Influence of Topography and Geological Structures on Road-Cut Failures in Central Highlands, Sri Lanka

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ABSTRACT: The geometric relationship between foliation or bedding planes of rock and topographical slope is a critical factor in determining slope stability of road-cuts. Under this study, an attempt was made to classify the attitudes of topography with respect to the geological structures to define susceptible classes for road-cut failures. Strike and dip of bedrock foliation, topographic slope angle and direction were measured at 136 road-cut failures along some selected roads in the Central Highlands. Deviation and apparent dip angles were calculated at each site to classify topography into over-dip, under-dip, steepened escarpment, and subdued escarpment. It was noted that road-cut failures are slightly higher in dip slopes than in scarp slopes and are rare in intermediate slopes. The 0^0 to 10^0 range of deviation angle is highly unstable in road construction and widening. Road-cuts in under-dip and subdued escarpment conditions are more favorable to failure than those in over-dip and steepened escarpment conditions. Road-cuts in slope angle range of 21^0 to 30^0 have a higher susceptibility to failure than in other ranges. Road-cut failures are rare in locations where slope angles are greater than 40^0 in dip slopes and less than 11^0 in scarp slopes.

1 INTRODUCTION

The free-way road network in the Central Highlands of Sri Lanka is extensively used to link the area with the rest of the country fulfilling public and commercial transportation needs, and hence it is rapidly developing. However, frequent road-cut failures especially in newly developed roads cause serious traffic disruption, and pose a danger to life, property and the environment. Such failures typically occur, when a natural slope is steep or a cut slope in soil and/or weathered rock contains weak materials or adverse slip surfaces (www.era.gov.et/Portals/0/three.pdf).

The Central Highlands is mainly underlain by well foliated, banded and highly jointed metamorphic rock formations (Cooray, 1974, 1984). Such terrains are highly susceptible to failure along their natural planes of weakness. Geometric relationship between topography and geological structure influence mass wasting (Freeze and Cherry, 1979; Selby, 1993). This is particularly evident where geological structure is characterized by penetrative discontinuities such as schistosity (foliation in hard rocks) (Sander, 1970; Cruden, 1989). The purpose of the present exercise is to understand the importance and the role of geological structures (strike and dip of foliation planes) and topographic attributes (slope direction and slope angle) in the development of road-cut failures.

2 METHODS OF STUDY

Field studies were done at 136 road-cut failure sites along major roads such as Kandy-Colombo, Kandy-Mahiyangana, Kandy-Nuwara Eliya, Kandy-Randenigala, Nuwaraeliya-Badulla, Peradeniya-Katugastota and minor roads such as Galigamuwa-Kiridana, Aranayaka-Debathgama in different parts of the Central Highlands of Sri Lanka. Structural attitudes of bedrock (Strike and dip of foliation planes) and attitudes of topographical slopes (slope directions and angles of topographic surfaces) at the particular locations was measured using Brunton compass.

2.1 Calculations of topographic parameters

2.1.1 Deviation angle (b)

It is defined as the horizontal angle between the azimuth (compass direction in degrees from North) of the slope direction (A; $0\text{-}360^0$) and the azimuth of the dip direction (α; $0\text{-}360^0$). The resulting deviation angle will vary in magnitude between zero to 180 degrees (NBRO Manual, 1995). Deviation angles were calculated for all the locations.

2.1.2 Apparent Dip (β)

Measurement of the inclination of the geological surface along the slope direction is termed as *apparent dip*. It can be expressed as,

$\tan\beta = (\tan\theta) * (\cos b)$ (1)

Where β is the apparent dip, θ is the true dip and b is the deviation angle (Jayathissa et al., 2009).

Apparent dips were calculated for all the locations using Eq. (1).

2.2 Classifications of topography

2.2.1 Classification based on deviation angle

Slopes are classified into Dip, Intermediate, and Scarp types based on deviation angle ranges. If the deviation angle range is 0 ± 60^0, dip slopes occur. Scarp slopes occur when deviation angle range is 180 ± 60^0. Intermediate slopes occur if the deviation angle is 90 ± 30^0 or 270 ± 30^0 (NBRO Manual, 1995). Number and percentage of failures in different slope divisions and types were calculated.

2.2.2 Classification based on apparent dip

Deviation angle does not provide integrating the influence of vertical changes of structural attitudes (dip angle). By calculating apparent dip, morphological slopes are divided mainly into two groups: dip slopes and scarp (reverse) slopes. Here, both deviation angle in the horizontal plane and dip angle in vertical plane are considered. Categories of the horizontal plane are fixed to two directions, exactly to dip and scarp slopes, and vertical angles are divided into different ranges (Jayathissa et al., 2009).

Apparent dip angle is varying from -90 to +90 degrees. Positive values represent the dip slopes whereas negative values represent the scarp slopes. Dip slope and scarp slope are further divided based on alignment between dip of the geological surface and topographic slope. Dip slopes which are steeper than the dip of the geological surface are referred to as over-dip slopes. Dip slopes that are less steep than the dip of the geological surface are under-dip slopes. Scarp slopes are divided into (a) steepened or (b) subdued escarpments depending on slope inclination exceed or subdued (Meetemeyer and Moody, 2000) (Fig. 1). Number and percentage of road-cut failures were calculated for all slope types.

2.2.3 Classification based on ground slope angle

Using ground slope angle (s), the topography is classified into seven slope ranges as (0^0-10°), (11^0-20°), (21° - 30°), (31° - 40 °), (41 ° - 50 °), >50°.

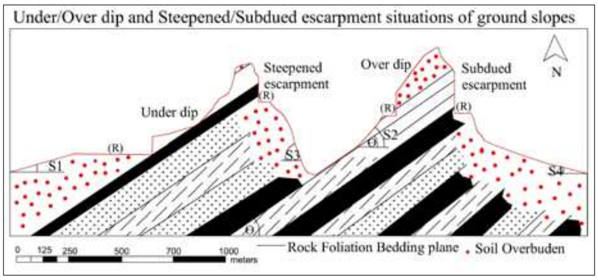

Fig. 1 Under-dip ($s_1<\theta$), over-dip ($s_2>\theta$), steepened escarpment ($s_3>\theta$), and subdued escarpment ($s_4<\theta$) situations of ground slopes relative to rock foliation at road cuts (r) (Jayathissa et al., 2009).

3 RESULTS AND DISCUSSION

Table 1. Number and percentage of road-cut failures in different deviation angle ranges

Deviation angle range (degree)	No of road-cut failures	Percentage of road-cut failures (%)
0-10	24	17.6
11-20	12	8.8
21-30	12	8.8
31-40	6	4.4
41-50	6	4.4
51-60	5	3.7
61-70	5	2.2
71-80	3	1.5
81-90	2	1.5
91-100	2	1.5
101-110	0	0
111-120	4	2.9
121-130	11	8.1
131-140	6	4.4
141-150	4	2.9
151-160	11	8.1
161-170	14	10.3
171-180	12	8.8

Fig. 2 Percentage of road-cut failures Vs deviation angle ranges (degree)

The highest percentage of road-cut failures was recorded when deviation angle is in the range of 0^0 to 10^0. Table 1 and Fig. 2 show that such failures decrease with increasing the deviation angle up to 110^0 whereas failures has tendency to increase again in deviation angle between 121^0 to180^0. It is also indicated that this angle range of 61^0 to120^0 shows a minimum number of road-cut failures.

Table 2. Variation of road-cut failures with classification of topography based on deviation angle classes

Deviation angle range	Type of slope	No. of road-cut failures	Percentage road-cut failures (%)
0^o-60^o	Dip	65	47.8
61^o-120^o	Intermediate	13	9.6
121^o-180^o	Scarp	58	42.6

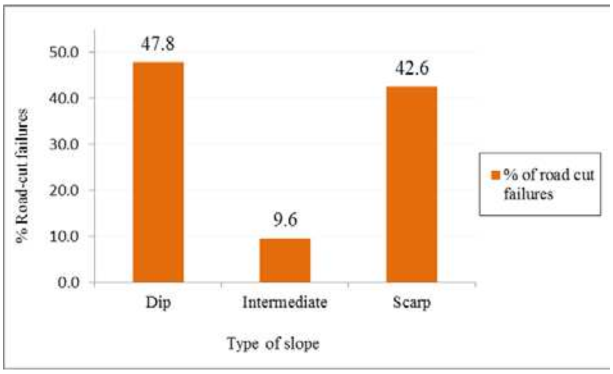

Fig. 3 Percentage of road-cut failures Vs type of slope (classification based on *deviation angle*)

According to calculations of Table 2, percentage of road-cut failures is considerably higher in both dip and scarp slopes than intermediate slopes. Failures are slightly higher in dip slopes than that in scarp slopes. Failures are rare in intermediate slopes (Fig. 03).

Road excavations in dip slopes may remove enough support to allow large chunks of rock and soil to slide into the road (Maerz, 2000). Poorly consolidated weathered residual material is lying as a thin cover above solid unweathered bed rock in such slopes (Dahanayake, 1994, 1995; NBRO Manual, 1995). For that reason, road-cut failures are easily occurred along well defined slip surfaces in dip slopes. Slip surfaces are may be along contact between bedrock and thin residual soil layer or along foliation planes. In such a situation, translational type road-cut failures can easily occur along the slip surface.

Scarp slopes often have thick accumulations of colluvium (NBRO Manual, 1995). As a result, the weak overburden is totally or partially exposed in road-cuts. Rotational type failures are easily occurred due to loss of toe support and higher thickness of colluvial layer.

Failures are rare in intermediate slopes due to less well defined slip surfaces toward the slope direction and thin overburden.

Table 3. Classification of topography based on apparent dip

Type of slope		No of road-cut failures	% of road-cut failures
Dip	Under dip	53	39.0
	Over dip	19	14.0
Scarp	Steepened escarpment	28	20.6
	Subdued escarpment	36	26.5

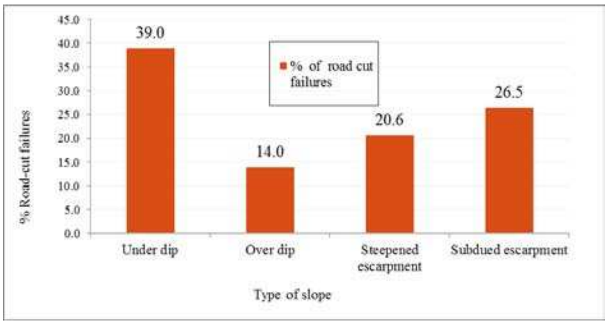

Fig. 4 Percentage of road-cut failures vs type of slope

According to Table 3, failures in under-dip slopes are higher than those in over-dip slopes. Fig. 4 shows that percentage of road-cut failures in subdued escarpments is higher than that of in steepened escarpments. Cooray in 1984 reported a contrary view to this observation. However, his work was not based on road-cut failures but on landslides.

Table 4. Variation of road-cut failures with classification of topography based on ground slope angle

Slope range	Dip slope		Scarp slope	
	No of road-cut failures	% road-cut failures	No of road-cut failures	% road-cut failures
0^0 –10^0	13	18.1	4	6.3
11^0 –20^0	12	16.7	16	25.0
21^0 –30^0	29	40.3	20	31.3
31^0 –40^0	15	20.8	17	26.6
41^0 –50^0	3	4.2	5	7.8
51^0 –60^0	0	0.0	2	3.1

According to Table 4, there is an increasing trend of failures in the slope angle range of 0^0 to 30^0 and then decreasing trend with the increase of slope angle in both the dip and scarp slopes. The highest failures were recorded in the slope category (21^0 -30^0) in both the slope types (Fig. 5). This diagram indicates that failures are rare in locations where slope angles are greater than 40^0 in dip slopes and less than 11^0 in scarp slopes.

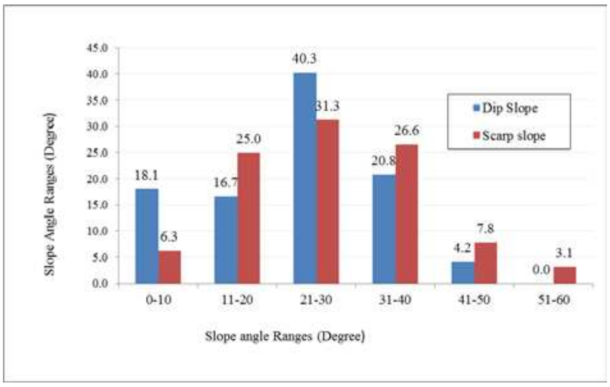

Fig. 5 Percentage of road-cut failures vs slope angle ranges (degree)

A relatively steeper slope, tangential component of gravity increases and perpendicular component of gravity decreases. The tangential component of gravity causes a shear stress parallel to the slope that pulls the object in the down-slope direction. Thus, down-slope movement is favored by steeper slope angles (Nelson, 2013). As a result, road-cut failures supposed to be increased with increasing slope angle. However, thick soil overburden in steeper slopes is less favor. Thickness of soil overburden in slope angle range of 21^0 to 30^0 is highest. Bedrocks or thin overburden are often exposed in such steeper slopes, cliffs, and escarpments. Consequently, bedrocks are commonly exposed at toe of the road-cuts and behave as a toe support. For that reason, rock falls are common whereas earth slips are rare in steeper slopes.

4 CONCLUSIONS

Based on the results of the present study, the following conclusions about the road-cut failures in the Central Highlands of Sri Lanka are made.

- Road-cuts in the deviation angle range of 0^0 to 10^0 are highly unstable.
- Dip slopes have a higher tendency to failure than scarp slopes whereas those in intermediate slopes are relatively safe.
- Under-dip slopes are more susceptible to failure than over-dip slopes.
- Subdued slopes are more favorable to failure than steepened slopes.
- Road-cuts in slope angle range of 21^0 to 30^0 have a higher susceptibility to failure than in other ranges.

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