RMR AND RHRS OF NGAIZEL ROAD CUTTING SECTION, AIZAWL, MIZORAM

H. Lalhlimpuia¹, Zairemmawii¹, Shiva Kumar¹ & Laldinpuia²*

¹Department of Geology, Mizoram University, Aizawl, Mizoram
²Department of Geology, Pachhunga University College, Aizawl, Mizoram

*Corresponding Author: dinpuiageo@gmail.com
Laldinpuia: https://orcid.org/0000-0001-5258-6785

ABSTRACT

Due to unfavourable topographical features roads in hilly areas are usually small as compared to plain areas, therefore several problems may arise whenever rockfall occurs. One of the busiest domestic road in Aizawl i.e. Ngaizel road often encountered rockfall along its cutting slope. This road act as an important gateway which connects the southern parts of Mizoram. This road is packed with human activities which adds on the hazard level to rise high. The main factors that contribute to rockfalls include slope degree, geomechanical properties of rock mass and anthropogenic activities. Taking into consideration of all the adverse effect of rockfalls, RMR (Rock Mass Rating) become indispensable to identify the actual condition of rock mass on the slope of the study area. RMR classification is carried out to determine the geomechanical condition of slope rock mass and Rockfall Hazard Rating System (RHRS) is applied for identifying the hazard-prone area of rockfall along the cut slope of Ngaizel road. RHRS depends on various parameter which include slope height, annual precipitation, block size, block volume, decision sight distance, average vehicle risk, road width and rockfall history which mainly concern about the safety of pedestrians along the road. The RMR and RHRS study along Ngaizel cut slope provides a detailed and useful information about the geological condition and delineating the hazard level. The study also gave awareness and alertness about the actual condition of the area.

Keywords: Aizawl, Ngaizel, hazard, rockfall, RMR, RHRS.

Introduction

The rock mass quality depends on its geomechanical properties. The physical properties of rock mass can be determined in the laboratory as well as in-field observation. In areas where physical rock sample test is inaccessible, rock mass classification RMR method can be carried out. Rock Mass classification after Benwaski (1989) is widely used to analyzed
slope stability in mining and other excavation, and is based on field investigations (Naithani, 2007).

RHRS was first developed by the Oregon Department of Transport (ODOT) in collaboration with the Federal Highway Administration (FHWA) to evaluate rockfall hazard for the existing slope. The Indian System for Rockfall Hazard Rating System (ISRHRMS), a modified version of both after Pierson et al., (1990) and Santi et al., (2009) is used for the present study with the addition of crucial parameter for Indian rock mass. Slope instabilities along highways not only increase maintenance costs, but also may pose hazards that lead to detours, traffic delays, and safety issues for the travelling public (NIATT, 2003). The purpose of RHRS is to provide information in dealing with hazard zoning, land-use planning, investment decisions regarding risk mitigation measures and the assessment of the necessity of further evaluations in case of detected threads (Eliasen & Springstom, 2007).

Location and Geology of the study area

Ngaizel road is located at the southern part of Aizawl anticlinal ridge between N23°42.371’ and E92°43.204’ under 84A/10 survey of India toposheet (Fig. 1 & 2). The geology of the study area composed of intercalation of sandstone and shale (Sardana et al., 2019). They exhibit moderate weathering conditions. Differential erosion took place as a result of soft shale overriding sandstone. Slopes along the cut slope may fail due to uneven oriented discontinuities in the rock mass distribution of different kind of joint such as longitudinal joints, normal or cross joint, diagonal or oblique joint, curvilinear joints and tensional joint formed as a result of tensional force are common in the study area (Sardana et al., 2019).

Materials and Methodology

Rock Mass Rating (RMR)

It involves certain kinds of parameters such as Uniaxial compressive strength (UCS) of intact rock, rock quality designation (RQD), spacing of discontinuity, condition of discontinuities, orientation of discontinuities and groundwater condition (Hoek et al., 1995).

The geophysical property of rock mass is analyzed by using rock schmidt, slake durability test and RMR. Rock schmidt is used to compute the mechanical properties of rock such as UCS, Tensile Strength and Young’s Modulus (Selcuk & Yabalak, 2014). In case where the borehole is unavailable the RQD is estimate from the number of joints per unit volume of rock mass, the number of joint per meter for each joint set are considered for RQD. Therefore, the RQD is calculated by using the formula (Equation 1; Palmstrom, 2005).

\[
RQD = 115 - 3.3 Jv \quad \text{(Equation 1)}
\]

Where, \(Jv\) is a number of joints per cu.m

Discontinuities refer to all the weakness plane that occur within the strata. The joints spacing is the distance between individual joint within the joint set. The block size and shape can be identified from the discontinuity spacing which in turn, the strength of the jointed block can be analyzed from this spacing. The joint aperture controls the interlocking of the rock walls.
Fig. 1: Location map of study area

Fig. 2: Aerial view of study area (Drone image)
Smaller the aperture, higher the chance of interlocking. Where there is no interlocking, the filling material contribute to the shear strength. Therefore, it is obvious that both the fillings and the block materials contribute to the shear strength (Palmstrom, 1995).

When the trend of the structural plane is the same as that of the slope, and the dip angle is smaller than the slope, the rockfall is easy to occur. The failure mode usually shows a pull-splitting rockfall. When the strike of the structural plane is consistent with the slope and nearly erect, the possibility of rockfall is slightly reduced (Wang et al., 2018). The characteristics of the joints, particularly where the walls are in direct rock to rock contact as in the case of unfilled joints, has a direct bearing on the strength of the rock mass (ISRM, 1978). The joint condition factor is meant to represent the friction properties of the block faces (Joints) and the relative scale effect imposed by the joints (Palmstrom, 1995).

Groundwater plays an important role for the stability of slope, seepage of water entered into the rock mass through discontinuities, as a result the effective normal stress across the joint decrease, which in turn reduce the shear strength of the rock mass. The effect of groundwater soften the infilling materials which distorted the interlocking property of the rock wall. It also reduces the cohesive strength and frictional strength. Water within the pores decrease the compressive strength of rock, and the rock is more prone to weathering. When a shale is soak with water, it begins to disintegrate and can be easily converted into slurries (Naithani, 2007). The cleft water applies hydraulic force on the rock wall which minimizes the frictional force that acts on the wall of the rock (Karaca & Goodman, 1993).

Rock mass classification focuses on determination of rock strength and also estimate the deformation properties of rock. It acquired different parameter so as to understand the rock mass quality. Table of rock mass classification used in this study after Bieniawski, 1989 is given below (Table 1).

As given in Table 1, rock mass classification is carried out using various geological and geotechnical parameters such as UCS of rock material, RQD, discontinuities spacing, discontinuities condition, groundwater conditions and discontinuities orientation. All these factors account for rock mass rating calculation. Each and every parameters are placed in separate column as shown in Table 1 which coincide with different value based on the field investigation. The collected data which corresponds to the most efficient value in the rating table are considered for rating.

**Rockfall Hazard Rating System (RHRS)**

Various modifications of the RHRS has made with respect to its compatibilities with different region. In this study RHRS for Indian rock mass modified after Pierson et al. (1990), and Santi et al. (2009) is used for the present study.

There are five classes with their two sub-classes to consider to access Rockfall hazard Rating system for India, such as slope condition, climatic condition, geological condition, traffic condition and rockfall history (Ansari et al., 2013).
### Table 1: Rock Mass Classification (Bieniawski, 1989)

| Parameters                     | Range of values                   | Rating |
|-------------------------------|-----------------------------------|--------|
| Strength of intact rock material | PLI >10 MPa 4-10 MPa 2-4 MPa 1-2 MPa |        |
| UCS                           | >250 MPa 100-250 MPa 50-100 MPa 25-50 MPa |        |
| For this low range, UCS test is preferred | 5-25 MPa 1-5 MPa <1 MPa |        |
| Rating                         | 15 12 7 4 2 1 0                |        |
| Drill core quality RQD         | 90%-100% 75%-90% 50%-75% 25%-50% <25% |        |
| Rating                         | 20 17 13 8 3                   |        |
| Spacing of discontinuities     | > 2 m 0.6-2 m 200-600 mm 60-200 mm < 60 mm |        |
| Rating                         | 20 15 10 8 5                   |        |
| Condition of discontinuities  | Very rough surfaces Not continuous No separation Unweathered wall rock |        |
| Slickensides surfaces Or Gouge < 5 mm thick Or Separation > 5 mm |        |
| Continuous                     | Slickensides surfaces Or Gouge < 5 mm thick Or Separation > 5 mm |        |
| Rating                         | 30 25 20 10 0                  |        |
| Inflow per 10 m tunnel length (l/m) | None < 10 10-25 25-125 >125 |        |
| Ground water (Joint water press)/(Major principal σ) | 0 < 0.1 0.1-0.2 0.2-0.5 > 0.5 |        |
| General conditions             | Completely dry Damp Wet Dripping Flowing |        |
| Rating                         | 15 10 7 4 0                   |        |
### A. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATION

| Strike and dip orientations | Very favorable | Favorable | Fair | Unfavorable | Very Unfavorable |
|-----------------------------|---------------|-----------|------|-------------|------------------|
| Tunnels & mines             | 0             | -2        | -5   | -10         | -12              |
| Foundations                 | 0             | -2        | -7   | -15         | -25              |
| Slopes                      | 0             | -5        | -25  | -50         |                  |

### C. ROCK MASS DETERMINED FROM TOTAL RATINGS

| Rating       | 100-81 | 80-61 | 60-41 | 40-21 | < 21 |
|--------------|--------|-------|-------|-------|------|
| Class Number | I      | II    | III   | IV    | V    |
| Description  | Very good rock | Good rock | Fair rock | Poor rock | Very poor rock |

### D. MEANING OF ROCK CLASSES

| Class Number | I      | II    | III   | IV    | V    |
|--------------|--------|-------|-------|-------|------|
| Average Stand-up time | 20 yrs for 15 m span | 1 year for 10 m span | 1 week for 5 m span | 10 hrs for 2.5 m span | 30 minutes for 1 m span |
| Cohesion of rock mass (kPa) | >400 | 300-400 | 200-300 | 100-200 | <100 |
| Friction angle of rock mass (deg) | >45 | 35-45 | 25-35 | 15-25 | <15 |

### E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY

| Discontinuity length (persistence) | >1 m | 1-3 m | 3-10 m | 10-20 m | >20 m |
|-----------------------------------|------|-------|--------|---------|-------|
| Rating                            | 6    | 4     | 2      | 1       | 0     |
| Separation (aperture)             | None | <0.1 mm | 0.1-1.0 mm | 1-5 mm | >5 mm |
| Rating                            | 6    | 5     | 4      | 1       | 0     |
| Roughness                         | Very Rough | Rough | Slightly Rough | Smooth | Slickenside |
| Rating                            | 6    | 5     | 3      | 1       | 0     |
| Infilling(gouge)                  | None | Hard filling >5 mm | Hard filling <5 mm | Soft filling < 5 mm | Soft filling > 5 mm |
| Rating                            | 6    | 4     | 2      | 2       | 0     |
| Weathering                        | Unweathered | Slightly weathered | Moderately weathered | Highly weathered | Decomposed |
| Rating                            | 6    | 5     | 3      | 1       | 0     |
### F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING

| Strike perpendicular to the tunnel axis | Strike parallel to the tunnel axis |
|----------------------------------------|-----------------------------------|
| Drive with dip - Dip 45-90°            | Drive with dip – Dip 20-45°       |
| Very favorable                         | Favorable                         |
| Drive against dip - Dip 45-90°         | Dip 0-20° Irrespective of strike  |
| Fair                                   | Fair                              |
| Unfavorable                            | Fair                              |

Table 2: RHRSI, modified after Pierson et al. (1990) and Santi et al. (2009)

| Category                  | 3 points | 9 points | 27 points | 81 points |
|---------------------------|----------|----------|-----------|-----------|
| Slope height              | 7.5 m    | 15 m     | 23 m      | 30 m      |
| Average Slope Angle Score | A        | B        | C         | D         |
| Vegetation                | Fully Vegetated | Patchy Vegetated | Isolated Plants | None |
| Lunching Features         | None Smooth Slope | Minor(<0.6m) Surface Variation | Many(0.6-1.8 m) Surface Variation | Major(>1-8m) Surface Variation |
| Ditch Catchment           | Good Catchment | Moderate catchment | Limited catchment | No catchment |
| Annual Precipitation      | 254 mm   | 508 mm   | 762 mm    | 1016 mm   |
| Annual Freeze/Thaw Cycle  | 1 to 5   | 6 to 10  | 11 to 15  | >16       |
| Seepage/water             | Dry      | Damp/Wet | Dripping  | Running Water |
| Slope Aspect              | W        | N,S,NW,SW | SE,NE, | E |
| Degree of undercutting    | 0 to 0.3 m | 0.3 to 0.6 m | 0.6 to 1.2 m | > 1.2 m |
| SDI                       | 95to 100% | 60 to 95% | 30 to 60% | <30%      |
| Degree of interbedding    | 1 to 2 weak interbed, <15 cm | 1 to 2 weak interbed, >15 cm | >2 weak interbed, <15 cm | > 2 weak interbed, >15 cm |
| Rock Character            | Homogeneous/ Massive | Small Fault/ Strong Veins | Schist Shear Zones < 15 cm | Weak pematite’s/ micas/shear zones > 15 cm |
| Degree of overhang        | 0 to 0.3 m | 0.3 to 0.6 m | 0.6 to 1.2 m | > 1.2 m |
| Weathering Grade          | Fresh | Surface Staining | Slightly Altered/Softened | Core Stone |
| Block Size/Volume         | 0.3m/2.3 m$^3$ | 0.6m/ 4.6 m$^3$ | 0.9m / 6.9m$^3$ | 1.2m / 9.2 m$^3$ |
| Block Shape               | Tabular | Blocky | Blocky to angular | Rounded and Smooth |
| Number of sets            | 1        | 1 plus Random | 2          | >2        |

© SJMS, 2019
Class 1, 2, 3, and 5 falls under the hazard category whereas class 4 falls under vulnerability category. Table of Rockfall Hazard System for India (RHRSI) shown in Table 2.

Detailed rating has been evaluated by giving scores depending upon the nature of the parameter involve in RHRS. The slope height is measured by total station. The exact score for Average Vehicle Risk (AVR) is calculated by using the formula given by Equation 2.

\[
AVR=\{(ADT/24)L_s/S\}\times100\% \quad \text{(Equation 2)}
\]

Where, ADT is the Average Daily Traffic, \(L_s\) is the slope length in kilometre, 24 is the number of hours per day and S is the speed limit. The Percentage Decision Sight Distance (PDSD) is calculated by Equation 3.

\[
PDSD=(ASD/DSD)\times100\% \quad \text{(Equation 3)}
\]

Where, ASD is the Actual Sight Distance. DSD is Decision Sight Distance. ASD is the distance at which a 15cm object disappears from the driver's sight (Ansari et al., 2013). DSD is calculated on the basis of the Post speed limit and the corresponding value describe by AASHTO is taken for calculation as shown in the Table 3.

### Table 3: Decision Sight Distance Based On Posted Speed Limits to Avoid Obstacles (AASHTO)

| Posted Speed Limit | Decision Site Distance (m) |
|--------------------|---------------------------|
| 40                 | 114                       |
| 48                 | 137                       |
| 56                 | 160                       |
| 64                 | 183                       |
| 72                 | 206                       |
| 80                 | 229                       |
| 89                 | 267                       |
| 97                 | 305                       |
| 113                | 335                       |

Average slope angle determines the average run out distance of the rock blocks. Slope angle between 35° to 85° act as an ideal condition for maximum damage. The modification made between slope angle and corresponding Average Angle Score after Maerz et al., 2005 is used for rating.
Fig. 3: Slope angle and corresponding Average Angle Score modified after Maerz et al., (2005)

Table 4: Exponent equation modified after Pierson et al., (1990)

| Parameter                        | Exponent (k)                                      |
|----------------------------------|--------------------------------------------------|
| Slope Height                     | Slope height (m) ÷ 25                             |
| Annual Precipitation             | Annual Precipitation ÷ 254                        |
| Block Size                       | Block Size (m) ÷ 0.3                              |
| Block Volume                     | Block Volume (m³) ÷ 2.3                           |
| Decision Sight Distance (DSD)    | {120 – (% DSD)} ÷ 20                              |
| Average Vehicle risk (AVR)       | (%AVR) ÷ 25                                      |
| Road width                       | {15.6 – Road width (m)} ÷ 2.4                     |
| Rockfall History                 | 1 + (0.25 * f)                                   |

Rating Results

The result obtained from the above studies based on Rock Mass Rating and Rockfall Hazard Rating are shown in Table 5 to 12.

Rock Mass Rating

Table 5: Table of GPS location of study area

| Spot No. | Location               | Elevation |
|----------|------------------------|-----------|
| 1.       | N23 42.371’ & E92 43204’ | 1043m     |
| 2.       | N23 42.252’ & E92 43.249’  | 1020m     |
| 3.       | N23 42.168’ & E92 43.275’  | 1061m     |
| 4.       | N23 42.125’ & E92 43.267’  | 1035m     |
| 5.       | N23 42.068’ & E92 43.315’  | 1034m     |
Table 6: Classification parameters and rating

| Spot No. | UCS   | QRD  | S.D  | D.L  | Aperture | Roughness | Infilling | Weathering | G.W |
|----------|-------|------|------|------|----------|-----------|-----------|------------|-----|
| 1.       | 48Mpa | 55%  | 0.69m| 4.8m | 4mm      | Rough     | None      | Slightly   | Dry |
| Rating   | 4     | 13   | 15   | 2    | 1        | 5         | 6         | 5          | 15  |
| 2.       | 66Mpa | 75%  | 1m   | 2.9m | 5mm      | Rough     | None      | Slightly   | Wet |
| Rating   | 7     | 17   | 15   | 4    | 1        | 5         | 6         | 5          | 7   |
| 3.       | 38Mpa | 82.5%| 453mm| 6m   | 1mm      | Rough     | None      | Slightly   | Dry |
| Rating   | 4     | 17   | 10   | 2    | 1        | 5         | 6         | 5          | 15  |
| 4.       | 66Mpa | 67.5%| 220mm| 5m   | 2mm      | Rough     | None      | Slightly   | Damp|
| Rating   | 7     | 13   | 10   | 2    | 1        | 5         | 6         | 5          | 10  |
| 5.       | 64Mpa | 87.5%| 386mm| 7m   | 1mm      | Rough     | None      | Slightly   | Damp|
| Rating   | 7     | 17   | 10   | 2    | 1        | 5         | 6         | 5          | 10  |

Whereas,

UCS = Uniaxial compressive strength
QRD = Quality Rock Designation
S.D = Spacing of discontinuity
D.L = Discontinuity length
G.W = Groundwater
ASUT = Average stand uptime

Rockfall Hazard Rating

Table 7: Rating of discontinuity orientation & rock mass determined

| Spot No. | Strike & Dip orientation | RMR value | Class No | Description                  | ASUT                    | Cohesion | Friction angle |
|----------|--------------------------|-----------|----------|-------------------------------|-------------------------|----------|----------------|
| 1.       | Unfavourable             | 16        | V        | Very poor rock                | 30 min for 1 m span    | <100     | <15            |
| Rating   | -50                      |           |          |                               |                         |          |                |
| 2.       | Fair                     | 42        | V        | Poor rock                     | 10 hours for 2.5m span  | 100-200  | 15-25          |
| Rating   | -25                      |           |          |                               |                         |          |                |
| 3.       | Unfavourable             | 15        | V        | Very poor rock                | 30 min for 1 m span    | <100     | <15            |
| Rating   | -50                      |           |          |                               |                         |          |                |
| 4.       | Unfavourable             | 9         | V        | Very poor rock                | 30 min for 1 m span    | <100     | <15            |
| Rating   | -50                      |           |          |                               |                         |          |                |
| 5.       | Unfavourable             | 13        | V        | Very poor rock                | 30 min for 1 m span    | <100     | <15            |
| Rating   | -50                      |           |          |                               |                         |          |                |

Table 8: Table of GPS location of study area

| Spot No. | Location                  | Elevation |
|----------|---------------------------|-----------|
| 1.       | N23°42.371’ & E92°43.204’ | 1043m     |
| 2.       | N23°42.252’ & E92°43.249’ | 1020m     |
| 3.       | N23°42.168’ & E92°43.275’ | 1061m     |
| 4.       | N23°42.125’ & E92°43.267’ | 1035m     |
| 5.       | N23°42.068’ & E92°43.315’ | 1034m     |
Table 9: Rockfall Hazard Rating for Slope and Climate

| Spot  | Slope Height | Average Slope Angle Score | Vegetation       | Lunching Features       | Ditch Catchment        | Annual Precipitation | Seepage/Water |
|-------|--------------|----------------------------|-----------------|-------------------------|-----------------------|----------------------|---------------|
| Spot 1 | 9.01 m       | D                          | Isolated plants | Minor <.6 surf. Variation | None                  | 183.24mm             | Dry           |
| Score | 3.7          | 81                         | 27              | 9                       | 81                    | 2.2                  | 3             |
| Spot 2 | 23.36 m      | D                          | Isolated plants | Minor <.6 surf. Variation | limited catchment    | 183.24mm             | Damp          |
| Score | 30.63        | 81                         | 27              | 9                       | 27                    | 2.2                  | 9             |
| Spot 3 | 25           | D                          | Isolated plants | Minor <.6 surf. Variation | Moderate catchment    | 183.24mm             | Dry           |
| Score | 38.94        | 81                         | 27              | 9                       | 27                    | 2.2                  | 3             |
| Spot 4 | 24 m         | D                          | Isolated plants | Many (.6-1-8)            | limited catchment    | 183.24mm             | Damp          |
| Score | 33.63        | 81                         | 27              | 27                      | 27                    | 2.2                  | 9             |
| Spot 5 | 17.12 m      | D                          | Isolated plants | Many (.6-1-8)            | Moderate Catchment    | 183.24mm             | Damp          |
| Score | 12.24        | 81                         | 27              | 27                      | 9                     | 2.2                  | 9             |

Table 10: Rockfall hazard rating for Geology and discontinuities

| Geology | Discontinuities |
|---------|-----------------|
| Degree of Undercutting | Block Size / Vol. | Blocky to Angular | Number of sets | Persistence/orient° | Aperture | Weathering condition | Friction | Infilling Material |
| Spot 1  | 0.9m 95%-100%   | >2 weak interbeded, >15cm | 0.3-2.3 m³ | 27 | >3meter s and dip into the slope | 4mm | Slightly altered | Roug h | None |
| Score   | 27 3 81 | 3 | 81 | 9 | 27 | 27 | 3 | 0 |
| Spot 2  | 1.8m 95%-100%   | >2 weak interbeded, >15cm | 0.3-2.3 m³ | 27 | >3meter s and dip into the slope | 5mm | Slightly altered | Roug h | None |
| Score   | 81 3 81 | 3 | 27 | 9 | 27 | 27 | 3 | 0 |
| Spot 3  | 1.2 m 94.83%   | >2 weak interbeded, >15cm | 0.3-2.3 m³ | 27 | >3meter s and dip into the slope | 2mm | Slightly altered | Roug h | None |
| Score   | 27 3 81 | 3 | 81 | 9 | 27 | 27 | 3 | 0 |
**Table 11: Rockfall hazard rating for traffic and rockfall frequency**

| Spot   | Percentage | Decision Sight Distance (DSD) | Average Vehicle Risk (AVR) | Blocky to Angular 27 | >2meters and dip into the slope | 2mm | Slightly altered | Rough | None |
|--------|------------|-------------------------------|---------------------------|----------------------|-----------------------------|-----|------------------|-------|------|
| 4      | 1.5        | 98.08%                        | 0.6-4.6 m<sup>3</sup>     | 9                    | 81                          | 9   | 27               | 27    | 3    |
| Score  | 81         | 3                             | 81                         |                      |                             |     |                  |       |      |
| 5      | 1.2m       | 97.43%                        | >2 weak interbed, >15cm    | Blocky to Angular 27 | >2meters and dip into the slope | 0.1-1mm | Slightly altered | Rough | None |
| Score  | 27         | 3                             | 81                         |                      |                             |     |                  |       |      |

**Table 12: Cumulative score for overall rating**

| Spot   | Cumulative Score | Slope     | Climate | Geology | Traffic | Discontinuity | Rock History | Total Score |
|--------|------------------|-----------|---------|---------|---------|---------------|--------------|-------------|
| 1      | 201.7            | 5         | 111     | 177     | 94.6    | 3             | 592.3        |
| 2      | 174.63           | 11.2      | 165     | 123     | 112.39  | 3             | 589.22       |
| 3      | 182.94           | 5.2       | 111     | 177     | 88.2    | 3             | 564.11       |
| 4      | 195.63           | 11.2      | 165     | 183     | 88.46   | 3             | 646.29       |
| 5      | 156.24           | 11.2      | 111     | 165     | 88.57   | 3             | 535.01       |
Conclusions

The mean RMR value is 15 out of 100 and under category V. This indicates the study area is comprised of very poor rock mass. The average period for the rock mass able to withstand without breaking is 30 minutes for 1(one) metre span. It means that detachment of rock from the slope can occur easily if the rock is exposed, and even small external force applied on the rock mass may trigger rockfall. The average cohesive force lies below 100kPa and the rock mass possess a very low shear strength. The mean value of the angle of friction is 15°, which is a well below the average. Rocks with high angle friction lies between 34° to 40° (Wyllie & Norish, 1996). Therefore, the RMR described in cut slope of Ngaizel road possess a bad quality of rock mass.

RFHR result shows that due to differential erosion, undercutting erosion is found between 0-3m in the study area which implies that an increase in length of undercutting increases the percentage of overhanging rock mass making a greater chance of rock fall. The ditch length is found to be quite narrow in various spots of the study area making a very little chance to arrest the rock/blocks after falling. The slope angle in the study area lies between 80° to 90° indicating that a possibility of rockfall along Ngaizel road is very high. Water condition plays an important role for stability of rock mass, most of the spot is dry other than rainy season which give overall status of low rating in precipitation. A set of 2 to 3 joints are encountered in which the majority of the joint are not day lighted out to slope and actually dip into the slope which supplement to the stability of rock mass. The PDSD in spot 1 and 2 are 80 % and 60% respectively. In these two spots, the vehicle driver has less time to react while encountering rockfall. While the other remaining spot 3, 4 and 5 acquired 100% PDSD, they have sufficient time to react while encountering rockfall. The average daily traffic is taken as 6000, so that the AVR (Average Vehicle Risk) in the study area stand high. The length of slope for spot 1, 2, 3, 4, 5 is 5m, 5m, 5m, 20m, 10m respectively and huge rockfall does not frequent in the study area, so the rating is put low in this study. Even though, a consistent rockfall of pebbles size occurs throughout the year, a disturbing type of rockfall is not very frequent in the area. The mean value of the Slake Durability Index is 96.78% which shows that its durability due to weathering is high and the rock can withstand more weathering conditions. According to Hoek et al., (1999), the slope with rating less than 300 is categorized as ‘Low Urgency’ while the rating between 300-500 is categorized as ‘Moderate Urgency’ and those with rating more than 500 is categorized as ‘High Urgency’ (Verma et al., 2019). Calculating scores from the rating parameter all the spot falls under High Urgency and are prone to rockfall failure.

Acknowledgements

The authors thank Geology Department, Pachhunga University College for providing laboratory facilities to conduct this study and referee for improving manuscript. This paper is supported by the Department of Science and Technology, India (No.: EEQ/2017/000539, SERB/F/6348/2018-2019; Dated: 4th
References

Ansari, M. K., Ahmad, M., Singh, R. & Singh, T.N. (2013). Rockfall Hazard Rating System for Indian scenario. *International Journal of Earth Sciences and Engineering*, 6(1), 18-27.

Duncan, C. W. & Norman, I. N. (1996). Rock Strength properties and their measurements. *Landslide, Investigation and Mitigation*, A.K. Turner and R. L. Schuster (Eds.), Washington DC, *Special report*, 247, 372-390.

Eliasen, T. D. & Springstom, G. E. (2007). Rockfall hazard rating of rock cuts on U.S. and state highways in Vermont. Research Project RSCH010-974.

Gullixson, C. F. & Peltz, T. R. (2013) Historic Columbia river highway rockfall hazard study. Oregon Department of Transport.

Hoek, E., Kaiser, P. K. & Bawden, W. F. (1995). *Rock Mass Classification. Support of Underground excavation in hardrock*. A. A. Balkema/Rotterdam/Brokfield/1995.

Karaca, M. & Goodman, R. E. (1993). The action of water on key blocks. Assessment and Preventive of failure phenomena in rock engineering. Balkema, Rotterdam. ISBN 90 54103094. 432.

Maerz, N. H., Youssef, A. & Fennessey, T. W. (2005). New risk-consequence rockfall hazard rating system for Missouri highways using digital image analysis. *Environmental and Engineering Geoscience*, 11, 229-249.

Naithani, A. K. (2007). RMR- A system for characterizing rock mass classification: A case study from Garhwal Himalaya, Uttarakhand. *Geological Society of India*, 70(40), 627-640.

NIATT, (2013). Development and Implementation of the Idaho highway slope instability and Management System (HiSIMS). NIATT Report # N03-7.

Palmstrom, A. (2005). Measurements of and correlations between block size and rock quality designation (RQD). *Tunnels and underground space technology*, 20(4), 362-377.

Palmstrom, A. (1995). RMR - A system for characterizing rock mass strength for use in rock engineering. *Journal of Rock Mechanics and Tunneling Technology*, 1(2), 69-108.

Pierson, L. A, Davis S. A. & Van Vickle, R. (1990). Rockfall Hazard Rating System Implementation Manual. Federal Highway Administration (FHWA) Report, U.S. Department of Transportation.

Sardana, S., Verma, A. K., Verma, R. & Singh, T. N. (2019). Rock Slope Stability along road cut of Kulikawn to Saikhamakawn of Aizawl, Mizoram, India. *Natural Hazards*, https://doi.org/10.1007/s11069-019-03772-4

Selcuk, L. & Yabalak, E. (2014). Evaluation of the ratio between uniaxial...
compressive strength and Schmidt hammer rebound number and its effectiveness in predicting rock strength. *International Journal of Geotechnical Engineering*, 9(4), https://doi.org/10.1080/10589759.2014.977789

Verma, A. K., Sardana, S., Sharma, P., Laldinpuia & Singh, T. N. (2019). Investigation of rockfall prone road cut slope near Lengpui Airport, Mizoram, India. *Journal of Rock Mechanics and Geotechnical Engineering*, 11(1), 146-158.

Wang, R., Wang, X., Liu, H., Wang, Y., Peng, Y., Sun, W. & Liu, J. (2018). Rockfall hazard identification and assessment of the Langxian Milin section of the transmission line passage of Central Tibet Grid Interconnection Project. *IOP Conf. Series: Earth and Environmental Science*, 189, https://doi.org/10.1088/1755-1315/189/5/052046.