a–c). These sections show the contact between overburden and in situ rocks at depth as an inferred one below the projected level of the failure plane.

**Site observations of Harmony landslide**

The slide materials in the landslide site are mainly debris derived from past landslide activities in the area. On the
northern and southern boundaries of the slide, two small perennial streams are present. During site visits after the rains of 2007, it was observed that the stream on the northern boundary was blocked in the middle level, resulting in water seepage into the slide debris. Seepage of water emerges close to the Karnaprayag–Gwalam Road. Along the slope, several arcuate cracks (open cracks, size between 5 and 10 cm) were observed above the road level. Due to past slope movements, the road was displaced to lower levels within the slide zone. The cut slope adjacent to the road is steep and is more prone to failures, particularly during the monsoon.

**Stability analysis of Harmony landslide**

In case of debris slopes, a strongly defined structural pattern does not exist. Hence the failure surface is free to find the line of least resistance through the slope. This failure generally tends to follow a rotational pattern resembling circular surfaces and is termed as ‘rotational’ or ‘circular’ failure. This pattern of failure has been adopted for stability analysis at the site. In fact, it is a commonly followed pattern around the world.

For detailed stability analysis, three representative sections were prepared (Figure 4) from the geological map. A number of soil samples were collected from the slopes to carry out direct shear test for determining their shear strength (C and Φ). For each section, three samples – one each from the scarp face, main body and just above road level of this slide, were collected. The stability analysis was carried out using circular failure charts (CFCs) as proposed by Hoek and Bray. It is a simplified and rapid analytical technique for stability analysis of circular failure in loose debris or soil type of materials. The possible groundwater conditions can also be incorporated in the analysis.

**Stability analysis using circular failure charts**

For the purpose of stability analysis of soil slopes, a set of five different CFCs were used for different subsurface hydrogeological conditions as given by Hoek and Bray. These hydrogeological conditions are shown in Figure 5. These conditions may correspond to the one observed in field or for predicted conditions, taking into account the type of slope material. The input parameters considered for analysis are slope angle (ψ), height of the slope (H), density of soil (γ), cohesion of soil (C) and angle of internal friction (Φ).

The general slope condition at the site is dry and becomes moist at depth for most part of the year. However it becomes saturated during rains. Since the slope material consists of assorted size fragments with matrix consisting of silty sand mixed with clayey material (70%) along with approximately 30% gravel and small boulders, it can be termed as a moderately drained slope. Hence in case of maximum saturation, the slope is likely to have about 50% subsurface saturation. In view of the above, the analysis has been done for dry, 25% and 50% satura-
tion using chart nos 1–3 respectively (Figure 6) as given in Hoek and Bray.

The analysis involves determination of a dimensionless ratio, which is given as \( C/\gamma H \tan \Phi \). This is used as a basic input for arriving at the factor of safety. Each chart contains the value of the dimensionless ratio on the outer periphery. By locating the exact value, one can follow the radial line up to the corresponding slope angle. From this intersection, by following the vertical and horizontal lines, the values of \( \tan \Phi/F \) on the Y intercept and \( C/\gamma HF \) on the X intercept are found out.

From this intersection, by following the vertical and horizontal lines, the values of \( \tan \Phi/F \) on the Y intercept and \( C/\gamma HF \) on the X intercept are found out. Depending upon the nature of slope-forming materials (cohesive or non-cohesive), one of the above two values is used to obtain \( F \). If the material is cohesive, the value on the X intercept is used, while for non-cohesive material the value on Y intercept is used. For Harmony landslide since the slope materials are a mixture of both cohesive and non-cohesive materials, \( F \) is calculated as the average of the two values.

**Calculation of factor of safety (\( F \)) for selected sections**

As discussed in the previous sections, the matrix of slope materials consists of silty sand mixed with clayey mate-

---

**Figure 4.** Geological section of the slope along section A–A' (a), B–B' (b) and C–C' (c).

**Figure 5.** Groundwater flow conditions used in circular failure charts (after Hoek and Bray).
rial (70%) containing approximately 30% gravel and small boulders. $F$ has been calculated for all three sections (Figure 2). The input data used in the analysis are presented in Table 1.

**Factor of safety for section A–A’**

Based on the input parameters $F$ has been calculated for dry, 25% and 50% saturation conditions. According to the existing condition, the $F$ value of slope along this section is 0.92, 0.79 and 0.68 for dry, 25% and 50% saturation conditions respectively (Table 2). The geological cross-section A–A’ is shown in Figure 4a.

**Factor of safety for section B–B’**

Slided material: Fine sand and clay-dominated. The boulder percentage is 40. Geology along the section is shown in Figure 4b.

By following the procedure as given for section A–A’, the $F$ value has been calculated for dry, 25% and 50% saturation conditions. According to the existing condition, $F$ value of slope along this section is 1.21, 0.89 and 0.76 for dry, 25% and 50% saturation conditions respectively (Table 2).

**Factor of safety for section C–C’**

Slided material: Fine sand and clay-dominated. The boulder percentage is 30. Geology along the section is shown in Figure 4c.

Again, by following the procedure as given for section A–A’, $F$ value has been calculated for dry, 25% and 50% saturation conditions. According to existing condition, $F$ value of slope along this section is 1.04, 0.83 and 0.68 for dry, 25% and 50% saturation conditions respectively (Table 2).

**Factor of safety for overall slope**

After averaging the $F$ values for all three sections (i.e. A–A’, B–B’, and C–C’), the overall $F$ value is 1.06 for dry condition.

**Discussion**

Stability analysis of Harmony landslide for three selected sections has been carried out using CFCs. The $F$ value obtained under dry condition varies between 0.92 and 1.21, with an average of 1.06. The analysis indicates that the slope is critically stable under dry condition. However, when rainfall occurs, the saturation of the slope may be of the order of 25–50%. Accordingly, stability analysis...
has been carried out for water-saturated conditions of 25–50%. The $F$ value obtained under 25% saturation varies from 0.79 to 0.89%, with an average of 0.84. Similarly, the $F$ value obtained under 50% saturation varies from 0.68 to 0.76, with an average of 0.71. Hence the analysis indicates that the subsurface water saturation may cause unstable slope conditions. A perusal of the results of stability analysis indicates that the slope is critically stable under dry condition. However, it becomes unstable on water saturation. This result corroborates with the observed field conditions that during rains the slope becomes unstable and fails every year.

### Control measures

From the stability analysis and field observations, it is clear that the slopes are unstable and are still in active state of instability. Even newly constructed houses just above the crown show cracks on the walls. Several prominent open-ground cracks are seen in the upper parts of the slide area as well as on the slopes close to the road. The field investigations reveal that the toe erosion of the slope by the Pinder river is a significant factor in inducing instability. Taking into consideration the nature of instability, type of slope materials and slope geometry, a set of control measures as suggested below may help improve the overall stability of the slopes (Figure 7).

- **Along the left bank of the Pinder river, two rows of concrete cubes (size: 1 m × 1 m × 1 m) be placed one over the other at the toe of the slide, mainly to prevent river erosion.**
- **Further above two rows of wirecrated gabion walls be constructed to provide effective toe support for slope materials below the road.**
- **The Karnaprayag–Gwaldam Road may be widened to about 8 m (generally 6 m in adjoining stretches) to facilitate locating toe drains on the hill side of the slope.**
- **On the valley side, the road shall be excavated to a suitable depth and two rows of drum-filled retaining walls may be placed. The individual drums may be tied to each other.**
- **The slope above the road be re-graded to an angle of 35°. For that purpose individual cut slopes with a vertical height of about 1.5 m and a bench width of about 2 m be excavated. The regraded slope will be more stable with an improved factor of safety of 1.5.**
- **On the hill side road-cut slope (unstable as indicated in analysis), toe support may be provided by constructing two rows of gabion walls (each 1.5 m height and 1 m width).**
- **The slope materials excavated from above the road be dumped behind the gabion wall and compacted well.**
- **A 50 cm wide and 60 cm deep lined drain be constructed at the toe of the gabion wall with gradient of 25 : 1.**
- **Lining of northern and southern streams located on the fringe of the slide may be helpful to prevent subsurface seepage.**
- **Grass turfing of barren slopes be done to prevent ingress of rainwater into the slope. Fast-growing plants and tree species be planted to provide resistance to surface erosion.**
The arcuate cracks be filled with silty clay or locally available fine-grained matrix.

During rains excessive seepage at road level takes place. Subsurface water can be tapped by inserting perforated pipes inclined downwards above the road and the tapped water can be drained into the lined drains located on the hill side end of the road.

Conclusion

The Harmony landslide is important, as it often blocks the strategically significant Karnaprayag–Gwaldam Road. The slide was initiated on the thick slope debris due to toe-cutting by the Pinder river. It gradually attained huge dimension over the years since 1986. The slide is a rotational failure which progresses further up with every passing year. The stability analysis of the slope has been carried out using CFCs of Hoek and Bray\(^6\) after obtaining shear-strength parameters of slope materials. The analysis indicates that the slope is critically stable under dry condition \((F = 1.06)\) and becomes unstable on water saturation \((F = 0.84\) and \(0.71\) under \(25\%\) and \(5\%\) saturation condition). Taking into consideration the nature of instability, type of slope materials and slope geometry, a set of control measures have been suggested to improve the overall stability and geoenvironmental balance of the area.


Received 3 September 2007; revised accepted 11 April 2008