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Identification and Location of Slide Prone Areas in Certain Hard Rock Profiles of Western Ghats

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Introduction

The stability of rock slopes along highway is severe in many parts of the Western Ghats. The problem is acute during monsoons in Idukki district of Kerala State (Fig. 1). Geomorphology of the region is controlled by active erosion along the drainage systems of Periyar and Manimala river and their tributaries. The highway connecting Kottayam in the midland region and Kumily in the east bordering Tamilnadu State stretches for about 110 kms. This is a vital communication artery for transport of hill produce and developmental projects of Kerala State. The stability of hill slopes along this highway has been studied in detail (Fig. 1). Many highway cuttings are hazardous and failure is frequent especially after heavy rain storms. A typical hard rock profile which is identified as slide prone is the Peermade profile (Fig. 1).

The prominent slope failure elements identified are the gradient of the hill slope, material properties of the rock, orientation and spacing of discontinuities and hydrological conditions. The rocks are traversed by innumerable joints. The orientation and spacing of these planes limit the extent of the free body within the rock slope that has a tendency to slip along open discontinuity planes. The hydrostatic thrust along joint planes caused by seepage and infiltration after heavy rainstorms is a contributing factor accelerating landslide.

Methodology and technique applied in this study are after Terzaghi (1962), Patton (1966), Jaegar (1971), Hoek and Bray (1977), Duncan and Wright (1980), Krishnanath (1985). After preliminary investigation such as

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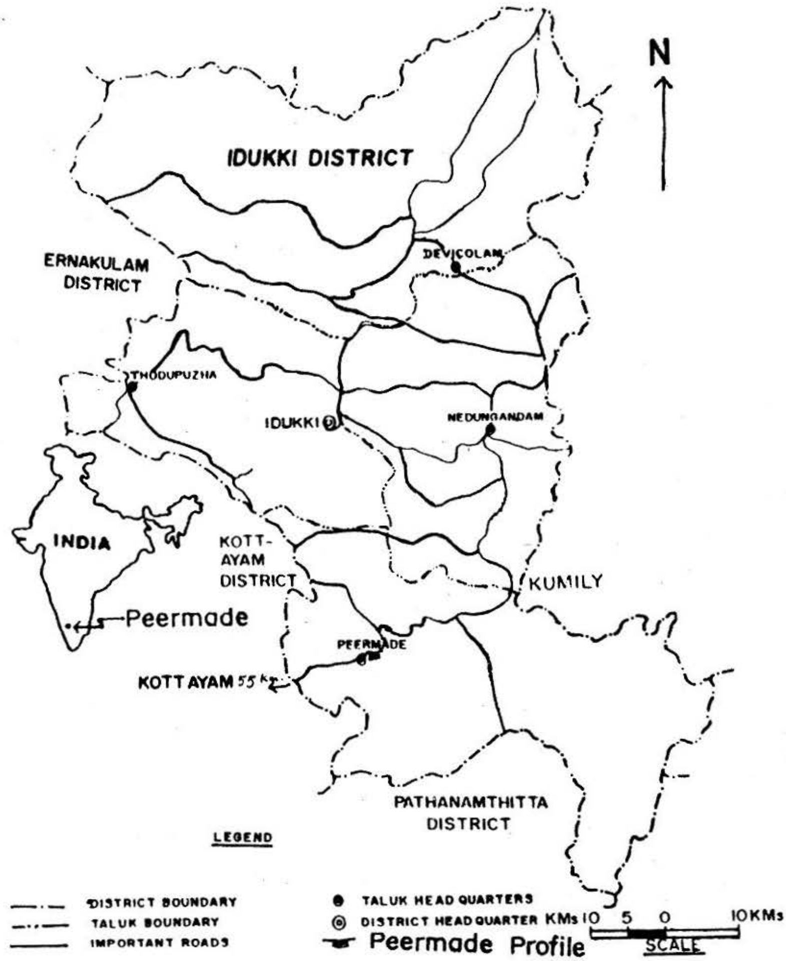

FIGURE 1 : Location Map of Peermade Profile

aerial photo interpretation, morphometric analyses and reconnaissance exercises, slopes have been classified into different categories (Krishnanath, 1985; Sreekumar et al., 1995). Beta (β) diagram for each sector and Pie (π) pole diagram for the entire profile are constructed from the orientation data. The circle representing the cone for the angle of internal friction and the trace of the great circle passing through the slope angle are also incorporated. The areas prone to wedge failure is determined using Markland's test (Markland, 1972). The convex periphery of the crescent moves towards the outer great circle when water is present in the cracks (Muller, 1964). Potential slide surfaces along which overhanging plane failure and toppling failure can occur are also determined (Hoek and Bray, 1977; Krishnanath, 1985). The distribution of joints on the road cut cliff is shown in Fig. 2. Geometric techniques (Krishnanath, 1985) are used to identify the potential slide surfaces which are pre-existing discontinuities such as joints and fracture planes. The volumes of the rock mass that may be wasted as consequence of probable slides also could be computed using geometric techniques. The factor of safety of each sector is calculated using the formula, $F = \cot\theta \times \tan\phi$ (where θ is the plunge of joint intersection and ϕ is the angle of internal friction). Factor of safety of the slope during wet condition is calculated using the equation $\tan\theta = (1 - rw/rt)\tan\phi$ (where rw is the density of water and is equal to 1gm/cc, rt is the bulk density of rock and water, ϕ is the angle of internal friction).

Peermade Profile

Peermade profile is located 78 km from Kottayam along the Kottayam-Kumily road at longitude 77°0'14" and latitude 9°34'9" in survey of India topsheet 58C/14 (Fig. 1). The road cut in this locality is very steep and is overhanging on to the road at places. The total length of the profile is 180 m (Fig. 2 and 3). The valley side is deep with high gradient and is locally known as 'Mathaikokka' and the very steep cliff with perennial water seepage is known as 'Ninnumullippara'. The road is at an elevation of 1000 m above MSL. The maximum height of the area is 1200 m and minimum elevation

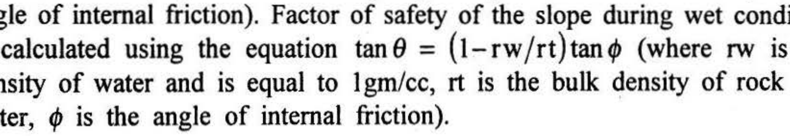

FIGURE 2 : Longitudinal Profile of the Road Cut Cliff.
A, B, C, D, E and F are Sectors

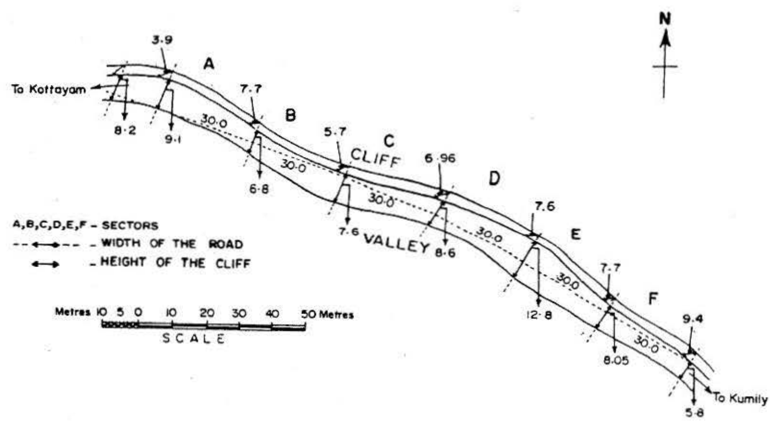

FIGURE 2 : Schematic of the Profile.
A, B, C, D, E and F are Sectors

is 750 m. The entire profile is divided into six sectors : A, B, C, D, E and F. All the sectors are of length 30 m (Fig. 2 and 3). Vegetation is sparce on the cliff.

The Rock Types

The import rock types forming the slopes are granitic gneiss, charnockite and pyroxene granulite. Pegmatite veins of width 2 cm to 10 cm also occur. The rocks are weathered to differing degrees. Granitic gneiss is medium to coarse grained. At sector C more weathered rocks are seen bounded on both sides by unweathered rocks. Gneiss is dominantly composed of quartz and feldspar. The crystalline rock is well jointed and may be classified into well developed gaping joints with width greater than 0.005 m (A type), joints with minimal separation (B type) and inferred joints (C type). Joint sets are dipping approximately in three directions, NE, SE and SW. The profile is divided into sectors A, B, C, D, E and F (Fig. 2 and 3) for detailed stability analysis. An assesment of stability of the slope along all sectors has been done.

The factor of safety in hard rock profiles has been calculated assuming that the cohesive strength across the potential slide surface is minimal and that the joints are planar surfaces. In this paper, the angles of internal friction are assigned after Hoek and Bray (1977).

Stability Analyses at Sector A

The length of the sector (Fig. 3) is 30 m and the height of the cut cliff is 3.9 m. The natural slope of the hill is 70° N 210° and the cliff scope is 82° N 210°. The first figure is the inclination of the slope or any plane with the horizontal and the second figure is the direction of the slope/dip in the azimuth from North in a clockwise direction. There are six major joints in the sector. Probability for the occurences of the wedge and overhanging plane failure is identified from diagram (Fig. 4). Factor of safety of the slope of this factor is one, when the rocks are dry. During rain storms water seeps through the discontinuities and in the presence of water along these joints, factor of safety may be further reduced to 0.65. The approximate quantity of material that may be wasted is calculated by estimating the volume of the free body from geometric constructions. On the basis of a conservative estimate, assuming that the joints do not propagate much into the rocks, the weight of potential debris is estimated at 31500000 kg. However, a detailed field investigation revealed that the joints persist and propagate far into the rockmass, thereby increasing the volume of the free body with a consequent increase in weight to 775297000 kg. Types of probable failure, factor of safety and free body weight are stated in Table 1.

Stability Analyses at Sector B

Length of the sector is 30 m. The height of the cut cliff is 7.6 m. The natural slope is 75° N 210°. The cliff slope is 84° N 210°. The major rock type is granitic gneiss. There are nineteen joints in the sector. Wedge failure and toppling are probable in this sector (Fig. 5). The amount of debris that may slide is estimated as 490000 kg. Factor of safety is less than one even when the rock is dry (Table 1).

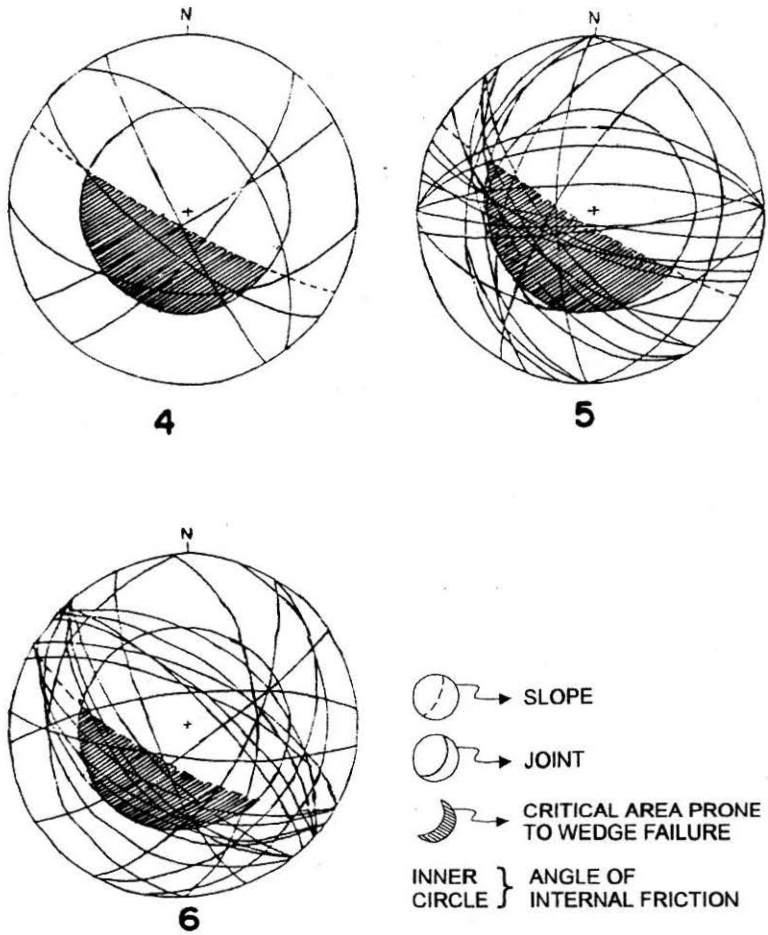

FIGURE 4 to 6 : β Diagram for Sectors A, B and C. Broken Arcs are the Traces of Slopes, the Inner Circles are the Angles of Internal Friction for the Materials, Crescent Shaped Shaded Areas Represent the Limit for Wedge Failure Caused by Intersection of Joint Planed

Stability Analyses at Sector C

This sector has a length of 30 m and the height of the cliff is 5.7 m. The slope is 72° N 210°. Granitic gneiss is relatively fresh and unaltered. Eighteen joints occur in this sector. This sector is prone to wedge failure, toppling failure and over hanging plane failure (Fig. 6). Factor of safety is below one. The amount of material that may slide is determined at 384000 kg (Table 1).

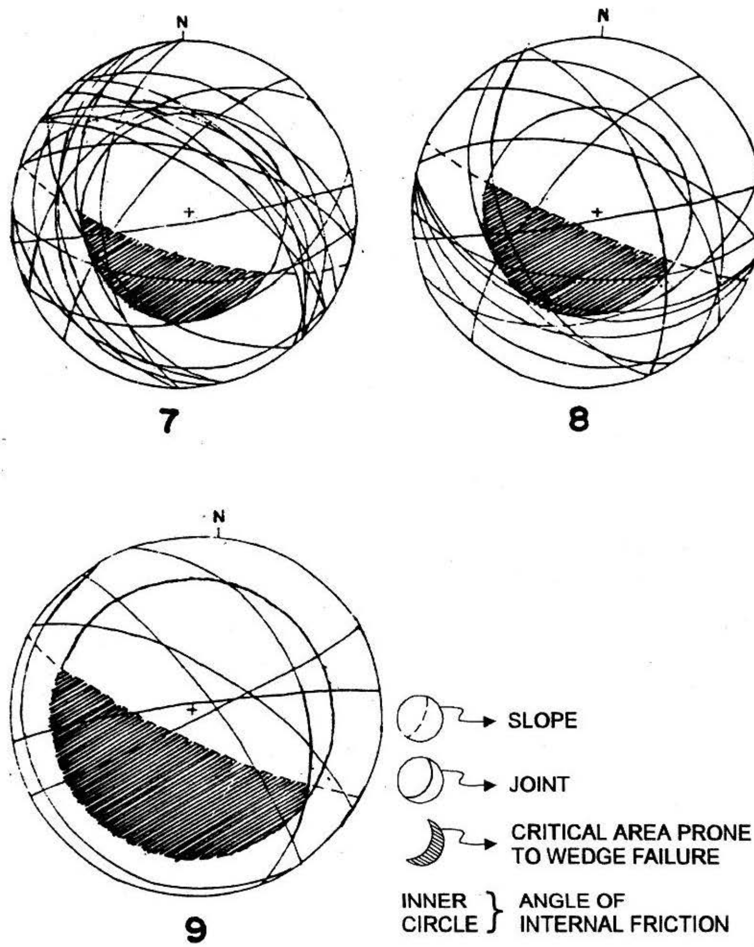

FIGURE 7 to 9 : β Diagram for Sectors D, E and F. Broken Arcs are the Traces of Slopes, the Inner Circles are the Angles of Internal Friction for the Materials, Crescent Shaped Shaded Areas Represent the Limit for Wedge Failure Caused by Intersection of Joint Planed

Table 1 Stability Status of the Rock Slopes along Peermade Profile, Kottayam - Kumli Road, Kerala State

Sector	A	B	C	D	E	F
Slope angle	82°/210°	84°/210°	72°/210°	70°/200°	81°/200°	80°/200°
Rock type	Granite gneiss	Granite gneiss	Granite gneiss	Charnockite	Charnockite	Charnockite (weathered)
Number of joints						
A - type	4	3	4	2	5	2
B - type	2	6	7	4	5	4
C - type	—	10	7	12	7	—
Angle of internal friction	40°	40°	40°	40°	40°	24°
Dip of joint intersection	40°	42°	41°	50°	40°	—
Type of probable failure	Wedge Plane	Wedge Plane	Wedge Plane	Wedge, Plane Toppling	Wedge Toppling	Toppling
Factor of Safety						
Dry	1	0.93	0.97	0.705	1	—
Wet	0.643	0.60	0.63	0.45	0.64	—
Free body weight (kg)	31500000	490000	384000	1622000	10692000	—

Stability Analyses at Sector D

The total length of the sector is 30 m and the cliff height is 6.96 m. The natural slope is 76° N 210° and road cut slope is 70° N 200°. Charnockite with fresh blue quartz and feldspar is the rock type. There are eighteen joints present in this sector. Sector is prone to wedge and over hanging plane failure and is unsafe even during dry condition (Fig. 7). The amount of material that may be wasted is estimated at 1622000 kg (Table 1).

Stability Analyses at Sector E

Sector E is 30 m long and the cliff height is 7.6 m. Seventeen joints are observed in the sector. Natural slope is 70° N 210° and cliff slope is 81° N 200°. Wedge failure and toppling can occur in this sector (Fig. 8).

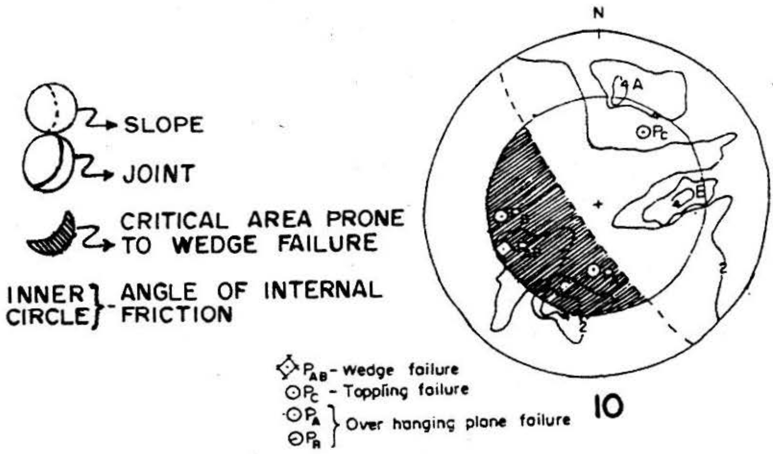

FIGURE 10 : π Pole Diagram for Peermode Profile. A, B and C are the Maxima of the Poles of the Joint Planes.

Sector is unsafe and the amount of material that may slide is estimated at 10692000 kg (Table 1).

Stability Analyses at Sector F

Length of the sector is 30 m and the height of the cliff is 7.7 m. The cliff slope is 80° N 200° and natural slope is 70° N 210°. The main rock type charnockite is highly weathered. Only six joints are observed in this sector. All the joints are dipping away from the cliff slope (Fig. 9). These joints are filled with mineral infillings and therefore, probability for toppling occurs only at a minimum level (Table 1).

Perspective Geometric Analyses

π Pole diagram has been constructed (Fig. 10) for perspective analyses of the discontinuities geometrically. A, B and C are the maxima of the poles of the joint planes. P_{AB} which falls in the crescent shaped shaded area is the pole to the great circle connecting the maxima A and B. This indicates the probability of wedge failure along the Peermade profile, in general P_c is the pole to the great circles passing through the maxima C. This is located diametrically opposite to the great circle for the slope indicating the probability for toppling failure. P_A and P_B are poles to the great circles passing through the maxima A and B respectively and these are located in the shaded area of the projection indicating the probability for overhanging plane failure on a perspective basis.

Conclusions

The stability status of different sectors A to F are summarised in Table 1. On the basis of the geometric analyses it is concluded that the profiles, in general are prone to wedge failure. The problem is severe in sectors A, B, C, D and E. Probability for the occurence of overhanging plane failure is identified at sectors B and C. Toppling is likely to occur in sector A, C, D and E. Factor of safety for each sector is calculated during dry and wet condition. Sectors A and E are at the geotechnical threshold whereas all the other sectors have factor of safety less than one. However, the material forming the slope remains in place even during dry season. It is obvious that some of the assumptions in determining the factor of safety is not valid. Many gaping joints have mineral infillings. Ocassionally plant roots 'bolt' the potential free body blocks. Deforestation can weaken the 'root bolts' and cause sudden slides in some sectors.

Total amount of slides debris that may be wasted on to the highway is estimated at 44304000 kg. The impact of these free body masses may be adequate to initiate severe slides along this highway slope causing damage to transport and communication arteries.

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