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A Field Study on the Stability of Road Cut Slopes in Nepal

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Abstract

The density of Nepal's road network has more than tripled in the last three decades. This growth has been rapid, extensive and in places haphazard, occurring on both the local and strategic road networks, and has resulted in the widespread failure of road cut slopes throughout Nepal. To further understand this effect, field assessments were carried out along roads of different governing grade in Nepal, focusing on the stability of cut slopes and effectiveness of stabilisation measures adopted. This paper summarises the key findings of this study. Although there are multiple guidelines from the Government of Nepal with recommendations on the design and construction of road cut slopes and stabilisation measures, the cut slopes were commonly found to be excavated to steeper inclinations than advised in these guidelines. The cut slopes that were steeper than the advised inclination remained stable before the monsoon, but often failed during the monsoon season due to rainwater infiltration that leads to dissipation of soil suction. Field observations also revealed that the roadside drainage was either not implemented or was blocked. The retaining walls were found to be designed to the same geometry, despite differences in cutting heights and slope materials. This resulted in overturning, bulging, and cracking of the walls. Based on the findings of this study, it is clear that to build resilient road infrastructure in Nepal, the road cuttings need to be excavated according to rigorous engineering guidelines, and standards for the practice of quality assurance need to be implemented.

Keywords: Slope Stability, Road cuttings, Nepal, Retaining Walls, Suction

1. Introduction

Roads are essential to the economic and societal development of a country (Sudmeier-Rieux et al., 2019). They provide critical infrastructure for the domestic and international transportation for goods over-land. They are also fundamental for the connectivity of people, providing one of the main means for people to access jobs and services (including hospitals and schools). In addition, road infrastructure offers employment through construction and maintenance, as well as in the transportation sector. For these reasons, the expansion of road networks is a priority for many low and lower-middle income countries' (LIC/LMICs) governments, including Nepal (Sudmeier-Rieux et al., 2019).

When roads are constructed, they often require excavation into the ground creating a cut slope. In hilly terrain, cut slopes generally take one of three profiles (Hearn, 2011): (1) full-cut, where the entire width of the road is generated through excavating into the hill; (2) part-cut/part-fill, where part of the road width is attributed to excavating the hillslope and part is the compaction of fill; and (3) full-fill, where the whole width of the road is on compacted fill and no excavation has taken place. Hearn (2011) identifies that the full-cut slope profile is generally much cheaper to construct than the alternatives in stable terrain as it minimises the need for compaction and removes the need for fill retaining walls.

Cuttings are generally excavated to a certain angle, based on the strength of their geomaterial, for stability. Lower angles are more stable but require greater volumes of excavation, and hence greater cost. Drainage can be implemented to control the groundwater in the cutting, preventing excess pore water pressure build up when the ground becomes saturated, which would reduce the strength of the cutting and, thereby, reduce the resisting forces on the cutting. Where additional stability is required, stabilisation measures are implemented (e.g. retaining wall, anchors or ground improvement). In most cases they act to increase the resisting forces of the slope. Slope stabilisation measures vary in typology, materials employed and cost, with their suitability depending on the geology, geometry, and hydrology of the slope. The slope stabilisation measures employed also strongly depend on the space constraints of the cutting, the economic importance of the road (i.e. daily vehicle rate and whether the road is a key goods or commuting route) and available budget.

Different countries have different protocols and standards to determine the most appropriate angle of a cutting and the most appropriate stabilisation measure for a cutting. In general, the cutting should be characterised according to its geomaterial and hydrological conditions through ground investigation. Designing slope stabilisation involves carrying out a stability analysis. Alternatively, guidelines can be followed which set out the appropriate action given characteristics of a cutting. However, guidelines vary in rigor and usability. It is important to design road cuttings to be stable, and hence resilient under the climatic conditions it may endure annually, and with a changing climate.

Despite the significant allocation of government and donor agency spending on road building, frequent cutting instabilities still occur globally, but especially in countries that host steep landscapes and that experience prolonged or intense rainfall (Hearn et al., 2017). In many LIC/LMICs, a lack of resources, weak design standards and challenging environments can result in the poor design and implementation of road cuttings and slope stabilisation, exacerbating the natural susceptibility of slope failure, resulting in widespread cutting failures along road networks every year (Hearn et al., 2017; Robson et al., 2020). According to Hearn (2011), 70% of slope failures on mountain roads are shallow instabilities in cuttings rather than larger 'natural' landslides.

This paper presents the findings of field assessments of road cuttings (full-cut) and stabilisation measures along roads of different governing grades in Nepal. We explore whether guidance set out in manuals in Nepal are being followed and what the key issues leading to instability may be. We finish by outlining some suggestions for improving the stability and hence the resilience of road cuttings in Nepal based on our findings.

2. Nepal background

2.1 Landslides

Nepal is situated in the Himalayan region, and its physical geography can be split into three well-defined regions forming belts: the mountains, the hills, and the Terai (Plains). Nepal receives about 80% of its rainfall during the monsoon season from June to September (Shakya & Nirula, 2008). The Himalayan arc experiences tectonic-induced uplifting and water-based down-wasting resulting in natural susceptibility to landslides. Froude & Petley (2018) determine that 10% of rainfall-triggered fatal landslides in the global database were recorded in Nepal, which is significant given that the population of Nepal is 0.4% of the global population.

2.2 Road building

The Department of Roads (DoR) is the central governing body for roads in Nepal and is responsible for the Strategic Road Network which includes national highways and strategic roads. The provincial and local governments are responsible for the Local Road Network (LRN). The LRN makes up 80% of the total road network in Nepal and comprises feeder roads that connect national highways, as well as local roads. The Department of Local Infrastructure (DoLI) provides technical support to the provincial governments.

Road building to improve the connectivity of settlements has been a priority of the Government of Nepal for at least the last three decades (Sudmeier-Rieux et al., 2019). The density of Nepal's road network more than tripled between 1990 and 2016 (from 0.14 to 0.50 km/km^2, DoR, 2017). According to the 'Nepal Economic Outlook 2018/19' (Regmi, et al. 2019), the 2017/18 Fiscal Year saw the greatest construction of new roads over the previous five years, from 27,496 km new roads being constructed in 2014/15 to 30,088 km new roads constructed in 2017/18. This expansion is set to continue as the Government of Nepal (2017) "Sustainable Development Goals" report outlined that they aim to increase Nepal's road density to 1.3 km per km^2 by 2030 (in 2015 it was 0.55 km per km^2). This growth is occurring on both the strategic and local road networks, in addition to undocumented informal roads (Hearn et al., 2017, Shakya & Nirula, 2008). This growth in the road network is amplifying the natural susceptibility of slope failure in Nepal, due to its rapid and haphazard nature (Froude & Petley, 2018).

2.3 Standards

Nepal has three key road manuals:

- 'Nepal road standards 2070' (DoR, 2013) is for strategic roads being constructed in rural areas of Nepal. It presents one table of cut slope gradients for soil, disintegrated rock, and soft to hard rock. The standards in this manual are mandatory, and authorities should check design and construction for compliance.

● 'Roadside Geotechnical Problems: A practical guide to their solution' (DoR, 2007) presents eight separate tables, from various sources, for cutting inclinations based on different rock characteristics. It also presents guidance on the construction criteria for retaining walls. This guidelines in this manual are advisory.

● 'Guide to road slope protection works' (DoR, 2003) provides protocol and guidelines for off-road maintenance including road cutting. It presents cutting inclinations for hard and soft rock, and soil. This guidelines in this manual are advisory.

DoR (2003) suggest that the inclinations for cuttings in hard and soft rocks should be 51-73° and 40-63°, respectively. This contradicts the guidance given by the DoR (2007), where inclinations for highly weathered rock are recommended to be as low as 35°. DoR (2003) and DoR (2007) recommend a maximum 51° (1V:0.8H) standard slope gradient for any cut slopes in soil, whilst DoR (2013) recommends a maximum of 45° for soil.

3. Methodology

Roads of different governing grades in Nepal were surveyed from 2017 to 2019 (see Figure 1 for map of road locations). Field visits were conducted in October and December 2017 (during the dry season), as well as in August 2018, during the monsoon season, on the following road:

● **Listikot to Daklang local road** in the Upper Bhotekoshi region (Sindhupalchok district). This is a 13.7 km stretch of district road connecting local villages to the Araniko highway, which is a major trade route linking Kathmandu to the Chinese border at Kodari. This road was being widened by hillslope excavation using heavy equipment in the dry season of 2017/2018.

A field visit took place in November 2019 (during the dry season) and the following four roads were surveyed:

● **Narayanghat to Mugling strategic road** in the district of Chitwan. This road is on the India to Kathmandu goods transport route. The road was originally excavated around 45 years ago using blasting. The road was widened in 2015, however there were several landslides during the 2016 and 2017 monsoon seasons. Several cuttings along the route were being re-stabilised with funding from the World Bank. The World Bank had spent $99 million on it from 2015-2019 (personal communications in 2019).

● **Madan Bhandari national highway** connecting the east-west of Nepal. A 30 km stretch from the east of Hetauda to the Bagmati river was visited (in the Makwanpur District). At the time of visiting the road was under construction with funding from the Government of Nepal. Around $120 million had been spent on the project at the time of visiting (personal communications in 2019).

● **Two feeder roads connecting Kulekhani (Makwanpur District) and Pharping (Kathmandu District)**: (1) via Sisneri and (2) via Fakhel. Both roads were constructed in 2005 and were widened from single to double lane around 10 years after construction. A new phase of stabilisation works was planned for 2020.

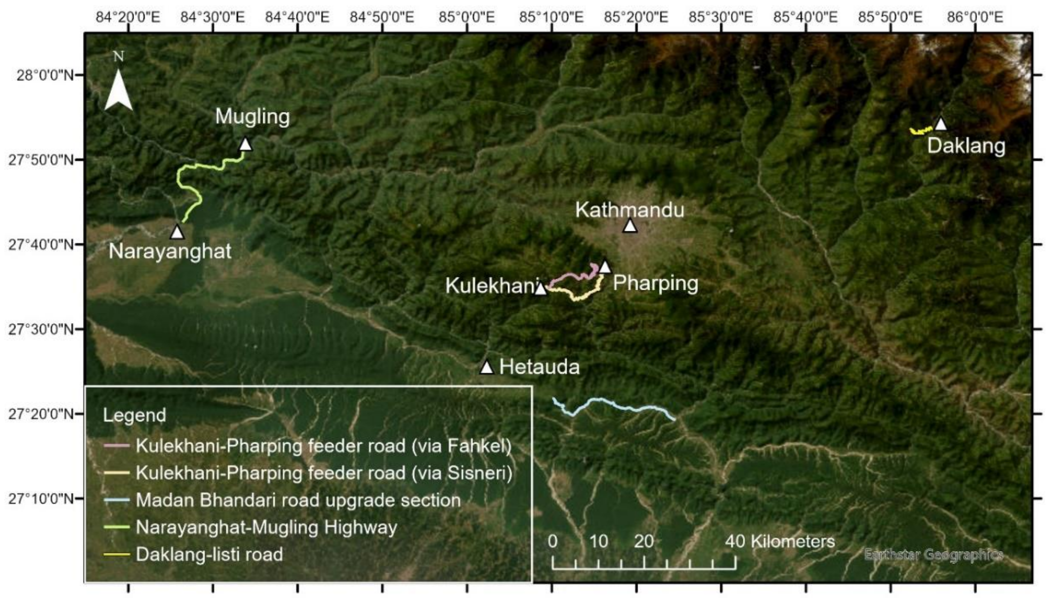

Figure 1: Map displaying location of roads surveyed in study.

At different localities along these roads, physical assessments were carried out on cutting failures. Information related to slope failures, signs of seepage, road cut angles, road cut heights and slope protection measures were recorded on survey forms. In addition, at every site, information on the location, features, mechanism, triggering factors, activity state, geology, hydrology, land cover/land use and any slope protection measures (if present) were recorded. A hand-held GPS was used to mark the location of the landslides. Cutting heights were estimated based on direct measurements using a measuring tape and/or laser distance meter. The depth of the landslide scarp was measured similarly. However, where access was deemed unsafe, the scarp depths were estimated from the road. A compass clinometer was used to measure the inclination and orientation of the slope, as well as the dip and strike of any geological features. Information of the geology and hydrology of the cutting and surrounding area were taken with careful field observation.

During the field visits in 2017/2018, field assessments were carried out in two phases along the Daklang-Listi Road: first, during the dry period (October/December 2017) to understand the immediate effects of road widening on the slope stability and second during the monsoon in August 2018 to assess the roadside slope failures triggered by heavy monsoonal rainfall. In the dry period (December 2017) 16 failures were recorded. In August, 117 cutting failures were recorded and surveyed in total.

During the field visit in November 2019, 34 site assessments were made: 7 on the Narayanghat-Mugling Road, 8 along the Madan Bhandari, 10 along the Kulekhani-Pharping via Sisneri and 9 along the Kulekhani-Pharping via Fakhel.

4. Results

4.1 Cut slope inclinations

107 of the cut slope failures examined along the Daklang-Listi Road were made up of soil (colluvium, talus, weathered soil, or other) whilst 10 were made up of rock. The cuttings along this road varied from 1-12 m in height. Of the field sites surveyed in 2019, 5 were made up of soil (clay or colluvium) and 29 were made up of rock. These cutting heights ranged from 5 to 50 m. During the field surveys in 2017 (along the Daklang-Listi Road), several of the soil road cuttings were found to be excavated at steeper cut angles than the recommended inclination from DoR (2003), 51°. At the end of the monsoon season in 2018 over 58% of the cut slope failures recorded along the Daklang-Listi Road occurred at locations where the cut slope angle was greater than 51°. All of the soil cuttings recorded in 2019 were at inclinations greater than 51°, ranging from 60-80°. Figure 2 displays the cut slope angles for all soil cutting sites assessed.

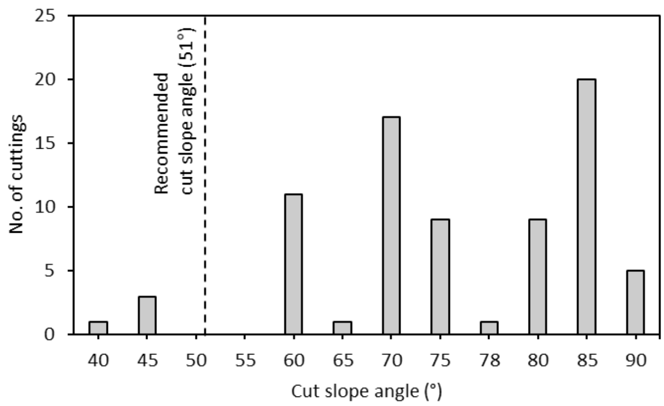

Figure 2: Cut slope angles for all soil cutting sites assessed. 51° is the maximum recommended soil cut slope angle from DoR (2003).

The DoR (2003) guidelines for cutting gradients state that hard rock should be between 34° to 73° for cutting heights up to 15 m. Of the 9 cuttings made up of hard rock of ≤15 m height surveyed, 3 were inclined to a greater angle than 73°. DoR (2007) present a table for cuttings of rock mass without structural control (Table C3.6). This table (in DoR, 2007) suggests that a cutting made up of phyllite which is blocky with no dominant structural orientation can have an inclination of 35-60°. Out of the 15 cuttings made up of phyllite recorded, 9 were inclined at a higher inclination than 60°.

Out of the 117 sites recorded along the Daklang-Listi Road, 100 had no stabilisation measures implemented. There were also multiple cuttings along the feeder roads connecting Kulekhani to Pharping and along the Madan Bhandari Road that had no stabilisation measures implemented.

4.2 The state of stabilisation measures

Where stabilisation measures were implemented, multiple examples had partially/fully failed during the previous monsoon season. Conversations with local residents revealed that failure occurred year on year during the monsoon season, with reconstruction occurring during the dry season.

Gabion walls were present along all of the roads surveyed. They are used as a low-cost stabilisation option as they can be built with material sourced locally using low skilled labourers and do not require any specialist equipment. The benefits of using gabion walls are that they are free draining and can accommodate settlement. However, the effectiveness of gabion walls can be compromised if inappropriate rocks (weathered or well-rounded) are used (Hearn, 2011). Deformation of the gabion baskets (bulging at the front) was observed at many of the sites. Figure 3 displays two sites where the gabion walls were ineffective. Figure 3a is on the Daklang-Listi Road. Seepage can be observed within the wall and there is no drainage implemented. Figure 3b is on the Kulekhani-Pharping Road showing overturning of the gabion wall and no drainage. DoR (2007) states that gabion walls up to 3 m in height can be designed by rule of thumb. There is no information in these guidelines on designing the height of a wall based on the height of a cutting.

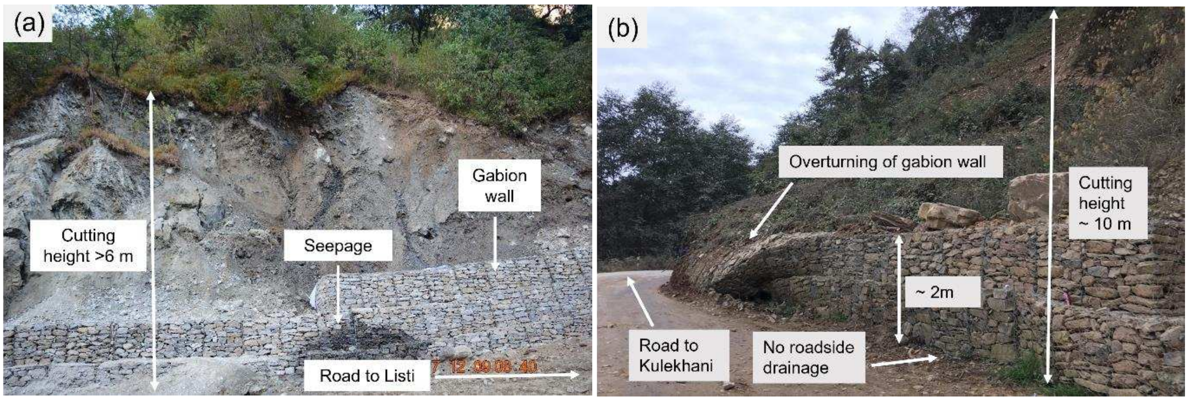

Figure 3: Examples of ineffective gabion walls on the: (a) Daklang-Listi Road and (b) Kulekhani-Pharping Road.

Mortared masonry walls were also present along each of the roads visited. They are another low-cost measure as they can be built with locally sourced material. Mortared masonry walls cannot withstand variable foundation settlement. During the field visits, it was observed that the masonry walls were constructed at a very similar geometry, despite the differences in slope geomaterial and geometry. Weep holes were present in most walls, spaced 0.5 m apart in both directions. However, they were often blocked. DoR (2007) state that cement masonry walls can be 1 to 8 m in height, with a base width of 0.25 times the height and a top width of 0.5 m. They state that mortared masonry walls up to 3 m in height can be designed by rule of thumb. Figure 4 shows an image of a mortared masonry wall at a cutting visited along the Madan Bhandari Road built to the common geometry observed. At this site, the collapse of loose debris had blocked the roadside drainage. Many of the weep holes within the wall were blocked. Seepage could also be observed on the surface of the cutting.

Figure 4: Example of an ineffective mortared masonry wall on the Madan Bhandari Road.

Reinforced concrete walls are generally more durable than gabion and mortared masonry walls. As with mortared masonry walls, they are unable to withstand variable foundation settlement without cracking or tilting. The reinforced walls observed generally were around 2-3 m in height. However, they often lacked backfill and stood away from the slope face. Reinforced concrete walls were only recorded along the Narayanghat-Mugling Road and the Kulekhani-Pharping Road.

Ground anchors were observed at two sites along the Narayanghat-Mugling Road. The anchor arrangement should be designed by taking into account the geology of the slope, and the manufacturers guidelines should be consulted in the design. Restraining mesh was also implemented at these sites.

Only 7 of the 117 cutting failures recorded along the Daklang-Listi Road had roadside drainage. All of these were blocked. 14 of the 34 cuttings recorded in 2019 had roadside drainage. Out of these, 13 were found to be clogged or blocked by landslide debris or vegetation.

5. Discussion

Along all the roads surveyed, cut slope inclinations were found to be steeper than the recommended standards produced by the DoR. This indicates that either engineers are not designing cuttings according to these standards, and/or designs are not followed during excavation. There are several reasons why the guidelines may not be followed including engineers not being aware of the guidelines, engineers not trained in how to use the guidelines, the guidelines not being user-friendly or a lack of trust in the guidelines. Robson (2022) suggest that the road cutting guidelines in Nepal are not user-friendly and lack rigor. If the designs are not followed by construction teams it indicates that quality assurance is not implemented.

Surveying cut slope stability along the Daklang-Listi Road during and after the monsoon season allowed us to observe the effect that suction has on the stability of a slope (100 cutting failures were triggered in the monsoon season). The cut slopes were excavated during the dry season. During this period, suction would have been present in soil which allows steeply excavated slopes to remain stable for an extended period. However, during the monsoon season rainwater infiltrates into the ground and suction in soil gradually dissipates. This reduces the shear strength of the soil causing failure.

It is also worth noting that the maximum recommended road cut soil slope angle of 51° is much higher than the typical angle of shearing resistance of the colluvial materials found in this area, 25° to 45° (ICIMOD, 1991, Pradhan et al. 2022). Therefore, in the absence of suction, soil slopes inclined at 51° can be susceptible to failure.

Due to budget constraints, measures that have lower construction costs, like gabion walls and mortared masonry walls, are highly common, and were found along all road types. More costly stabilisation measures like reinforced concrete walls and anchoring systems are only adopted along strategic roads, where budgets are greater. This is justifiable as the consequence of failure is greater on strategic roads as they are heavily trafficked and act as key goods transportation routes.

The field study revealed that mortared masonry walls and concrete walls were not built to standard geometry, despite differences in cutting height and material. They were often found to have failed through overturning or collapse. Gabion walls were found to be bulging and/or overturning. DoR (2007) states that retaining walls can be built by rule of thumb if they are <3 m and does not give any advice on designing the size of the wall according to the height of the cutting.

Another finding of this field study is that there is a general lack of maintenance in road slope stabilisation measures; roadside drainage and weep holes were often blocked, resulting in a build up of seepage in the cutting slopes. Multiple walls were also cracked.

6. Conclusions and recommendations

This paper presents the findings of field assessments carried out on cuttings and slope stabilisation measures along roads of different governing grade in Nepal. Through reviewing cut slope gradients before and during a monsoon season, it was found that soil slopes that were stable prior to the monsoon season would fail with the onset of heavy rain resulting in positive pore pressures. Local residents stated that stabilisation measures that were implemented during the dry season, would fail during the following monsoon season. Cuttings were commonly found to be steeper than recommended in guidelines. Retaining walls were found to be constructed to a common geometry, despite the differences in slope material and cutting heights.

Based on these findings we recommend that the cutting inclinations guidelines are revised so that they include more options for material types and are user-friendly for engineers. Retaining wall guidance should also be updated in the manuals to discourage the use of designing walls to a common geometry. Training should be carried out with engineers across the country in the use of the revised manuals.

We also recommend that standards for quality assurance are implemented in protocols to ensure that construction is carried out according to design. Regular maintenance should also be implemented to unblock and reinstate drains.

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