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ROCKFALL HAZARDS ALONG ABURI-ACCRA ROAD, GHANA

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ABSTRACT

The expansion of the Peduase-Ayi Mensa road along a section of the Akwapim-Togo Range required excavation forming rock-cut slopes. These exposed the rocks face to geologic and climatic conditions influencing weathering. Even though ditches and benches have been constructed in some sections, rock falls still occur. The exposure of road users to rock fall hazards puts human lives and properties at risk. This study, therefore, sought to determine the factors influencing rock fall and evaluate slope face using the Modified Colorado Rock Fall Hazard Rating System (MCRHRS) for contribution to policy considerations on measures to prevent these failures. The study area was purposively divided into thirty-five sites. In determining the factors influencing the failure, observations were made to identify types of rocks and describe the nature of distinct joints. Interviews were also conducted to seek information on the causes and management of rock falls. Furthermore, observations and measurements of parameters were used to evaluate sites with MCRHRS. Total RHRS scores obtained from the evaluation of sites, in addition to aerial photographs, were used to map the degree of rock fall hazards at each site. Findings from the study indicated that rock fall hazards are influenced by the physical disturbance of the geology of the area during the construction of the road and buildings, unfavourable slope angles at some sites, in addition to rock mining and rainfall. Also, evaluation of sites indicated that RS11 is most likely to fail and hence requires higher priority of remedial works. In the course of the study, vegetation along the slope face and a section of the natural slope from RS35 to 18 were removed for the installation of wire mesh. Since it still occurs, the removal of weathered rocks and spraying of fibrecrete onto the slope face could also be considered.

***Keywords**: hazards, metamorphic rocks, Modified Colorado Rock fall Hazard Rating System, Peduase-Ayi Mensa, rock fall*

INTRODUCTION

Landslides refer to the movement of materials which are less resistant to gravity downslope (Morelli, Utili, Pazzi, Castellanza, & Fan, 2019). Such materials may include debris, rock and earth (Landslides in New Jersey, 2020). Their occurrence is influenced by the presence of excess water, gravity, unfavourable slope angle and shear strength of slope forming materials (El Jazouli, Barakat, & Khellouk, 2019; Pradhan & Siddique, 2019). The movements of volumes of these weathered materials may involve a fall, topple, slide, spread or flow (Vasanthakumary, 2019). The most common classification of landslides is based on materials under the effect of gravity and five types of kinetically distinct movements which include fall, topple, slide, spread and flow. A combination of any of these two properties, that is, type of material and movement, enables the most common classifications such as debris fall, debris flow, mudflow, earthflow, earth slide, earth spread, rock slide, rock spread, rock flow, rock topple and rock fall (Landslides in New Jersey, 2020).

Varnes (1978) referred to a rock fall as an abrupt fall of detached rock fragments from a slope (Khatiwada & Dahal, 2020). The movements of rocks along slopes do not make up a hazard unless the weathered material is likely to cause harm. Landslides occur along a few roads in Ghana. One such road is the Peduase-Ayi Mensa road. Recently, a mudslide and rock fall also occurred on 18 and 2 October 2019, respectively (Ansah, 2019). The exposure of road users to rock falls puts human lives and properties at risk. There is therefore the need to conduct additional studies to assess the nature of rock fall sites and evaluate rock fall sites using Modified Colorado Rock fall Hazard Rating System (MCRHRS) to determine the site where the construction or installation of adaptation measures should be given higher priority.

The nature of rock fall sites was centred on identifying rocks and describing the nature of distinct joints observed at each site as well as factors influencing rock falls and management of rock falls in the study area. In addition to these, the usage of total Rock fall Hazard Rating System (RHRS) scores indicating different levels of hazards to generate a rock fall hazard map was also done. These objectives will aid in the identification and prioritization of hazardous sites for construction or installation of adaptation measures with limited resources. The findings of this study could contribute to policy considerations on measures to prevent these failures which threaten human lives. It could also to add up to existing knowledge on rock fall hazards in Ghana.

STUDY AREA

The Peduase-Ayi Mensa road is a section of the Aburi-Accra road, which is considered the shortest route to Accra from Aburi through Peduase to Ayi Mensa. This is one of the reasons for the vehicular traffic along the route. On average, 7,922 vehicles travel along the Aburi-Accra Road daily (Ghana Highway Authority, 2015). The study site is approximately a 4-kilometer dual carriageway stretching from Peduase in the Akwapim South District of the Eastern Region to Ayi Mensa in the Ga East District of the Greater Accra Region in Ghana (Ghana Statistical Service, 2014). This site lies at the foothill of a section of the Akwapim-Togo Range.

A section of this highland was excavated for construction expansion of the road about sixteen years ago. The physical disturbance of the geology of the area left behind rock-cut slopes characterized by the presence of curves which could limit a driver's ability to notice fallen rocks on the southbound section of the road. The Peduase-Ayi Mensa road was selected based on how close its slopes were to the road as well as the frequent reports on rock fall hazards within this area (Dapatem, 2013; Bentil, 2014; Bentil, 2015; Bentil, 2016, Ansah, 2019). Furthermore, the study focused on rock-cut slopes even though soil slopes were also found in the study area. This was due to inadequate funds to conduct similar analyses on these slopes. Figure 1 below is a map of the study area.

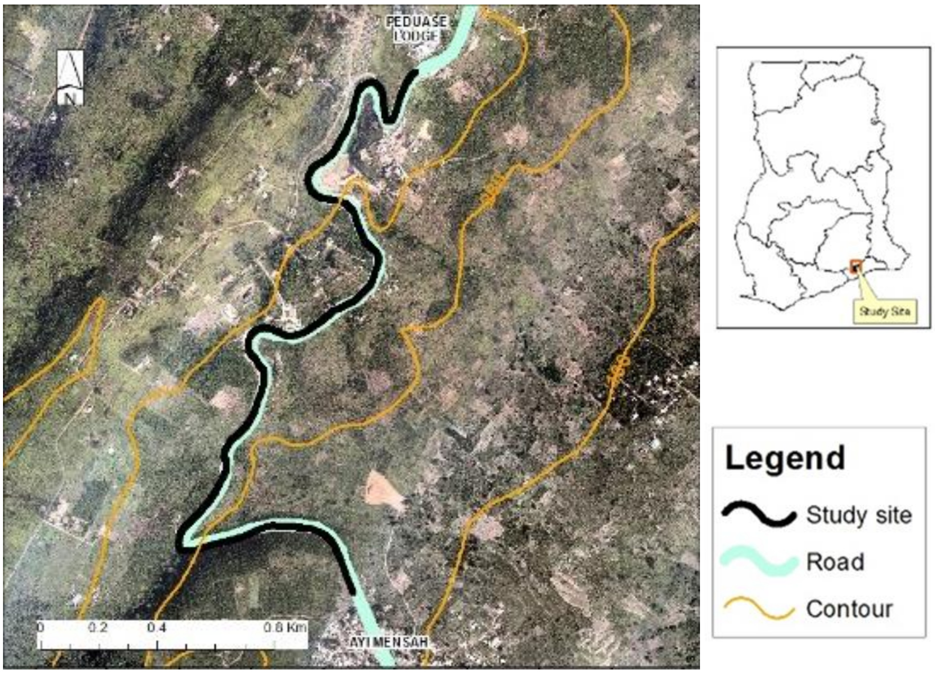

Figure 1. Map of the Study area
Source: Cartography and Geographic Information System Unit, Department of Geography and Regional Planning, University of Cape Coast (2016)

Climate and vegetation

The study area lies within a region with bi-modal rainfall distribution (Ghana Statistical Service), which begins in May and peaks in July and thereafter continues from September to October (Nyarko, 2008). Annual precipitation within the area is about 1278 mm. Average annual temperature ranges between 25.1^{o} C in August and 28.4^{o} C in February and March.
Vegetation is dominated by shrubslands and grasslands, with the shrublands mostly occurring in the western environs and in the north towards the Aburi hills. This vegetation consists of dense clusters of small trees and shrubs that grow to an average height of about five metres (Food and Agriculture Organisation, 2005).

Topography

The Akwapim-Togo Range, along which sites have been selected for the study, rises steeply above the western end, lies generally at about 375-420 metres north of Aburi, and falls to 300 metres southward in Okaikwee. This highland generally consists of a rugged complex of folded strata, with several well-known heights composed of volcanic rock (Food and Agriculture Organisation, 2005).

Geology

The study area is mainly made up of rocks of the Togo Series. It was formerly made up of alternating arenaceous and argillaceous sediments (Kesse, 1985) which are presently metamorphosed into phyllite, schist, silicified limestone and quartzite forming the Akwapim-Togo Range (Kesse; Ghana Statistical Service, 2014) with a number of sections composed of unaltered sandstones and shale. Quartzite is usually permeable by water when fractured. Predominantly, this formation is made up of rocks such as quartzite, quartz-schist, sericite-quartz schist, sericite schist and phyllite. However, hematite quartz-schist, hornstones and jaspers also occur in this formation.

Also, the Akwapim-Togo Range is made up of rocks which represent the lowest portion of a much thicker sequence whose upper part has been eroded. Generally, the strata dips towards east-south-east (Duku, 2015). The interspersions of erosion resistant quartz-schist and quartzite with phyllite give rise to asymmetric topography characterized by gentle dip-slopes facing east-southeast and steep cliff-slopes facing the west-northwest. In a north easterly direction, this range stretches from Senya Bereku, West of Accra towards the Republic of Togo (Duku). Kesse also observes that Togo beds have undergone intense folding, faulting and fracturing due to intense directed pressure metamorphism. According to this author, recumbent folds present sometimes dips less than 30°. Also, the axial planes of folds of isoclinal folding are inclined to east south-east at 30°-60°.

Seismicity

Seismic activity in Southern Ghana is associated to active faulting between a northeast-southwest trending Akwapim fault zone and an east-west trending Coastal boundary fault (Opoku, 2013; Amponsah, 2014). The Akwapim fault zone runs through Accra, the Akwapim Mountains, Ho through to Togo. In Ghana, it meets the Coastal boundary fault along the coast near Accra (Opoku). Historical records indicate that the western part of Accra, where the Akwapim fault zone and the Coastal boundary fault intersect is the most seismically active area in Ghana (Amponsah).

Human activities

Observations made revealed that there are a number of hotels and residential houses at the crest of the slopes along the road. The presence of these buildings may act as loads adding up to the extra weight attributed to rainfall. Furthermore, a few residents sold rocks close to the Ayi - Mensa toll booth. Heaps of rocks were also gathered along the pedestrian walkway. These rocks are often used to construct beautiful wall facing.

METHODOLOGY

On account of type of material likely to fail, source of rock fall, presence or absence of joints as well as the presence of drainage and cross roads, sites were purposively selected during slope survey (Pierson & Van Vickle, 1993). Thirty five rock fall sites identified during this phase were grouped into sites with high, moderate and low rock fall potential during preliminary rating. The study involved the use of primary and secondary data for assessing the nature of sites. Primary data included the collection of rock samples as well as the taking of photographs and hand written notes on description of identified rocks and nature of distinct joints. Audios were also recorded during interviews. These were also conducted to collect data on rock fall frequency, factors influencing rock falls and managements of rock falls from thirty two respondents.

The collection of additional primary data for evaluation using the MCRHRS also involved data on slope aspect, heights and angles, Actual Sight Distance (ASD) and length of hazard zone. Observations were also carried out to describe weathering conditions at sites. Secondary data which included elevation and aerial photographs were collected from the Lands Commission specifically, the Survey and Mapping Division of the Photogrammetry and Remote Sensing Unit, Accra. Also, data on Average Daily Traffic (ADT) and Decision Sight Distance (DSD) were collected from Ghana Highway Authority. Posted speed limits were also recorded during field studies. Instruments such as a veneer calliper, abney level, measuring tape and compass were used in the collection of quantitative data.

The format of MCRHRS was made to reflect the unique climatic and geological conditions of the study area. As such the parameter, annual freeze and thaw was not considered since such conditions do not prevail in Ghana. Each parameter under the categories in the rating system was rated with corresponding points in the exponential system. Results obtained were recorded on the worksheets. The sum of points scored for each parameter was the total RHRS score. Also, the total RHRS score expressed the degree of hazard at each site. From this score, sites with values greater than 500 will be classified as sites requiring immediate stabilization whiles those with scores less than 300 will be classified as sites whose remedial works require low priority. Furthermore, rock fall sites with scores between 300-399 and 400-499 will be classified as sites whose remedial works require high and higher priority respectively.

The entire study area was explored on foot within the last quarter and first quarter of 2015 and 2016 respectively. Slope survey was conducted on October, 30, 2015 while preliminary rating was conducted on November, 28, 2015. Rock samples collected from among talus at each site were placed in plastic bags and labelled appropriately. These samples were taken for identification of rocks. Features to observe were obtained from MCRHRS. Field notes on observation made were on nature of distinct joints and management of hazards at the study areas. These were done to familiarise myself with the nature of rock fall hazards for better descriptions of features. The geographic coordinates of each site were recorded using global positioning system (GPS), Juno SD handheld.

On account of site characteristics, specifically exposure of different material properties (size of catchment area and presence of joints) as well as the presence of slope interruptions (drainages and cross road) sites were purposively selected during slope survey. Thirty five sites identified during this phase were grouped into sites with high, moderate and low rock fall potential during preliminary ratings. These sites can be found within 5°48'06.57"N, 0°10'55.55"W at an elevation of about 318m and 5°47'12.16"N, 0°11'00.64"W at an elevation of about 142m. All sites were named RS (Rock fall Site) in addition to a unique number. Detailed rating for sixteen selected sites was carried out with the aid of the adapted MCRHRS composed of four categories of factors influencing rock falls.

RESULTS AND DISCUSSION

On account of type of material likely to fail, source of rock fall, presence of joints as well as the presence of drainage and cross road, 16 exposed rock cut slopes whose spatial distribution is shown in Figure 2 were selected.

Spatial Distribution of Rock fall sites

Figure 2. Location map of Rock fall Sites
Source: Geographic Information System (GIS) and Remote Sensing, University of Cape Coast (2016)

Nature of Rock fall sites

Types of rock

The type of metamorphic rock exposed at each site is indicated in Table 1.

Table 1: Identified Rocks at Rock fall Sites

RS	Rocks
10	quartzite
11	quartzite
15	metamorphosed schist
18	quartzite and schist
19	quartzite
20	quartzite
23	quartzite
24	quartzite
25	quartzite
26	quartzite
27	quartzite
28	quartzite
29	quartzite
30	quartzite
31	quartzite
32	quartzite and schist

Source: Field data (2016)

Observations revealed that sites along the road were made up of quartzite, schist or both. These rocks can be differentiated by lustre and presence of foliations on schist and the lack of these features on quartzite. From Table 1, RS18 and 32 were made up of both schist and quartzite. RS15 was made up of metamorphosed schist whiles the remaining sites were made up of quartzite.

Nature of Joints

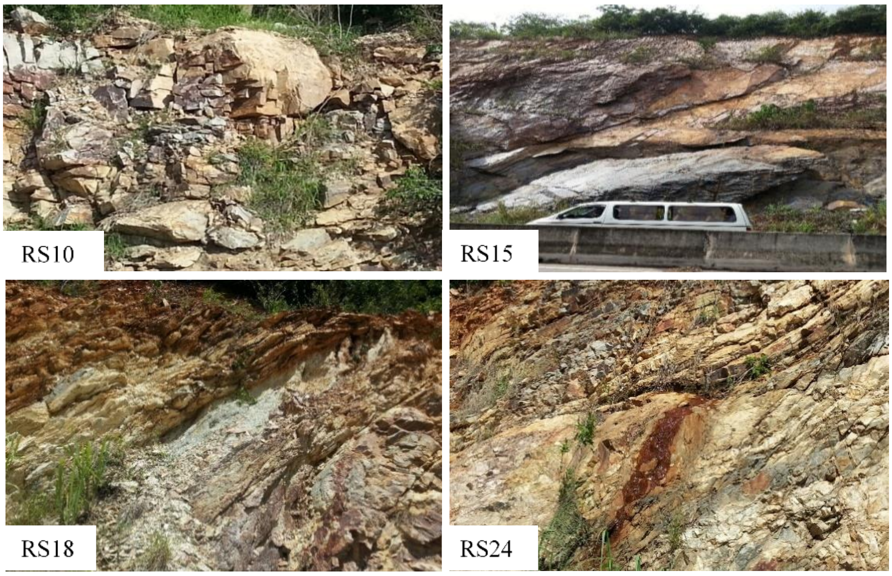

Figure 3. Nature of distinct joints on slope face
Source: Field data (2016)

As shown in Figure 3, rocks on RS10 were heavily crushed by gradual movements overtime and previous disturbances. Hence it is characterized by several random joints. Also, there were several random joints on RS10 whiles RS15 had few of these features. On RS18 weathering had exposed two schist shear zones. Water was also seen seeping through a zone of weakness in RS24. These highly fractured rocks are likely to slide and fall. On the other hand, RS15 had distinct joints and a few random cracks. As shown in Figure 3, the intersection of two joints was facilitating the removal of a huge slab, an event which was said to have occurred about two years ago. Presently, this rock has been removed. Furthermore, weathering along the slope face of RS18 had exposed two schist shear zones across a bench. These are features which could be made up of deformed weathered rocks within a rock mass (Renato, 2018). These features are distinguished by sudden variation in colour (Jamaluddin & Deraman, 2000) from light to dark reddish zones are made up of schist. It was also observed that weathered schist from these zones gradually piled up beneath these features. The presence of these joints increase the exposure of the rock mass to physical and chemical weathering.

Duku (2015) indicated that quartzite are permeable by water when fractured. Observations made indicated that out of the 5 sites where water seeped through zones of weakness, all sites were made up of quartzite. One of such sites was RS24. Water was seen seeping through a zone of weakness in this site. Seepage of water on slope face during the wet season leaves behind water streaks when dried as shown in Figure 3.

Factors influencing rock falls

During the interviews, respondents identified four factors influencing rock falls along the road. Generally, rocks fall in response to changes in climatic and geologic conditions as well as physical disturbances to inclined surfaces of appreciable heights (Mineo, Pappalardo, & G, 2020). The main climatic condition mentioned by respondents was rainfall. Majority of respondents, specifically, 27 out of 32 respondents stated that rock falls were caused by severe rain fall. This confirms indications that landslides (rock falls) are primarily triggered by severe rainfall (Nan, Hai-bo, Ming-sheng, Jie-yuan, & Jia-wen, 2020) The presence of water on these slopes may increase the weight of the rocks and eventually increase the shear stress of the material. This may cause rocks to slip along zones of weakness in response to gravity.

Fourteen respondents also pointed out that the construction of buildings on the slope induces rock fall. Construction at the crest of these slopes affects the equilibrium of the slopes since it adds additional load to the weight of the rock mass. This may gradually increase its shear stress as shear strength decreases (Yongwei, Xianmin, & Han-Lee, 2020). Also, three respondents added that the mining of quartzite and schist which is now prohibited also influence such failures. During field studies, a few people within the area were seen selling quartzite which are often used to construct beautiful wall facing. The removal of these rocks may also decrease the shear strength of the rock mass as cohesion decreases. Furthermore, two respondents also attributed the severity of the hazard to the unfavourable slope angles at sites. Slope angles determine the run-out distance of fallen rocks. Rocks falling from slopes with unfavourable slope angles are likely to reach the roadway and cause harm to road users.

Management of Rock fall Hazards

Figure 4 shows adaptation measures observed during field studies. The benches, ditches and drain were constructed to control rock falls along the road before the installation of the wire mesh began on 22nd June, 2016 (Allotey, 2016). Rock fall signs have also been placed at vantage points. The most recent signs were placed by CST Limited in 2016.

Figure 4. Rock fall Adaptation measures along the Peduase-Ayi Mensa road
a) ditch and drain b) benches c) rock fall warning signs d) installed wire mesh
Source: Field data (2017)

Observations made during the field studies revealed that anticipation of these movements led to the provision of adaptation measures which include the placing of warning signs at vantage points and construction of ditch and drain along the entire road. Benches were constructed at RS18, 30, 31 and 32. Furthermore, a respondent indicated that inhabitants go to clean rock fragments on the road periodically.

Evaluation of Rock fall Sites using MCRHRS

Rock fall sites along the Peduase-Ayi Mensa road were assessed by scoring parameters in each category in the MCRHRS to determine the site whose remediation should be given higher priority. The total RHRS score which is the sum of points recorded for each parameter was used to determine the degree of hazard at each site. Findings from the study revealed that three degree of hazard descriptions; low, low-moderate and moderate with respective scores less than 300, 300-399 and 400-499 were assigned to sites. The urgency of remedial works classified based on RHRS score at each site also had three descriptions. These were low priority, high and higher priority for scores less than 300, between 300-399 and 400-499 respectively as indicated in Table 2.

Table 2: Degree of Hazard and Urgency of Remedial works

RS	Total RHRS scores	Degree of Hazard	Urgency of Remedial works
10	273	low	low priority
11	429	moderate	higher priority
15	363	low-moderate	high priority
18	261	low	low priority
19	219	low	low priority
20	390	low- moderate	high priority
23	249	low	low priority
24	213	low	low priority
25	267	low	low priority
26	216	low	low priority
27	195	low	low priority
28	185	low	low priority
29	195	low	low priority
30	252	low	low priority
31	225	low	low priority
32	219	low	low priority

Source: Field data (2016)

The total RHRS scores ranged between 185 and 429. The findings from the evaluation of these sites implied that RS11 with the highest score of 429 was the site most likely to fail along the road.

Figure 5. Slope face of RS11

Modelling of rock fall hazards

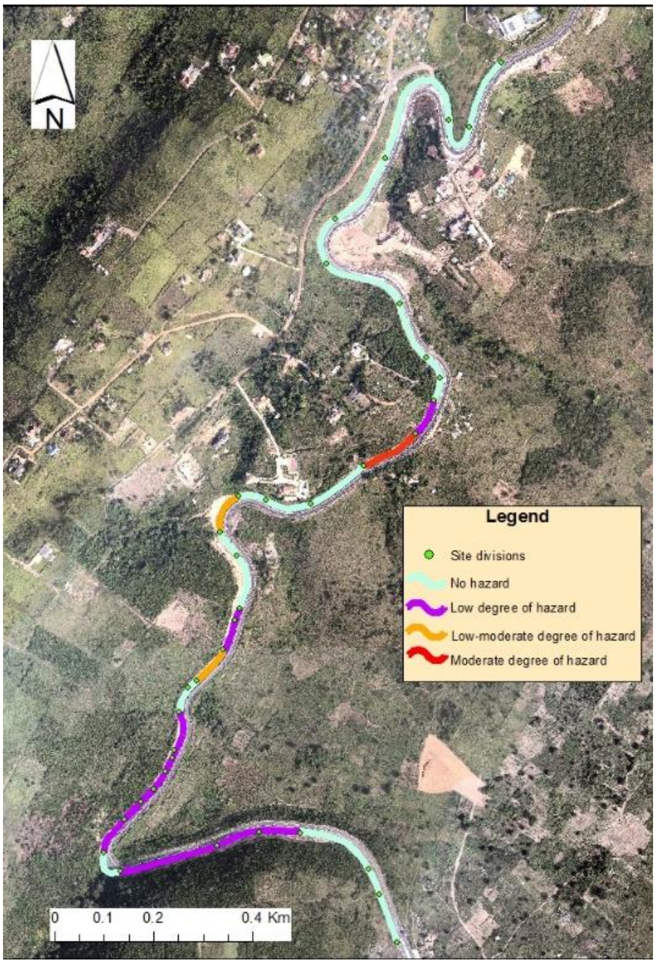

Figure 6. Spatial Distribution of Sites with related Degree of Hazard
Source: Cartography and Geographic Information System Unit,
Department of Geography and Regional Planning, University of Cape Coast (2016)

As shown in Figure 6, road segment along RS11indicated with red was classified as section requiring higher priority of remedial works. Also, road segments along RS15 and 20 indicated with yellow were classified as segments whose remedial works are worth given high priority. Furthermore, road segments along 13 sites indicated with purple were classified as segments whose remedial works require low priority. The remaining segments indicated with a shade of green may currently not require any remedial works since rock falls are not likely to occur along these slopes.

CONCLUSION AND RECOMMENDATION

On an average, 7,922 vehicles travel along the Aburi-Accra road daily. Occupants of these vehicles travel along weathered rock cut slopes of appreciable heights which are liable to failure. Analysis of rock fall hazards was carried out on sites along the Peduase-Ayi Mensa road to assess the nature of rock fall sites and evaluate of rock fall sites using MCRHRS to determine the rock fall site which is most likely to fail for prioritisation of remedial measures. Observations revealed that RS18 and RS32 were made up of both quartzite and schist. RS15 was made up of metamorphosed schist while the remaining thirteen sites were made up of quartzite.

Also, there were several random joints on RS10 whiles RS15 had few of these features. Weathering had exposed two schist shear zones on RS18. Water was also seen seeping through a zone of weakness in RS24. The presence of these joints increase the exposure of the rock mass to both physical and chemical weathering since these features enhance the movement and storage of water. Remarks from respondents indicated that the physical disturbance of the geology of the area during the construction of the road and buildings, unfavourable slope angles at some sites in addition to rock mining and rain fall are the causes of rock falls.

Findings also revealed that in managing rock fall hazards, catchment areas have been constructed along the entire road. Benches have also been constructed at RS18, 30, 31 and 32. Rock fall warning signs have also be placed at vantage points along the road. Installation of wire mesh along all sites also began on 22 nd June, 2016. Findings from the evaluation of the sites using MCRHRS also revealed that RS11 with a score of 429 is most likely to fail. Furthermore with respect to total RHRS scores, RS11, was assessed as site with moderate degree of hazard and its segment along road was classified as section requiring higher priority of remedial works.

The Akwapim-Togo Range has undergone intense folding, faulting and fracturing. Further physical disturbance of the geology of the area influences of rock falls. For this reason, the Ministry of Roads and Highways could consider including stabilization of slopes to any intense construction activities along slopes of appreciable height. Engineers could also consider removing weathered rocks with hydraulic rock hammer to clean these features off slope faces sites which failed after the installation of the wire. Preferably, the spraying of fibrecrete on slope face could be considered since it will maintain and enhance the aesthetic of the slopes along the road. Also, the evaluation of sites using MCRHRS indicated that RS11 with the highest score of 429 was most likely to fail. RS11 was also assessed as a site with moderate degree of hazard and requiring higher priority of remedial works. Therefore, Ghana Highway Authority (GHA) could consider prioritizing routine monitoring and maintenance of wire mesh along RS11.

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