Detailed field-based geotechnical characterization of the two conspicuous rockslides affecting the strategic Hayuliang -Metengliang-Chaglogam (H-M-C) Road corridor, Anjaw district, Arunachal Pradesh

*Chasie, Megotsohe, Theophilus, P. K. & * Sarkar, Niroj Kumar*
Geological Survey of India, NER, Shillong.
Corresponding author: Niroj Kumar Sarkar, email: niroj4@gmail.com

Abstract

Detailed Geological evaluation and field based geotechnical characterization of the two conspicuous rockslides affecting the strategic H-M-C road corridor, Anjaw district, Arunachal Pradesh was carried out to understand the stability condition of these active rock slide and thereby formulating mitigation measures. The RMR (Rock Mass Rating) and Slope mass rating (SMR) as per Beiniawski (1973) and (Romana, 1985) were estimated from the attributes of the discontinuity surfaces and on field determination of the rock-mass strength using Schmidt Hammer. C (Cohesion) and Ø (angle of internal friction) of the rock mass was estimated from the determined RMR value and utilized for kinematic analysis. At Km 9 location RMR_b value of the rock mass is estimated to be 50 (Class III, Fair Rock) and corresponding SMR (Romana (1985) is 23 (Class IV, Bad)). Kinematic analysis shows that condition of planar failure along a discontinuity dipping 64°→N145°. Based on the field evaluation and geotechnical characterization, removal of the overhang to the upslope, consolidation of the profusely jointed rock-mass through application of steel fibre reinforced shotcrete (SFRS) and spot bolting (25°-30°→N320°-N330°), etc. has been recommended as remedial measures. In the studied rockslide at KM 29.9, a prominent central depression divides the affected slope face into the left (56°-60°→N315°-N320°) and right slopes (60°-63°→N215°-N220°). The obtained RMR_b value is 44 (Class III, Fair Rock) and corresponding SMR value obtained for the right slope is 17 (Class V, Very bad) whereas SMR value for the left slope is 2 (Class V, Very bad). In the right slope, planar failure along the foliation plane ($F_{J:}$ 54°→ N200°), wedge failure along the intersection plane of F_J & J_6 (the wedge dipping 46°→N242°) and toppling failure along the 75°→N34° disposed discontinuity has been interpreted through kinematic analysis. In the left slope, planar failure along the 46°→N302° plane and toppling failure along N32°E /sub vertical plane was similarly interpreted. In the central part, distinct wedge failure (wedge plunging 32°→N264°) along the intersection plane of F_J (54°→ N200°) & J_5 (44°→N51°) was seen and interpreted. Based on the above, remedial measures like removal of the overhanging rock mass on the upslope of the road bench, treatment of the slope with SFRS (Steel Fibre Reinforced shotcrete), staggered bolting has been suggested. Further, provision of multilevel transverse structures across the central depression, construction of a two-tier retaining wall to the down slope, stitching/anchoring with the foundation of the retaining walls to the bedrock etc. has been recommended.

1. Introduction:

The Hayuliang-Metengliang-Chaglogam(H-M-C) road corridors of Anjaw districts, Arunachal Pradesh reported to have experienced frequent landslides of sizeable magnitude that affects this strategic arterial communication corridor some times for month during the active monsoon season. Considering the importance of this road corridors as a strategic communication route connecting to the frontier and a lifeline to major townships and settlements, both regional and site specific landslide hazard assessment is felt necessary for formulation of a comprehensive combative strategy. The terrain being geologically located in a tectonically active zone, traversed by major prominent regional thrusts, comes under maximum rainfall and maximum earthquake prone area, added further significance for such studies, in understanding the landslide initiation process and relations of the same with that of the active geodynamics and seismicity in the area. Accordingly, a project was launched by Geological survey of India, during 2013-14, for regional landslide susceptibility assessment along the said road corridor and also for site specific assessment of a few conspicuous trouble spots. The paper presented the field based geotechnical characterisation of the two conspicuous rockslides affecting the road bench. The same was taken up along with field assessment of some other trouble spots part of the endeavor taken up at the request of the Road maintaining authority and aimed at providing necessary geological and geotechnical input for formulation of an appropriate remedial measure (Chaise and Theophilus, 2014). The two conspicuous landslides studied and presented are located at a distance of roughly 9 km and 29.9 km respectively from the Hayuliang Township along Hayuliang – Metengliang - Chaglogam road corridor.

2. Regional Geological and Tectonic Set-up:

The study area is located proximal to the eastern syntaxial bend of Himalayan range, geodynamical very active and traversed by a number of prominent regional thrusts and sympathetic structural elements. The Precambrian crystallines represented by an array of Meta-Psammo-peletic rock are the major litho variants in the area which is found subjected to polyphase deformation, metamorphism and late magmatism in the form of intrusion by younger granites. The quaternary geomorphic processes acting over this bed rock at many places modified the surficial litho variants to a greater extent. The regional tectonic trends, as such, follows the NW-SE trend of the eastern syntaxis, the major tectonic feature of Eastern Himalayas, and found conformable with that of the formational contacts. The disposition of the rock assemblages and their spatio-temporal association is thus interpreted to be largely controlled by these tectonic and structural features. The observed inherent fragile rock-mass conditions at places in the area are related to the intense tectonic activity and have its bearing in the strength character and consequent failure potentiality.

3. Site Evaluation and Geotechnical Characterisation:

Figure 1 Perspective view of rock slide (Mosaic photo)

3.1 Location Km 9:

About 75 m of the road stretch has been affected by the prominent rock slides (figure 1) due to the slided rock mass, toppled rock boulders and rock falls. The slope forming material is dominantly feldspathic schist with quartz-muscovite-sericite as other mineral constituents present in varying volumetric proportion. The feldspathic schist is found inter-banded at places with quartzo feldspathic gneisses. The weathering grade of the rockmass found varies from slightly weathered (W_1) to moderately weathered (W_2) category. In the last few years, descended dislodged rock boulders from the near-vertical up-slope, has reported to pound and severely affect the road bench for a number of occasion. The road stretch for a length of 25 m - 30 m proximal to the stream channel is found to be most affected. The dimensions of the active part of rockslide is estimated to be 40 m along slope, 45 m along road with a depth of failure surface varying between 4 to5 m.

The slope face is sub vertical (69°-75°$^{)}$ and directed towards S20°E. Foliation, the most pervasive planar element disposed 77°→N33° and is found to be tightly spaced (figure 2 & figure 3). Besides the foliation, the rock-mass is found to be variably traversed by a number of other discontinuities having varying disposition and persistence (table 1). Apart from the jointed rock mass, somehow massive variety is also documented in the slope. Among the identified discontinuities (table1), the steeply dipping joint ($J_{1:}$ 64°→N145°) is found to have its strike disposed at a low angle (10° to 15°) to the slope direction and therefore is vulnerable (figure 2). The attitude and attributes (persistence, spacing, aperture, roughness and weathering condition) of all the discontinuities were documented and presented in (table 1). RMR basic values of the rock mass were estimated following (Beiniawski, Z. T. (1973 & 1979), using (i) UCS (average value determined in the field using Schmidt Hammer) ii) RQD determined using Palmstrong formula (115-3.3* J_v) and relevant joint attributes listed in table 1. The estimated RMR_b value designates the rock as class III category (fair rock). The input parameters for estimation of RMR basic, their rating, the RMR value and corresponding C and Φ value of the rock-mass is presented in table 2.

The SMR value estimated from empirical approach proposed by Romana (1985) is found to be 23. The said value categorized the slope mass as Class IV (Bad) and therefore has higher probability of failure. Kinematic analysis of the rock slope (figure 4) was carried out using the geometrical disposition of the slope, discontinuities and angle of internal friction estimated from RMR basic value. The same is done to examine the modes of failure that can possibly occur in the rock mass and is done through Stereographic representation (stereo nets) of the discontinuity planes, slopes and intersecting lines. The kinemetic analysis (figure 4) indicates that prominent planar failure along JI discontinuity and insipient wedge failure along intersection of J1 and foliation and J1 and J4 which is collaborated by field documentation. (figures 1 to 3).

Figure 2 Prominent vulnerable discontinuity

Figure 3 Down slope of road bench, toe erosion and vulnerable discontinuity plane.

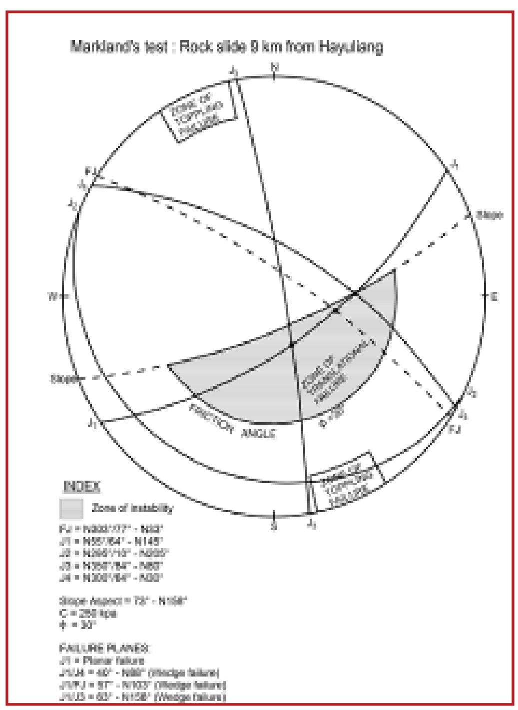

Figure 4 Markland’s test of 9 km rock slide

Table 1
Attitude and properties of discontinuity planes at the 9 km rock slide.

Attitude of Discontinuity Plane	Properties of Discontinuity Plane
(Strike/Dip amount → Dip Direction) F_J: N303°/77°→N33°.	a) Strike persistence: 5-6 m (medium) b) Spacing: 2 mm to 90 cm (very close to moderately close) c) Aperture: Tight d) Roughness: Smooth, planar e) Condition: Slightly weathered to moderately weathered (W_1 to W_2).
J_1: N55°/64°→N145°	a) Strike persistence: 5 m (medium) b) Spacing: 3 cm to 60 cm (moderately close) c) Aperture: Open (up-to 2 mm) d) Roughness: Smooth, planar e) Condition: Slightly weathered (W_1).
J_2: N295°/10°→N205°	a) Strike persistence: 6 m (medium) b) Spacing: 4 m-5 m (very wide) c) Aperture: Tight d) Roughness: Smooth, planar e) Condition: Slightly weathered (W_1).
J_3: N350°/84°→N80°	a) Strike persistence: 3 m (medium) b) Spacing: 4 m (very wide) c) Aperture: Tight d) Roughness: Smooth, planar e) Condition: Slightly weathered (W_1).
J_4: N300°/64°→N30°	a) Strike persistence: 1 m (low) b) Spacing: 1 m (moderately close) c) Aperture: Tight d) Roughness: Smooth, planar e) Condition: Slightly weathered (W_1).

Table 2
RMR_b ratings for the rock slope at the 9 km rock slide.

RMR_b parameters	**Rating**	**Rock Class**	**Cohesion (c)**	**Friction angle (Φ°)**
Strength of Intact Rock Material (UCS)	7 (57-76 MPa as per the Schmidt Hammer)	50 (Class-III, Fair rock)	250 KPa	30°
RQD	8 (50%)			
Spacing of Discontinuities	10			
Condition of Discontinuities	15			
Groundwater condition	10 (damp)			

3.2 Location Km 29.9:

The prominent rockslide in the specified location affecting nearly 80 m of the road bench. The rockslide reported to be initiated in the steep slope in 2010, reactivated during the successive monsoon, is responsible for destruction of the road bench at some specified stretch (figure 5). The rock slide is accompanied by rock falls which has completely destroyed a few constructed retaining structures due to the impact of large falling rock boulders from the up slope. The dimension of the rockslide measured is 170 m in length, 90 m in width and having a total run-out distance of 150 m. The slope forming material is dominantly quartzo-feldspathic gneiss inter-banded at places with relatively mica-rich layers. In terms of weathering grade, the rock mass is observed to be slightly (W_1) to moderately weathered (W_2). The penetrative planar fabric in the rock mass is defined by foliation along gneissic bands which is found disposed 68°→N200° . Beside the same, the rock-mass across the distressed slope face, is also found variably traversed by recognizable discontinuities, attitude and attributes of which are presented in table 3. To maintain the operability of the road bench, the very steep rocky slope was successively shifted towards the hill side with a near V-shaped alignment (figure 6), the apex of which is aligned towards the hill side.

The rock slope, accordingly described as left and right slope in respect of the prominent central depressions located at maximum curvature of V. The left slope is found inclined 56°-60° towards N315°-N320°. The right slope is oriented 60° towards N215° direction. Planar (along foliation) and toppling failure along steep discontinuity has been observed in the left slope. The central depression is found oriented along a vulnerable wedge formed due to the intersection of the foliation and a prominent discontinuity dipping 48° towards 320° (figure 7).

Figure 5 Perspective view of 29.9 km rock slide, view from opposite slope

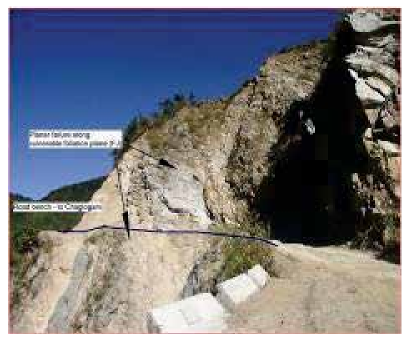

Figure 6 Perspective view of rockslide, visible prominent vulnerable discontinuity plane

Figure 7 Prominent vulnerable discontinuity planes along the central depression

Table 3
Attitude and properties of discontinuity planes at 29.9 km rock slide.

Attitude of Discontinuity Plane	Properties of Discontinuity Plane
(Strike/Dip amount → Dip Direction) F_J: N110°/54°→N200°.	a) Strike persistence: 6 m (medium) b) Spacing: 2 cm to 50 cm (very close to close) c) Aperture: Tight d) Roughness: Smooth, planar e) Condition: Slightly weathered (W_1).
J_1: N212°/subvertical	a) Strike persistence: 5 m (medium) b) Spacing: 30 cm to 170 cm (moderately close) c) Aperture: Open (up-to 5 mm) d) Roughness: Smooth, planar e) Condition: Moderately weathered (W_2).
J_2: N32°/46°→N302°	a) Strike persistence: 9-10 m (medium) b) Spacing: 5 cm to 2.5 m (close to wide) c) Aperture: Tight d) Roughness: Smooth, planar e) Condition: Moderately weathered (W_2).
J_3: N141°/44°→N51°	a) Strike persistence: 1 m (low) b) Spacing: 20 cm to 125 cm (moderately close to wide) c) Aperture: Open (up-to 5 mm) d) Roughness: Smooth, planar e) Condition: Moderately weathered (W_2).
J_4: N54°/78°→N146°	a) Strike persistence: 3 m (low) b) Spacing: 40 cm to 200 cm (moderately close to wide) c) Aperture: Open (up-to 5 mm) d) Roughness: Smooth, planar e) Condition: Moderately weathered (W_2).
J_5: N230°/48°→N320°	a) Strike persistence: 5-6 m (medium) b) Spacing: 2-3 m (wide) c) Aperture: Extremely wide (vein quartz infilling of 80-85 cm) d) Roughness: Rough, planar e) Condition: Moderately weathered (W_2).
J_6: N52°/80°→N332°	a) Strike persistence: 1 m (low) b) Spacing: 8.5 cm to 110 cm (moderately close to wide) c) Aperture: Open (up-to 5 mm) d) Roughness: Smooth, planar e) Condition: Moderately weathered (W_2).
J_7: N304°/75°→N34°	a) Strike persistence: 4 m (medium) b) Spacing: 20 cm to 55 cm (close to moderately close) c) Aperture: Tight d) Roughness: Rough, planar e) Condition: Moderately weathered (W_2).

RMR_b for the rock-mass estimated following (Beiniawski, Z. T. (1973 & 1979), is 44 (class III, fair). Table 4 shows the parameters considered for estimation of RMR, their rating, RMR_b value and corresponding cohesion and friction angle. SMR value estimated from RMRb and geometrical relations between slope and the discontinuities is found to be 17 and 2 respectively for right slope and left slope respectively for planar failure. (Class V, Very bad). The same clearly indicate the highest probability of failure under prevailing condition.

Table 4
RMR_b ratings for the rock slope at 29.9 km rock slide.

RMR_b parameters	Rating	Rockmass Class	Cohesion (c)	Friction angle (Φ°)
Strength of Intact Rock Material (UCS)	7(64-90 MPa as per the Schmidt Hammer)	44 (Class-III, Fair rock)	220 KPa	27°
Drill Core Quality (RQD)	8 (25-50%)			
Spacing of Discontinuities	8			
Condition of Discontinuities	11			
Groundwater condition	10 (damp)			

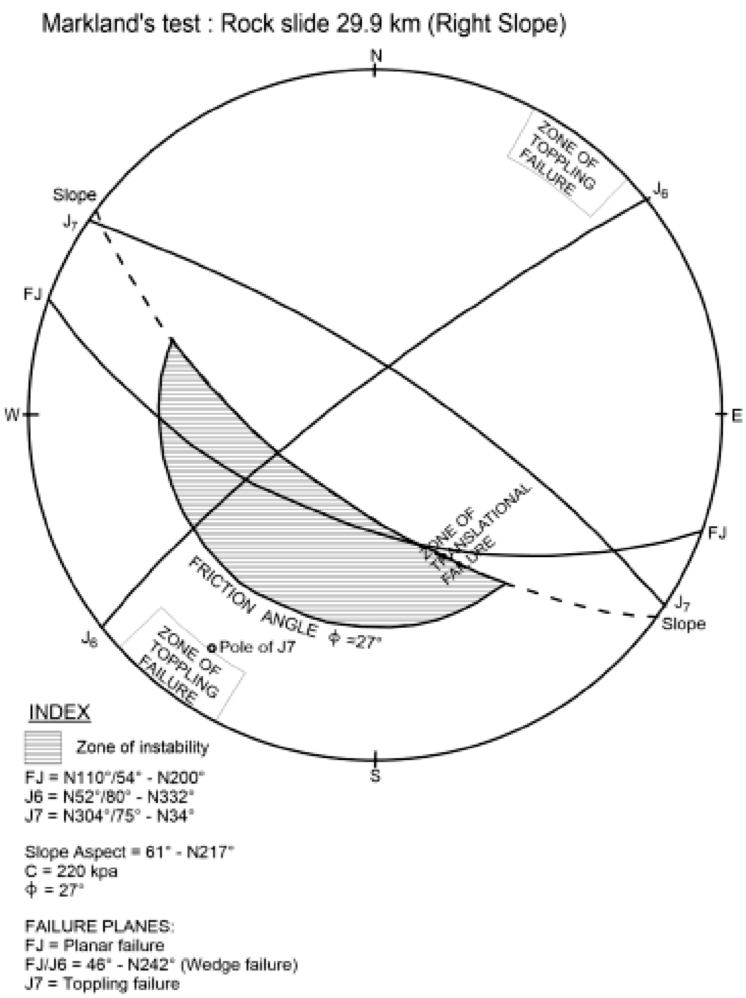

Figure 8 Markland's test, right slope

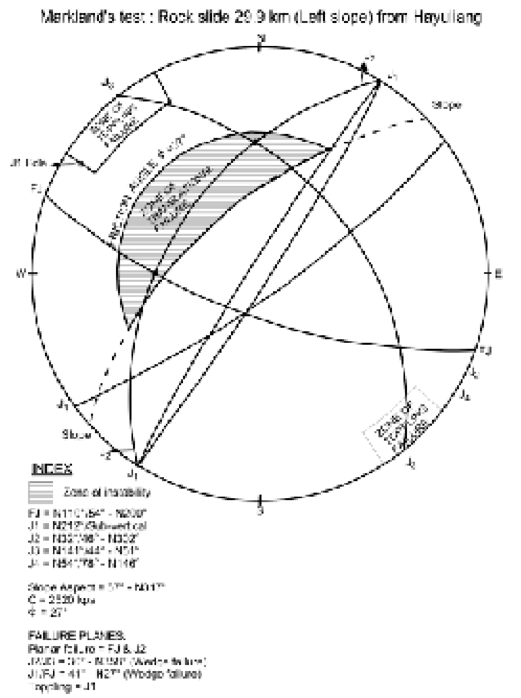

Figure 9 Markland's test, (left slope) indicated vulnerable planar and toppling failure

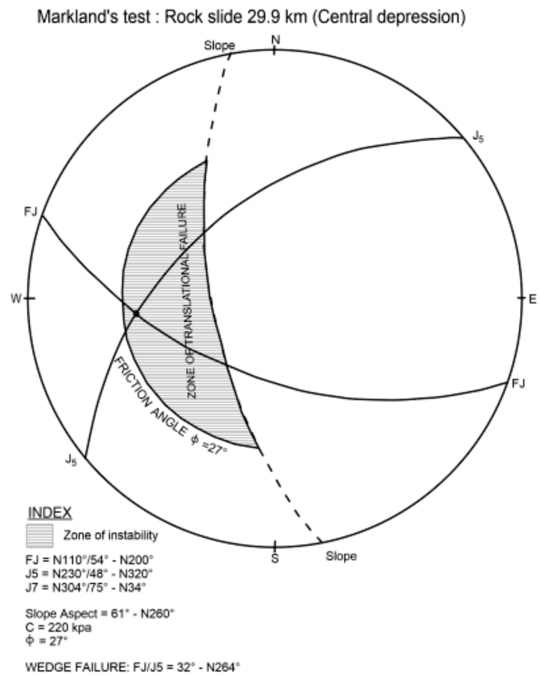

Figure 10 Markland's test, Central depression, indicated vulnerable planar failure

Since the left, central and right slope at 29.9 km location has different slope aspects, therefore, kinematic analysis using the disposition of slope, discontinuities and estimated angle of internal friction for them are separately done to understand the failure mechanism.

The kinemetic analysis for right slope (figure 8) reveals planar failure along the foliation plane (F_J), probable wedge failure along the intersection plane of F_J & J_6 and toppling failure along J_7 (the pole falling near the boundary of the zone of toppling failure). Similarly the same for left slope (figure 9) indicate planar failure along the J_2 plane and possible toppling failures along the J_1 plane (the pole falling at the boundary of the zone of toppling failure). In the central depression (figure 10) prominent wedge failure interpreted along the intersection plane of F_J & J_5, which is well corroborated from the field observation. Therefore, it emerges, that the rockslide exhibit combination of planar, wedge as well as toppling failure modes.

4. Recommendations:

Based on the field attributes and above geotechnical characterization following remedial measures were suggested.

4.1 Km 9 Rock Slide:

The remedial recommendation includes:

i. Removal of the unstable rock overhangs (figure 1&2) above the identified discontinuity plane J1 N55°/64°→N145° (J_1) along which the planar failure is anticipated.
ii. Consolidation of the profusely jointed rock mass (figure 2) both on the upslope and down slope of the road bench through the use of steel fibre reinforced shotcrete (SFRS).
iii. Systematic bolting in staggered fashion in the down slope rock-mass, spot bolting in the massive rock-mass to the up-slope of the road bench (figure 3). The rock bolts to be driven at 25°-30°→N320°-N330° (at/or near orthogonal relation to the J_1 plane)

4.2: The recommendation are given separately for left, right and central slope based on field, geotechnical data and SMR values**.**

On the left slope face: i) Removal of the unstable rock overhangs (figure 3*)* above the identified discontinuity plane J_2 and at places above J_1 and toppling along which the planar failure is anticipated. Once the overhang is removed, the slope may be further treated with SFRS (Steel Fibre Reinforced Shotcrete). The same is required considering quality of the rock mass (Class-III). Construction of a lined hillside drains.

On the right slope face: i) Complete removal of the rock mass resting on/above the intersecting plane of F_J. ii) The trimmed slope may be further treated with SFRS (Steel Fibre Reinforced Shotcrete). iii) Provision of rock bolting (staggered), the bolts to be driven at 45°-50°→ N20°-N25°. iv) Construction of lined hillside drains.

At the central depression: i) Removal of the overhanging rock-mass to the up-slope of the road bench through controlled blasting ii) Provision of multilevel transverse structures across the central depression and to the upslope of the road bench to dissipate and channelize the surface run-off iii) provision of a culvert at the road bench level for draining-out the surface run-off descending from the upslope iv) construction of retaining walls to the down slope of the road bench, the foundation of the retaining walls are to be stitched/anchored to the bedrock through horizontal as well as vertical bolts/rods/dowels.

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