GEOTECHNICAL STUDIES OF SELECTED ROCKFALL SITES IN AND AROUND AIZAWL, MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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Certify that ***Mr H. Lalhlimpuia*** has carried out research work under our supervision and guidance in the Department of Geology, Mizoram University. The results of research work by ***Mr H. Lalhlimpuia*** have been presented in this theis entitled **"Geotechnical Studies of Selected Rockfall Sites in an around Aizawl, Mizoram"** and the same has been submitted to the Mizoram University, Aizawl, Mizoram, for the degree of Philosophy.

Mr. H. Lalhlimpuia has fulfilled all the requirements under the Ph. D regulation of the Mizoram University. To the best of our knowledge, this thesis as a whole or any part thereof has not been submitted to this University or any other institution for any degree.

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DECLARATION

I ***H. Lalhlimpuia***, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institute.

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ABBREVIATIONS

ADT	:	Average Daily Traffic
AVR	:	Average Vehicle Risk
COR	:	Coefficient Of Restitution
CSMR	:	Continuous Slope Mass Rating
DSD	:	Decision Sight Distance
et al.	:	*et alia* (And others)
GSI	:	Geological Strength Index
G.S.I	:	Geological Survey of India
Hr	:	Hammer Rebound
KE	:	Kinetic Averagec Energy
ONGC	:	Oil & Natural Gas Corporation
PLI	:	Point Load Index
RHRS	:	Rockfall Hazard Rating System
RMR	:	Rock Mass Rating
Rn	:	Normal Restitution
RQD	:	Rock Quality Designation
RSF	:	Rock Bolt Supporting Factor
Rt	:	Tangential Restitution
SDI	:	Slake Durability Index
SMR	:	Slope Mass Rating
SRF	:	Strength Reduce Factor
UCS	:	Unconfined Compressive Strength

ABSTRACT

As the city grows development of infrastructure began to take place everywhere, Construction or enlargement of highways occur all over the states. Excavation of roadside buildings is ubiquitous. People began to settle not seeking a safe area. These demanding development happens ceaselessly resulting in slope instability and create a problem and may even lead to fatal disaster. Meanwhile, what has to remember is that take precautions and look at the detailed safety measure before the onset of any construction.

Rockfall is a catastrophe that frequently encounters in a hilly region, which is disastrous and may cause roadblocks and even casualties to the people that traverse or lived in the vicinity of the area, but the time of occurrence cannot be predicted.

Rockfall usually happens along the highway region. There is much reason that may cause rockfall, the common problem that trigger rockfall is improper excavation along the highway and construction side. Another important factor is the lack of detailed geotechnical investigation before the implementation of project work.

In this research, we considered three important road-cutting sections around Aizawl such as NH-54 Bawngkawn-Durtlang, Bawngkawn-Edenthar, and Ngaizel. These roads act as an important economic gateway to the entire city as well as a vital trade route to the southern parts of Mizoram.

The geology of the study area is mainly intercalation of shale and sandstone, these intercalation may lead to unequal erosion on the strata itself. Persistence erosion may form overhang rock. Stress applied on the overhanging rock can easily trigger rockfall. Therefore lithology plays an important role in the stability of rock slope. Also, the geological structure such as orientation, spacing, etc, and even groundwater condition is an important factor to consider in the study of rockfall. As mentioned above the occurrence of rockfall depend on the Geological structure. Therefore in areas of complex geological structures like Aizawl, there are certain areas where rockfall might happen. Therefore continuous research is very much required. Since rockfall may occur persistently, monitoring rockfall in a regular basis can reduce its fatal effect.

Light detection and ranging (LiDAR), laser scanning, geographical information systems (GIS), video image recognition etc. are the commonly used technologies for rockfall monitoring.The main objective of this research is to investigate the characteristic of rock mass concerning the stability condition of the slope. It also aims to identify the hazard region in the study area and suggest mitigation and provide an available protective measure to minimize the adverse effect of rockfall. Detailed geotechnical investigation is carried out in these areas.

The geotechnical investigation performed in the research are Uniaxial Compressive Test, RQD, RMR, SMR, Rockfall Hazard Rating System for Indian Landmass, GSI, SDI Test, and Point Load Index Test. The detailed investigation is carried out through Field and Laboratory analysis. Besides mention above analysis using Software such as Kinematic analysis and Rockfall analysis are performed in this research.

The overall result obtained from the studies reveals that the study area possesses bad rock mass, unstable condition, high probability of rockfall, and required immediate measures or action to stabilised the area.

Some of the mitigative measures suggested for the study area are trim blasting, re-sloping, wire meshing, scale down overhanging rock using hand or machine, and removal of tree roots that traverse the crack or that grow into cracks.

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

A rockfall is a fragment of rock or a block detached by sliding, toppling or falling, that falls along a vertical or sub-vertical cliff, proceeds downslope by bouncing and flying along trajectories or by rolling on talus or debris slopes (Varnes, 1978). The falling material may range in size from pebble size to thousand cubic meters.

A fall begins with the detachment of soil or rock, or both, from a steep slope along a surface on which little or no shear displacement has occurred. The material subsequently descends mainly by falling, bouncing, or rolling. Rockfalls are abrupt, downward movements of rock or earth, or both, that detach from steep slopes or cliffs. The falling fragments usually strike the lower slope at angles less than the angle of fall, causing bouncing. The falling mass may break on impact, may begin rolling on steeper slopes, and may continue until the terrain flattens (Lynn & Peter, 2008).

One of the most devastating natural agency which we often encounter is landslide. Even though it occurs naturally but also caused by human (anthropogenic) activities. Landslide is a downslope movement of rock or soil or both, acquiring a surface of rupture either curved (Rotational slide) or planar (Translational slide) rupture in which much of the material often move as a coherent or semi-coherent mass with little internal deformation. It should be noted that, in some cases, landslides may also involve other types of movement, either at the inception of the failure or later, if properties change as the displaced material moves downslope (Lynn & Peter, 2008).

Depending upon the nature, type of movement and material involved, landslides can further be divided into several types such as fall, topple, slide, spread or flow. The rate of movement may vary greatly and it is mainly controlled by the material, moisture content, and topography of the occurrence. Some required days or even years to be known while some landslides are very rapid and occurred in the blink of an eye. In the past number of serious and fatal landslides had struck India and some of which are; Guwahati Landslide that took place in September 1948 over 500 people died (KSDMA,2019). Darjeeling landslide that happened around October 4, 1968, 667 lives were lost along with the destruction of a tea garden (Biswas & Pal 2016). Miapa landslide of Uttarakhand occurred on 18th August 1998 more than 200 people died (Paul *et al*., 2000). In November 2001 due to heavy rainfall fatal landslide happened in Amboori Kerela, over 40 were reported dead. Kedarnath landslide, Uttarakhand occurred on June 16 2013 due to Uttarakhand floods, over 5700 were reported dead due to flood and post floods landslide (Barik, 2016). Malin Maharastra landslide occurs on July 30, 2014, around 151 people died in that incident (Saha & Parkash, 2016). Many minor landslides had been reported throughout India to date. Some of the worst landslides that exist in Mizoram include Hlimen Quarry landslide (August 1992; Kumar *et al*. 1996), Keifang Quarry landslide, Rangvamual landslide (2014), Hunthar landslide, Laipuitlang landslide (11th May 2013; Laldinpuia *et al.* 2013, 2014), Rulchawm landslide (2nd October 2020), Phullen landslide (4th October 2020), Zemabawk landslide (7th October 2020), Ngaizel rockfall (Lalhlimpuia *et al*. 2019), Thuampui landslide (11th June 2021; 4 persons died), etc.

As development arises, the construction of a highway in the hilly area creates a problem, resulting in slope instability. The triggering mechanism of landslide may involved undercutting of a slope by stream or river, differential erosion, human activities such as excavation during construction, earthquake shaking or intense vibration, heavy rainfall, Overburden external load, increase in pore pressure due to over-saturation, etc. Various techniques and methods have been carried out to investigate different kinds of landslides. A scientific study of landslides is required for determining and reducing the hazardous impact of the area. Landslides are natural hazards *i.e*. geohazards, because this environmental process is responsible for direct damages that can be expressed in thousands of deaths and injuries each year and monetary losses in the billions.

Landslide in the form of rockfall frequently affected at the study area. Rockfall is the detachment of rock particles under the influence of gravity triggered by various factors and is often encountered in the mountain region where infrastructure such as highways, railways, power generation, buildings, etc are processed. All these activities are subjected to rockfall hazards. This hazard which in turn can result in huge economic loss, as well as loss of life. In India, rockfalls are encounter along with the Himalayan mountain ranges and their extension.

Due to the unfavorable topographical features roads in hilly areas are usually small as compared to plain areas, therefore several problems may arise whenever rockfall occurs. The responsible factor that contributes to rockfall includes slope degree, geomechanical properties of rock mass such as the orientation of discontinuities, condition of discontinuities, lithology, degree of interbebed, slope condition, etc. We all know that the strength of rock differs by its kinds and types. The rock mass quality depends on its geomechanical properties. The physical property of rock mass can be determined in the laboratory as well as in-field observation. A significant and notable rockfall that observed in Aizawl in the past few years include Ngaizel rockfall (30th May 2014; 23rd August 2015; 2nd April 2016; 5th August; 2017; 27th March 2018; 22nd May 2019; 26th May 2019; 17 June 2019; 11th November 2019; 17th April 2020; 21st July 2020; 14th June 2021), NH-54 Durtlang road rockfall (11th September 2017; 3rd August 2019), Bawngkawn-Edenthar road rockfall (23rd August 2015). 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 traveling public (NIATT, 2003)

As the city grows development of infrastructure began to take place everywhere, people began to settle not seeking a safe area. Taking into consideration all the adverse effect of rockfall detailed analysis of the slope become indispensable. Various methods of studies such as field investigation, laboratory, and analysis using software are applicable to probe the stability condition. In areas where the sample of rock for physical testing is unavailable due to the remote location of the site and due to some other unfavorable conditions, an alternative method for rock mass classification RMR can be carried out. Rock mass classification after Benwaski (1989) is considered the best classification (Naithani, 2007). It is widely used to analyzed slope stability in mining and other excavation. This system of classification is based on field investigations. RMR enables the identification of the actual condition of rock mass on the slope. Therefore, RMR system of classification is done to determine the geomechanical condition of rock mass in the prone area of rockfall. RMR based Slope

Mass Rating (SMR) introduced by Romana (1973) is also an important tool to investigate or assess slope stability in the natural condition as well as the engineering slope. In the case of rockfall, understanding the trajectory furnishes the ways of mitigation to the rockfall-prone zone. To suggest the most appropriate mitigative measures one must have a defined understanding of the type of failure. Kinematic analysis is imposed to identify the possible mode of slope failure and Rockfall analysis using software defines the trajectory of rockfall.

The Rockfall Hazard Rating System (RHRS) is introduced by Brawner and Wyllie for the Canadian pacific (Ansari *et al.* 2013). The purpose of the 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). The Indian System for Rockfall Hazard Rating System (ISRHS) is a modified version of both Pierson *et al.* and Santi *et al.* with the addition of crucial parameters for Indian rock mass. All the RHRS parameters concern with the safety of the pedestrians that traverse the region. Therefore detailed analysis provides useful information to delineating out the hazard level. This study gave awareness and alertness about the actual condition of the area.

1.2 GENERAL GEOLOGY OF MIZORAM

Due to the remoteness of the state, geological studies have become meager. Some of the first research that describes the geology of Mizoram were La Touche (1891), Hayman (1937), Franklin (1948), Das Gupta (1948), and Brunnschweiler (1966), etc. Later the more detailed work is done by Ganju (1975), Ganguly (1975), Jokhan Ram *et al*. (1984), Nandy (1972, 1983), Nandy *et al*. (1983), Shrivastava *et al.* (1979), etc. According to their studies, this region is a part of the eugeo-synclinal domain of the Assam-Arakan geosyncline which evolved from the arc-trench type subduction and later accretion of the sediments. The sediments are characterised by various primary-sedimentary structures indicating a shallow marine environment of deposition.

Mizoram Fold Belt (MFB) is the easternmost extension of Surma basin, covering an area of about 25000km^2 accommodate about 5000m thick sequence of tertiary sediments. The entire terrain is hilly and bounded in the west by Tripura and Chittagong Hill Tracts (Bangladesh) in the north by Assam and Manipur, in the east by Chin Hills, and in the south by Arakan Hill Tracts (Myanmar) (Borgohain *et al*. 2020).

Mizoram is geologically a part of the Tripura-Mizoram miogeosynclinal basin which evolved after the regional uplift of the Barail Group of sediments (Evans 1964). The area is composed of a repetitive succession of Neogene arenaceous and argillaceous sediments which were later thrown into a series of approximately N-S trending, longitudinally plunging, anticlines, and synclines (G.S.I. 1974). The trend of the rock formation Mizoram is N-S. The outcrop of older rock is found toward the east at the same time the sedimentary deposit increase in thickness in the argillaceous component is observed toward the same (Shrivastava *et al.* 1979).

Mizoram lies in the Surma basin which is accompanied by the folded structure of westerly convex with prominent sinuosity ridge and valley. This formed the basin wider toward the northern part and narrower toward the southern part

The fault of NE-SW and NW-SE dominated the basin. The northwestern boundary of the Surma basin is demarcated by the NE Sylhet lineament/fault running from near Dhaka, Bangladesh to the northeastern corner of the Bengal basin. The Bengal and the Surma basins are traversed by the NE trending Gumti fault. Mat fault and Tuipui fault in Mizoram are the NW-SE trending lineament.

With the increase in the intensity of folding the magnitude of faulting increases towards the east. Many of the oblique faults like Mat, Tuipui, Saitual, and Sateek faults in Mizoram are sinistral whereas Aizawl and Koladan are dextral (Nandy 2000; Tiwari *et al.* 2002).

Controversy arose in the occurrence of Barail Group in Mizoram. The occurrence of Barial sediments in the eastern part of Mizoram has reported by the geologists of the Geological Survey of India like Munshi (1964), Nandy (1972, 1982), and Nandy *et al*. (1983) while from the opinion of geologists of the ONGC namely

Ganju (1975), Ganguly (1975), Shrivastava *et al*. (1979) and Jokhan Ram *et al.* (1984) considered the absence of Barial in the state, they consider them to be a part of Surma Group.

The distribution of litho-units reveals that the Lower Bhubhan formation is confined at the anticline cores of high altitude fold. The exposure of Middle Bhuban succession is observed on the limbs of the folds and the cores of low amplitude anticlines. The anticline of the western part of Mizoram exposes Upper Bhuban rocks while in the central and eastern parts it is restricted to the synclinal cores. Boka Bil rocks are limited to the cores of synclines in the western and north-western parts only. Tipam sediments also follow a distribution pattern similar to that of Boka Bil rocks (Jokhan Ram *et al*. 1984).

1.2.1 Surma Group

Mizoram is a part of the Neogene Surma basin it is limited by the post Barail unconformity, subsequently faulted to the east, E-W Dauki Fault and Disang Thrust to the north and Sylhet Fault and Barisal-Chandpur High, concealed below the alluvium of Bangladesh, to the west and north-west respectively The folded sediments of the Surma Group further continue to the south up to the Ramri Island of Myanmar (Nandy *et al*. 1983).

1.2.2 Bhuban Subgroup

This subgroup consists of a hybrid, intergrading, and interdigitating association of rhythmically alternating argillaceous and arenaceous beds (Ganguly 1975). It has been divided into Lower, Middle, and Upper Bhuban Formations based on the predominance of sandstones over shales and siltstones and vice versa (Ganju, 1975). The study area consists of Middle and Upper Bhuban formation of Surma Group.

1.2.3 Lower Bhuban Formation

The appearance of fined grained hard sandstone with dark grey shale just below very thick siltstone/mudstone – shale alternation sequence has been taken as the boundary between the lower and middle Bhuban formation. On megascopic examination, the sandstone looks grey on fresh and buff on the weathered surface, fine-grained, moderately to poor sorted, hard, and current bedded, While the shales are dark grey thinly laminated and at places fissible (Ganju, 1975).

1.2.4 Middle Bhuban Formation

This formation conformably overlies the rocks of the Lower Bhuban Formation is about 3000m. It mainly consists of shale, sandy shale, shale silt, and shale silt sand, interlamination and intercalations, siltstone-mudstone, sandstone, shale-sandstone alternation. Occurrence of rapid alternations of siltstones/ claystone – shales, shales, and sandstones. Grey to bluish-grey siltstones/ claystone, thinly bedded to massive and hard with small scale cross-stratifications observed. Shales are of grey to dark grey or pale green. Laminated Fine-grained sandstone with thinly bedded to massive demarcate Middle Bhuban formation.

1.2.5 Upper Bhuban Formation

The Middle Bhuban Formation is conformably overlain by the Upper Bhuban Formation with a transitional contact. This unit is exposed along all the road sections around Aizawl and Lunglei. The formation attains a maximum thickness of about 1200 m along the Rangvamual- Sairang road section. It is mainly composed of shale and siltstone. A large number of sedimentary structures and trace fossils are observed. A small number of Mega fossils have been encountered. Lenticular bedding and flasher bedding are common. Interbedded shale and sandstone with the presence of digenetic nodules are observed (Bharali *et al*., 2017).

1.2.6 Structure and Tectonics of Mizoram

Structurally, Mizoram falls in the frontal folded and mobile belt of Assam-Arakan geosynclines. The structural features observed in general are serried of doubly plunging en-echelon anticlines and synclines (Ganju 1975).

The shape of the Mizoram fold belt is slightly acuate and convex westward. It is arranged in an echelon structure of strongly folded anticlines and synclines (Ganguly 1975). This fold belt continues northward into the Surma Valley and Western Manipur Hills with approximately NNE-SSW trend and into the Naga Hills and Patkai Range with a NE-SW trend. It extends into the Arakan Hill Tracts of Myanmar with approximately NNW-SSE trend in the southward direction (Ganguly 1975), while its trend in Mizoram is approximately N-S.

Mizoram is related to the eastward subduction of the Indian plate along the Arakan Yoma Suture during Eocene time and the subsequent development of the Indo-Burman Orogenic belt. The sediments of the basin yield by folding and faulting in a compressive stress field as an upper crustal decollement or 'Supra Structure', the intensity of the deformation was maximum in the east, near the zone of subduction and collision due to eastward drift of the Indian Plate during Mio-Pliocene time. The folded belt is under the E-W stress field even to the present day (Nandy *et al.* 1983).

The generalized stratigraphic succession as worked out by Munshi (1964), Nandy *et al*. (1972, 1983), Ganju (1975), and Shrivastava *et al*. (1979) is shown in the following table:

Table 1. 1: Stratigraphic Succession of Mizoram (After Munshi, 1964; Nandy *et al*. 1972, 1983; Ganju, 1975; Shrivastava *et al*. 1979)

Age	**Group**	**Subgroup**	**Formation**	**Generalized Lithology**
Recent	Alluvium			**Silt, clay and gravel**
Unconformity				
Early Pliocene to Late Miocene	Tipam (+900m)			Friable sandstone with occasional clay bands
Conformable and transitional contact				
Miocene	S	Bokabil (+950m)		Shale, siltstone and sandstone
		Conformable and transitional contact		
	U	B	Upper Bhuban (+1100m)	Arenaceous predominating with sandstone, shale and siltstone
		H	Conformable and transitional contact	
To	R	U	Middle Bhuban (+3000m)	Argillaceous predominating with shale, siltstone-shale alternations and sandstone
	M	B	Conformable and transitional contact	
Upper Oligocene	A (+5950m)	A N	Lower Bhuban (+900m)	Arenaceous predominating with sandstoneand silty-shale
Unconformity obliterated by faults				
Oligocene	Barail (+3000m)			Shale, siltstone and sandstone
Lower contact not seen				

1.3 LOCATION AND GEOLOGY OF THE STUDY AREA

1.3.1 NH-54 Bawngkawn – Durtlang road section

The study area Bawngkawn – Durtlang road which is the National Highway No 54 lies between N 23º46.138'& N 23º45.857' to E 92º44.334' & E 92º44.257', and locates under toposheet number 84A/10 of Survey of India (Fig. 1.1). The Geology of the study area consists of the Middle Bhuban Unit comprises a succession of sandstone, silty-sandstone, siltstone, silty-shale, sandy–shale, and mudstone. Fined to medium-grey and brown-colored sandstone of this unit is bioturbated and bears diverse assemblages of trace fossils (Tiwari *et al*., 2013) (Badekar *et al*., 2013). The general slope direction of the study area is N-W. It exhibits differential erosion, high angle slope with isolated vegetation cover. Numerous sets of joints are observed in the study area.

1.3.2 Ngaizel road section

Ngaizel road lies between N 23º42.331"& E 92º43.204" to N 23º42 068' E 92º43.315', and locate under toposheet number 84A/10 of Survey of India (Fig. 1.1). The Geology of the study area consists of Middle Bhuban formation. The lithology is defined by the presence of Crumpled shale, Shale Sandstone alteration, shale-siltstone alteration. Thickly bedded sandstone of Upper bhuban formation is exposed in the area (Rahul, 2014). They exhibit moderate weathering conditions. Differential erosion took place as a result of soft shale overriding sandstone. It acquired a high angle slope, a negative slope can be seen in some areas. The strata are encompassed by cracks and Joints. Slopes along the cut slope may fail due to uneven oriented discontinuities in the rock mass (Sardana *et al*., 2019). Distribution of a different kind of joint such as longitudinal joints (Parallel to bedding), normal or cross joint (Intersecting the bedding), Diagonal or Oblique Joint (Intersect the bedding obliquely), curvilinear joints (parallel sheet or slab), and tensional Joint formed as a result of tensional force (Naithani, 2007) are common in the study area.

1.3.3 Bawngkawn –Edenthar road section

Bawngkawn – Edentar road section lies between 23^0 45.3439 N & 92^0 43.600 E to 23^0 45.272 N & 92^0 43.365 E of Survey of India and locates under toposheet number 84A/10 (Fig. 1.1). The study area represents Middle Bhuban unit, it is mainly composed of sandstone, shale, buff sandstone, grey sandstone, and silty sandstone. (Badekar *et al*., 2013). Intercalation of sandstone and shale dominated the area. A number of joints traverse the area. The locality is rich in ichnospecies (Tiwari *et al*., 2011).

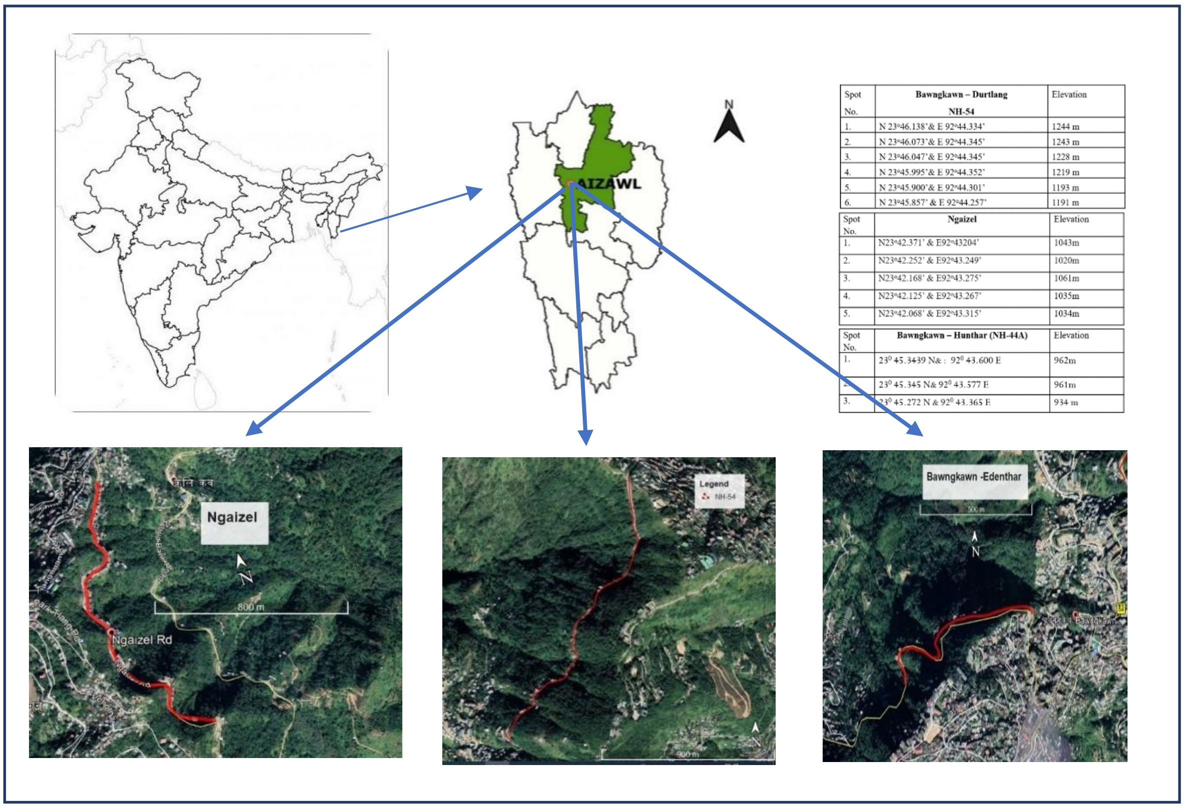

Figure 1. 1: Location of the study area

1.4 LITERATURE REVIEW

Basahel & Mitri (2017) had evaluated various rock mass classification systems against known rock slope conditions in a region of Saudi Arabia. Also, they performed empirical methods on 22 rock cuts which werJe selected based on their failure mechanisms and slope materials. They identified the stability conditions, and a comparison is made for the results of each rock slope classification system. The limitations of the empirical classification methods used in the study and proposed future research directions are highlighted.

Brook & Hutchinson (2008) had analyzed the applicability of the three rock mass classifications such as rockmass strength, RMR, and SMR in Ruahine Range, North Island, New Zealand. He concluded that all three systems of classification had some limits and required modification for weak rock masses.

Budetta (2003) proposed a modified version of the RHRS developed by Pierson *et al.* 1990. He applied the modification of the RHRS version to a 2 km long section of the Sorrentine road (no 145) in Southern Italy. The analysis showed that the risk was unacceptable, required urgent remedial works.

Keykha and Huat (2011) had reviewed the role of joints in the determination of RGD. They had shown the estimation of RQD by using volumetric joint count and compared it with weighted joint density (WJD). Their finding indicated that the method was effective in the determination of RQD.

Khatiwada and Dahal (2020) studied rockfall hazards in the Imja Glacial Lake, eastern Nepal. They confirmed that the rockfall hazard in the region was critical because the rockfall can generate huge surges which may bring Tsumani like surge in the lake leading to breaching of the morain dam.

Mohamadi and Hosssaini (2017) introduced the concept of RSF for modification of RMR system to be used in rock mass consisting of an interbedding of strong and weak layers. The Alborz Tunnel of Iran was used as case examples for the development of the theoretical approach.

Palmstorm (2005) had done correlation between various measurements of block size. He had found difficult to carry out a reliable correlation between RQD and other block size measurement. He proposed an adjusted equation between RQD and Jv better than the existing one.

Pierson *et al*. (1990). developed the RHRS. It was implemented by the Oregon Department of Transportation. The system provided a rational way to make informed decisions on where and how to spend construction funds. This manual documented the components of the RHRS, the steps an agency should follow to implement the system, and discussed the level of commitment required. It also described the benefits of implementation.

Sorogluo *et al.* (2012) had carried out stability and rockfall analysis in the historical site of Monemvasia, Greece. Planer wedges and toppling failure are common in this area. From their analysis, mitigative measures such as rock bolt and wire rope net were suggested.

Sabatakakis *et al.* (2008) performed a laboratory test which includes total porosity, dry unit weight, schmidt hammer value, and point loading index as well as the strength under uniaxial and triaxial compression test on intact chemical and clastic sedimentary rocks (Marlstones, sandstones, and limestones). They establish regression equations from the statistical analysis of the data among rock material parameters, also determined conversion factors related to index properties and strength of sedimentary rock. The Mineral composition and microstructure were analyzed in thin sections and the intrinsic influence on the measured strength parameters was investigated.

Wang *et al*. (2017) had provided a convenient tool for engineers to determine UCS rating values with which to estimate rock mass quality, the correlation between Hr and UCS was investigated in this paper.

Ahmad *et al*. (2013) had investigated the slope along National highway -72 (SH-72) from Mahabaleshwar town. They performed Kinematic analysis, rockfall analysis using Rockfall 4.0 software. The result of the numerical analysis showed that varying slope angle geometry created more problems as compared to the mass of blocks in the scenario of rockfall.

Ansari *et al*. (2013) had proposed RHRSI modified after Pierson *et al.* and Santi *et al.* They added parameters such as the geologic and climatic condition in RHRS for Indian landmass. They proposed RHRSI under the complex geological condition of India.

Ansari *et al*. (2013) had introduced the RHRS of classification for Indian Landmass which was modified after Pierson *et al.* and Santi *et al*. Parameters like geological and climatic condition were added and/or modified in RHRSI.

Ansari *et al*. (2015) had identified a correlation between Schmidt hardness of slabs and balls with normal COR. It found that the normal COR is sensitive with examined parameters whereas tangential COR does not have any correlation with examined parameters. An empirical equation had been proposed based on regression analysis and will be applicable to calculate the Rn for different rock types from their Schmidt hardness.

Mithresh and Krishna (2017) had mentioned that rockfalls were caused by the disorientation of joints that triggered during heavy rainfall and seismic events leading to the falling of rock blocks from the crown portion of the slope. Their investigation of rockfalls at Theng situated in the Sikkim Himalayas was carried out using RocFall 5.0 numerical simulation program to predict the rockfall trajectory.

Nazir *et al*. (2013) had proposed a correlation between UCS and Tensile Strength. For this purpose, they conducted the UCS test and Brazilian Test in the laboratory. 40 limestone samples were used for testing. From the laboratory results, a new correlation with high reliability and degree of accuracy i.e R=0.9 was proposed for predicting UCS of limestone specimens from its BTS results.

Sangra *et al.* (2017) conducted a Geotechnical Investigation on the Slopes Failures along the Mughal Road from Bafliaz to Shopian, Jammu, and Kashmir, India. They applied RMR, SMR, and Kinematic analysis for this study. The study concluded that the presence of multiple sets of discontinuities was the principal governing factor affecting slope stability in the study area.

Sarkar *et al.* (2016) imposed kinematic analysis and CSMR to the NH-44 Sonapur Landslide. The possible type of failure was a wedge type of failure along with a few toppling and planar failures. The CSMR showed a partially stable condition of the area. Which required immediate treatment for the long-term stability of the slope.

Sazid M. (2019) had analyzed rockfall along Al-hada road. Based on his investigation the instability of the study area was governed by its jointed rock mass. Kinematic analysis revealed that planar, wedge, and toppling failure are the main failure mode in the study area. He concluded that there was a high probability to create extensive risks to the commuter.

Sharma *et al.* (2020) carried out a rockfall hazard assessment along the hill slope of Mumbai –Pune expressway, Maharastra, India. The assessment showed stability during the dry condition and become critical during the rainy season.

Sharma *et al.* (2020) had assessed the rockfall hazard of hill slope along with Mumbai – Pune Expressway, Maharastra, India using a combination of rockfall simulation and 2D slope stability analysis. They found that the presence of three sets of joints, torrential rainfall, and high-density traffic was the major factor for the instability of the slope.

Siddique *et al*. (2020) had done geotechnical investigation along NH-58. From their investigation, a critical SRF was determined. They suggested modification in the profile or slope geometry by designing benches and reducing slope angles.

Siddique *et al*. (2015) had done a detailed investigation using SMR and kinematic analysis of slopes along the national highway-58 near Jonk, Rishikesh, India. Based on their study the area fall under stable class and low to moderate vulnerability to landslide.

Singh *et al*. (2016) stated that the occurrence of stratified rock cut slopes (Shale-sandstone-siltstone layers) with highly jointed which cannot sustain significant engineering load are common in some part of the Himalayas. They considered that the existence of such similar rock in the North-Eastern part of Himalaya (Mizoram) along cut slopes for analysis. They investigated the effective loading direction and zones of maximum displacement. Maximum flow rates were observed along the slope face. They observed unplanned settlement along the crest of the slope as well as the slope face, persistent heavy rainfall followed by the improper drainage system, and highly weathered condition of the slope. Their results obtained from numerical simulation showed the stability of slope only on gravity loading condition. But when a constant load of 1Mpa was applied on the crest of the slope displacement at a maximum of 0.14m occur. In other cases under coupled hydromechanical loading, the displacement increases to 1.2m.

Singh *et al.* (2013) had carried out studies along the Amboli roadcut hill Maharastra, India to understand the stability of the cliff face. A combination of field study and 2D computer simulation was performed to assess surface characteristics of the cliff face. They had estimated the bounce height, translational kinetic energy, translational velocity, and factor of safety for saturated conditions. They determined the unstable condition of the study area, and they suggested compatible mitigative measures.

Singh *et al.* (2015). had done numerical analysis and field investigation to study Malin Village landslide at Pune District. Maharastra. The estimated geotechnical parameter was utilized in their work. The result obtained from their study shows that the hillslope was unstable with factor safety less than 1 and prone to failure. Their study revealed that the landslide in Malin was due to various man-made and natural factors like heavy rainfall, unscientific construction activities at the top of the hill and along the hill, unplanned cultivations, and lack of drainage system.

Vasudevan & Ramanathan (2011) had reported that the results of field investigations for six landslide sites in north, northeast, and South India. They concluded that the main cause of these landslides was due to heavy rainfall, a saturation of the overburdened material, improper drainage system, water seepage through rock joints, and bedding intersection.

Verma *et al.* (2018) had conducted a rockfall analysis near Solang Valley, Himachal Pradesh India. The analysis showed that the optimized ditch is effective to arrest a large number of falling rocks, and the kinematic energy can be decreased by trimming the slope. They have suggested a 2.5m height. barier of 100kj capacity.

Verma *et al*. (2019) analyzed NH-44A of Aizawl to Lengpui Airport road by using RHRS, three-dimensional 3D stability analysis, and kinematic analysis. The assessment revealed that one out of three slopes was highly prone to rockfall. The geological condition, differential weathering, and high intensity of pre-monsoon rainfall were the causes of rockfall activity on the studied location.

Vishal *et al.* (2016) performed a hazard assessment along NH– 58, India, reveals that the unstable slope can be optimized by modifying the slope angle, ditch width, and ditch angle.

Lalhlimpuia *et al*. (2019) assessed the road section of Ngaizel using RHRS and RMR. The result indicated poor rock mass and required immediate action for stabilization of the slope.

1.5 SCOPE OF THE STUDY

The rugged mountainous terrain of Mizoram possesses a very complex geological structure. Because of these complex geological settings, different kinds of landslides are found to exist. Among different kinds of landslides, rockfall is often encountered along the highways. Even though rockfall is very frequent proper investigation is not yet done. A detailed investigation is required to understand the nature of rockfall. Therefore this study aims to understand the geo-mechanical properties of rock mass. Geotechnical investigations such as Slope stability analysis, kinematic analysis, and rockfall hazard rating are carried out in this study. Therefore from the present study, we can understand the stability condition, type of rockfall, and even delineate the hazard area.

1.6 OBJECTIVES

The objective of this research are as follows:

1. To assess rockfalls using Rockfall Hazard Rating System (RHRS);
2. To determine the physicomechanical properties of the rock and rock mass;
3. To suggest appropriate mitigation and protective measures.

CHAPTER 2

METHODOLOGY

2.1. ROCK MASS RATING (RMR)

Rock Mass Rating is proposed by Bieniawski (1976) is also called the Geomechanics Classification (Table 2.1). It was initially designed for tunnels, in recent years, it has been applied to the preliminary design of rock slopes and foundations as well as to the estimation of the in-situ deformation modulus and strength of rock masses (Zhang, 2016). Rock mass classification focuses on the determination of rock strength and also estimates the deformation properties of rock (Lalhlimpuia *et al*., 2019). The RMR uses the following six parameters that can be determined in the field (Hoek *et al*., 1995), UCS of intact rock, RQD, spacing of discontinuity, condition of discontinuities, orientation of discontinuities and groundwater condition.

Table 2. 1: Rock Mass Classification Bieniawski (1989)

<table>
<tr><td colspan="10">A. CLASSIFICATION PARAMETERS AND THEIR RATINGS</td></tr>
<tr><td colspan="3">Parameters</td><td colspan="7">Range of values</td></tr>
<tr><td rowspan="3">1</td><td rowspan="2">Strength of intact rock material</td><td>PLI</td><td>>10 MPA</td><td>4-10 MPa</td><td>2-4 MPa</td><td>1-2 MPa</td><td colspan="3">For this low range, UCS test is preferred</td></tr>
<tr><td>UCS</td><td>>250 Mpa</td><td>100-250 MPa</td><td>50-100 MPa</td><td>25-50 MPa</td><td>5-25 MPa</td><td>1-5 MPa</td><td><1 MPa</td></tr>
<tr><td colspan="2">Rating</td><td>15</td><td>12</td><td>7</td><td>4</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Drill core quality RQD</td><td>90%-100%</td><td>75%-90%</td><td>50%-75%</td><td>25%-50%</td><td colspan="3"><25%</td></tr>
<tr><td colspan="2">Rating</td><td>20</td><td>17</td><td>13</td><td>8</td><td colspan="3">3</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">Spacing of discontinuities</td><td>> 2 m</td><td>0.6-2 m</td><td>200-600 mm</td><td>60-200 mm</td><td colspan="3">< 60 mm</td></tr>
<tr><td colspan="2">Rating</td><td>20</td><td>15</td><td>10</td><td>8</td><td colspan="3">5</td></tr>
<tr><td rowspan="2">4</td><td colspan="2">Condition of discontinuities</td><td>Very rough surfaces Not continuous No separation Unweathered wall rock</td><td>Slightly rough surfaces Separation < 1 mm Slightly weathered walls</td><td>Slightly rough surfaces Separation < 1 mm Highly weathered walls</td><td>Slickenside surfaces Or Gouge < 5 mm thick Or Separation 1-5 mm Continuous</td><td colspan="3">Soft gouge > 5 mm thick Or Separation > 5 mm Continuous</td></tr>
<tr><td colspan="2">Rating</td><td>30</td><td>25</td><td>20</td><td>10</td><td colspan="3">0</td></tr>
</table>

5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10-25	25-125	>125
		(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
Ratings	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 filing >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	Decompose d

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°	Dip 45-90°	Dip 20-45°		
Very favorable	Favorable	Very favorable	Fair		
Drive against dip- Dip 45-90°	Drive against dip- Dip 20-45°	Dip 0-20° Irrespective of strike			
Fair	Unfavorable	Fair			

2.1.1 Uniaxial compressive strength of intact rock

It is also known as the unconfining compressive strength of rock. It is the maximum axial load or stress in which a body or material can withstand before breaking or failing. Point Load Index is used to determine the UCS of a rock. Schmidt hammer can also be used to compute the mechanical properties of rock such as UCS, tensile strength and Young's Modulus (Selçuk & Yabalak, 2015; Singh *et al*. 2011; Table 2.2)

Table 2. 2: Application of Hr in RMR (Wang *et al.*, 2017)

	UCS (MPa)	>250	100–250	50–100	25–50	5–25	1–5	<1
Range of Schmidt hammer rebound Value	Rating	15	12	7	4	2	1	0
	Singh and Elkington (1983)	>125	50–125	25–50	12.5–25	2.5–12.5	0.5–2.5	<0.5
	Shoerey *et al.* (1985)	>634	259–634	134–259	71.5–134	21.5–71.5	11.5–21.5	<11.5
	Haramy and Demarco (1985)	>251.9	101.0–251.9	50.7–101.0	25.5–50.7	5.4–25.5	1.4–5.4	<1.4
	Ghose (1986)	>308.1	137.6–308.1	70.6–137.6	42.2–70.6	19.4–42.2	14.9–19.4	<14.9
	Sachpazis (1990)	>74.0	39.0–74.0	27.4–39.0	21.6–27.4	16.9–21.6	16.0–16.9	<16.0
	Tugˇrul, and Zarif (1999)	>79.7	61.7–79.7	55.7–61.7	52.8–55.7	50.4–52.8	49.9–50.4	<49.9
	Yilmaz and Sendir (2002)	>79.7	64.2–79.7	52.4–64.2	40.7–52.4	13.4–40.7	<13.4	–
	Dinçer *et al.* (2004	>104.3	49.8–104.3	31.6–49.8	22.5–31.6	15.2–22.5	13.8–15.2	<13.8
	Aydin and Basu (2005	>73.6	60–73.6	50–60	40–50	17.1–40	<17.1	–
	Shalabi *et al.* (2007)	>92.7	45.8–92.7	30.2–45.8	22.4–30.2	16.1–22.4	14.9–16.1	<14.9
	Yagiz (2009)	>82.4	57.8–82.4	44.2–57.8	33.8–44.2	18.1–33.8	9.7–18.1	<9.7

2.1.2 Rock quality designation (RQD)

RQD is the determination of drill core quality of rocks. The degree of jointed or fractures indicates the quality of rock core measured in percentage. Pieces of a core that are not hard and sound should not be included in the RQD evaluation even if they are at least 100 mm in length. RQD classification with rating given in table 2.3.

In areas where drill core is unavailable volumetric joint count is used to calculate RQD. In this calculation, the RQD is estimated from the number of joints per unit volume of rock mass *i.e* the number of joint per meter for each joint set are considered for RQD. Therefore RQD is calculated by using the formula,

$$RQD = 115- 3.3\ J_v,$$

Where J_V is the number of joints per cubic meter (Palmstrom, 2005).

Table 2. 3: RQD Classification and Rating (Bieniawski, 1979)

RQD (%) Qualitative	Description	Rating
90 to 100	Excellent	20
75 to 90	Good	17
50 to 75	Fair	13
25 to 50	Poor	8
<25	Very poor	3

2.1.3 Spacing of discontinuity

Discontinuities refer to all the weakness planes within the strata. The spacing of joints is the distance between individual joint within the joint set. The block size and shape can be identified from the discontinuity spacing. The spacing of joints is of great importance to access the rock mass structure. The very presence of joints reduces the strength of a rock mass and their spacing governs the degree of such a reduction. The joint aperture controls the interlocking of the rock walls. Smaller the aperture higher the chance of interlocking. In the case where there is no interlocking, the filling material contributes to the shear strength. Therefore it is obvious that both the fillings and the block materials contribute to the shear strength. (Palmstrom, 1995). Discontinuity spacing rating given in table 2.4.

Table 2. 4: Discontinuity Spacing (Bieniawski, 1979)

Parameters	Range of values				
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

2.1.4 Condition of Discontinuities and Orientation of Discontinuities

Orientation of discontinuities controls the type of movement in an unstable rock mass. The failure mode of Rockmass can be identified, Planar failure where discontinuities are parallel at some angle, intersect, or daylighting of two or more discontinuities can trigger wedge failure. Therefore orientation of discontinuities may define the stability of rock masses (Table 2.5 & 2.6).

Table 2. 5: Condition of Discontinuities (Bieniawski, 1979)

Parameter	Rangeof Value				
Condition of discontinuities	Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickenside surfaces Or Gouge < 5 mm thick Or Separation 1-5 mm Continuous	Soft gouge > 5 mm thick Or Separation > 5 mm Continuous
Rating	30	25	20	10	0

Table 2. 6: Rating Adjustment for Orientation of discontinuities (Bieniawski, 1979)

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

2.1.5 Groundwater Condition

Groundwater plays an important role in the stability of the slope, seepage of water entered into the rock mass through discontinuities, as a result of the effective normal stress across the joint decrease, which in turn reduce the shear strength of the rock mass (Table 2.7). The effect of groundwater softens the infilling materials which distorted the interlocking property of the rock wall and act as lubricating agents. It also reduces the cohesive strength and frictional strength. Water within the pores decreases the compressive strength of rock, and the rock is more prone to weathering (Lalhlimpuia *et al.*, 2019). When shale soak with water began 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).

Table 2. 7: Groundwater Condition (Bieniawski, 1979)

Parameter	Range of Value					
Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10-25	25-125	>125
	(Joint water press)/ (Major principal σ)	0	< 0.1	0.1-0.2	0.2-0.5	> 0.5
	General conditions	Completly dry	Damp	Wet	Dripping	Flow-ing
Rating		15	10	7	4	0

2.2 ROCKFALL HAZARD RATING

RHRS is a qualitative assessment method of rockfall vulnerability along the road cut slope for the assessment of rockfall hazards. It is a proactive system that consists of a primilinary rating and detailed rating of slope (Verma *et al.*, 2019). The rockfall Hazard Rating system of India is composed of five classes with sub-class which are important elements that contributed to the overall rating. These five classes, under two categories such as hazard categories i.e. slope condition, climatic condition, geological condition, rock fall history and vulnerability categories i.e. traffic condition (Ansari *et al.*, 2013).

2.2.1 Slope condition

The condition of the slope explains how far the rock travel during rockfall events. The slope condition is given in table 2.8.

Table 2. 8: Rockfall Hazard Rating System for India (Modified after Pierson *et al*., 1990 and Santi *et al*., 2009)

Category		3 points	9 points	27 points	81 points
Slope	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

2.2.2 Slope height

Slope height is the vertical height of the slope. The height of the slope is directly proportional to the risk associated with rockfall. The potential energy increase with the increase in height, the associated kinetic energy of rockfall will also increase as velocity builds up with an increase in height. The intensity of rockfall impact depends on the slope height. The exact point/score can be calculated using the equation proposed by Pierson *et al*.

$$\text{Slope height} = 3^{\{\text{Slope height (m)}/7.5)}$$

2.2.3 Average Slope Angle

The average slope angle provides useful information about the run-out distance of rock blocks. (Ansari *et al*. 2013). The most influencing slope angles are 30^{o} and 85^{0}, which cause maximum possible damage (Maerz *et al*., 2005). The slope angle controls the trajectory of the falling material.

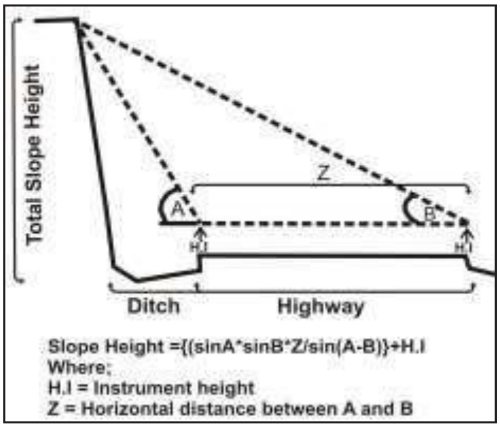

Figure 2. 1: Diagram Showing Total Slope Height

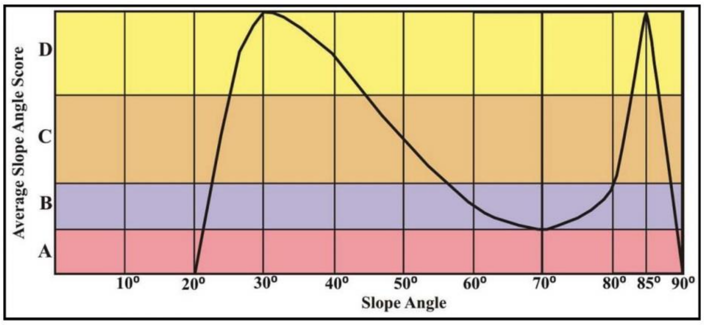

Figure 2. 2: Slope Angle and Corresponding Average Slope Angle Scores (Modified after Maerz *et al*., 2005)

2.2.4 Ditch Effectiveness

It measures the ability to capture or restrict rockfall reaching the roadway or public place. It is an important factor in response to the impact of rockfall. Good Catchment indicates sufficient space available to restrict or capture rockfall. Danger imposes due to rockfall can be minimized in a good catchment. Little or no rocks will enter the roadways, resulting in a low hazard. On the other hand in areas of no catchment or bad catchment adverse effects can be anticipated.

2.2.5 Vegetation

Vegetation plays an important role in slope instability. Tree root that traverses the discontinuity may trigger rockfall.

2.2.6 Launching feature

Lunching feature measures the smoothness of the slope. It is useful in predicting the position of the slope.

2.2.7 Climatic condition

The rating for climatic condition is shown in table 2.9.

2.2.8 Annual precipitation

Table 2. 9: Rockfall Hazard Rating System for India (Modified after Pierson *et al*., 1990 and Santi *et al*., 2009)

Category	3 points	9 points	27 points	81 points
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

Annual Precipitation is the actual amount of rainfall within a year measured in millimeters. Seepage usually follows weakness planes which act as lubricating agents reducing cohesion and friction. It has been identified by a different author that the slope aspect will dramatically affect the climatic conditions a rock slope experiences throughout a year (Flatland, 1993; Mazzoccola & Hudson, 1996).

$$\text{Exact score for annual precipitation} = 3^{(\text{Annual Precipitation in mm}/\ 254)}$$

2.2.9 Seepage

The presence of water on the slope is considered. It takes a rating minimum at the dry condition and a maximum rating at the wet condition.

2.2.10 Slope aspect

It has been identified that the slope aspect dramatically affects the climatic condition of rock slope experiences throughout the year (Flatland, 1993) (Mazzoccola & Hudson, 1996).

2.2.11 Geological condition

The Geology of a particular area affects the stability condition. Areas with highly jointed rock mass signify the unstable condition. In sedimentary rock undercutting and differential, erosion makes the rockfall happen (Ansari *et al*. 2013). Therefore Geological condition plays an important role in RHRS (Table 2.10).

Table 2. 10: Rockfall Hazard Rating System for India (Modified after Pierson *et al*., 1990 and Santi *et al*., 2009)

Geology	Sedimentary Rock	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, <15cm	> 2 weak interbed, >15 cm
	Crystalline Rock	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
	Discontinuities	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
		Persistence / Orientation	<3m and Dip into slope	>3m and dips into slope	<3 meter and daylight out of the slope	>3m and Daylight out of the slope
		Apertures	Closed	0.1 to 1 mm	1 to 5 mm	>5mm
		Weathering Condition	Grade I & II	Grade III	Grade IV	Grade V & IV
		Friction	Rough	Undulating	Planar	Slickensided
		Infilling material	Heal infilling	Course Grain Fault Gouge	Fine Grain Fault Gouge	Clay Infilling

2.2.12 Sedimentary rock

In sedimentary rocks parameters such as degree of undercutting, Slake Durability Index (SDI), degree of interbedded are considered for rating. The degree of undercutting refers to differential erosion due to the intercalation of a competent and incompetent layer. This may result in a negative slope, highly prone to rockfall.

SDI determines the weathering nature of the rock slope, highly weathered surface favor instability.

The degree of interbed refers to the lithological variation and their corresponding layer thickness within the rock slope that leads to differential erosion and causes rockfall hazard (Ansari *et al*., 2013).

Prolonged exposure of the rock slope to the atmosphere results in weathering and weakening of the rock slope which may break the rock and cause rockfall. Therefore rating the weathering condition of intact rock is required.

2.2.13 Discontinuities

This parameter is associated with block size/ volume, shape, discontinuity set, orientation, apertures, weathering condition (Table 2.11), friction infilling material.

Block size/ volume is an important parameter in dealing with rockfall, the intensity of damage depends upon the size and volume of rockfall. The kinetic energy also increases with an increase in size. Therefore huge block holds more kinetic energy as it falls. Large block falls are usually accompanied by secondary falls.

$$\text{Exact score for block size} = 3^{(\text{ block size in m/0.3})}$$

$$\text{The exact score for block Volume} = 3^{(\text{ block volume meter cube /2.3})}$$

Block shape can be correlated to the type of movement such as roll, bouncing, sliding. Etc. It is also known that a well-rounded rock shape offers more hazards than an angular one (Vandewater *et al*., 2005).

Discontinuities at slope increase the amount of infiltration, the action of frost wedging, and chemical weathering (Maerz *et al*., 2005; Romana 1988; Vandewater *et al*., 2005). Therefore facilitate more for weathering. Persistence refers to the persistence of discontinuity. Aperture is a perpendicular distance or spacing adjacent to each discontinuity. Discontinuity orientation reveals the kinematic behavior of rock mass. It can either promote stability or aid the instability.

Reduction of cohesion and friction along the discontinuities can occur due to weathering at the surface of discontinuities.

Table 2. 11: Weathering Condition and Grades (After Hoek and Bray, 1981)

Grade	Term	Description
I	Fresh	No. Visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surface
II	Slightly Weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering and maybe somewhat weaker externally than in its fresh condition
III	Moderately weathered	Less than half of the rock material is decomposed and/or disintegrate to soil. Fresh or discolored rock is present either as a continuous framework or as corestone
IV	Highly weathered	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as a corestone.
V	Completely Weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is largely intact.
VI	Residual Soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume but the soil has not been significantly transported.

The shear strength may decrease due to infilling materials. Calcite infilling increased shear strength and is known as healed infilled material (Hoek and Bray, 1981). Infilling plays an important role in the stability of a slope.

The rating of infilling material from lowest to highest is as follows:

1. Heal infilling: Material comprises of heal type (eg. Calcite)
2. Coarse grain fault gouge infilling: Higher friction angle infill material
3. Fined grain fault-gauge infilling: Lower infilling friction angle infill material
4. Clay infilling: Clay infill material like montmorillonite and bentonite etc. has the lowest friction angle and cause more hazard. (Fatland, 1993)

2.2.14 Traffic Condition

The parameter under traffic conditions is percent decision sight distance (DSD), average vehicle risk (AVR), road width with pavement including paved shoulder and number of accident. Shown in table 2.12.

DSD compares the actual amount of sight distance available through the rockfall section to the low design amount provided by AASTHO (Table 2.13). Decision sight distance depends on the speed of the vehicles. This can be applicable in the field that if the speed of the vehicle is high the driver has little time to react to the obstacle It is calculated by using the following formula.

DSD = 100*(Actual sight Distance/Decision Sight Distance)

Actual decision sight distance is a distance in which a 15cm object placed on the corner of the road disappears from a driver. (Pierson *et al*., 2005) . The exact score can be calculated by using the formula,

Exact Score For DSD = $3^{\{(120\text{-}\%DSD\}/20}$

Table 2. 12: Traffic condition and Rockfall History

Category		3 points	9 points	27 points	81 points
Traffic	Percentage Decision Sight Distance (DSD)	100%	80%	60%	40%
	Average Vehicle Risk (AVR)	25%	50%	75%	100%
	Road width including Pave Shoulder (m)	13,2m	10.8m	8.4 m	6m
	No of accident	0 to 2	3 to 5	6 to 8	9 and Over
Rock History/ Frequency		0 to 3 per year	4 to 7 per year	8 to 12 per year	>12per year

2.2.15 Average Vehicle Risk (AVR)

It gives a rating that relates to the percentage of time a vehicle is present in the rockfall prone zone 100% rating can be interpreted as vehicle is present all the time at the rockfall region which adds on to higher hazard. It can be calculated by using the formula given below.

AVR = {ADT* (Slope Length/24)* Post Speed Limit)*100}

Exact Score For AVR = $3^{(\%AVR/25)}$

Table 2. 13: Decision Sight Distance based on Posted Speed Limits to avoid Obstacles (AASTHO,1984)

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

The large road width can reduce rockfall impact. It is one type of mitigative measure.

$$\text{Exact score for roadway width (RW)} = 3^{\{15.6-RW(m)\}/24}$$

The information of a number of accidents is also considered in RHRS.

2.2.16 Rockfall history

It is an important parameter that can help in future rockfall prediction. The exact score for rockfall history can be calculated by using the formula:

$$\text{Exact score for rockfall history/ Frequency (f)} = 3^{(1+0.25*f)}$$

2.3 SLOPE MASS RATING (SMR)

It was Introduce by Romana (1973). It is based on the RMR system. Useful preliminary tool to investigate or assess slope stability in the natural condition as well as the engineering slope. SMR gives the simple rule for instability mode and requires support measures. Which can be express by using the formula,

$$SMR = RMR(Basic) + (F_1*F_2*F_3)+F_4$$

The four-factor depend on the discontinuities, slope inclination, slope geometry, or geometry between the joint and slope. F_1 factor depends upon the parallelism between the slope strike **(∝s)** and joint**(∝j).**In the case of a wedge, failure F_1 depends upon the trend of the intersection of two joint **(∝i)** and slope strike **(∝s).**

Factor range from 1 - 0.15. Where 1 represents the exact parallelism. When the value of strike of the slope and joint exceed more than 30 the value will be 0,15. SMR adjustment factor is given in table 2.14, 2.15 and 2.16.

Empirical relationship = $(1\text{-}SinA)^2$

where A is the angle between the joint plane and the slope face strike

F_2 factor in case of planar failure depends on the Joint dip angle **(ßj)**, and in the case of wedge failure, F_2 geometry factor depends on the plunge of joint(**ßi),** F_2 factor represents a sense of the probability of joint shear. And the value range from 0.15–1.

Empirical formula = Tan^2 (ß) where B is joint dip

For planar F_3 Factor depend on the relationship between slope face(**ßs)** and joint dip. (**ßj).** For wedge failure F_3 depends on the relationship between the plunge of a line of intersection **(ßi),..** and the slope dip (**ßs),.**

F_4 factor represents the type of slope.

Table 2. 14: SMR Adjustment Factor

Case of slope Failure		Very Favourable	Favourable	Fair	Unfavourrable	Very Unfavourable
P T W	**(∝j-∝s)** **(∝j-∝s-180)** **(∝i-∝s)**	>30°	30 ° –40°	20° – 10°	10°- 5°	<5°
P/W/T	F_1	0.15	0.40	0.70	0.85	1
P W	**ß** j **ß** i	<20°	20° – 30°	30° –35°	35° – 45°	>45°
P/W	F_2	0.15	0.40	0.70	0.85	1
T	F_3	1	1	1	1	1
P W	**(ß** j-**ß** s) **(ß** i- **ß** s)	>10°	10° – 0°	0°	0° – (-10°)	<-10°
T	**(ß** j + **ß** s)	<110°	110°–120°	>120°	-	-

Table 2. 15: F4 adjustment Factor

Method of Excavation	F_4 Value
Natural Slope	15
Pre – Splitting	10
Smooth Blasting	8
Nortmal Blasting 0r Mehanical excavation	0
Poor Blasting	-8

Table 2. 16: SMR rating

Class No.	V	IV	III	II	I
SMR Value	0 -20	21 – 40	41 – 60	61 – 80	81 – 100
Rock Mass Description	Very Bad	Bad	Normal	Good	Very Good
Stability	Completely Unstable	Partially Stable	Stable	Stable	Completely stable
Failures	Big Planar or Circular	Planar or Big Wedges	Planar along with some joint and many Wedges	Some Block Failure	No Failure
Probability of Failure	0.9	0.6	0.4	0.2	0

2.4 POINT LOAD INDEX

This equipment is based on IS:8764-1978. It is used for the determination of the point load strength index of rocks. The point load strength index can be used to estimate or correlate other characteristics of intact rock such as uniaxial compressive strength and tensile strength.

The core shall be selected to represent a true average of the rock type under consideration. The number of cores taken must be adequate for performing at least 5 tests. The diameter of the core should be between 25mm and 100mm and the length of the core specimens between the ends at their nearest points shall not be less than 1.4 times the diameter.

The core specimens should be soaked in water for 24 hours to bring the specimen to the same condition as that in the field. Hold the specimen horizontally between the two loading platens. The length of the nearest end face of the core specimen from the load point must not be less than 0.7 times the core diameter. This length shall be recorded in mm. The correct position of the specimen shall be checked first by rotating the specimen longitudinally to see that the distance between the loading points is the minimum possible. The correct position of the specimen shall also be checked by moving it laterally to see that the distance between the loading platens is maximum. Make sure that the platens are in contact along a single plane of weakness or within the same material in the case of bedded rock. Operate the handle of the pump after closing the release valve. Slowly continue applying load to the core specimen in this manner till it fails. The failure load indicated on the pressure gauge by the red maximum pointer should be recorded

The point load index is calculated from the formula as follows.

$$Is = P/D^2 MN/m^2$$

$$Is = 100P/D^2\ Kgf/cm^2$$

Where, Is = point load Strength Index, P = Fasilure Load in N and D = Core diameter in mm

Correction: For cores other than those with a diameter of 50mm, the strength index value obtained shall be corrected to Is950) using the chart given

Uniaxial Compressive Strength: The prediction of Uniaxial Compressive strength shall be done from the formula:

$$QC = 22 * Is(50)$$

Where, QC = Uniaxial Compressive strength im $MN/m^2(kgf/cm^2)$

Figure 2. 3: Point load Test

2.5 SLAKE DURABILITY TEST

As per IS:10050-1981 slake durability test is performed. It is used to assess the resistance offered by rock samples to weakening and disintegration when subjected to two standard cycles of drying and wetting in a slaking fluid. It is used to determine the durability of rock mass on weathering. It can be calculated as the percentage ratio of the final to the initial dry sample weight

Procedure:

a) A representative sample comprising ten rock lumps is selected. Each should weigh 40-60 grams to give a total sample weight of 400-600 grams. Lumps should be roughly spherical and their corners should be rounded off during preparation.

b) Remove the lid on one side of the brass drum and transfer the sample into it. Dry the sample at a temperature of 105 ± 5°C until it attains a constant weight. The weight A of the brass drum together with the sample should be recorded. The sample should then immediately be used for testing.

c) The lid of the drum should then be placed in position and locked and then mounted in the water tank. Make sure that the coupling to the motor with the help of flexible coupling is fixed to the shaft of the water tank properly.

d) The water tank should be filled with slaking fluid, usually tap water, up to the red line on the tank. The Motor should then be switched on for 10 minutes. The brass drum is designed to rotate at 20 rev./min.

e) The brass drum should then be removed from the water tank and the lid should be opened. The brass drum without lid along with the retained portion of the samples should be dried to a constant weight at 105 ± 5°C. The weight B' of the Brass Drum along with the retained portion of the samples should then be recorded.

f) With the same sample, the test should be repeated as in (d) and (e) for a further period of 10 minutes. The weight 'C' of the drum with a retained portion of the sample should now be recorded.

g) The drum should then be brushed clean and its weight 'D' recorded.

Calculation: The slake durability index (second cycle) is calculated as a percentage ratio of the final to the initial dry sample weight as follows:

$$\text{SDI, Percentage (\%) } (Id_2) = (C\text{-}D/A\text{-}D)*100$$

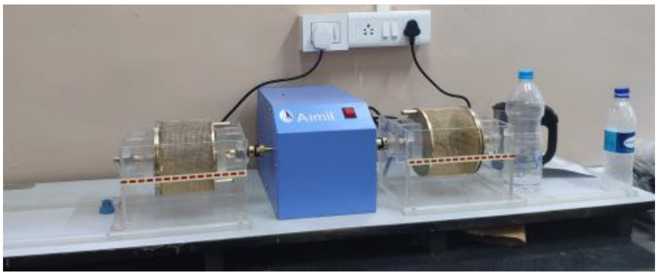

Figure 2. 4: Slake Durability Test Instrument

2.6 GEOLOGICAL STRENGTH INDEX (GSI)

The GSI system is proposed by Evert Hoek in 1994. It is a unique system of rock mass classification widely used in mining. It is based on rock mass strength and deformation parameters after Hoek-Brown and Mohr-Column failure criteria. The GSI value can be obtained from the standard chart provided and field observation of rock mass blockiness and discontinuity surface condition. The GSI value gives a numerical representation of the overall geotechnical quality of rock mass (Hong *et al*., 2017). The GSI index is based on an assessment of lithology, structure, and discontinuity condition in the rock mass, it can be obtained from visual interpretation of the outcrop, inroads cut section, tunnels, and boreholes (Marinos *et al*., 2007)

To provide a more quantitative numerical basis for evaluating the GSI, the GSI classification was modified by Somnez & Ulusay, 1999. They introduce two-term such as Structural rating (SR) and Surface condition rating (SCR). This is based on Volumetric joint count and SCR is based on RMR parameters such as surface roughness (R_r), weathering (R_w), and infilling (R_f). The rating of SR and SCR is plotted in the chart provided by Somnez and Ulsay to produce a GSI value. Block size is an extremely important indicator of a rock mass and it must be considered in any proposed rock mass classification (Taheri & Tani, 2007)

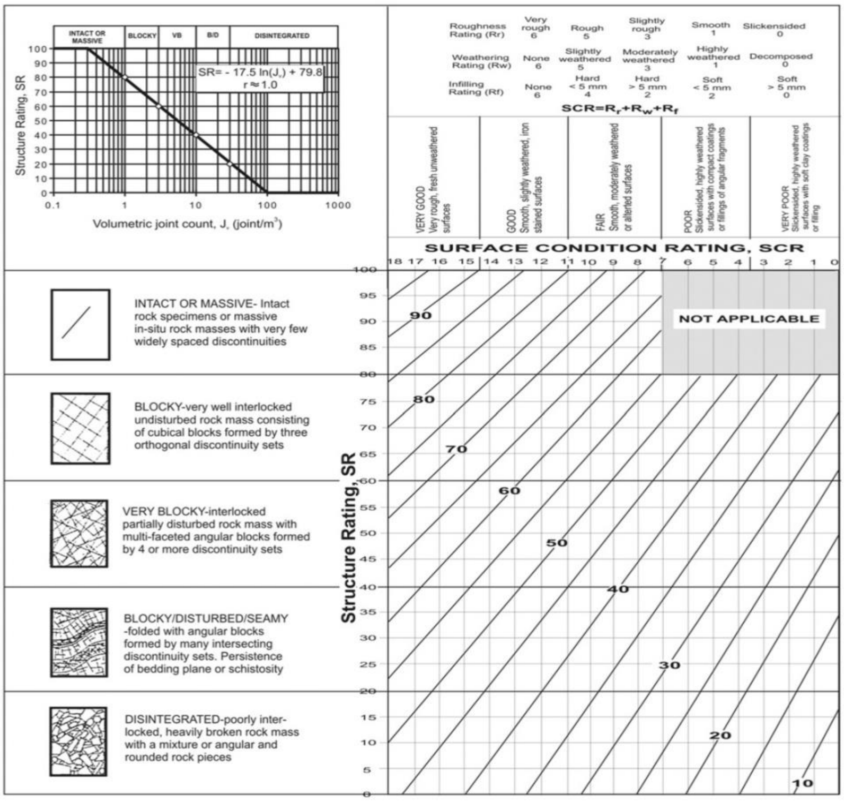

Figure 2. 5 The Quantitative GSI chart proposed by Somnez and Ulusay (Somnez and Ulusay, 1999)

CHAPTER 3

ROCKFALL ANALYSIS AND KINEMATIC ANALYSIS

3.1 ROCKFALL ANALYSIS

Rockfall analysis is done using Rocfall software, a lump mass method is utilized in this analysis. A variety of input parameters are required for this analysis which includes the geometry of the study side, cohesion, coefficient of restitution, etc. The coefficient of restitution plays an important role in the analysis of rockfall, it is associated with energy dissipation during rockfall (Verma *et al*., 2019). Block trajectory, motion, bounce height, energy, velocity, and run-out distance of falling rocks can be determined by this program, which is based on the laws of motion and collision theory (Keskin, 2013). The maximum bounce height and peak total kinetic energy are analyzed in this research. The used parameter for the coefficient of restitution given by rockfall software is shown below.

Table 3. 1: Coefficient of restitution for surface type.

Surface Type	Normal Rn		Tangential Rt	
	Mean	SD*	Mean	SD*
Rock surface (Sandstone)	O.530	0.040	0.990	0.990
Rock Talus	0.320	0.040	0.820	0.040
Asphalt	0.384	0.133	0.687	0.130

3.1.1 Rockfall Analysis Bawngkawn-Durtlang

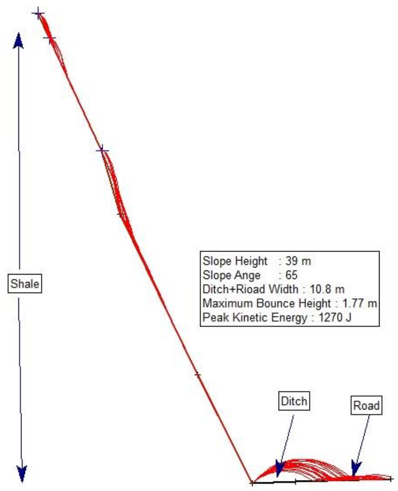

Figure 3. 1: RockFall Analysis of Bawngkawn-Durtlang Spot 1

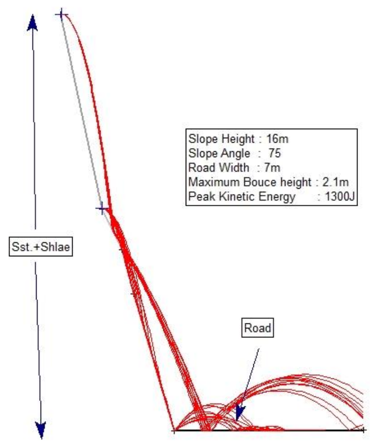

Figure 3. 2: RockFall Analysis of Bawngkawn-Durtlang Spot 2

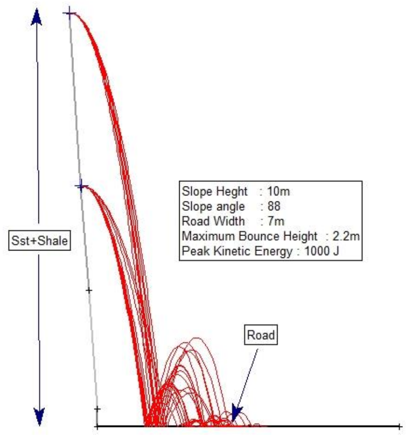

Figure 3. 3: RockFall Analysis of Bawngkawn-Durtlang Spot 3

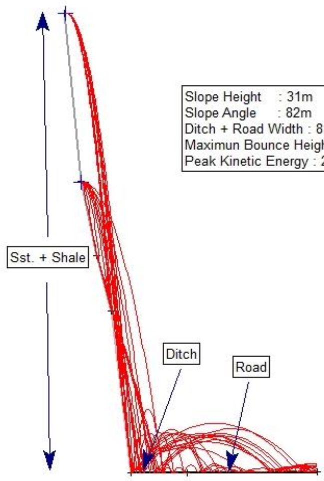

Figure 3. 4: RockFall Analysis of Bawngkawn-Durtlang Spot 4

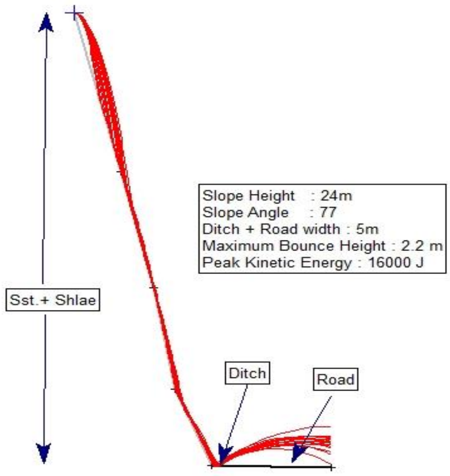

Figure 3. 5: RockFall Analysis of Bawngkawn-Durtlang Spot 5

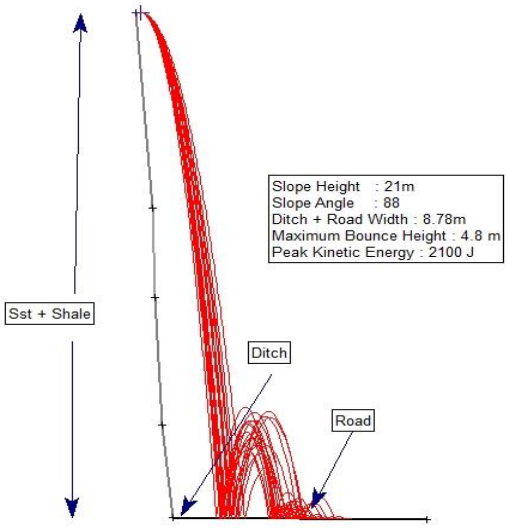

Figure 3. 6: RockFall Analysis of Bawngkawn-Durtlang Spot 6

3.1.2 Rockfall Analysis Ngaizel

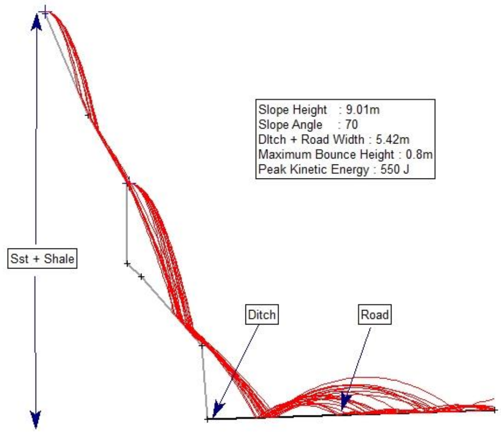

Figure 3. 7: RockFall Analysis of Ngaizel Spot 1

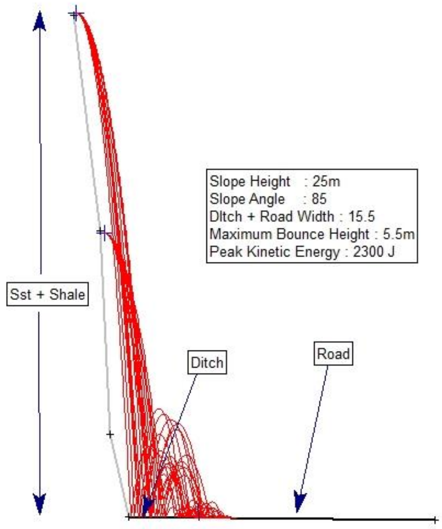

Figure 3. 8: RockFall Analysis of Ngaizel Spot 2

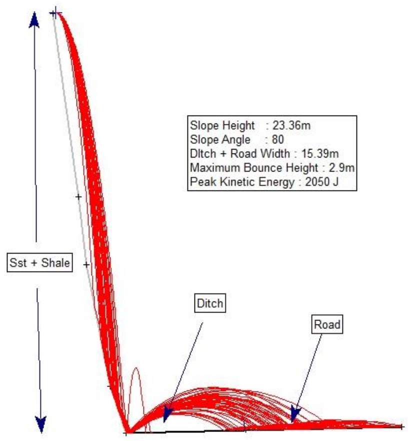

Figure 3. 9: RockFall Analysis of Ngaizel Spot 3

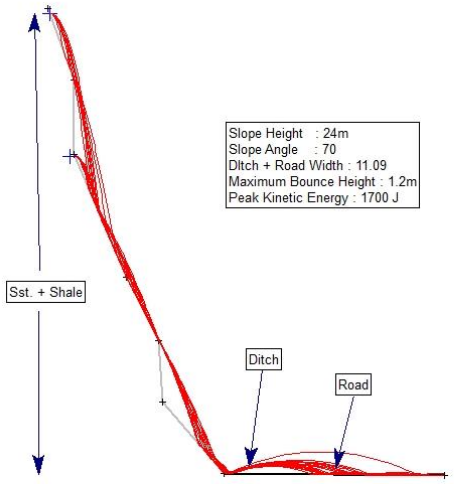

Figure 3. 10: RockFall Analysis of Ngaizel Spot 4

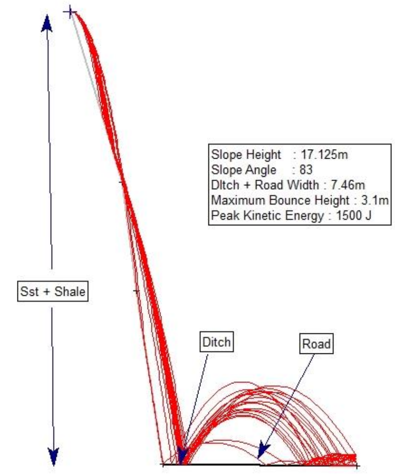

Figure 3. 11: RockFall Analysis of Ngaizel Spot 5

3.13. Rockfall Analysis Bawngkawn-Edernthar

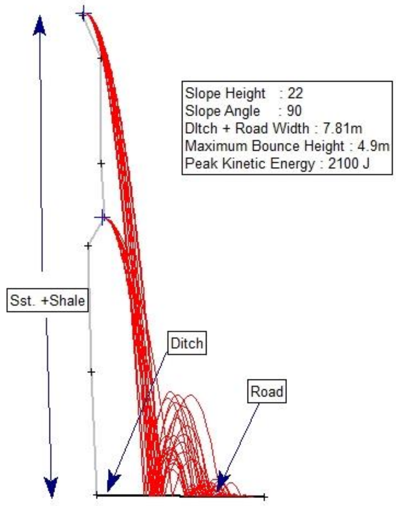

Figure 3. 12: RockFall Analysis of Bawngkawn- Edenthar Spot 1

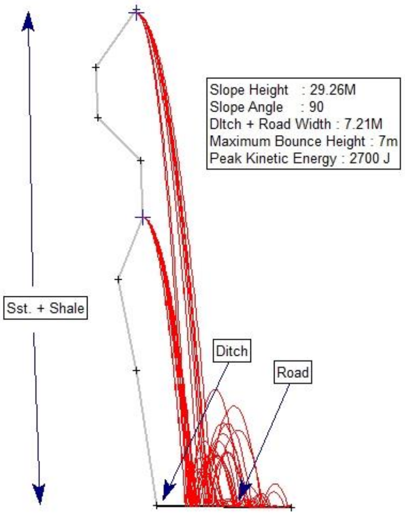

Figure 3. 13: RockFall Analysis of Bawngkawn- Edenthar Spot 2

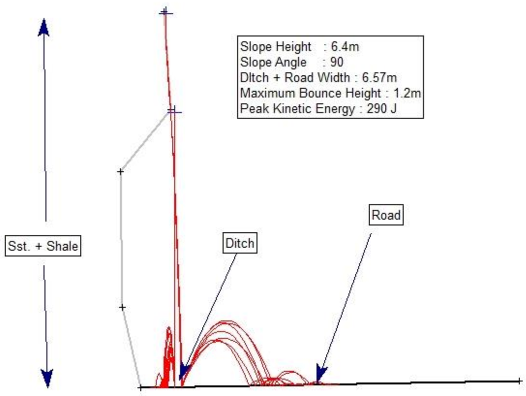

Figure 3. 14: RockFall Analysis of Bawngkawn- Edenthar Spot 3

From Rockfall analysis of NH-54 (Bawngkawn-Durtlang) area it is observed that the maximum bounce height range from 1.77m to 4.8m . The peak or maximum KE range from 1000J to 16000J.

The maximum bounce height obtained from the Rocfall analysis of Ngaizel study area range from 0.8m to 5.5m. The peak or maximum KE range from 550J to 2300J.

Again The maximum bounce height obtained from the Rocfall analysis of Bawngkawn -Edenthar area range from 0.12m to 7m. The peak or maximum KE range from 290J to 27000J.

3.2 KINEMATICS ANALYSIS

The objective of the kinematic analysis is to define a set or sets of discontinuities that will control the stability of rock slopes. (Wyllie and Mah 2005). The orientation of geological discontinuities is the prime factor which majorly influencing rock stability. The orientation data (Dip and dip direction) was collected from the exposed rock-cut face. It is used to represent the three-dimensional field orientation data to be in two dimensions (Singh *et al*., 2016; Ahmad *et al*., 2013; Yoon *et al*., 2002; Markland, 1972).

The potential modes of rock failure (Planar, Wedge, and/or Toppling) can be determined. In this study, the measured field orientation data are interpreted by Rocscience DIP software to identify the potential mode of rock failure (Sazid, 2019).

Planar failure: The plane on which the sliding occurs must strike parallel or near parallel (within approximate ±20 to the slope face). The sliding must daylight in the slope face. This means that the dip of the plane must be less than that of the slope face. The dip of the sliding plane must be greater than the angle of friction of this plane. The upper end of the sliding surface either intersects the upper slope or terminates in tension crack.

Wedge failure: Two planes will always intersect in a line. On the sterionet the line of the two great circles of the plane intersect and the orientation of the line is defined by its trend and its plunge. The plunge of the line of intersection must be flatter than the dip of the face, and steeper than the average friction angle of the two slide planes. The inclination of the slope face is measured in the view at a right angle to the line of intersection. The line of intersection must dip in a direction out of the face for sliding to be feasible.

Toppling Failure: The discontinuities should be at a higher angle than the slope face.

The potential modes of rock failure in ten road cut sites/ slopes were assessed by kinematic analysis using Dips 6.0 (Rocscience Inc. 2010). A stereograph was plotted for each slope using joint data, bed, slope orientation, and internal friction angle.

3.2.1 Kinematic analysis of Bawngkawn – Durtlang

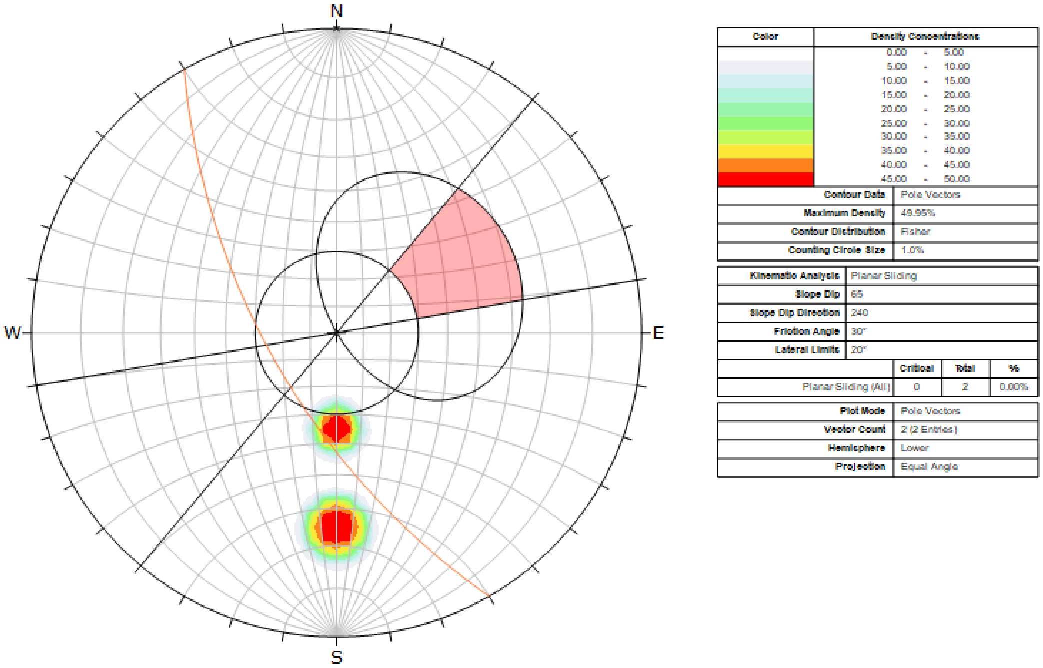

Figure 3. 15: Kinemattic analysis for planar failure (Spot 1)

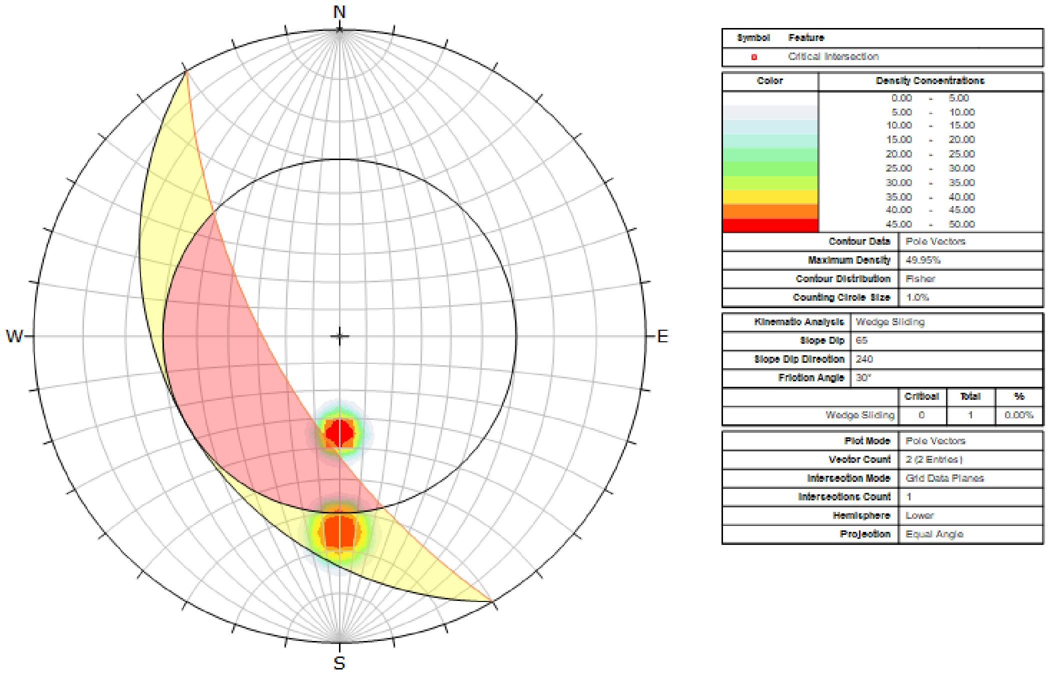

Figure 3. 16: Kinemattic analysis for wedge failure (Spot 1)

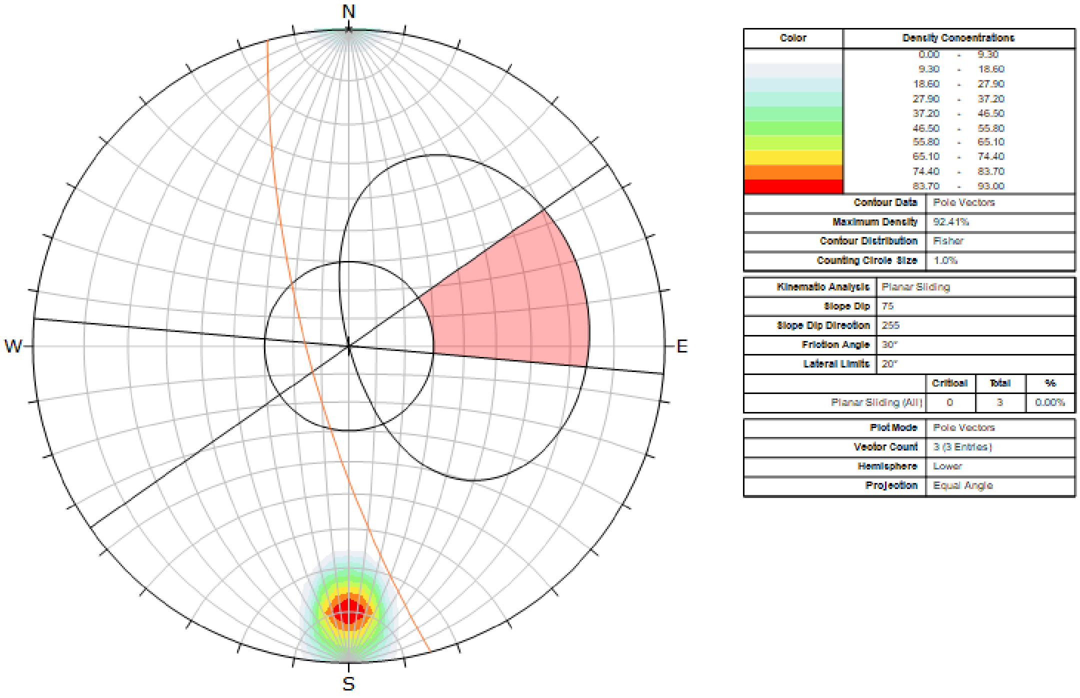

Figure 3. 17: Kinemattic analysis for planar failure (Spot 2)

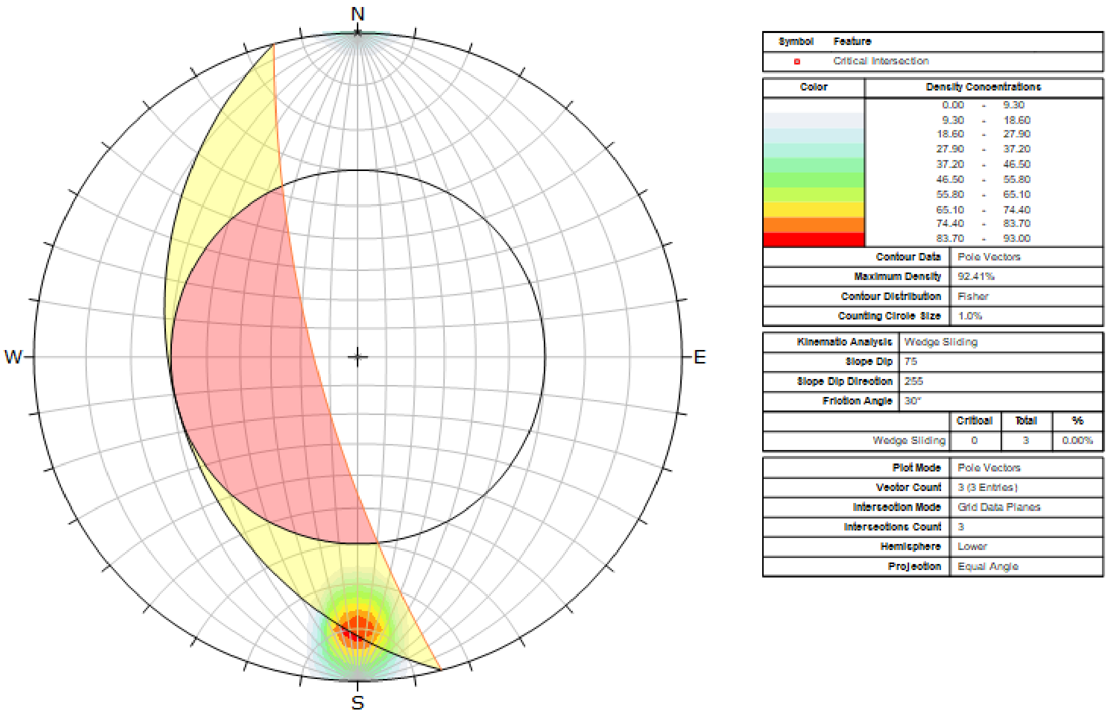

Figure 3. 18: Kinemattic analysis for wedge failure (Spot 2)

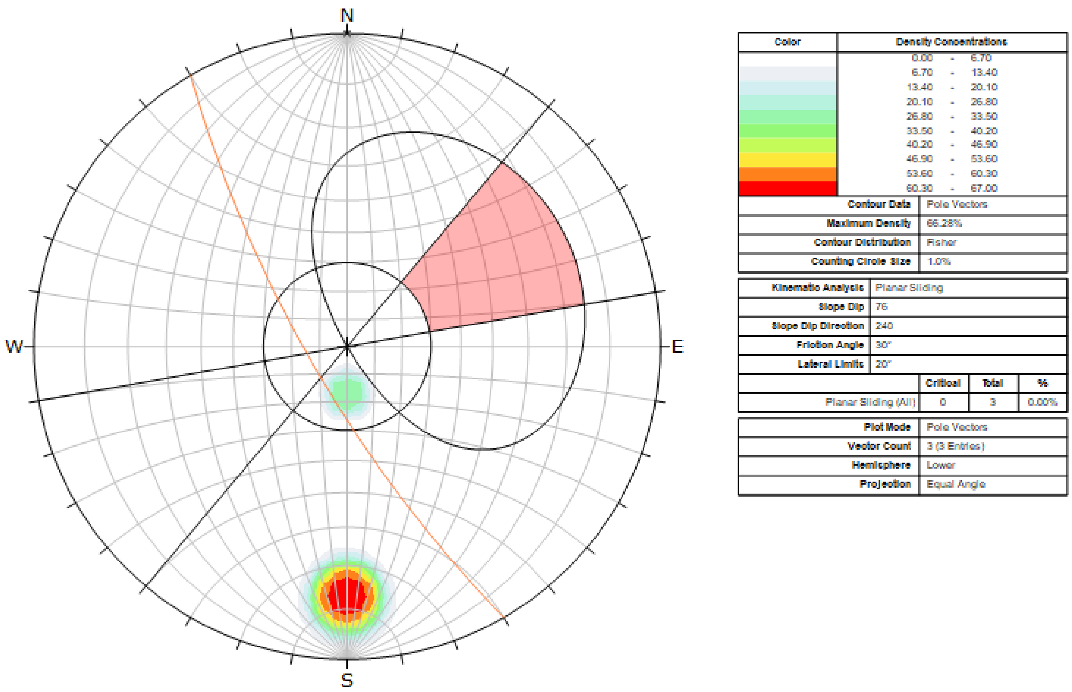

Figure 3. 19: Kinemattic analysis for planar failure (Spot 3)

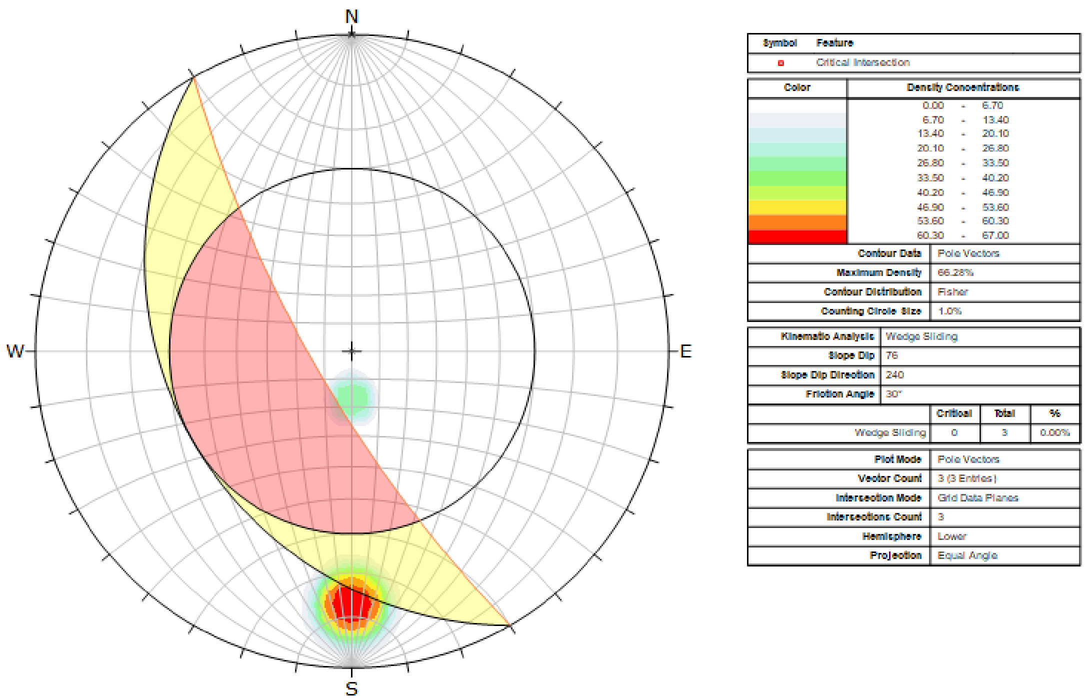

Figure 3. 20: Kinemattic analysis for wedge failure (Spot 3)

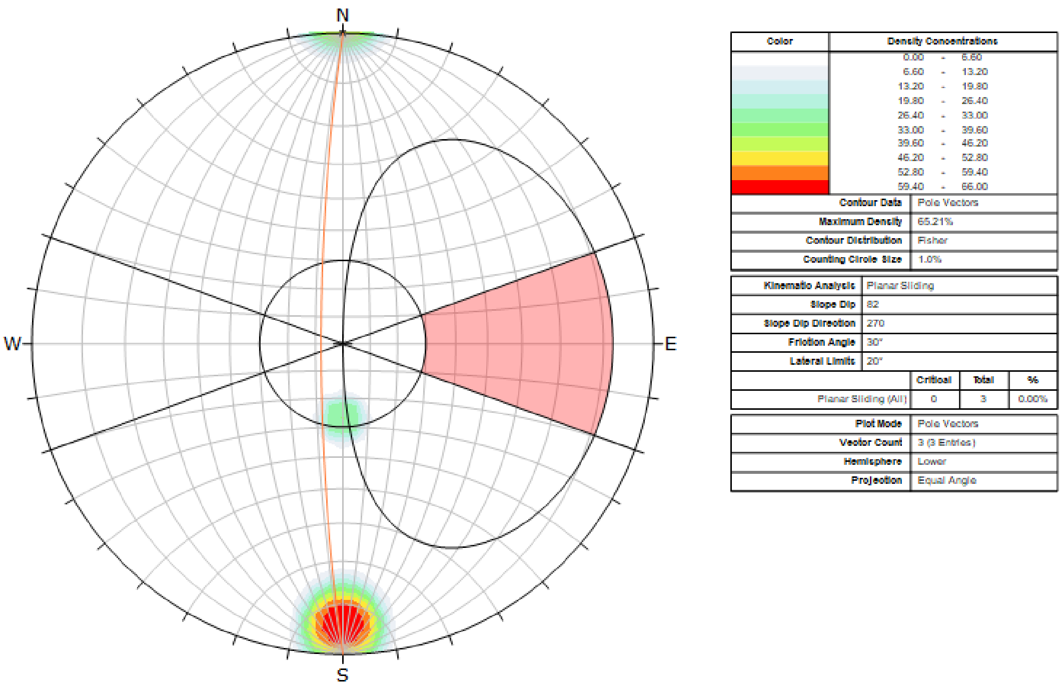

Figure 3. 21: Kinemattic analysis for planar failure (Spot 4)

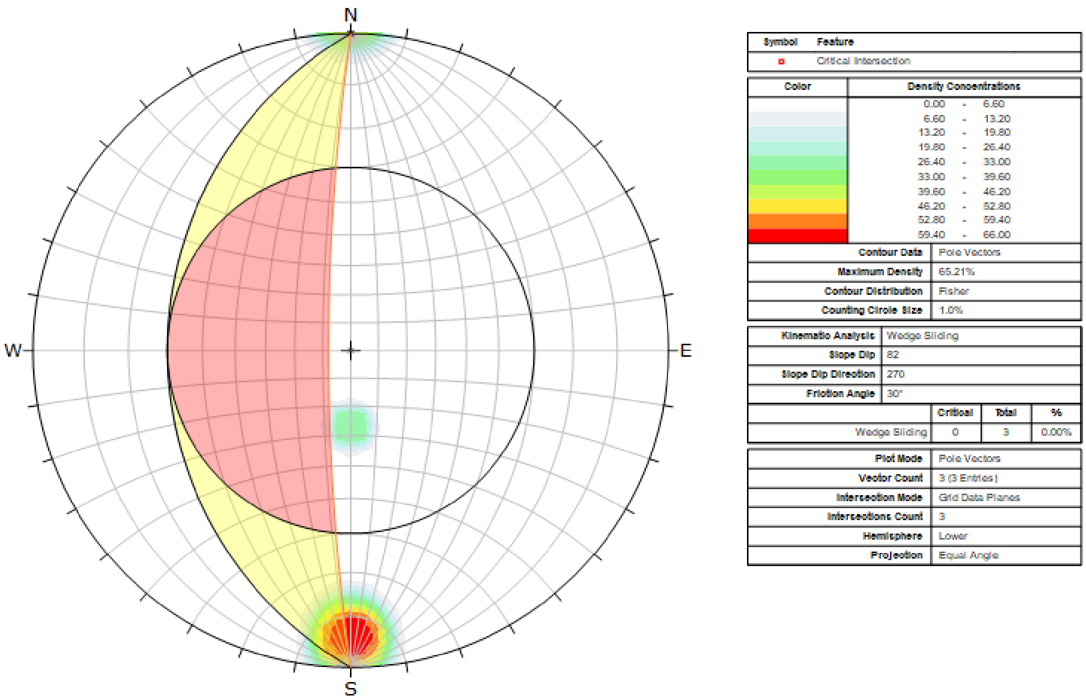

Figure 3. 22: Kinemattic analysis for wedge failure (Spot 4)

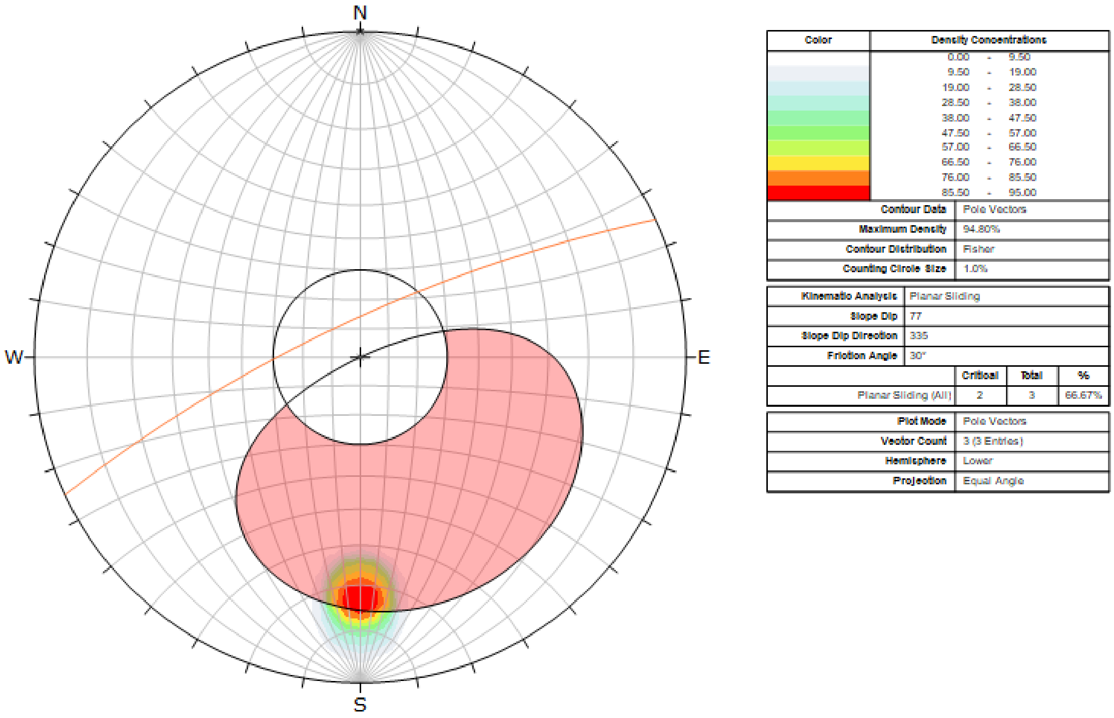

Figure 3. 23: Kinemattic analysis for planar failure (Spot 5)

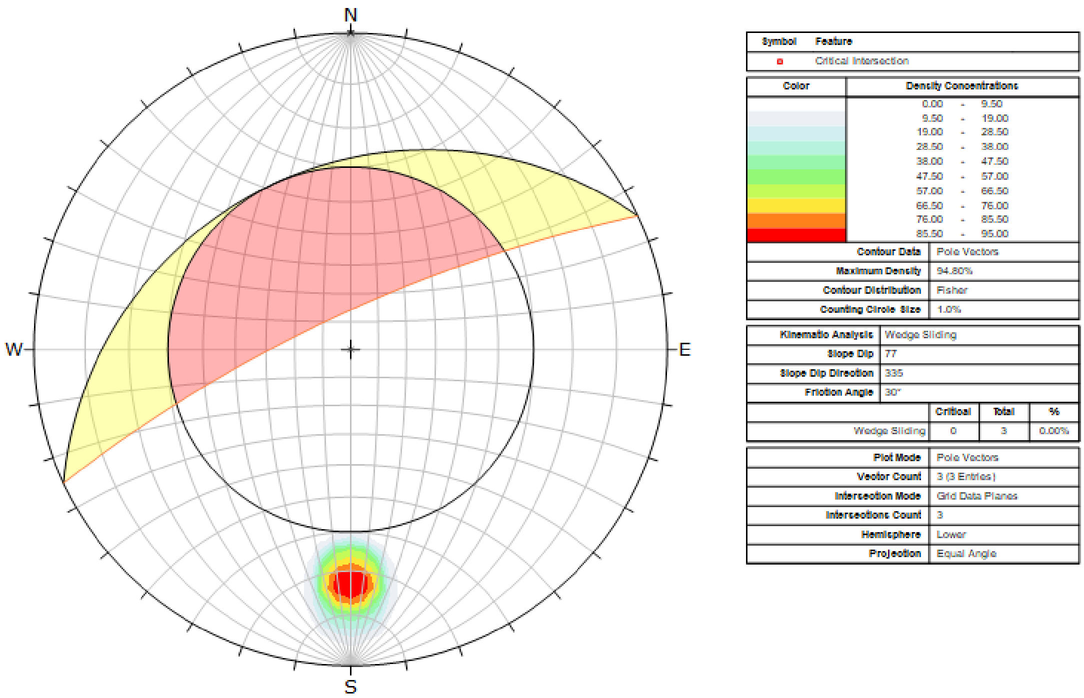

Figure 3. 24: Kinemattic analysis for wedge failure (Spot 5)

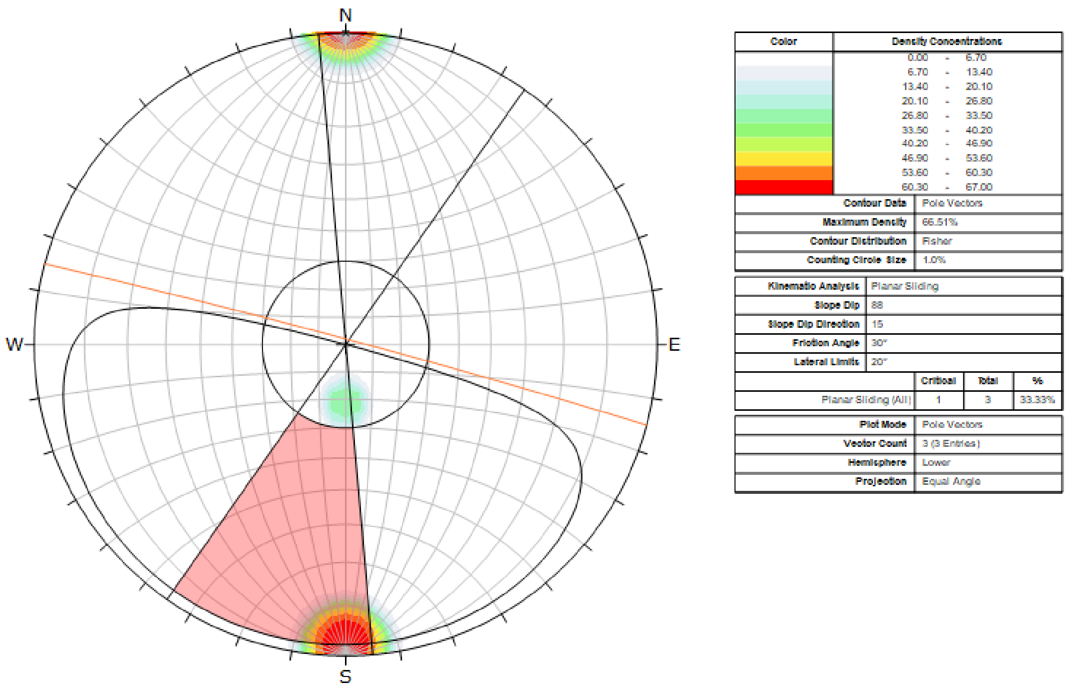

Figure 3. 25: Kinemattic analysis for planar failure (Spot 6)

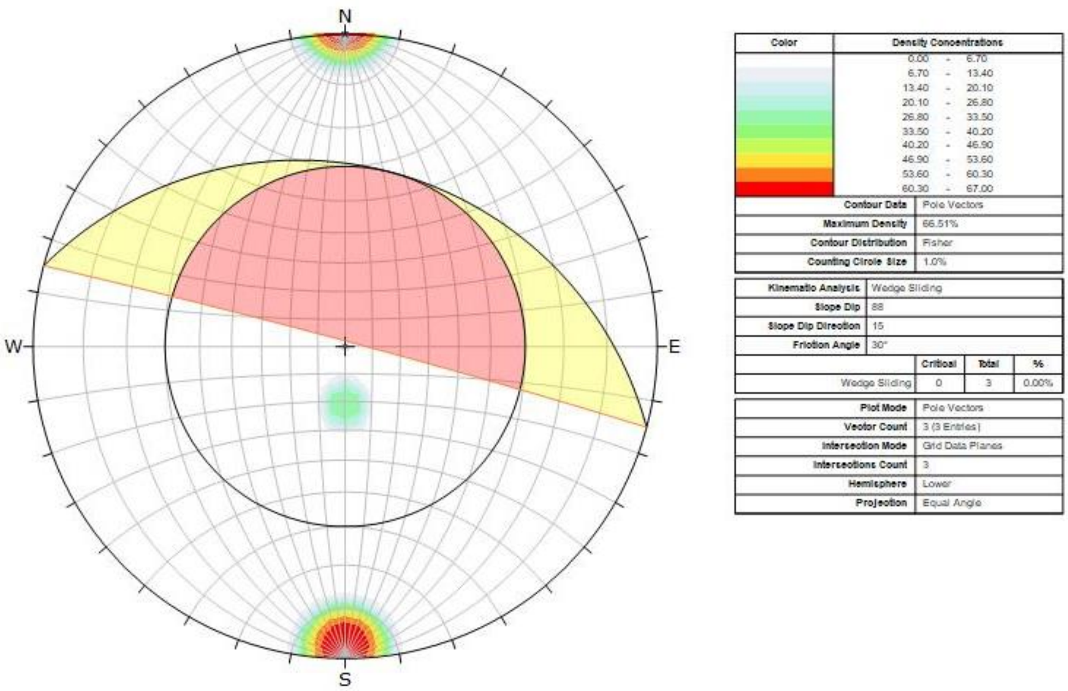

Figure 3. 26: Kinemattic analysis for wedge failure (Spot 6)

3.2.2 Kinematic analysis of Ngaizel

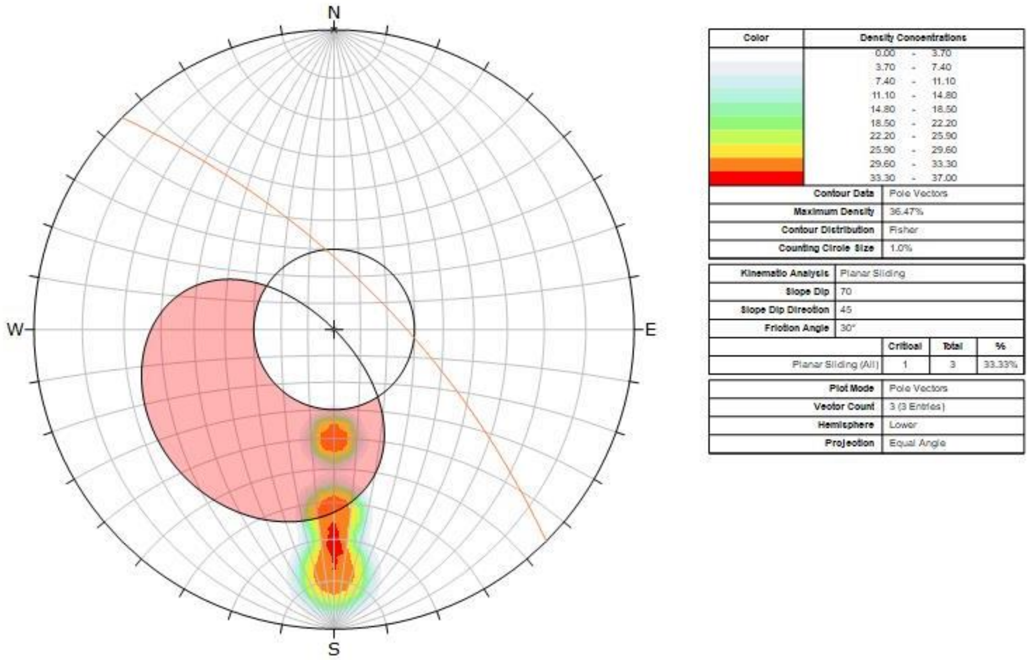

Figure 3. 27: Kinematic analysis for planar failure (Spot 1)

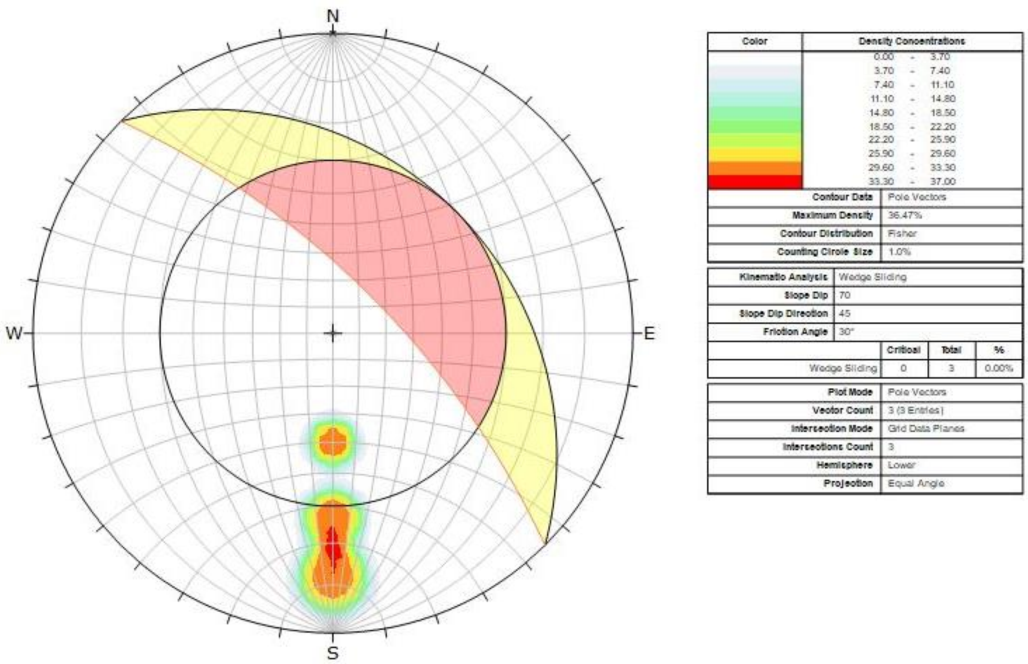

Figure 3. 28: Kinematic analysis for wedge failure (Spot 1)

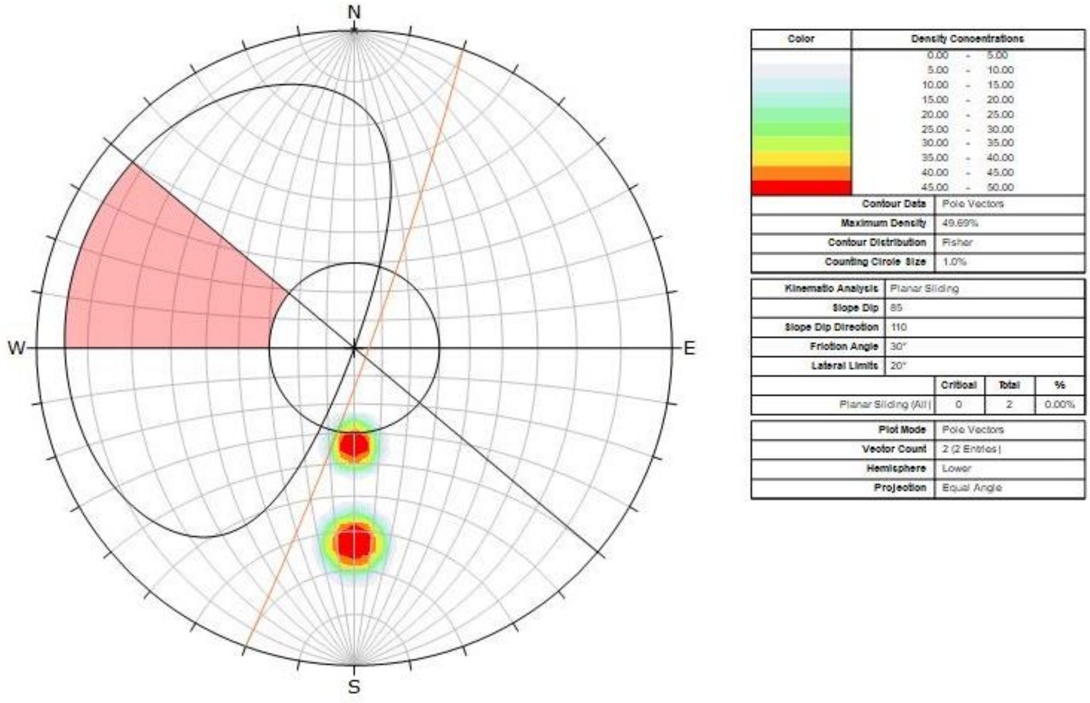

Figure 3. 29: Kinematic analysis for planar failure (Spot 2)

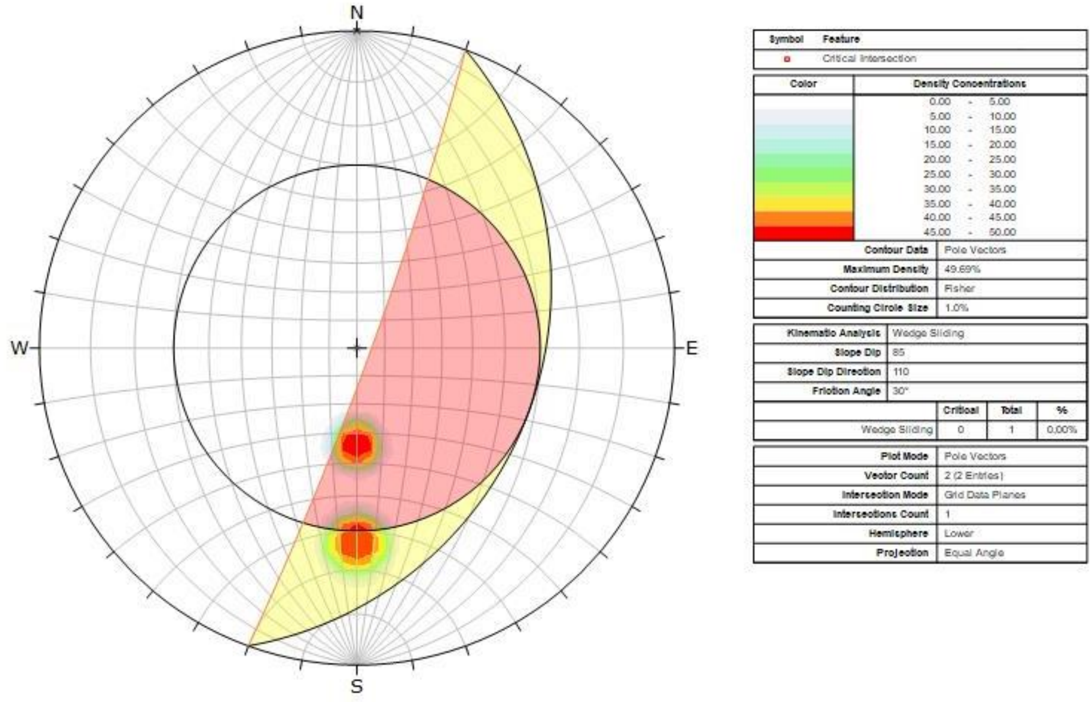

Figure 3. 30: Kinematic analysis for wedge failure (Spot 2)

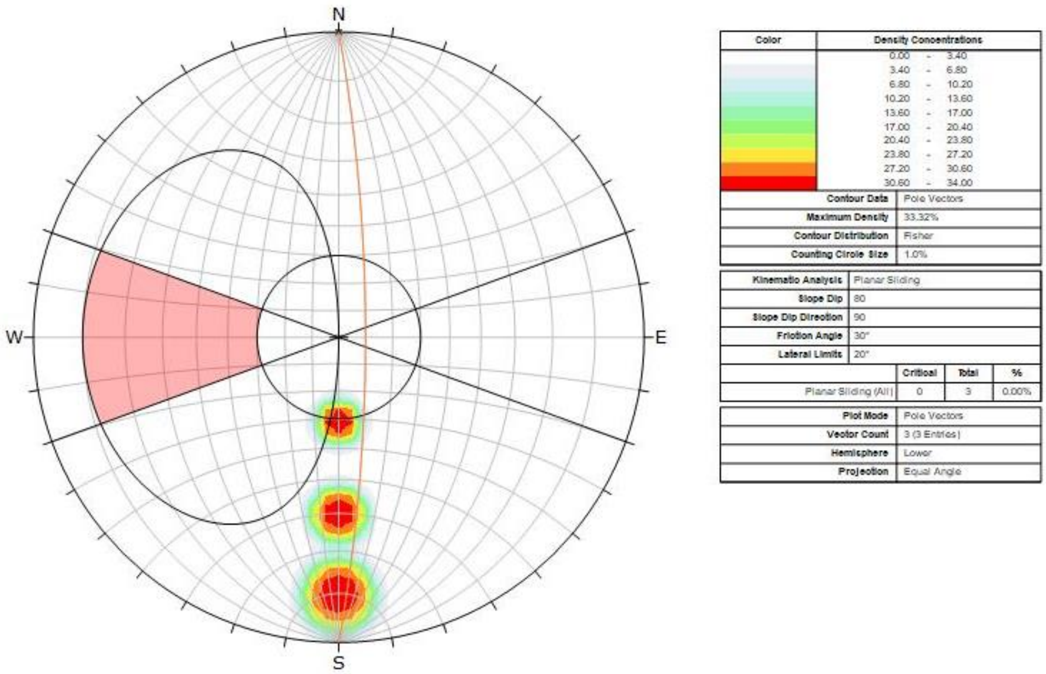

Figure 3. 31: Kinematic analysis for planar failure (Spot 3)

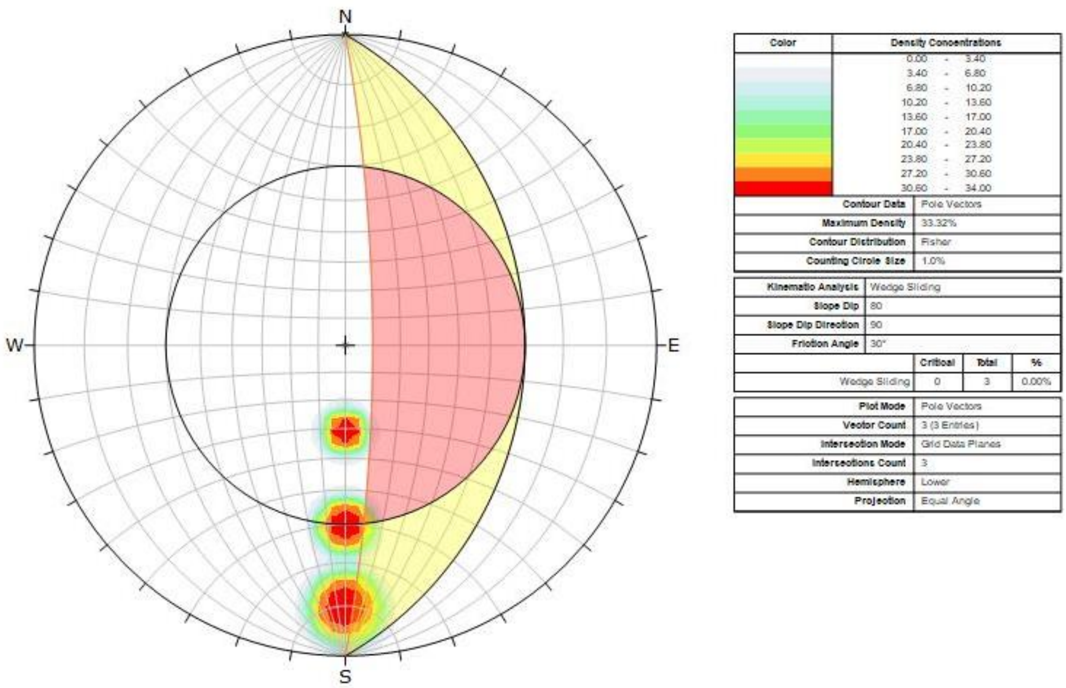

Figure 3. 32: Kinematic analysis for wedge failure (Spot3)

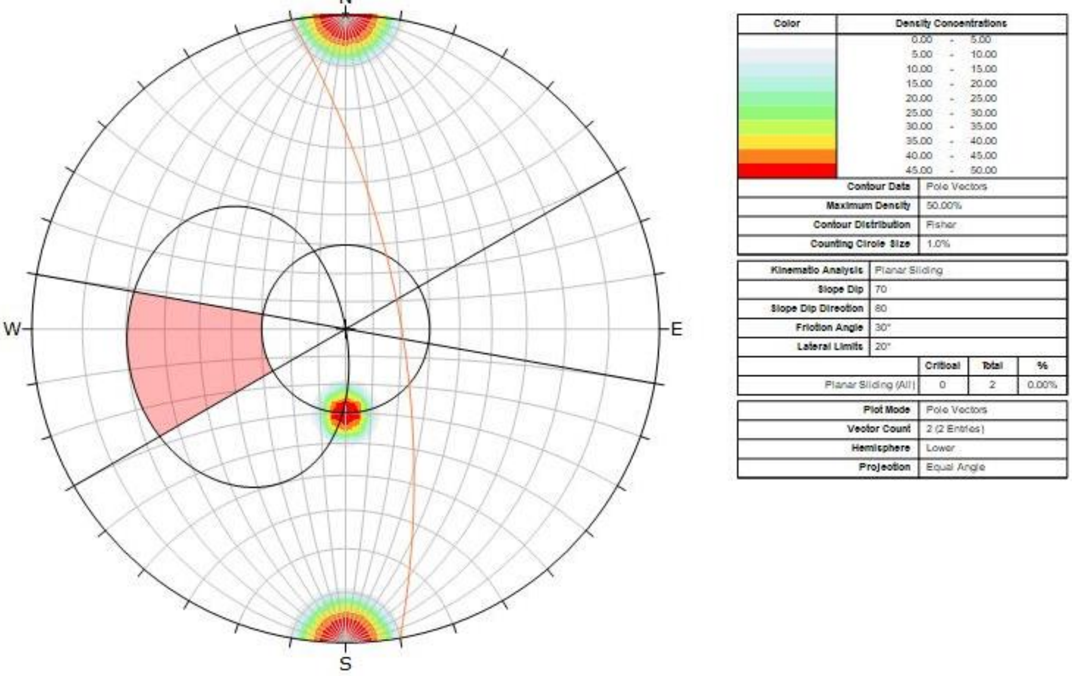

Figure 3. 33: Kinematic analysis for planar failure (Spot 4)

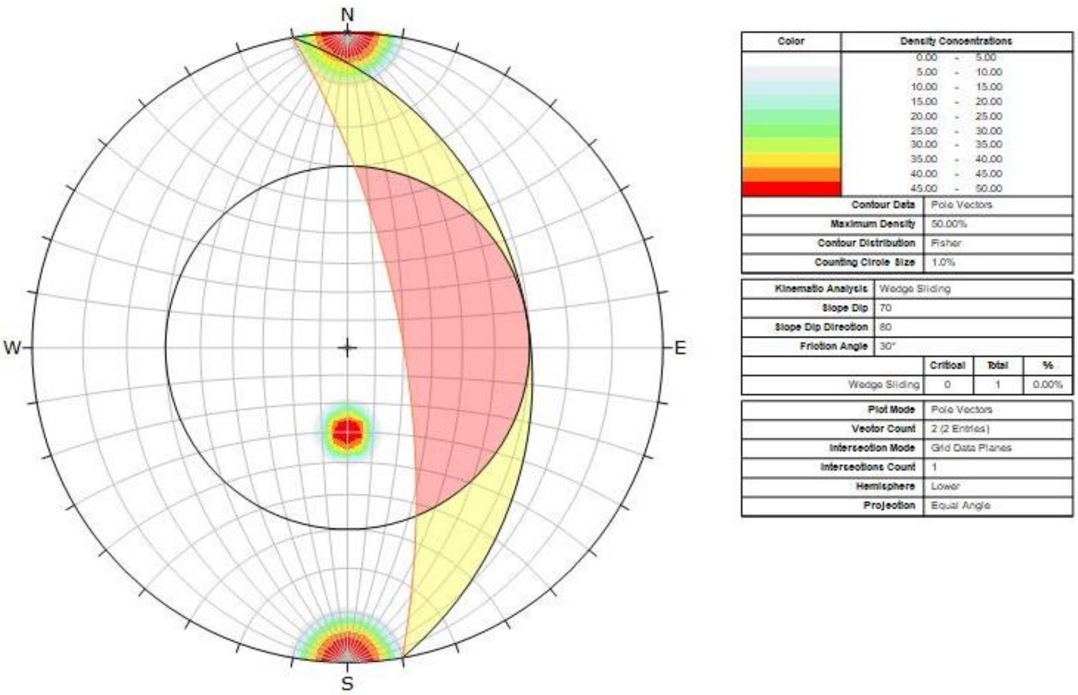

Figure 3. 34: Kinematic analysis for wedge failure (Spot 4)

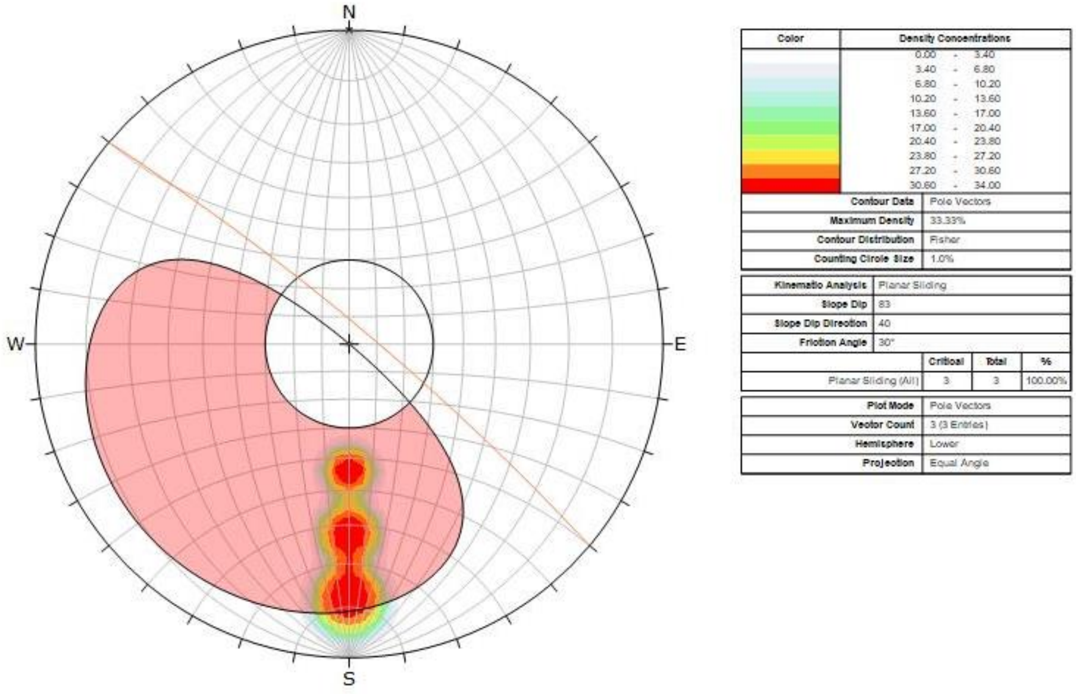

Figure 3. 35: Kinematic analysis for planar failure (Spot 5)

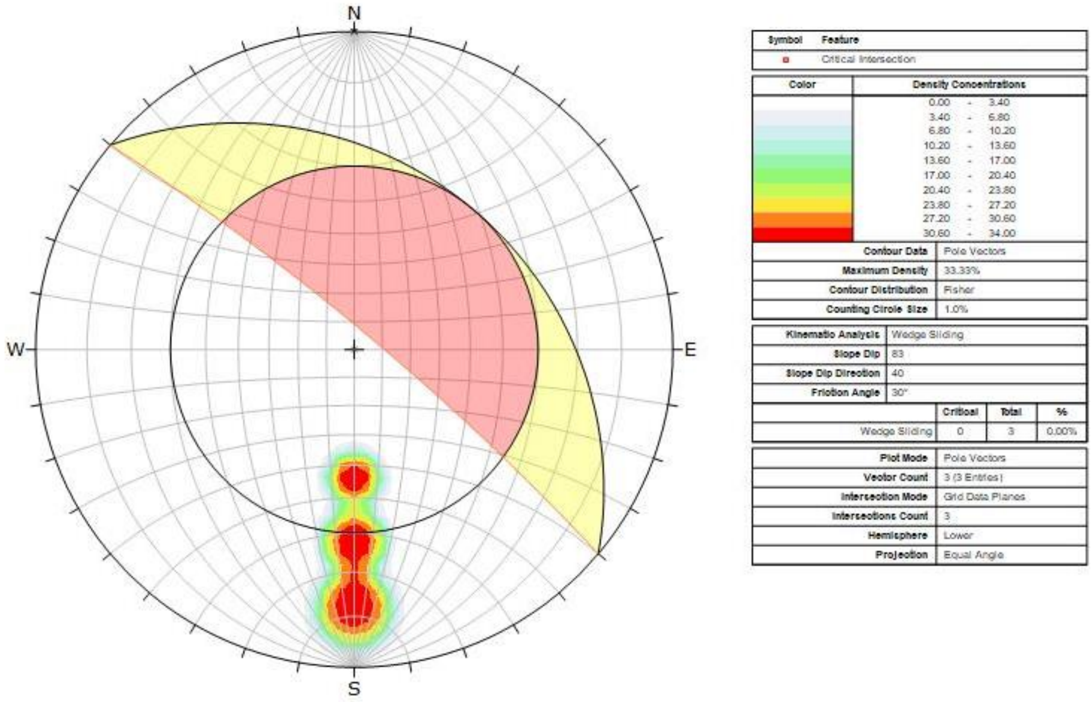

Figure 3. 36: Kinematic analysis for wedge failure (Spot 5)

3.2.3 Kinematic analysis of Bawngkawn – Edenthar

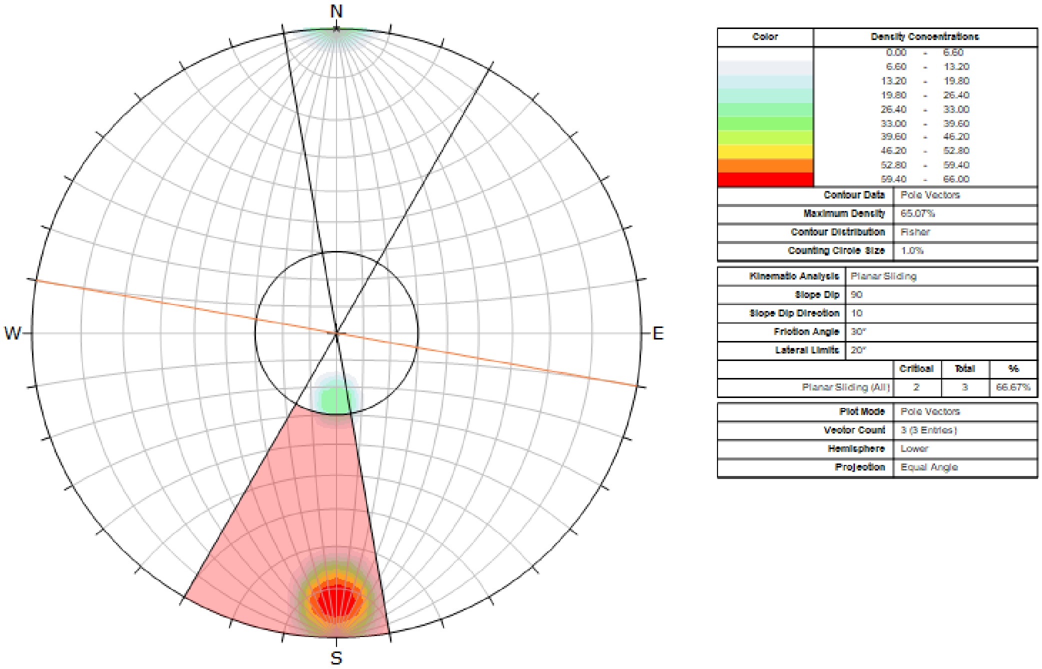

Figure 3. 37: Kinematic analysis for planar failure (Spot 1)

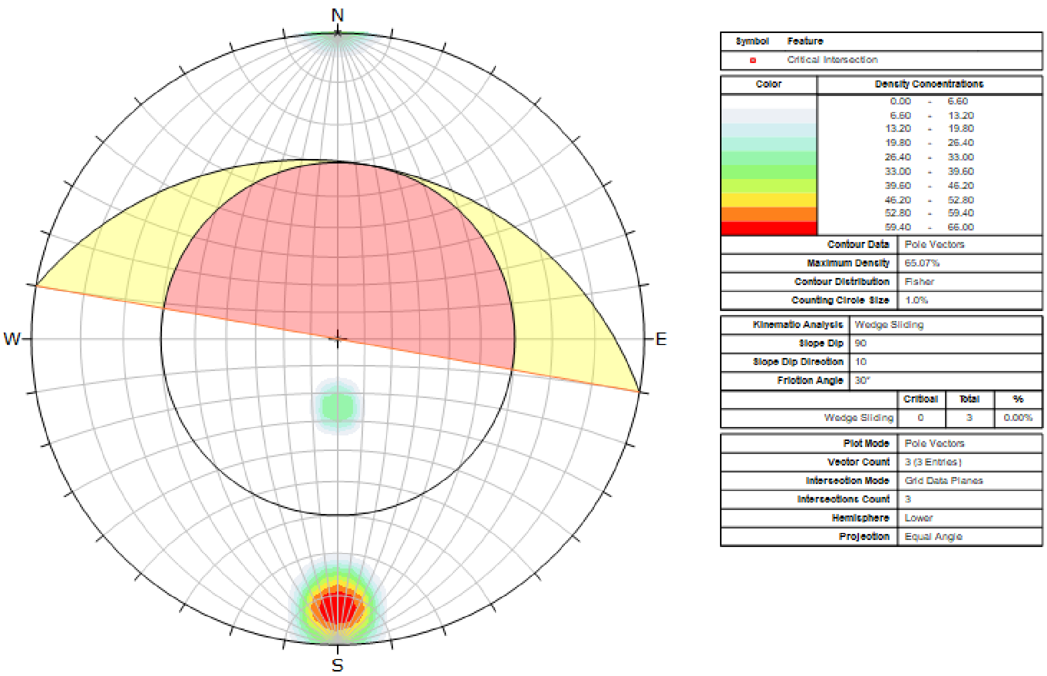

Figure 3. 38: Kinematic analysis for wedge failure (Spot 1)

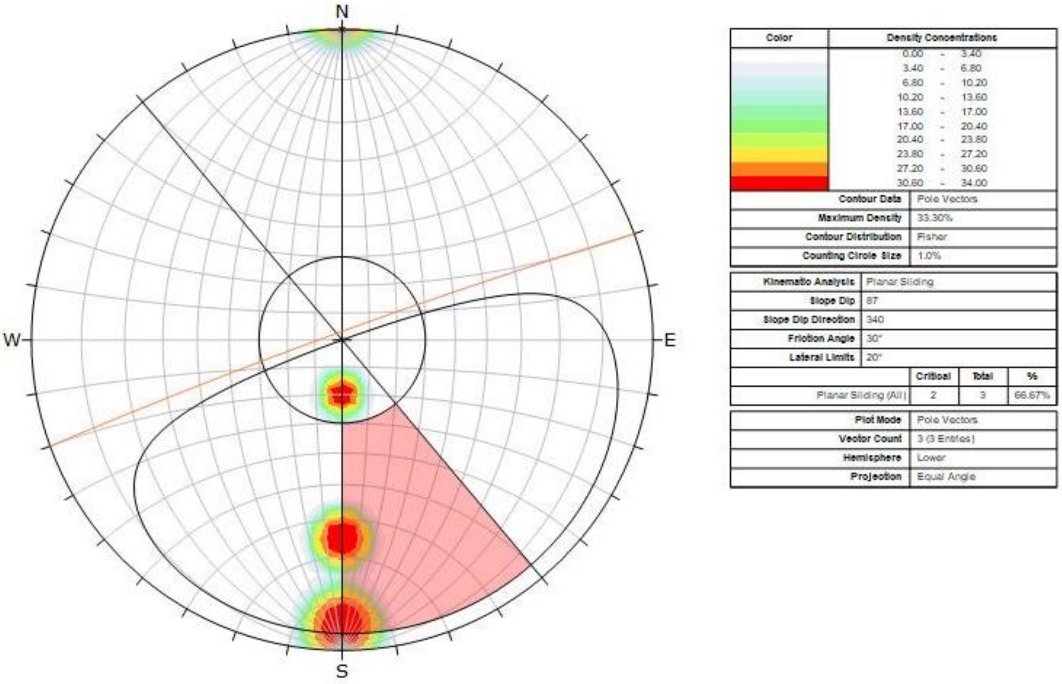

Figure 3. 39: Kinematic analysis for planar failure (Spot 2)

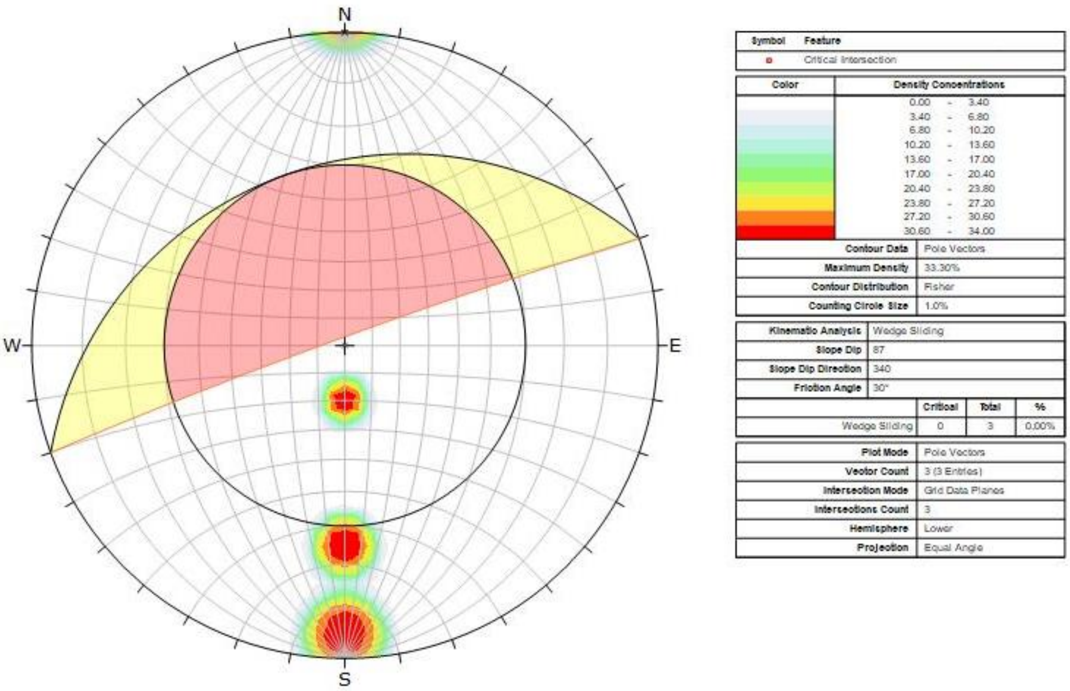

Figure 3. 40: Kinematic analysis for wedge failure (Spot 2)

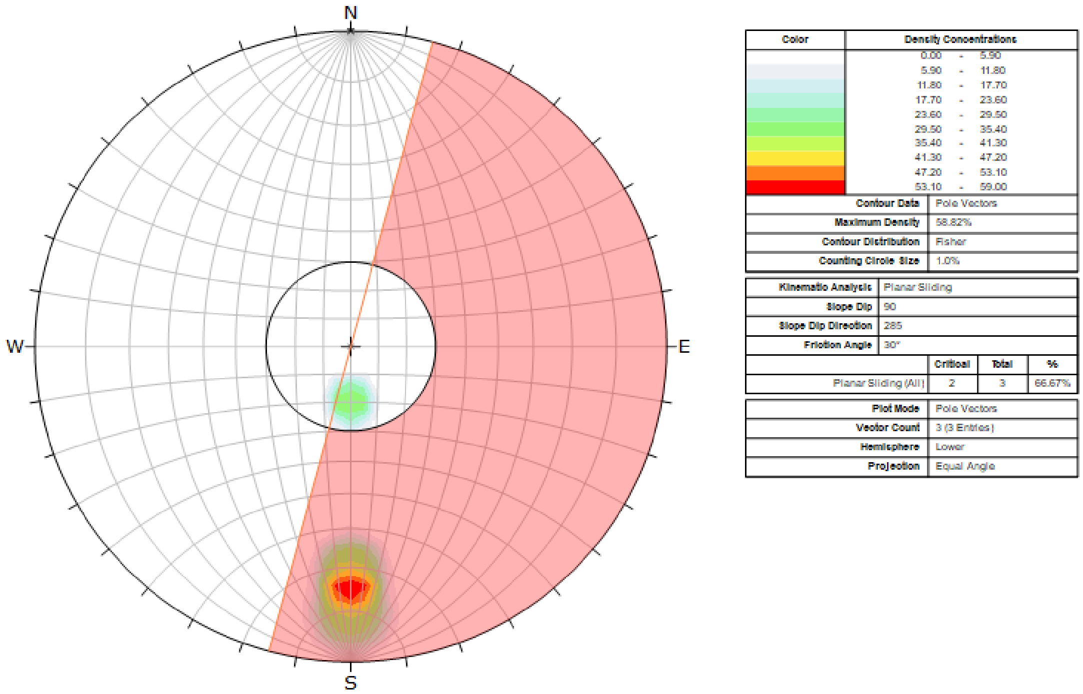

Figure 3. 41: Kinematic analysis for planar failure (Spot 3)

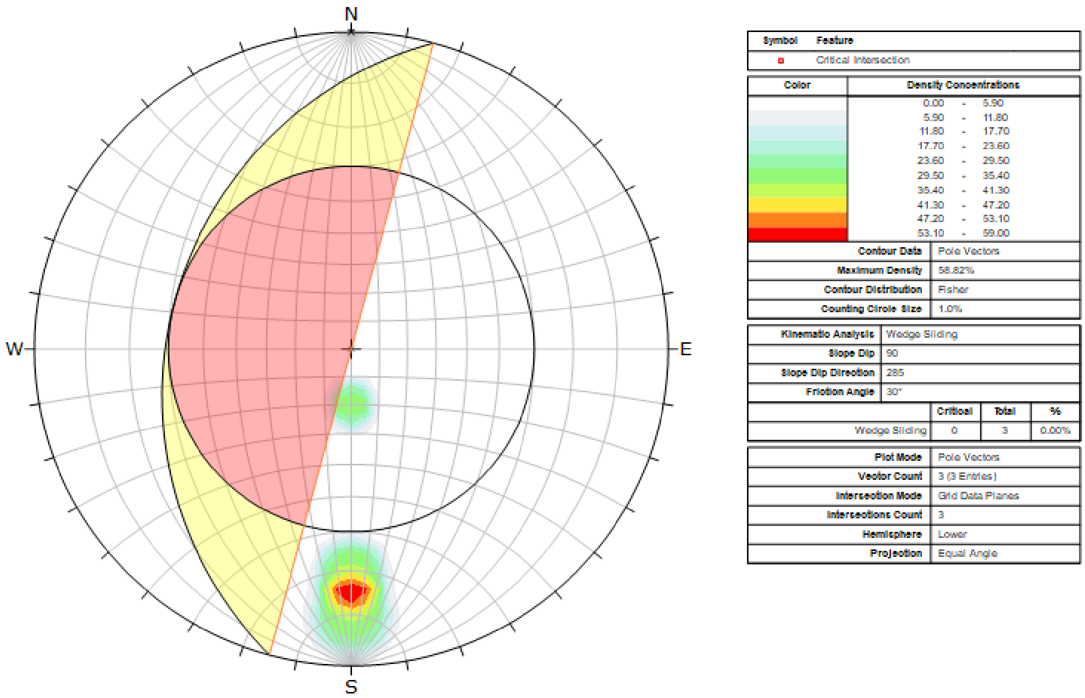

Figure 3. 42: Kinematic analysis for wedge failure (Spot 3)

The overall analysis obtained from *Bawngkawn- Durtlang* area shows 33.33% chance of Planar failure. Spot 5 shows 66.67% chance of Planar failure and Spot 6 shows 33.33% chance of Planar failure. Both Wedge failure and Topple failure are not given by the analysis.

Kinematic analysis of *Ngaizel* revealed that 40% probability of Planar failure. Spot 1 give 33.33%chance of Planar failure while Spot 5 shows 100% chance of Planar failure. Again from these five specific spot considered from Ngaizel area, wedge failure and topple failure does not produce by the analysis.

All the spot from *Bawngkawn- Edenthar* shows 66.67% chance of Planar failure, while no probability of wedge and topple failure is given by the analysis.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, the result obtained from various studies are presented. The information given by these results represents the nature and condition of the study area. Field observation, software analysis, stability analyses, and laboratory observations are written in this chapter.

4.1 FIELD DATA

4.1.1 NH- 54 (Bawngkawn – Durtlang)

Table 4. 1: Bawngkawn – Durtlang Spot 1

Spot: Leitan 1	Elevation: 1244 m	
Latitude: N 23°46.138’	Longitude: E 92°44.334’	
Slope Height: 39 m	Slope Direction: N240°	
Ditch Width: 3.3m	Road Width:7.5m	
Joint Volume: 7	Slope angle: 65°	
Block size: 2x2x1, 4x2x1	Rock type: Shale	
Rebound number: 28 R		
Joint Properties		
	J1 (Bedding)	J2
Discontinuity length (m)	<20	5
Discontinuity spacing (m)	5cm	3
Aperture (mm)	>1 mm	
Infilling	-	
Roughness	Rough	
Weathering	Highly weathered	
Groundwater condition	Damp	
Strike	N 335°	N 340°
Dip	N 60°	N 240°
Dip Amount	35°	65°

Table 4. 2: Bawngkawn – Durtlang Spot 2

Spot: Leitan 2	Elevation: 1243 m		
Latitude: N 23°46.073'	Longitude: E 92°44.345'		
Slope Height: 16 m	Slope Direction: N 255°		
Ditch Width:	Road Width:7m		
Joint Volume: 5	Slope angle: 75°		
Block size: 1x1x1	Rock type: Shale with small amount of sandstone bed		
Rebound number: 37R			
Joint Properties			
	J1 (Bedding)	J2	J3
Discontinuity length (m)	20	5	5
Discontinuity spacing (m)	4inch	2m	4m
Aperture (mm)	<1		
Infilling	-		
Roughness	Slightly rough		
Weathering	Slightly weathered		
Groundwater condition	Dry		
Strike	N 250°	N 340°	N 320°
Dip	N 160°	N 255°	N 45°
Dip Amount	80°	75°	N 85°

Table 4. 3: Bawngkawn – Durtlang Spot 4

Spot: Leitan 3	Elevation: 1228 m		
Latitude: N 23°46.047'	Longitude: E 92°44.345'		
Slope Height:	Slope Direction: N 240°		
Ditch Width: 3ft	Road Width: 7.5 m		
Joint Volume: 12	Slope angle: 76°		
Rebound number:	32 R		
Joint Properties			
	J1 (Bedding)	J2	J3
Discontinuity length (m)	20	5	5
Discontinuity spacing (m)	3ft, 4inch	1ft,3inch	2,8inch
Aperture (mm)	1-5 mm		
Infilling	-		
Roughness	Slightly rough		
Weathering	Slightly weathered		
Groundwater condition	Damp		
Strike	N 325°	N 330°	N 35°
Dip	N 60°	N 240°	N 315°
Dip Amount	17°	76°	78°

Table 4. 4: Bawngkawn – Durtlang Spot 4

Spot: Leitan 4	Elevation: 1219 m		
Latitude: N 23°45.995'	Longitude: E 92°44.352'		
Slope Height: 34 yards	Slope Direction: N 270°		
Ditch Width: 3ft	Road Width: 7.5m		
Joint Volume: 10	Slope angle: 82°		
Rebound number:	54.5R		
Joint Properties			
	J1 (Bedding)	J2	J3
Discontinuity length (m)	20	4	4
Discontinuity spacing (m)	4inch	1-2ft	1-2ft
Aperture (mm)	<5		
Infilling	-		
Roughness	Slightly rough		
Weathering	Slightly weathered		
Groundwater condition	Damp		
Strike	N 99°	N 175°	N 65°
Dip	N 11°	N 270°	N 150°
Dip Amount	27°	82°	86°

Table 4. 5: Bawngkawn – Durtlang Spot 5

Spot: Leitan 5	Elevation: 1193m			
Latitude: N 23°45.900'	Longitude: E 92°44.301'			
Slope Height: 24m	Slope Direction: N 335°			
Ditch Width:4ft	Road Width:35m			
Joint Volume: 7	Slope angle: 77°			
Rebound number:	51.5R			
Joint Properties				
	J1 (Bedding)	J2	J3	J4
Discontinuity length (m)	10	3	5	5m
Discontinuity spacing (m)	1.5ft	1.5ft	2.5ft	2m
Aperture (mm)	<5mm			
Infilling	Hard infilling			
Roughness	Slightly rough			
Weathering	Slightly weathered			
Groundwater condition	Damp			
Strike	N 165°	N 60°	N 0°	N 150°
Dip	N 80°	N 335°	N 275°	N 55°
Dip Amount	70°	77°	71°	80°

Table 4. 6: Bawngkawn – Durtlang Spot 6

Spot: Leitan 6	Elevation: 1191 m			
Latitude: N 23°45.857’	Longitude: E 92°44.257’			
Slope Height: 21 m	Slope Direction: N 15°			
Ditch Width: 4ft	Road Width: 7.57m			
Joint Volume: 7	Slope angle: 88°			
Rebound number:	50R			
Joint Properties				
	J1 (Bedding)	J2	J3	J4
Discontinuity length (m)	1	1ft	1.5ft	1.5ft
Discontinuity spacing (m)	1.5m			
Aperture (mm)	<5			
Infilling	-			
Roughness	Slightly rough			
Weathering	Slightly weathered			
Groundwater condition	Dry			
Strike	N 100°	N 15°	N 335°	N 250°
Dip	N 15°	N 280°	N 240°	N 350°
Dip Amount	21°	88°	87°	84°

4.1.2 Ngaizel

Table 4. 7: Ngaizel Spot 1

Location : RL Hair Cutting Saloon	Slope height : 9.01m
Latitude : N 23°42.331”	Slope angle : 70
Longitude : E 92°43.204”	Joint Volume : 8
Elevation : 1043 m	Ditch width: 1.4ft
Slope Direction : N 45	Road Width : 5m

Joints			
Joint Properties	J1	J2	J3
Discontinuity length	3-10 m		
Discontinuity Spacing	9cm	3ft	3 ft-
Aperture	4mm		
Infilling	Nil		
Roughness	Rough		
Weathering	Highly weathered		
Groundwater Condition	Dry		
Rebound No.			

Joint Orientation			
J1	J2	J3	Fracture
Direction : N270 Amount : 31	Direction : N40 Strike : N290 Amount : 80	Direction : N115 Amount : 60	

Table 4. 8: Ngaizel Spot 2

Location: Aizawl City bus Owners Building		Slope height: 25 m	
Latitude : N 23°42.168”		Slope angle : 85	
Longitude : E 92°43.275”		Joint Volume : 7	
Elevation : 1061 m		Ditch width : 4 m	
Slope Direction: N 110		Road width: 11.5 m	
Joints Properties			
Discontinuity length	3-10 m		
Discontinuity Spacing	2.5 ft	1.5ft	.5 ft
Aperture	1		
Infilling	Nil		
Roughness	Rough		
Weathering	Highly weathered		
Ground water Condition	Dry		
Rebound No.	40		
J1	J2	J3	
Direction : N260 Amount : 40	Direction : N220 Amount : 63	Direction : N120 Amount : 78	

Table 4. 9: Ngaizel Spot 3

Location: Petrol Pump		Slope height: 23.36 m
Latitude : N 23°42.252"		Slope angle : 80
Longitude : E 92°43.249"		Joint Volume : 10
Elevation : 1020 m		Ditch width : 7.61 m
Slope Direction : N 90		Road width : 8.3293
Joint Properties		
	J1	J2
Discontinuity length	1-3 m	
Discontinuity Spacing	14cm	1.86 m -
Aperture	5mm	
Infilling	Nil	
Roughness	Rough	
Weathering	Highly weathered	
Ground water Condition	Wet	
Rebound No.		
J1	J2	
Direction : N260 Amount : 34	Direction : N5 Strike : N290 Amount : 63	

Table 4. 10: Ngaizel Spot 4

Location : LR Feed		Latitude : N 23°42.125'	
Longitude : E 92°43.267'		Elevation : 1035 m	
Road width: 7.14 m		Slope Direction: N80	
Slope height: 24 m		Slope angle : 70	
Joint Volume : 13		Ditch width : 3.95 m	
Joints Properties			
	J1	J2	J3
Discontinuity length	3-10 m		
Discontinuity Spacing	8cm	1 ft	1 ft
Aperture	2mm		
Infilling	-		
Roughness	Rough		
Weathering	Highly weathered		
Groundwater Condition	Damp		
Rebound No.	40		
J1	J2	J3	
Direction : N250 Amount :44	Direction : N285 Amount :62	Direction : N134 Amount :78	

Table 4. 11: Ngaizel Spot 5

Location: TK Two-wheeler Workshop	Slope height: 17.125 m		
Latitude : N 23o42 068’	Slope angle : 83		
Longitude: E 92o43.315’	Joint Volume : 5		
Elevation : 1034 m	Ditch width : 1.86 m		
Slope Direction: N 40	Road width : 5.6 m		
Joint Properties			
	J1	J2	J3
Discontinuity length	3-10 m		
Discontinuity Spacing	.5ft	3 ft	9 inch
Aperture	NIl		
Infilling	Nil		
Roughness	Rough		
Weathering	Highly weathered		
Ground water Condition	Damp		
Rebound No.	53		
J1	J2	J3	
Direction : N265 Amount : 30	Direction : N45 Amount : 90	Direction : N175 Amount00 : 90	

4.1.3 Bawngkawn – Edenthar

Table 4. 12: Bawngkawn - Edenthar Spot 1

Spot : 1		Latitude : 23^0 45.3439 N
Longitude : 92^0 43.600 E		Elevation : 962
Rock type : Sandstone, shale		Slope Direction : N10^o
Slope height : 22 m		Slope angle : 90
Joint Volume : 7		Ditch width : 4.ft
Road width : 6.6m		Block Size : 14.58 m^3
Joint Properties		
Discontinuity length	15ft, 2ft, 2ft	
Discontinuity Spacing	1ft, .6ft, 2ft, 10 yrd	
Aperture	1ft, 5mm, 20yrd	
Infilling	-	
Roughness	Rough	
Weathering	Highly weathered	
Groundwater Condition	dry	
Rebound No.	44R	
J1	J2	J3
Strike : N50 Dip Direction : N135 Amount : 25	Strike : N87 Dip Direction : N350 Amount : 80	Strike : N15 Dip Direction : N285 Amount : 85

Table 4. 13: Bawngkawn - Edenthar Spot 2

Spot : 2		Latitude : 23^0 45.345 N
Longitude : 92^0 43.577 E		Elevation : 961
Rock type : Sandstone, shale		Slope Direction : N340^o
Slope height : 29.26 m		Slope angle : 90
Joint Volume : 9		Ditch width : 4.ft
Road width : 6m		Block Size : 0.6 m^3
Joint Properties		
Discontinuity length	3ft, 2ft	
Discontinuity Spacing	1ft, .6ft, 2ft, 10 yrd	
Aperture	>5mm	
Infilling	-	
Roughness	Rough	
Weathering	Highly weathered	
Groundwater Condition	dry	
Rebound No.	33R	
J1	J2	J3
Strike : N220 Dip Direction : N120 Amount : 20	Strike : N54 Dip Direction : N310 Amount : 65	Strike : N300 Dip Direction : N29 Amount : 85

Table 4. 14: Bawngkawn - Edenthar Spot 3

Spot : 3	Latitude : 23^0 45.272 N	
Longitude : 92^0 43.365 E	Elevation : 934	
Rock type : Sandstone, shale	Slope Direction : N285°	
Slope height : 6.4 m	Slope angle : 90	
Joint Volume : 13	Ditch width : 4.ft	
Road width : 5.45m	Block Size : 0.3-2.3m^3	
Joint Properties		
Discontinuity length	20ft, 2ft, 0.6ft	
Discontinuity Spacing	.6ft,	
Aperture	<5mm	
Infilling	-	
Roughness	Rough	
Weathering	Highly weathered	
Groundwater Condition	dry	
Rebound No.	22R	
J1	J2	J3
Strike : N190 Dip Direction : N105 Amount : 20	Strike : N155 Dip Direction : N240 Amount : 80	Strike : N85 Dip Direction : N340 Amount : 70

4.2 STEREONET AND ROSE DIAGRAM

4.2.1 Bawngkawn – Edenthar

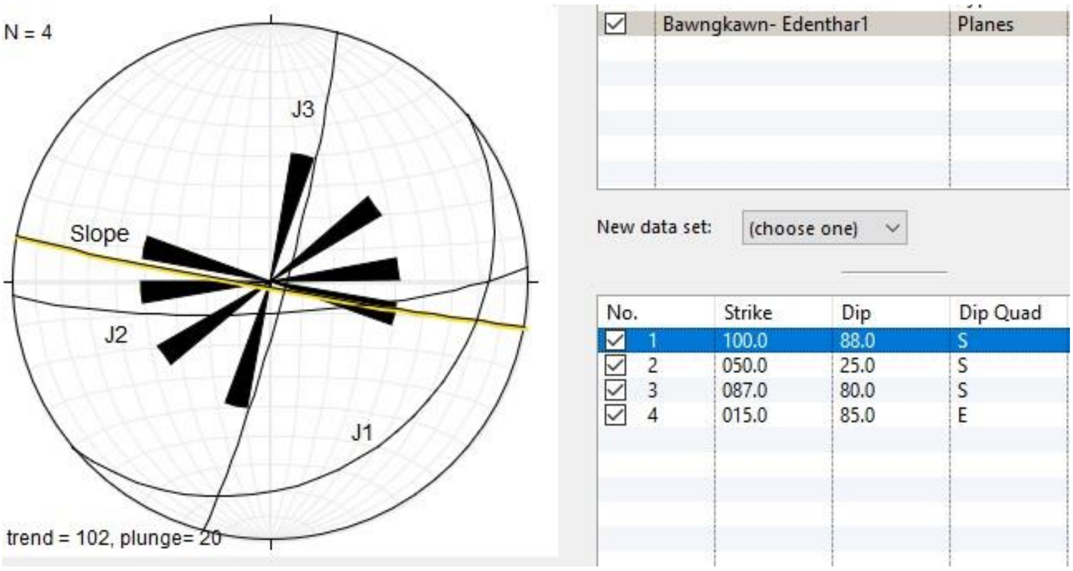

Figure 4. 1: Sterionet and Rose Diagram (Bawngkawn-Edenthar Spot 1)

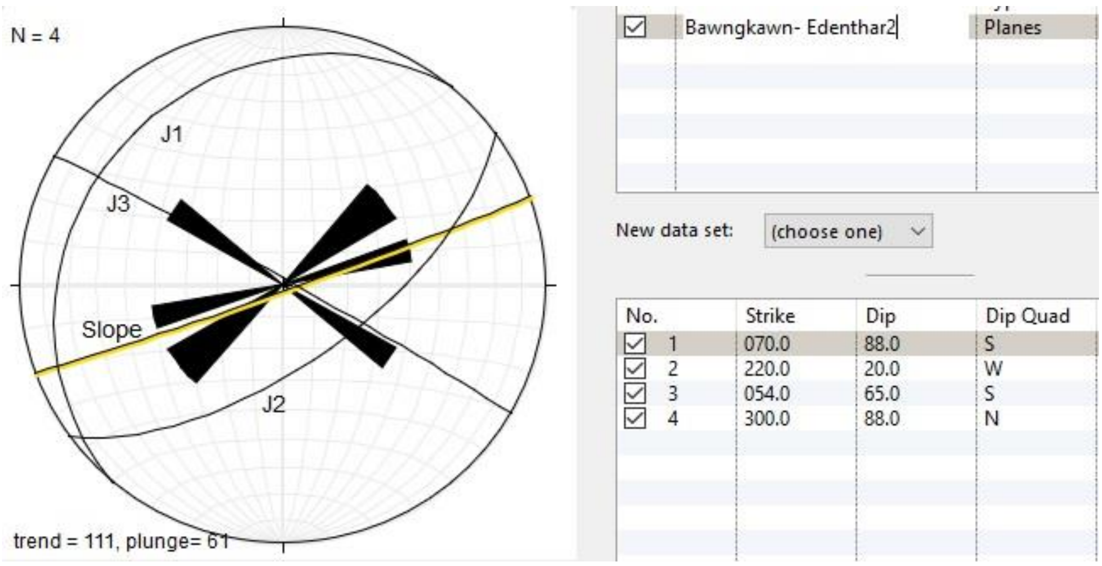

Figure 4. 2: Sterionet and Rose Diagram (Bawngkawn durtlang Spot 2)

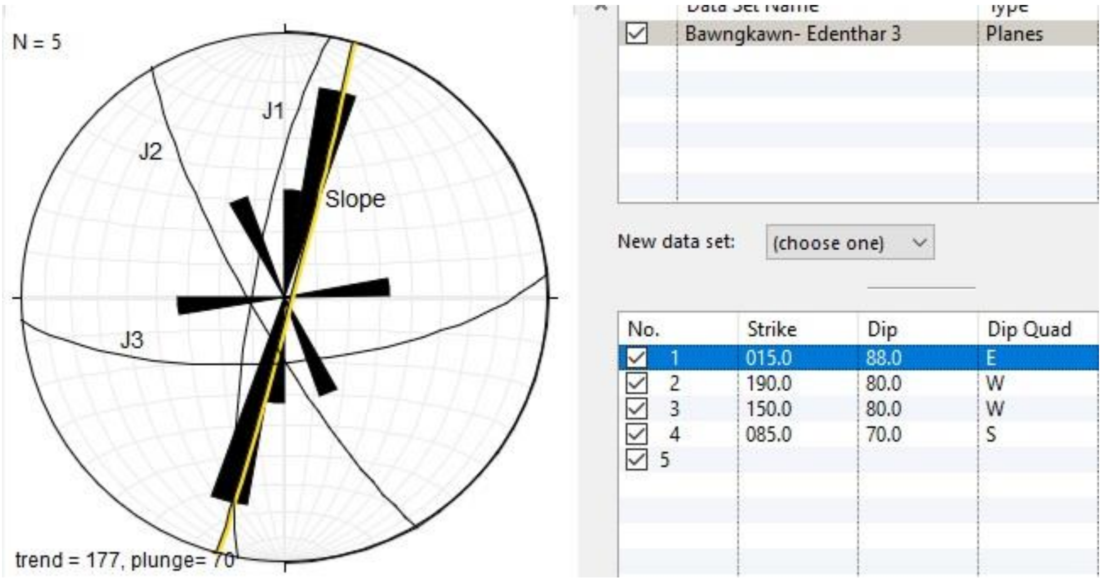

Figure 4. 3: Sterionet and Rose Diagram (Bawngkawn Edenthar Spot 3)

4.2.2 NH- 54 (Bawngkawn – Durtlang)

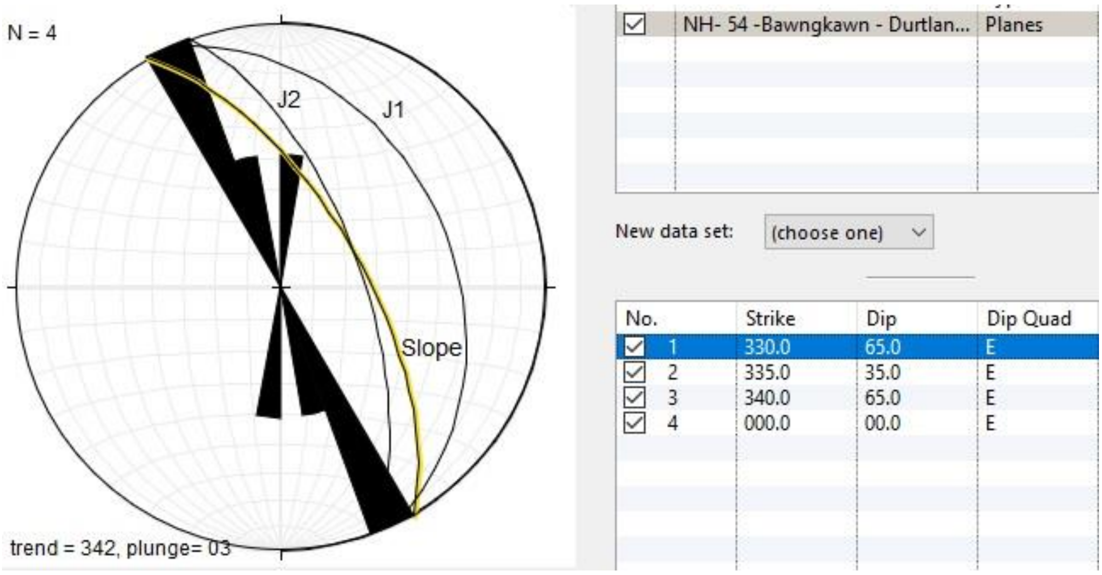

Figure 4. 4: Sterionet and Rose Diagram (Bawngkawn Durtlang Spot 1)

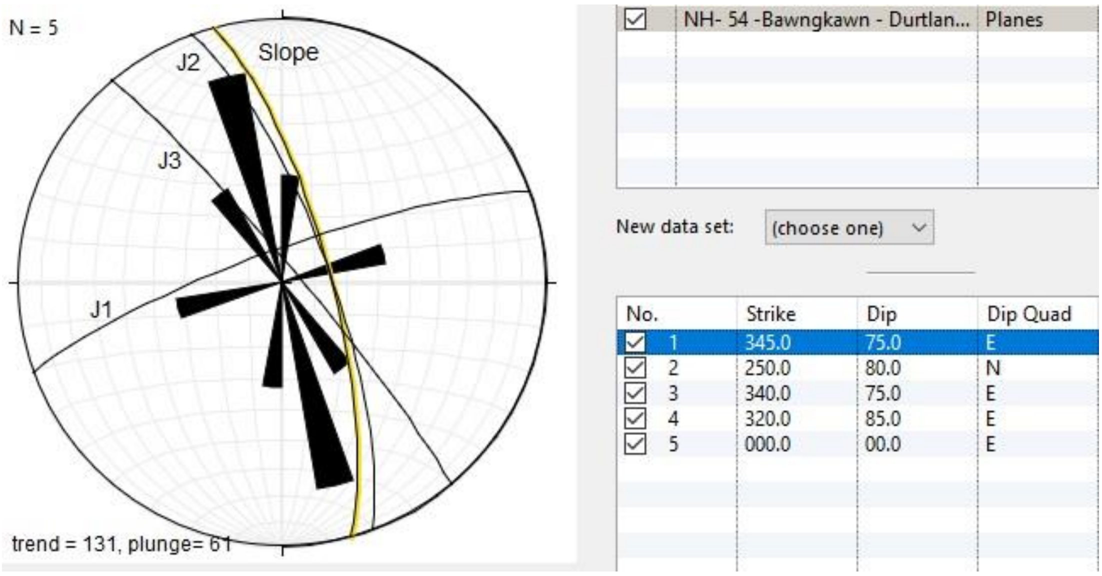

Figure 4. 5: Sterionet and Rose Diagram (Bawngkawn Durtlang Spot 2)

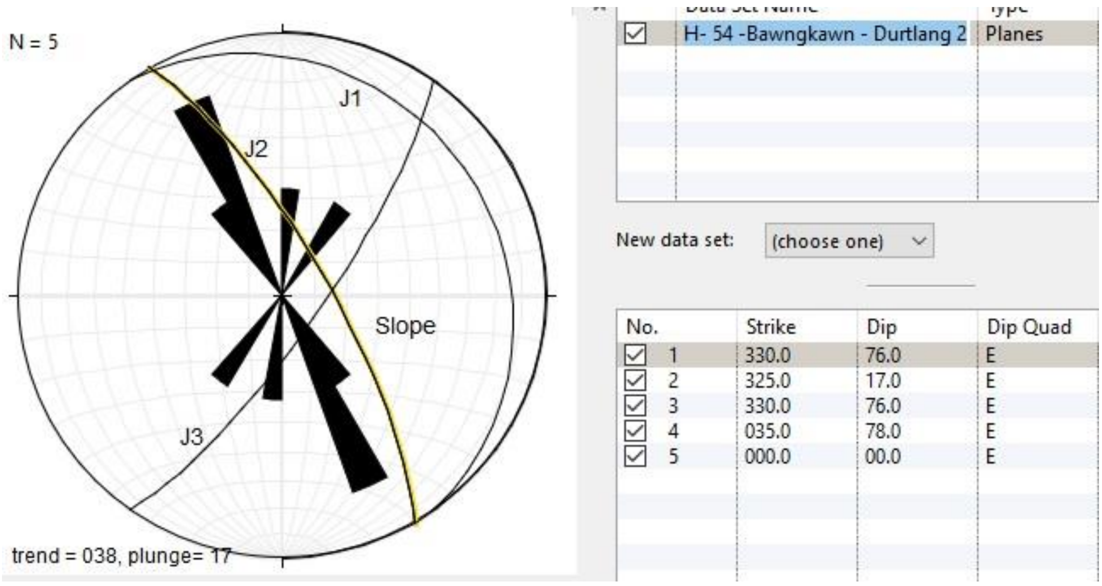

Figure 4. 6: Sterionet and Rose Diagram (Bawngkawn Durtlang Spot 3)

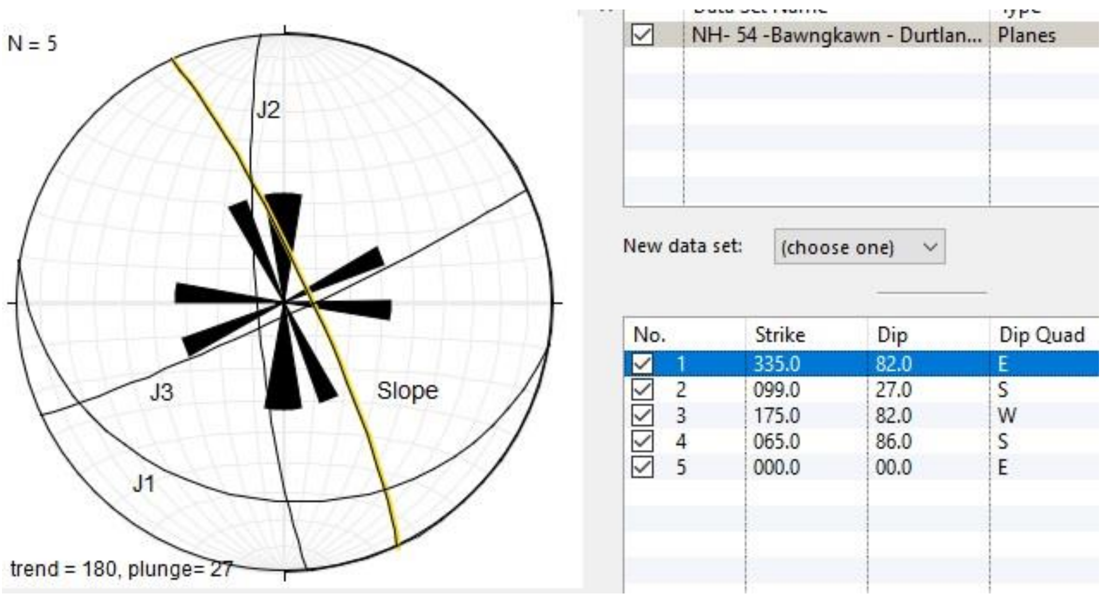

Figure 4. 7: Sterionet and Rose Diagram (Bawngkawn Durtlang Spot 4)

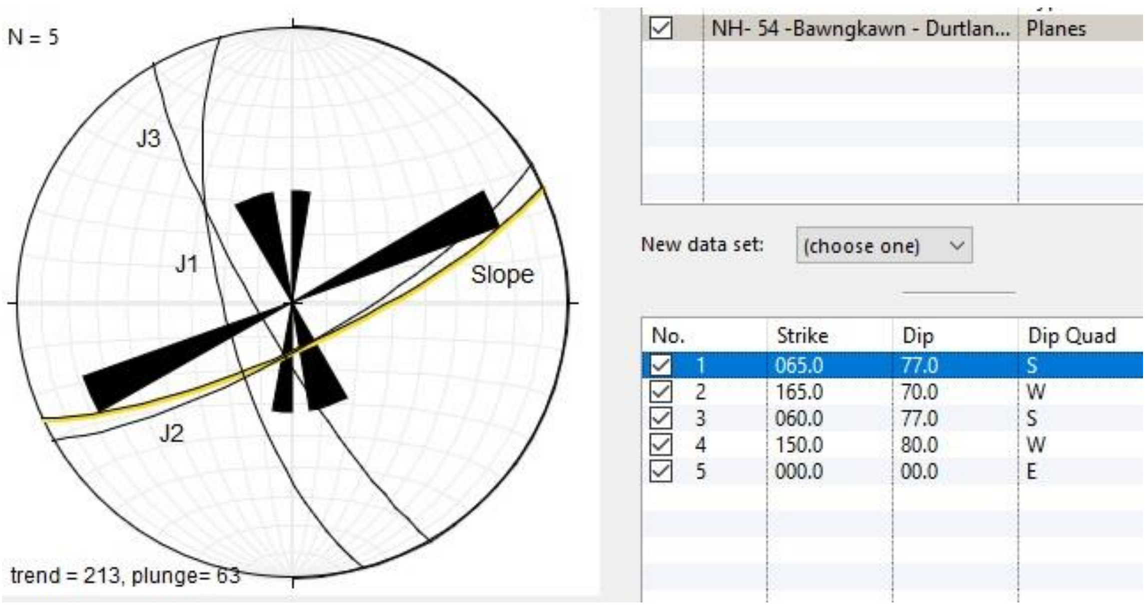

Figure 4. 8: Sterionet and Rose Diagram (Bawngkawn Durtlang Spot 5)

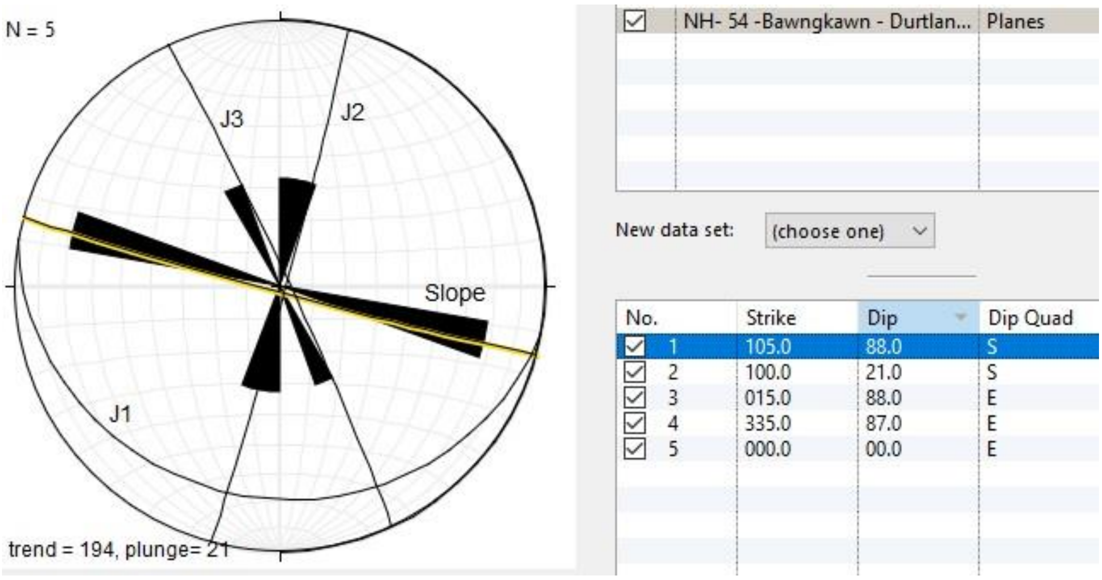

Figure 4. 9: Sterionet and Rose Diagram (Bawngkawn Durtlang Spot 6)

4.2.3 Ngaizel

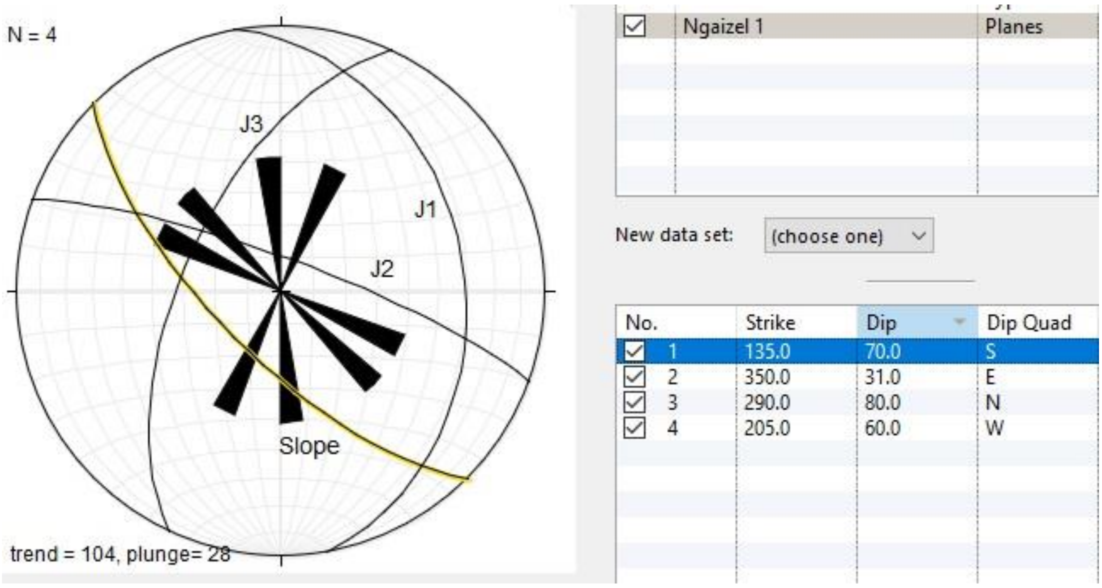

Figure 4. 10: Sterionet and Rose Diagram (Ngaizel Spot 1)

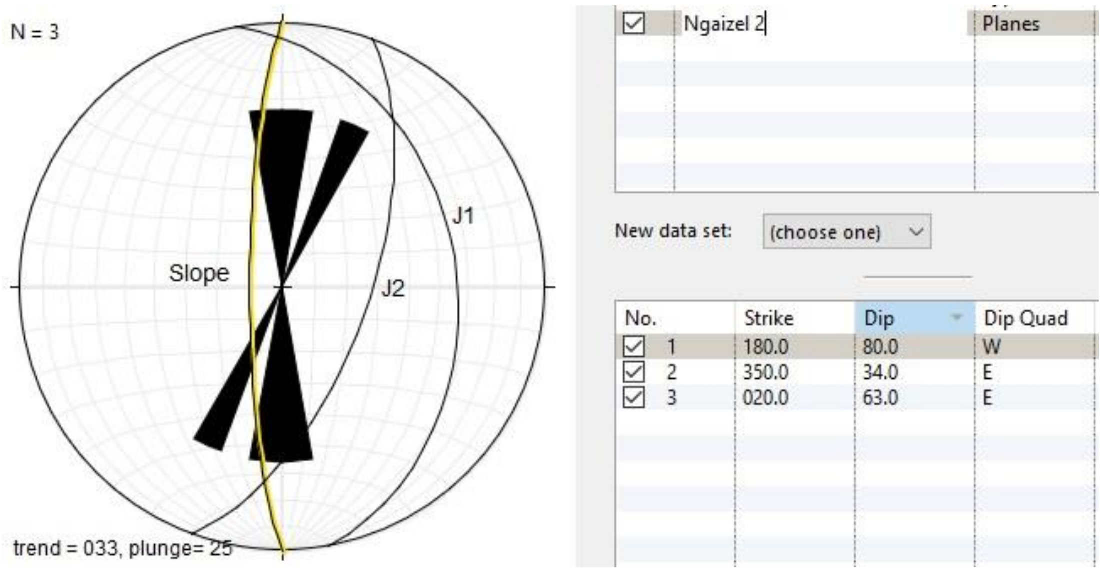

Figure 4. 11: Sterionet and Rose Diagram (Ngaizel Spot 2)

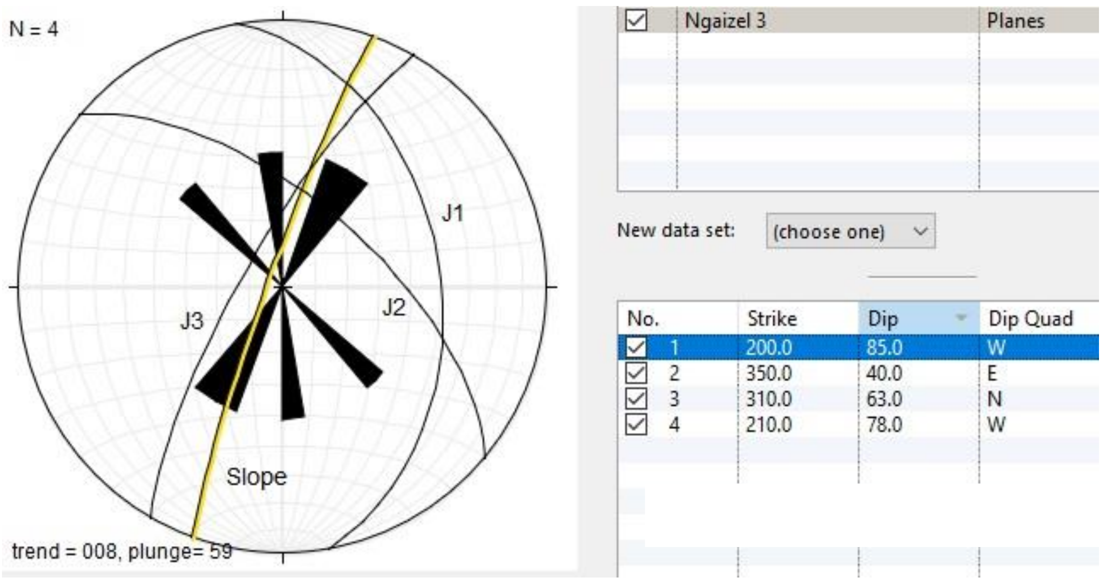

Figure 4. 12: Sterionet and Rose Diagram (Ngaizel Spot 3)

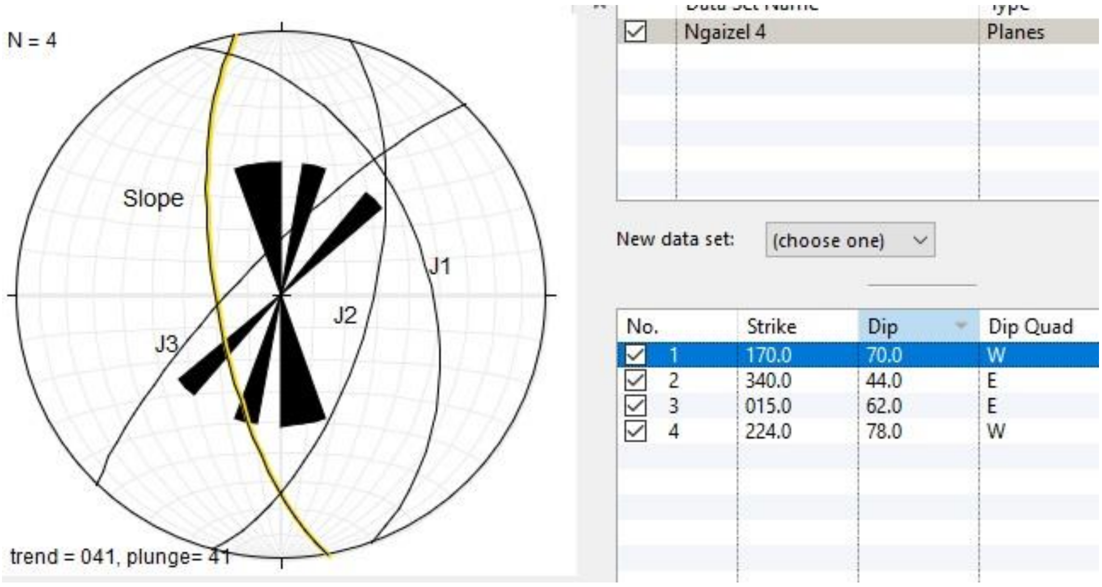

Figure 4. 13: Sterionet and Rose Diagram (Ngaizel Spot 4)

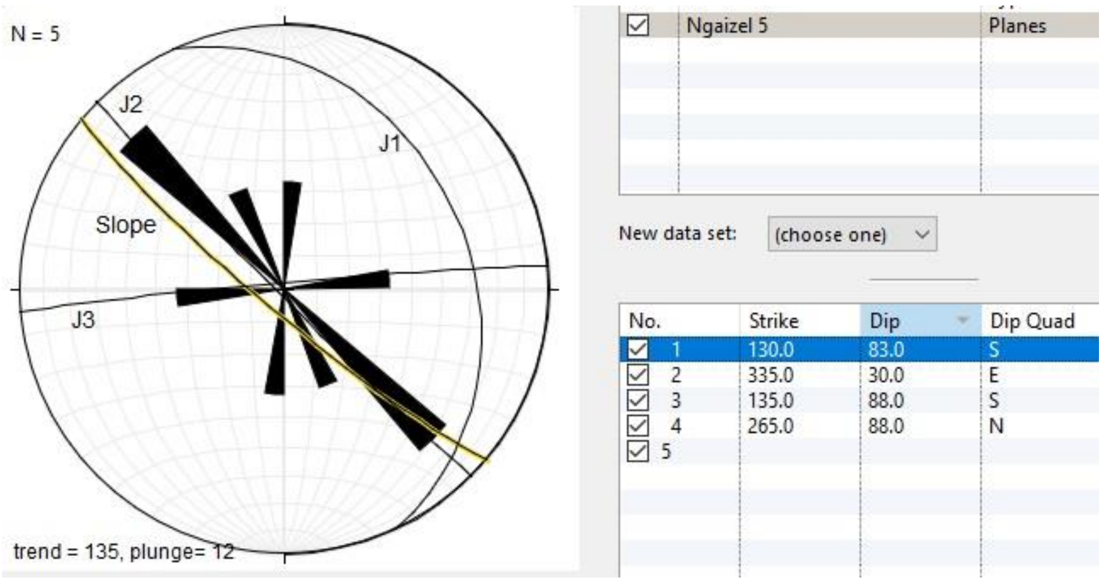

Figure 4. 14: Sterionet and Rose Diagram (Ngaizel Spot 5)

4.3 UNCONFINED COMPRESSIVE STRENGTH : (ROCK SMIDTH)

Table 4. 15: Result of Unconfined Compressive Strength

NH-54 Bawngkawn- Durtlang							
Spot	**1**	**2**	**3**	**4**	**5**	**6**	**Avg.**
UCS	14Mpa	35Mpa	25Mpa	68Mpa	59Mpa	58 Mpa	43.16 MPa
Ngaizel							
UCS	48Mpa	66Mpa	38Mpa	66Mpa	64Mpa		56.4 Mpa
Bawngkawn- Edenthar							
UCS	37Mpa	32Mpa	18Mpa				29Mpa

4.4 ROCK QUALITY DESIGNATION (RQD)

Table 4. 16: Result of Rock Quality Designation

NH-54 Bawngkawn- Durtlang							
Spot	**1**	**2**	**3**	**4**	**5**	**6**	**Avg.**
RQD	91.9%	98%	75.4%	82%	91.5%	90.5%	88.21%
Ngaizel							
RQD	53%	75%	82.5%	67.5%	87.5%		73.1%
Bawngkawn- Edenthar							
RQD	91.9%	85%	72.9%				83.3%

4.5 LABORATORY ANALYSIS

4.5.1 Slake Durability Index

Table 4. 17: Result of Slake Durability Index

NH-54: Bawngkawn- Durtlang							
Spot	**1**	**2**	**3**	**4**	**5**	**6**	**Avg.**
SDI	86.6%	96.8%	95.72%	96.13%	96.89%	96.67%	94.8%
Ngaizel							
SDI	95%	96%	94.83%	98.08%	97.43%		96.26%
Bawngkawn – Edenthar							
SDI	97.36%	92.81%	97.06%				95.75%

4.5.2 Point Load Index

Table 4. 18: Result of Point Load Index

Ngaizel					
Parameters	**1**	**2**	**3**	**4**	**5**
PLI (Is50)	0.19	0.11	0.17	0.13	0.17
UCS (kgf/cm2)	4.18	2.42	3.74	2.86	3.72
PLI (Is50)	0.08	0.07	0.06	0.06	0.07
UCS (kgf/cm2)	1.7	1.54	1.32	1.32	1.54
Bawngkawn-Edenthar					
PLI (Is50)	0.01	0.03	0.01	0.032	
UCS (kgf/cm2)	0.2	0.6	0.2	0.7	
PLI (Is50)	0.038	0.035	0.01	0.01	
UCS (kgf/cm2)	0.8	0.7	0.2	0.2	
NH-54, Bawngkawn- Durtlang					
PLI (Is50)	2.18	1.33	1.82	0.18	0.1
UCS (kgf/cm2)	47.96	29.26	40.04	3.96	.22

4.6 ROCK MASS RATING

4.6.1 NH-54 (Bawngkawn – Durtlang)

Table 4. 19: Rock Mass Rating (Bawngkawn – Durtlang)

CLASSIFICATION PARAMETERS AND RATINGS									
Spot No.	UCS	QRD	S.D	D.L	Aperture	Roughness	Infilling	Weathering	G.W
1.	14Mpa	91.9%	4mm	12.5m	1mm	Rough	None	Highly	Damp
Rating	2	20	5	1	4	5	6	1	10
2.	35Mpa	98%	2.1m	10 m	1mm	Slightly	None	Slightly	Dry
Rating	4	20	20	1	4	3	6	5	15
3.	25Mpa	75.4%	731. 5 mm	10m	3mm	Slightly	None	Slightly	Damp
Rating	4	17	15	1	1	3	6	5	10
4.	68Mpa	82%	1.01m	7m	>5mm	slightly	None	Slightly	Damp
Rating	7	17	15	2	0	3	6	5	10
5.	59Mpa	91.5%	2.6m	5.75m	3mm	Rough	None	Slightly	Damp
Rating	7	20	20	2	1	5	6	5	10
6.	58Mpa	90.5%	1.5m	1.4 m	4mm	Rough	None	Slightly	Dry
Rating	7	20	15	4	1	5	6	5	15

DISCONTINUITY ORIENTATIONS & ROCK MASS DETERMINED							
Spot No	Strike &Dip orientation	RMR value	Class No	Description	ASUT	Cohesion (kPa)	Friction angle
1.	Unfavourable	4	V	Very poor rock	30 min for 1 m span	<100	<15°
Rating	-50						
2.	Unfavourable	28	IV	Poor rock	10 hours for 2.5m span	100-200	15 ° -25 °
Rating	-50						
3.	Unfavourable	12	V	Very poor rock	30 min for 1 m span	<100	<15 °
Rating	-50						
4.	Uufavourable	15	V	Very poor rock	30 min for 1 m span	<100	<15 °
Rating	-50						
5.	Unfavourable	22	IV	Poor rock	10 hours for 2.5m span	100-200	15 ° -25 °
Rating	-50						
6.	Unfavourable	28	IV	Poor Rock	10 hours for 2.5m span	100-200	15 ° -25 °
	-50						

4.6.2 Ngaizel

Table 4. 20: Rock Mass Rating (Ngaizel)

CLASSIFICATION PARAMETERS AND RATINGS									
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

DISCONTINUITY ORIENTATIONS & 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	IV	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.	Uufavourable	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						

4.6.3 Bawngkawn - Edenthar

Table 4. 21: Rock Mass Rating (Bawngkawn – Edenthar)

CLASSIFICATION PARAMETERS AND RATINGS									
Spot No.	**UCS**	**RQD**	**S.D**	**D.L**	**Aperture**	**Roughness**	**Infilling**	**Weathering**	**G.W**
1.	37Mpa	91.9%	152.4mm	1.58m	>5mm	Very Rough	None	Highly	Dry
Rating	4	20	8	4	0	6	6	1	15
2.	32Mpa	85%	0.91m	1.21 m	3mm	Very Rough	None	Highly	Dry
Rating	4	17	15	4	1	6	6	1	15
3.	18Mpa	72.9 %	101 mm	.48m	2mm	Very Rough	None	Highly	Dry
Rating	2	13	8	6	1	6	6	1	15

DISCONTINUITY ORIENTATIONS & ROCK MASS DETERMINED							
Spot No	**Strike &Dip orientation**	**RMR value**	**Class No**	**Description**	**ASUT**	**Cohesion (kPa)**	**Friction angle**
1.	Unfavourable	14	V	Very poor rock	30 min for 1 m span	<100	<15°
Rating	-50						
2.	Unfavourable	19	V	Very poor rock	30 min for 1 m span	<100	<15°
Rating	-50						
3.	Unfavourable	6	V	Very poor rock	30 min for 1 m span	<100	<15°
Rating	-50						

4.7 ROCKFALL HAZARD RATING

4.7.1 NH-54 (Bawngkawn – Durtlang)

Table 4. 22: RHR for Geology (Bawngkawn – Durtlang)

	Geology		
	Degree of Undercutting	**Slake Dura-bility Index**	**Degree of inter-beded**
Spot1	0 to 0.3m	86.6%	>2 weak interbeded, >15cm
Score	**3**	**9**	**81**
Spot2	0 to 0.3m	96.8%	>2 weak interbeded, >15cm
Score	**3**	**3**	**81**
Spot3	0 to 0.3m	95.72%	>2 weak interbeded, >15cm
Score	**3**	**3**	**81**
Spot4	0 to 0.3m	96.13%	>2 weak interbeded, >15cm
Score	**3**	**3**	**81**
Spot5	0 to 0.3m	96.89%	>2 weak interbeded, >15cm
Score	**3**	**3**	**81**
Spot 6	0 to 0.3m	96.67%	>2 weak interbeded, >15cm
Score	**3**	**3**	**81**

Table 4. 23: RHR for Traffic (Bawngkawn – Durtlang)

	Traffic				
	Percentage Decision Sight Distance (DSD)	Average Vehicle Risk (AVR)	Road Width including Pave Shoulder	No of accident	Rockfall History/ Frequency
Spot 1	87.71%	100%	7.69 m	0-2	0-3
Score	**5.86**	**81**	**37.13**	**3**	**3**
Sopt 2	59.64%	100%	7.09 m	0-2	0-3
Score	**27**	**81**	**48.86**	**3**	**3**
Spot 3	43.85%	100%	7.1m	0-2	0-3
Score	**65.02**	**81**	**48.86**	**3**	**3**
Spot 4	83.33%	100%	7m	0-2	0-3
Score	**7.46**	**81**	**51.06**	**3**	**3**
Spot 5	74.12%	100%	11.6m	0-2	0-3
Score	**12.37**	**81**	**6.19**	**3**	**3**
Spot 6	70.1%	100%	7.2m	0-2	0-3
Score	**15.41**	**81**	**46.76**	**3**	**3**

Table 4. 24: RHR for Discontinuities (Bawngkawn – Durtlang)

Discontinuities							
Block Size/ Vol.	**Block Shape**	**Number of sets**	**Persistence /orient^{n}**	**Apertures**	**Weathering condition**	**Friction**	**Infilling Materials**
0.3-2.3m^3	Blocky to Angular	2	>3meters and dip into the slope	1mm	IV	Rough	None
3	27	27	9	9	27	3	0
0.3-2.3m^3	Blocky to Angular	2	>3meters and dip into the slope	1mm	II	Rough	None
3	27	27	9	9	3	3	0
0.3-2.3m^3	Blocky to Angular	2	>3meters and dip into the slope	3mm	II	Rough	None
3	27	27	9	27	3	3	0
0.3-2.3m^3	Blocky to Angular	2	>3meters and dip into the slope	>5mm	II	Rough	None
3	27	27	9	81	3	3	0
0.3-2.3m^3	Blocky to Angular	3	>3meters and dip into the slope	3mm	II	Rough	None
3	27	81	9	27	27	3	0
0.3-2.3m^3	Blocky to Angular	3	>3meters and dip into the slope	4mm	II	Rough	None
3	27	81	9	27	3	3	0

Table 4. 25: RHR for Slope and Climate (Bawngkawn – Durtlang)

	Slope					Climate		
Spot	**Slope Height**	**Average Slope Angle Score**	**Vegetation**	**Lunching Features**	**Ditch Catchment**	**Annual Precipitation**	**Seepage/ Water**	**Slope**
Spot 1	39 m	B	Isolated plants	Minor <.6 surf. Variation	Moderate	183.24mm	Damp	SW
Score	**81**	**9**	**27**	**9**	**9**	**2.2**	**9**	**9**
Spot 2	16 m	B	Isolated plants	Minor <.6 surf. Variation	limited catchment	183.24mm	Dry	SW
Score	**12.51**	**9**	**27**	**9**	**27**	**2.2**	**3**	**9**
Spot 3	23 m	B	Isolated plants	Minor <.6 surf. Variation	Limited Catchment	183.24mm	Damp	SW
Score	**28.8**	**9**	**27**	**9**	**27**	**2.2**	**9**	**9**
Spot 4	34m	C	Isolated plants	Minor <.6 surf. Variation	limited catchment	183.24mm	Damp	W
Score	**81**	**27**	**27**	**27**	**27**	**2.2**	**9**	**3**
Spot 5	24 m	B	Isolated plants	Minor <.6 surf. Variation	limited catchment	183.24mm	Damp	NW
Score	**33.6**	**9**	**27**	**27**	**27**	**2.2**	**9**	**9**
Spot 6	21 m	A	Isolated plants	Minor <.6 surf. Variation	limited catchment	183.24mm	Dry	NW
Score	**21.6**	**3**	**27**	**27**	**27**	**2.2**	**3**	**9**

Table 4. 26: RHR Cumulative Score (Bawngkawn – Durtlang)

	Cumulative Score					
	Slope	**Climate**	**Geology**	**Traffic**	**Discontinuity**	**Rock History**
Spot 1	135	20.2	93	126.99	105	3
Spot 2	84.51	14.2	87	159.86	81	3
Spot 3	100.8	20.2	87	197.86	99	3
Spot 4	189	14.2	87	142.52	153	3
Spot 5	123.6	20.2	87	102.56	177	3
Spot 6	105.6	14.2	87	146.17	153	3

4.7.2 Ngaizel

Table 4. 27: RHR for Geology (Ngaizel)

	Geology		
	Degree of Undercutting	Slake Durability Index	Degree of inter-beded
Spot1	0.9m	95%-100%	>2 weak interbeded, >15cm
Score	**27**	**3**	**81**
Spot2	1.8m	95%-100%	>2 weak interbeded, >15cm
Score	**81**	**3**	**81**
Spot3	1.2 m	94.83%	>2 weak interbeded, >15cm
Score	**27**	**3**	**81**
Spot4	1.5	98.08%	>2 weak interbeded, >15cm
Score	**81**	**3**	**81**
Spot5	1.2m	97.43%	>2 weak interbeded, >15cm
Score	**27**	**3**	**81**

Table 4. 28: RHR for Traffic (Ngaizel)

	Traffic				
	Percentage Decision Sight Distance (DSD)	**Average Vehicle Risk (AVR)**	**Road Width including Pave Shoulder**	**No of accident**	**Rockfall History/ Frequency**
Spot 1	80%	100%	5 m	0-2	0-3
Score	**9**	**81**	**1.6**	**3**	**3**
Sopt 2	60%	100%	8.32 m	0-2	0-3
Score	**27**	**81**	**1.39**	**3**	**3**
Spot 3	100%	100%	11.5 m	0-2	0-3
Score	**3**	**81**	**1.20**	**3**	**3**
Spot 4	100%	100%	7.14 m	0-2	0-3
Score	**3**	**81**	**1.46**	**3**	**3**
Spot 5	100%	100%	5.6m	0-2	0-3
Score	**3**	**81**	**1.57**	**3**	**3**

Table 4. 29: RHR for Discontinuities (Ngaizel)

Discontinuities							
Block Size/ Vol.	**Block Shape**	**Number of sets**	**Persistence /orientn**	**Aperture s**	**Weathering condition**	**Friction**	**Infilling Material s**
0.3-2.3m3	Blocky to Angular	>2	>3meters and dip into the slope	4mm	Slightly altered	Rough	None
3	27	81	9	27	27	3	0
0.3-2.3m3	Blocky to Angular	2	>3meters and dip into the slope	5mm	Slightly altered	Rough	None
3	27	27	9	27	27	3	0
0.3-2.3m3	Blocky to Angular	>2	>3meters and dip into the slope	2mm	Slightly altered	Rough	None
3	27	81	9	27	27	3	0
0.6-4.6m3	Blocky to Angular	>2	>3meters and dip into the slope	2mm	Slightly altered	Rough	None
9	27	81	9	27	27	3	0
	Blocky to Angular	>2	>3meters and dip into the slope	0.1 -1mm	Slightly altered	Rough	None
	27	81	9	9	27	3	0

Table 4. 30: RHR for Slope and Climate (Ngaizel)

	Slope					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	23.36m	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 m	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 4. 31: RHR Cumulative Score (Ngaizel)

	Cumulative Score					
	Slope	**Climate**	**Geology**	**Traffic**	**Discontinuity**	**Rock History**
Spot 1	201.7	5	111	177	94.6	3
Spot 2	174.63	11.2	165	123	112.39	3
Spot 3	182.94	5.2	111	177	88.2	3
Spot 4	195.63	11.2	165	183	88.46	3
Spot 5	156.24	11.2	111	165	88.57	3

4.7.3 Bawngkawn – Edenthar

Table 4. 32: RHR for Traffic (Bawngkawn-Edenthar)

	Traffic				
	Percentage Decision Sight Distance (DSD)	**Average Vehicle Risk (AVR)**	**Road Width including Pave Shoulder**	**No of accident**	**Rockfall History/ Frequency**
Spot 1	87 %	100%	6.6 m	0-2	0-3
Score	**6.12**	**81**	**61.54**	**3**	**3**
Sopt 2	80%	100%	6m	0-2	0-3
Score	**9**	**81**	**64**	**3**	**3**
Spot 3	43.85%	100%	5.45m	0-2	0-3
Score	**68.69**	**81**	**81**	**3**	**3**

Table 4. 33: RHR for Geology (Bawngkawn-Edenthar)

	Geology		
	Degree of Undercutting	**Slake Durability Index**	**Degree of inter-beded**
Spot1	0.6 to 1.2m	97.36%	1 to2 weak interbeded, >15cm
Score	**27**	**3**	**9**
Spot2	0.6 to 1.2m	92.81%	1 to2 weak interbeded, >15cm
Score	**27**	**9**	**9**
Spot3	0 to 0.3m	97.06%	>2 weak interbeded, <15cm
Score	**3**	**3**	**27**

Table 4. 34: RHR for Discontinuities (Bawngkawn-Edenthar)

Discontinuities							
Block Size/ Vol.	**Block Shape**	**Number of sets**	**Persistence /orientation**	**Apertures**	**Weathering condition**	**Friction**	**Infilling Materials**
14.58 m^3	Blocky to Angular	3	>3meters and dip into the slope	>5mm	IV	Rough	None
81	27	81	9	81	27	3	0
$0.6m^3$	Blocky to Angular	3	>3meters and dip into the slope	>5mm	IV	Rough	None
9	27	81	9	81	27	3	0
0.3-$2.3m^3$	Blocky to Angular	3	<3meters and dip into the slope	0.1 to 3 mm	IV	Rough	None
3	27	81	3	9	27	3	0

Table 4. 35: RHR for Slope and Climate (Bawngkawn-Edenthar)

	Slope					**Climate**		
Spot	**Slope Height**	**Average Slope Angle Score**	**Vegetation**	**Lunching Features**	**Ditch Catchment**	**Annual Precipitation**	**Seepage / Water**	**Slope**
Spot 1	22m	A	Isolated plants	Major> 1.8m surf. Variation	moderate	183.24mm	Dry	NE
Score	**25**	**3**	**27**	**81**	**9**	**2.2**	**3**	**27**
Spot 2	29.26 m	A	Isolated plants	Major> 1.8m surf. Variation	moderate	183.24mm	Dry	NW
Score	**72.57**	**3**	**27**	**81**	**9**	**2.2**	**3**	**9**
Spot 3	6.4 m	B	Isolated plants	Minor <.6 surf. Variation	moderate	183.24mm	Dry	NW
Score	**2.54**	**9**	**27**	**9**	**9**	**2.2**	**3**	**9**

Table 4. 36: RHR Cumilative Score (Bawngkawn-Edenthar)

	Cumulative Score					
	Slope	**Climate**	**Geology**	**Traffic**	**Discontinuity**	**Rock History**
Spot 1	145	32.2	39	151.66	236	3
Spot 2	192.57	14.2	45	157	237	3
Spot 3	56.54	14.3	33	233.69	153	3

4.8 SLOPE MASS RATING

Table 4. 37: Slope Mass Rating (Bawngkawn-Durtlang Spot 1)

Calculation For Slope Mas Rating						
Parameter	**Slope No 1**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	340	330	132	65	61	65
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	10	-170	-198	0	-4	130
	For Planar		**For Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**0.15**	(∝j-∝s-180)	**1**	(∝i-∝s)	**1**
	10		-170		-198	
f2	ß j	**1**	**1**		ß i	**1**
	65				61	
f3	(ß j-ß s)	**-25**	(ß j + ß s)	**-25**	(ß i- ß s)	**-50**
	0		130		-4	
RMR Basic	4	**Class V**	4	**Class V**	4	**Class V**
F1	0.15	**Very bad**	1	**Very bad**	1	**Very bad**
F2	1	**completely Unstable**	1	**completely Unstable**	1	**completely Unstable**
F3	-25	**Big Planar or Circular**	-25	**Big Planar or Circular**	-50	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	0.25		-21		-46	

Table 4. 38: Slope Mass Rating (Bawngkawn-Durtlang Spot 2)

Calculation For Slope Mas Rating						
Parameter	**Slope No 2**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	250	315	136	80	43	75
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	-65	-245	-179	5	-32	155
	For Planar		**For Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**0.15**	(∝j-∝s-180)	**1**	(∝i-∝s)	**1**
	-65		-245		-245	
f2	ß j	**1**	**1**		ß i	**0.85**
	80				43	
f3	(ß j-ß s)	**-6**	(ß j + ß s)	**-25**	(ß i- ß s)	**-60**
	5		155		-32	
RMR Basic	28	**Class IV**	28	**Class V**	28	**Class V**
F1	0.15	**Bad**	1	**Very bad**	1	**Very bad**
F2	1	**Unstable**	1	**completely Unstable**	0.85	**completely Unstable**
F3	-6	**Planar or Big Wedges**	-25	**Big Planar or Circular**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.6**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	27.1		3		-23	

Table 4. 39: Slope Mass Rating (Bawngkawn-Durtlang Spot 3)

Calculation For Slope Mas Rating						
Parameter	**Slope No 3**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	325	330	40	17	16	76
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	-5	-185	-290	-59	-60	93
	For Planar		**For Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s) -5	**1**	(∝j-∝s-180) -185	**1**	(∝i-∝s) -290	**1**
f2	ß j 17	**0.15**	**1**		ß i 16	**0.15**
f3	(ß j-ß s) -59	**-60**	(ß j + ß s) 93	**0**	(ß i- ß s) -60	**-60**
RMR Basic	12	**Class V**	12	**Class V**	12	**Class V**
F1	1	**Very bad**	1	**Very bad**	1	**Very bad**
F2	0.15	**completely Unstable**	1	**completely Unstable**	0.15	**completely Unstable**
F3	-60	**Big Planar or Circular**	0	**Big Planar or Circular**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	3		12		3	

Table 4. 40: Slope Mass Rating (Bawngkawn-Durtlang Spot 4)

Calculation For Slope Mas Rating						
Parameter	**Slope No 4**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	99	355	245	27	15	82
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	-256	-436	-110	-55	-67	109
	For Planar		**Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**1**	(∝j-∝s-180)	**1**	(∝i-∝s)	**1**
	-256		-436		-110	
f2	ß j	**0.4**	**1**		ß i	**0.15**
	27				15	
f3	(ß j-ß s)	**-60**	(ß j + ß s)	**0**	(ß i- ß s)	**-60**
	-55		109		-67	
RMR Basic	15	**Class V**	15	**Class V**	15	**Class V**
F1	0.15	**Very bad**	1	**Very bad**	0.15	**Very bad**
F2	0.4	**completely Unstable**	1	**completely Unstable**	-60	**completely Unstable**
F3	-60	**Big Planar or Circular**	0	**Big Planar or Circular**	0	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	11.4		15		15	

Table 4. 41: Slope Mass Rating (Bawngkawn-Durtlang Spot 5)

Calculation For Slope Mas Rating						
Parameter	**Slope No 5**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**	**Dip of joint**	**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	ß j	ß i	ß s
	60	65	50	77	86	77
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	-5	-185	-15	0	9	154
	For Planar		**Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**1**	(∝j-∝s-180)	**1**	(∝i-∝s)	**1**
	-5		-185		-15	
f2	ß j	**1**	**1**		ß i	**1**
	77				86	
f3	(ß j-ß s)	**-25**	(ß j + ß s)	**-25**	(ß i- ß s)	**-6**
	0		154		9	
RMR Basic	22	**Class V**	22	**Class V**	22	**Class V**
F1	1	**Very bad**	1	**Very bad**	1	**Very bad**
F2	1	**completely Unstable**	1	**completely Unstable**	1	**completely Unstable**
F3	-25	**Big Planar or Circular**	-25	**Big Planar or Circular**	-6	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probabilit y of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	-3		-3		16	

Table 4. 42: Slope Mass Rating (Bawngkawn-Durtlang Spot 6)

<table>
<tr><th colspan="7">Calculation For Slope Mass Rating</th></tr>
<tr><th>Parameter</th><th colspan="6">Slope No 6</th></tr>
<tr><th>Joint angle Parameter</th><th>Joint Strike</th><th>Slope strike</th><th>Plunge direction of line of intersection</th><th></th><th>Plunge amount</th><th>Angle of slope</th></tr>
<tr><td></td><td>∝j</td><td>∝s</td><td>∝i</td><td>Dip of joint ß j</td><td>ß i</td><td>ß s</td></tr>
<tr><td></td><td>100</td><td>105</td><td>315</td><td>21</td><td>52</td><td>88</td></tr>
<tr><td></td><td>(∝j-∝s)</td><td>(∝j-∝s-180)</td><td>(∝i-∝s)</td><td>(ß j-ß s)</td><td>(ß i- ß s)</td><td>(ß j + ß s)</td></tr>
<tr><td></td><td>-5</td><td>-185</td><td>210</td><td>-67</td><td>-36</td><td>109</td></tr>
<tr><td></td><td colspan="2">For Planar</td><td colspan="2">Toppling</td><td colspan="2">For Wedge</td></tr>
<tr><td></td><td>Value</td><td>Rating</td><td>Value</td><td>Rating</td><td>Value</td><td>Rating</td></tr>
<tr><td rowspan="2">f1</td><td>(∝j-∝s)</td><td rowspan="2">1</td><td>(∝j-∝s-180)</td><td rowspan="2">1</td><td>(∝i-∝s)</td><td rowspan="2">0.15</td></tr>
<tr><td>-5</td><td>-185</td><td>210</td></tr>
<tr><td rowspan="2">f2</td><td>ß j</td><td rowspan="2">0.4</td><td colspan="2" rowspan="2">1</td><td>ß i</td><td rowspan="2">1</td></tr>
<tr><td>21</td><td>52</td></tr>
<tr><td rowspan="2">f3</td><td>(ß j-ß s)</td><td rowspan="2">-60</td><td>(ß j + ß s)</td><td rowspan="2">0</td><td>(ß i- ß s)</td><td rowspan="2">-60</td></tr>
<tr><td>-67</td><td>109</td><td>-36</td></tr>
<tr><td>RMR Basic</td><td>28</td><td>Class V</td><td>28</td><td>Class IV</td><td>28</td><td>Class V</td></tr>
<tr><td>F1</td><td>1</td><td>Very bad</td><td>1</td><td>Bad</td><td>0.15</td><td>Very bad</td></tr>
<tr><td>F2</td><td>0.4</td><td>completely Unstable</td><td>1</td><td>Unstable</td><td>1</td><td>complete ly Unstable</td></tr>
<tr><td>F3</td><td>-60</td><td>Big Planar or Circular</td><td>0</td><td>Planar or Big Wedges</td><td>-60</td><td>Big Planar or Circular</td></tr>
<tr><td>F4</td><td>0</td><td rowspan="2">Probability of Failure = 0.9</td><td>0</td><td rowspan="2">Probabil ity of Failure = 0.6</td><td>0</td><td rowspan="2">Probabil ity of Failure = 0.9</td></tr>
<tr><td>SMR = RMR basic + (F1*F2*F3) + F4</td><td>4</td><td>28</td><td>19</td></tr>
</table>

4.8.2 Ngaizel

Table 4. 43: Slope Mass Rating (Ngaizel Spot 1)

Calculation For Slope Mas Rating						
Parameter	**Slope No 1**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersect ion**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	355	135	31	31	29	70
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	220	40	-104	-39	-41	101
	For Planar		**For Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**0.15**	(∝j-∝s-180)	**0.15**	(∝i-∝s)	**1**
	220		40		-104	
f2	ß j	**0.7**	**1**		ß i	**0.4**
	31				29	
f3	(ß j-ß s)	**-60**	(ß j + ß s)	**0**	(ß i- ß s)	**-60**
	-39		101		-41	
RMR Basic	15	**Class V**	15	**Class V**	15	**Class V**
F1	0.15	**Very bad**	0.15	**Very bad**	1	**Very bad**
F2	0.7	**completely Unstable**	1	**completely Unstable**	0.4	**completely Unstable**
F3	-60	**Big Planar or Circular**	0	**Big Planar or Circular**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	8.7		15		-9	

Table 4. 44: Slope Mass Rating (Ngaizel Spot 2)

Calculation For Slope Mas Rating						
Parameter	**Slope No 2**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**	**Dip of joint**	**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	ß j	ß i	ß s
	260	180	90	34	32	80
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	80	-100	-90	-46	-48	114
	For Planar		**For Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**0.15**	(∝j-∝s-180)	**1**	(∝i-∝s)	**1**
	80		-100		-90	
f2	ß j	**0.7**	**1**		ß i	**0.7**
	34				32	
f3	(ß j-ß s)	**-60**	(ß j + ß s)	**-6**	(ß i- ß s)	**-60**
	-46		114		-48	
RMR Basic	42	**Class IV**	42	**Class IV**	42	**Class V**
F1	0.15	**Bad**	1	**Bad**	1	**Very bad**
F2	0.7	**Unstable**	1	**Unstable**	0.7	**completely Unstable**
F3	-60	**Planar or Big wedges**	-6	**Planar or Big wedges**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.6**	0	**Probability of Failure = 0.6**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	35.7		36		0	

Table 4. 45: Slope Mass Rating (Ngaizel Spot 3)

Calculation For Slope Mas Rating						
Parameter	**Slope No3**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**	**Dip of joint**	**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	ß j	ß i	ß s
	310	200	12	63	36	85
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	110	-70	-188	-22	-49	148
	For Planar		**For Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s) 110	**0.15**	(∝j-∝s-180) -70	**1**	(∝i-∝s) 12	**0.7**
f2	ß j 63	**1**	**1**		ß i 36	**0.85**
f3	(ß j-ß s) -22	**-60**	(ß j + ß s) 148	**0**	(ß i- ß s) -49	**-60**
RMR Basic	16	**Class V**	16	**Class V**	16	**Class V**
F1	0.15	**Very Bad**	0.15	**Very Bad**	0.7	**Very Bad**
F2	1	**Completely Unstable**	1	**Completely Unstable**	0.85	**Completely Unstable**
F3	-60	**Big Planar or Cirular**	1	**Big Planar or Cirular**	-60	**Big Planar or Cirular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	7		16		-19.7	

Table 4. 46: Slope Mass Rating (Ngaizel Spot 4)

Calculation For Slope Mas Rating						
Parameter	**Slope No 4**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plung e amou nt**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	340	170	44	44	42	70
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	170	-10	-126	-26	-28	114
	For Planar		**For toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**0.15**	(∝j-∝s-180)	**1**	(∝i-∝s)	**1**
	170		-10		-126	
f2	ß j	**0.85**	**1**		ß i	**0.85**
	44				42	
f3	(ß j-ß s)	**-60**	(ß j + ß s)	**-6**	(ß i- ß s)	**-60**
	-26		114		-28	
RMR Basic	9	**Class V**	9	**Class V**	9	**Class V**
F1	0.15	**Very bad**	1	**Very bad**	1	**Very bad**
F2	0.85	**completely Unstable**	1	**comple tely Unstabl e**	0.85	**completel y Unstable**
F3	-60	**Big Planar or Circular**	-6	**Big Planar or Circula r**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probab ility of Failure = 0.9**	0	**Probabilit y of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	1.35		3		-42	

Table 4. 47: Slope Mass Rating (Ngaizel Spot 5)

Calculation For Slope Mas Rating						
Parameter	**Slope No 5**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	355	130	81	30	29	83
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	225	45	-49	-53	-54	113
	For Planar		**For topple**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**0.15**	(∝j-∝s-180)	**0.15**	(∝i-∝s)	**1**
	225		45		-49	
f2	ß j	**1**	**1**		ß i	**0.4**
	30				29	
f3	(ß j-ß s)	**-60**	(ß j + ß s)	**-6**	(ß i- ß s)	**-60**
	-53		113		-54	
RMR Basic	13	**Class V**	13	**Class V**	13	**Class V**
F1	0.15	**Very bad**	0.15	**Very bad**	1	**Very bad**
F2	1	**completely Unstable**	1	**completely Unstable**	0.4	**completely Unstable**
F3	-60	**Big Planer or Circular**	-6	**Big Planer or Circular**	-60	**Big Planer or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	4		12.1		-11	

4.8.3 Bawngkawn – Edenthar

Table 4. 48: Slope Mass Rating (Bawngkawn-Edenthar Spot 1)

Calculation For Slope Mass Rating						
Parameter	**Slope No 1**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	87	100	102	80	20	88
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	-13	-193	2	-8	-68	168
	For Planar		**Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s) -13	**1**	(∝j-∝s-180) -193	**1**	(∝i-∝s) 2	**0.85**
f2	ß j 80	**1**	**1**		ß i 20	**0.4**
f3	(ß j-ß s) -8	**-50**	(ß j + ß s) 168	**-25**	(ß i- ß s) -68	**-60**
RMR Basic	14	**Class V**	14	**Class V**	14	**Class V**
F1	1	**Very Bad**	1	**Very Bad**	0.85	**Very Bad**
F2	1	**Completely Unstable**	1	**Completely Unstable**	0.4	**Completely Unstable**
F3	-50	**Big Planar or Circular**	-25	**Big Planar or Circular**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	-36		-11		-6.4	

Table 4. 49: Slope Mass Rating (Bawngkawn-Edenthar Spot 2)

Calculation For Slope Mass Rating						
Parameter	**Slope No 2**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	54	70	111	65	61	88
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	-16	-196	41	-23	-27	153
	For Planar		**Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s)	**1**	(∝j-∝s-180)	**1**	(∝i-∝s)	**0.85**
	-16		-196		41	
f2	ß j	**1**	**1**		ß i	**1**
	65				61	
f3	(ß j-ß s)	**-60**	(ß j + ß s)	**-25**	(ß i- ß s)	**-60**
	-23		153		-27	
RMR Basic	19	**Class V**	19	**Class V**	19	**Class V**
F1	1	**Very bad**	0.15	**Very bad**	0.85	**Very bad**
F2	1	**completely Unstable**	1	**completely Unstable**	1	**completely Unstable**
F3	-60	**Big Planar or Circular**	-25	**Big Planar or Circular**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	-41		15.25		-32	

Table 4. 50: Slope Mass Rating (Bawngkawn-Edenthar Spot 3)

Calculation For Slope Mass Rating						
Parameter	**Slope No 3**					
Joint angle Parameter	**Joint Strike**	**Slope strike**	**Plunge direction of line of intersection**		**Plunge amount**	**Angle of slope**
	∝j	∝s	∝i	Dip of joint ß j	ß i	ß s
	190	15	159	20	19	88
	(∝j-∝s)	(∝j-∝s-180)	(∝i-∝s)	(ß j-ß s)	(ß i- ß s)	(ß j + ß s)
	175	-5	144	-68	-69	108
	For Planar		**Toppling**		**For Wedge**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
f1	(∝j-∝s) 175	**0.15**	(∝j-∝s-180) -5	**1**	(∝i-∝s) 144	**0.15**
f2	ß j 20	**0.4**	**1**		ß i 19	**0.15**
f3	(ß j-ß s) -68	**-60**	(ß j + ß s) 108	**0**	(ß i- ß s) -69	**-60**
RMR Basic	6	**Class V**	6	**Class V**	6	**Class V**
F1	0.15	**Very bad**	1	**Very bad**	0.15	**Very bad**
F2	0.4	**completely Unstable**	1	**completely Unstable**	0.15	**completely Unstable**
F3	-60	**Big Planar or Circular**	0	**Big Planar or Circular**	-60	**Big Planar or Circular**
F4	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**	0	**Probability of Failure = 0.9**
SMR = RMR basic + (F1*F2*F3) + F4	2.4		6		4.65	

4.9 GEOLOGICAL STENGTH INDEX

4.9.1 Bawngkawn –Edenthar

Table 4. 51: Geological Strength Index (Bawngkawn –Edenthar)

Spot No	Structure Rating (SR) SR=-17.5jn(Jv)+79.8	Surface Condition Rating (SCR)			Total SCR Rating	GSI Value from Graph (SR Vs SCR)
		Roughness Rating (Rr) Weathering Rating (Rw) Infilling Rating (Rf)				
Spot 1	Jv=7	Rough	Highly	None	**12**	**49**
Rating	42.7	5	1	6		
Spot 2	Jv=9	Rough	Highly	None	**12**	**50**
Rating	41	5	1	6		
Spot 3	Jv= 13	Rough	Highly	None	**12**	**45**
Rating	35	5	1	6		

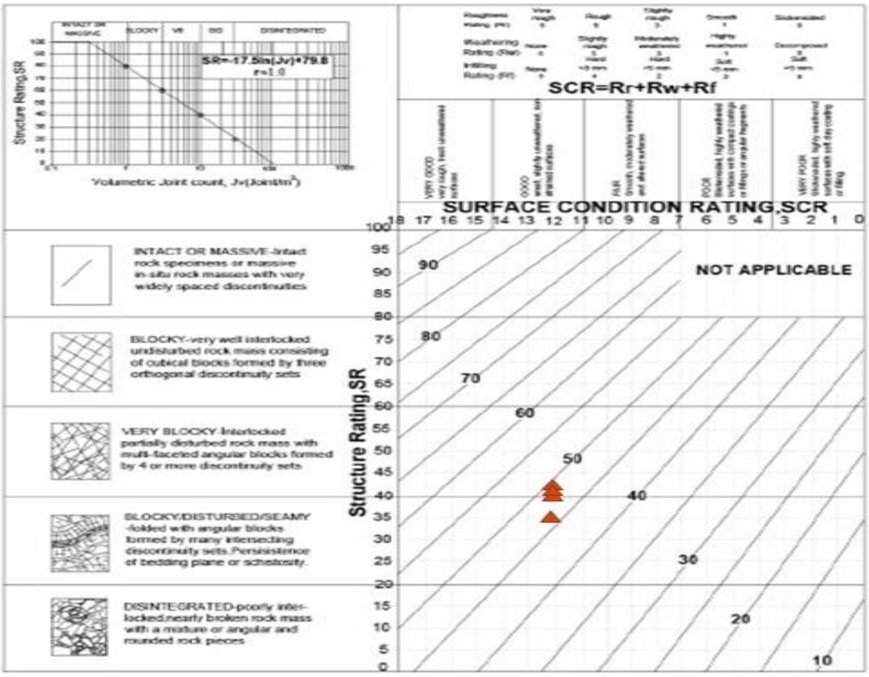

Figure 4. 15: Bawngkawn –Edenthar Plot on GSI Chart

4.9.2 Ngaizel

Table 4. 52: Geological Strength Index (Ngaizel)

Spot No	**Structure Rating (SR) SR=-17.5jn(Jv)+79.8**	**Surface Condition Rating (SCR)**			**Total SCR Rating**	**GSI Value from Graph (SR Vs SCR)**
		Roughness Rating (Rr) Weathering Rating (Rw) Infilling Rating (Rf)				
Spot 1	Jv=7	Rough	Highly	None	**12**	**49**
Rating	42.7	5	1	6		
Spot 2	Jv=10	Rough	Highly	None	**12**	**50**
Rating	40	5	1	6		
Spot 3	Jv= 8	Rough	Highly	None	**12**	**51**
Rating	42	5	1	6		
Spot4	Jv =5	Rough	Highly	None	**12**	**54**
Rating	51	5	1	6		
Spot 5	Jv=13	Rough	Highly	None	**12**	**46**
Rating	35	5	1	6		

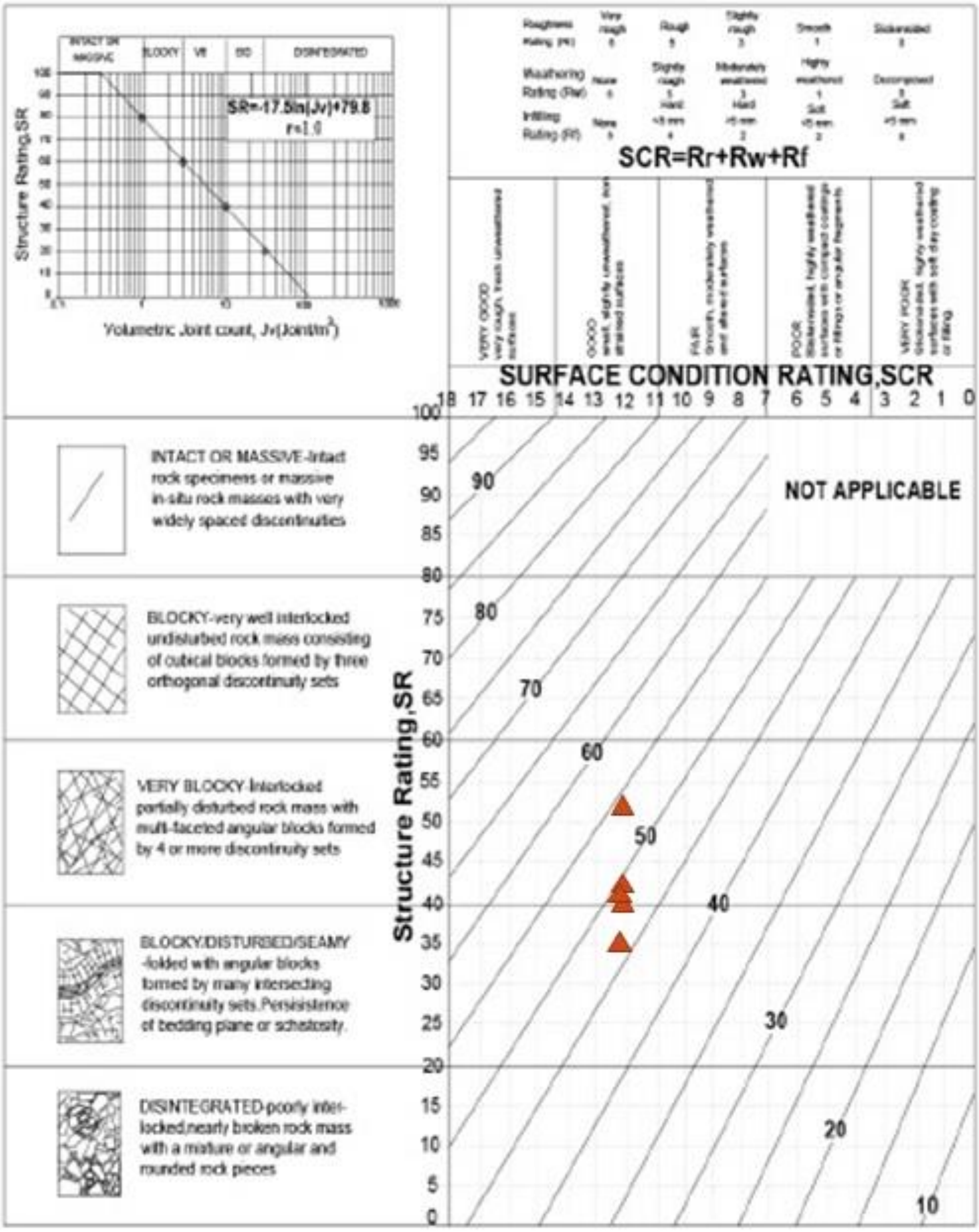

Figure 4. 16: Ngaizel Plot on GSI Chart

4.9.3 NH-54 (Bawngkawn – Durtlang)

Table 4. 53: Geological Strength Index (Bawngkawn - Durtlang)

Spot No	Structure Rating (SR) SR=-17.5jn(Jv)+79.8	Surface Condition Rating (SCR) Roughness Rating (Rr) Weathering Rating (Rw) Infilling Rating (Rf)			Total SCR Rating	GSI Value from Graph (SR Vs SCR)
Spot 1	Jv=7	Rough	Highly	None	**12**	**49**
Rating	42.7	5	1	6		
Spot 2	Jv=5	Slightly Rough	Slightly	None	**14**	**60**
Rating	51	3	5	6		
Spot 3	Jv= 12	Slightly Rough	Slightly	None	**14**	**54**
Rating	38	3	5	6		
Spot4	Jv =10	Slightly Rough	Slightly	None	**14**	**53**
Rating	40	3	5	6		
Spot 5	Jv=7	Slightly Rough	Slightly	None	**14**	**55**
Rating	42.7	3	5	6		
Spot 6	Jv=7	Slightly Rough	Slightly	None	**14**	**55**
Rating	42.7	3	5	6		

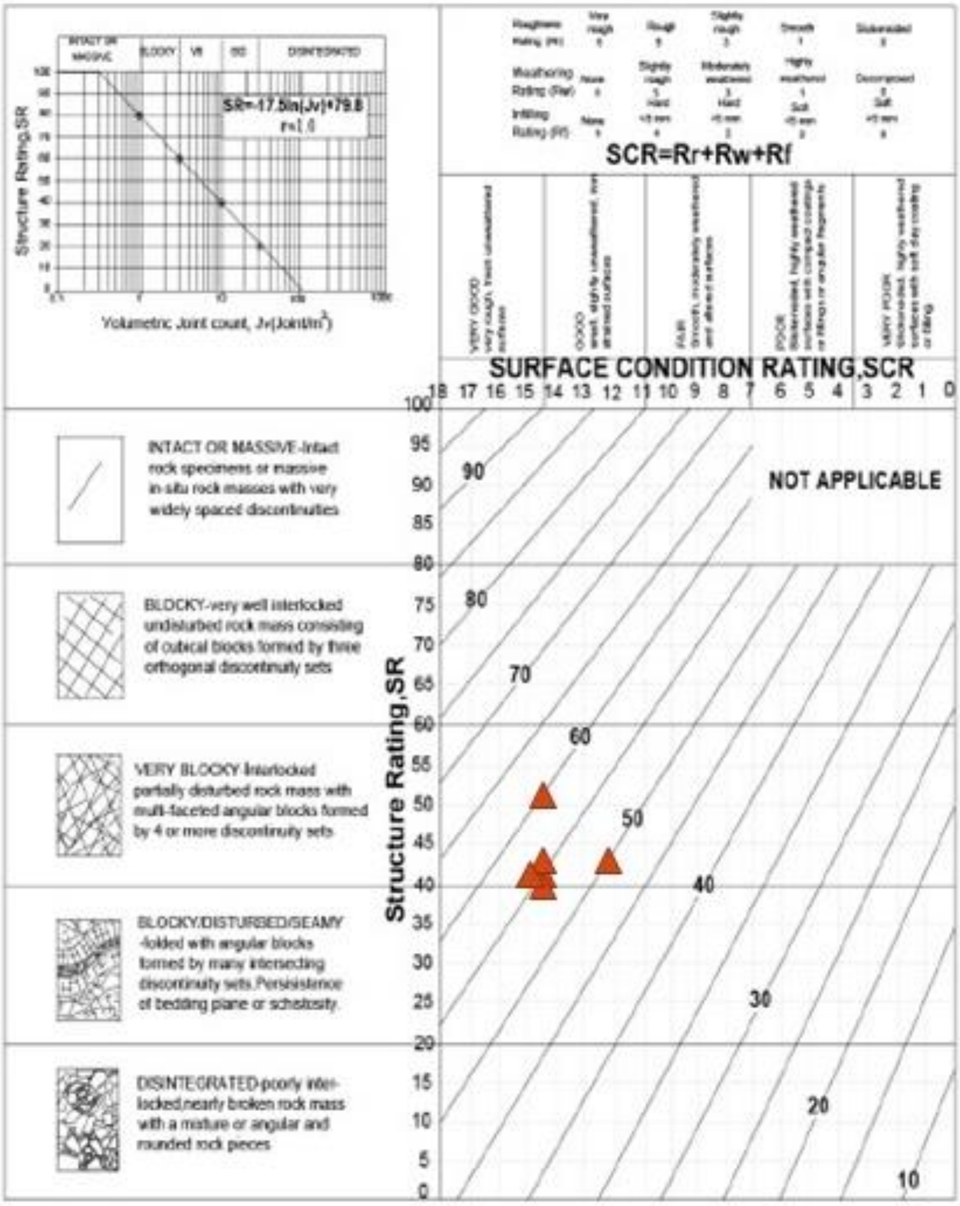

Figure 4. 17: Bawngkawn-Durtlang Plot on GSI Chart

4.10 CUMULATIVE RESULT

4.10.1 Unconfined Compressive Strength Test

Table 4. 54: Cumulative Result of UCS

UNIAXIAL COMPRESSIVE STRENGTH (Rock Schmidt Hammer)	
Average UCS (NH-54 Durtlang- Bawngkawn)	43.16 Mpa
Average UCS Ngaizel	56.4 Mpa
Average UCS Bawngkawn-Edenthar	29Mpa

4.10.2 Slake durability index

Table 4. 55: Cumulative Result of SDI

SLAKE DURABILITY INDEX (SDI)	
Average SDI (NH-54 Durtlang- Bawngkawn)	94.8%
Average RQD Ngaizel	96.26%
Average RQD Bawngkawn-Edenthar	95.75%

4.10.3 Point Load Index

Table 4. 56: Cumulative Result of PLI

POINT LOAD INDEX (PLI)	
Average PLI (NH-54: Bawngkawn- Durtlang)	**1.12 (UCS=24.68 kgf/cm^2)**
Average PLI Ngaizel	**0.184 (UCS=2.438 kgf/cm^2)**
Average RQD Bawngkawn-Edenthar	**0.025 (UCS=.552kgf/cm^2)**

4.10.4 Rock Mass Rating

Table 4. 57: Cumulative RMR Score of Bawngkawn-Durtlang

Cumulative RMR Score of NH-54 Bawngkawn- Durtlang						
Site	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6
Total Score	4	28	12	15	22	28

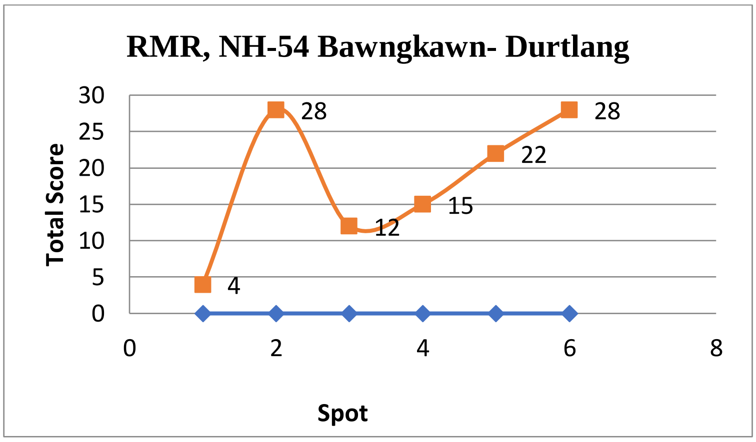

Figure 4. 18: Line chart representing RMR Bawngkawn-Durtlang

Table 4. 58: Cumulative RMR Score of Ngaizel

Cumulative RMR Score of Ngaizel					
Site	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Rating	16	42	15	9	13

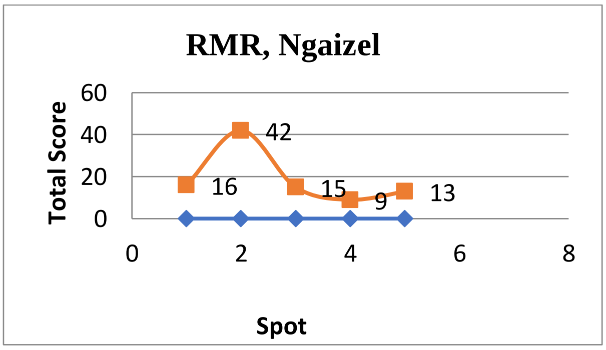

Figure 4. 19: Line chart representing RMR Ngaizel

Table 4. 59: Cumulative RMR Score of Bawngkawn-Edenthar

Cumulative RMR Score of NH-54 Bawngkawn- Edenthar			
Site	Spot 1	Spot 2	Spot 3
Total Score	14	19	6

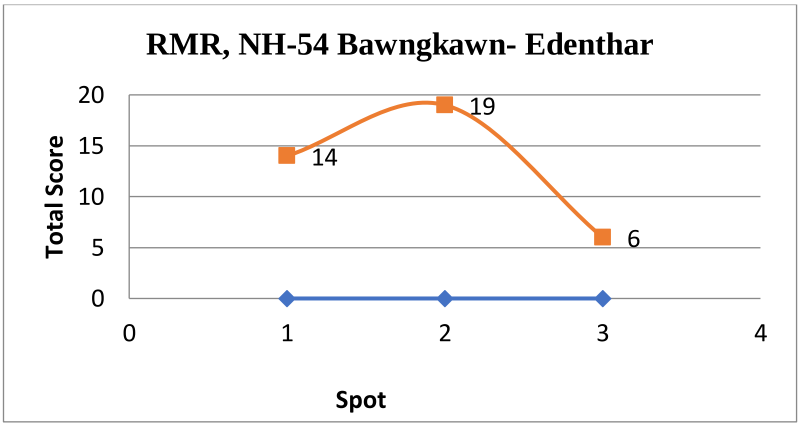

Figure 4. 20: Line chart representing RMR Bawngkawn-Edenthar

4.10.5 Rockfall Hazard Rating

Table 4. 60: Cumulative RHRS Score of Bawngkawn-Durtlang

Cumulative RHRS Score of NH-54 Bawngkawn- Durtlang						
Site	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6
Total Score	483.19	429.57	507.86	588.72	512.80	508.97

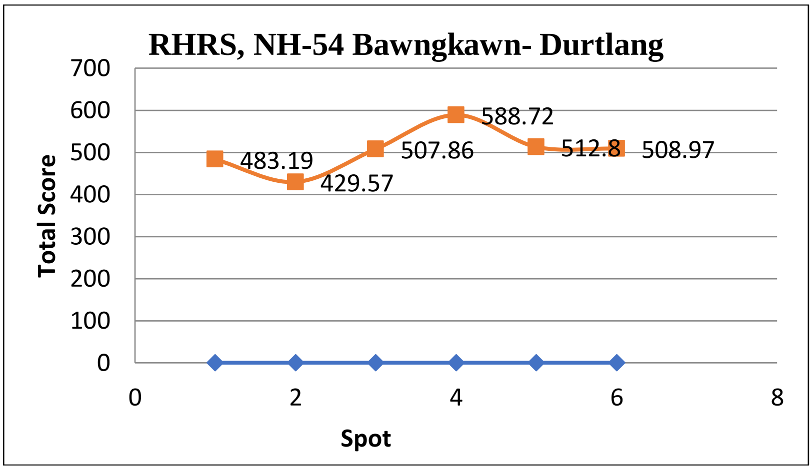

Figure 4. 21: Line chart representing RHRS Bawngkawn-Durtlang

Table 4. 61: Cumulative RHRS Score of Ngaizel

Cumulative RHRS Score of Ngaizel					
Site	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Total Score	592.30	589.22	564.11	646.29	535.01

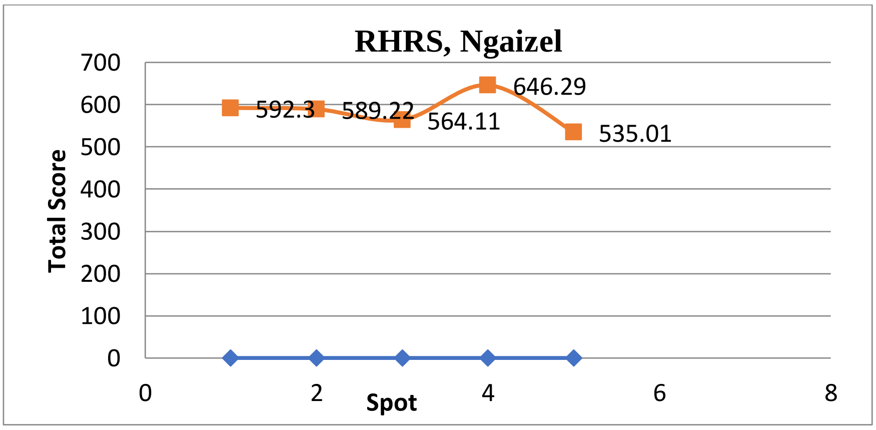

Figure 4. 22: Line chart representing RHRS Ngaizel

Table 4. 62: Cumulative RHRS Score of Bawngkawn-Edenthar

Cumulative RHRS Score Bawngkawn-Edenthar			
Site	Spot 1	Spot 2	Spot 3
Total Score	606.86	603.81	493.53

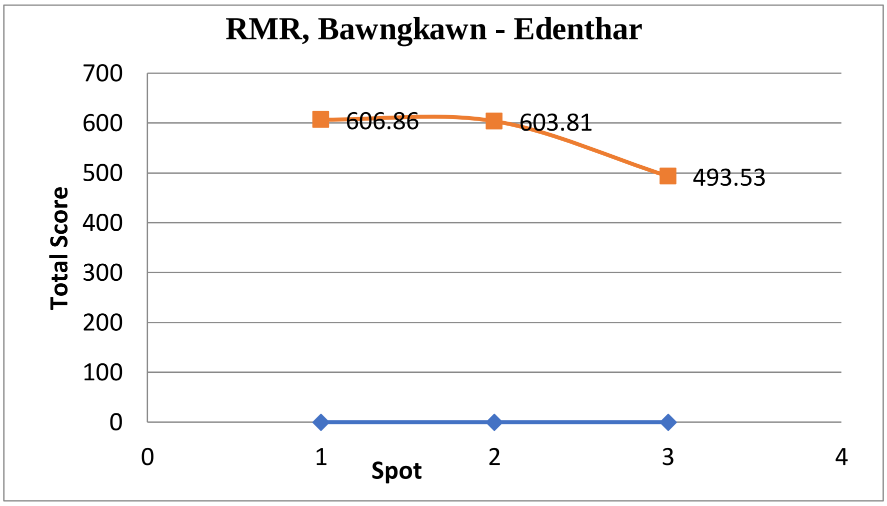

Figure 4. 23: Line chart representing RHRS Bawngkawn-Edenthar

4.10.6: Slope Mass Rating

Table 4. 63: Cumulative SMR Score of Bawngkawn- Durtlang

Cumulative SMR Result For NH-54: Bawngkawn-Durtlang						
Site	*Spot 1*	*Spot 2*	*Spot 3*	*Spot 4*	*Spot 5*	*Spot 6*
Rating	0.25	27.1	12	15	16	28

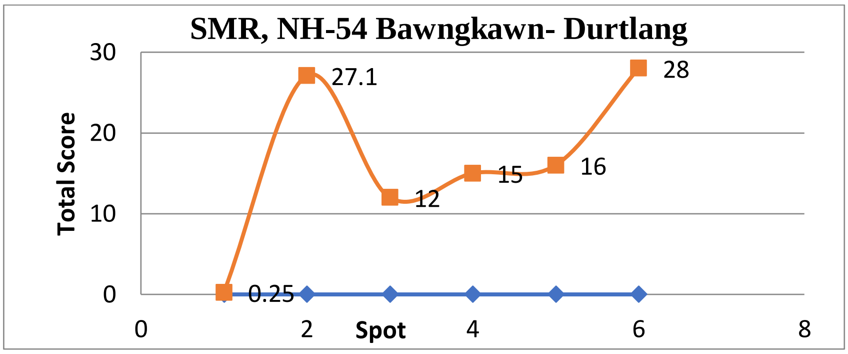

Figure 4. 24: Line chart representing SMR Bawngkawn-Durtlang

Table 4. 64: Cumulative SMR Score of Ngaizel

Cumulative SMR Result For Ngaizel					
Site	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Rating	15	36	16	3	12.1

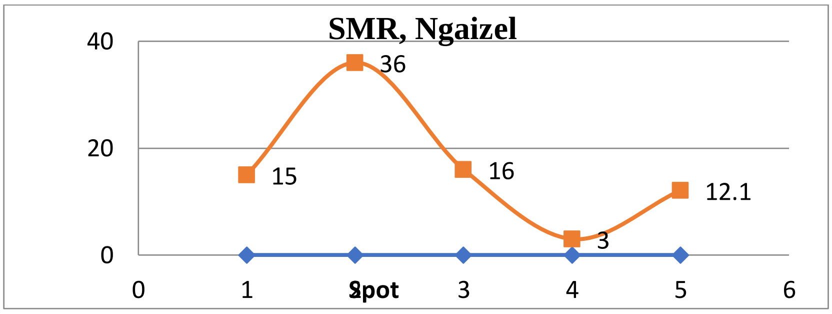

Figure 4. 25: Line chart representing SMR Ngaizel

Table 4. 65: Cumulative SMR Score of Bawngkawn Edenthar

Cumulative SMR Result For Bawngkawn – Edenthar			
Site	*Spot 1*	*Spot 2*	*Spot 3*
Rating	-6.4	15.25	6

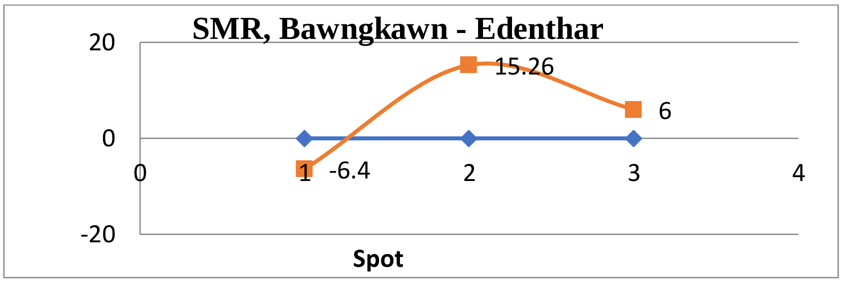

Figure 4. 26: Line chart representing SMR Bawngkawn Edenthar

4.10.7 Geological Strength Index

Table 4. 66 Cumulative GSI Score of Bawngkawn-Durtlang

Cumulative result of GSI: NH-54 Bawngkawn- Durtlang						
Site	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6
GSI	49	60	54	53	55	55

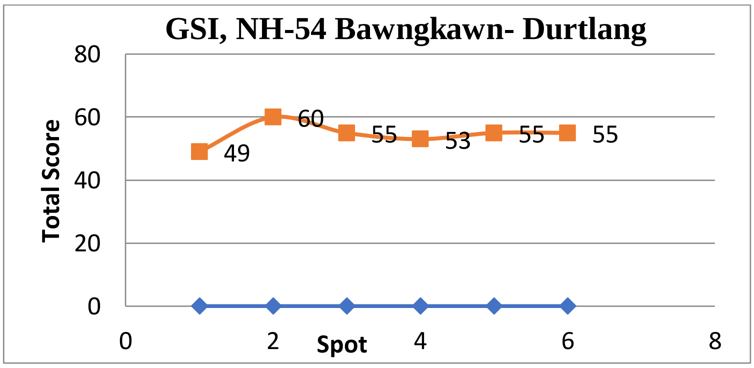

Figure 4. 27: Line chart representing GSI Bawngkawn-Durtlang

Table 4. 66: Cumulative GSI Score of Ngaizel

Cumulative result of GSI: Ngaizel					
Site	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
Rating	49	50	51	54	46

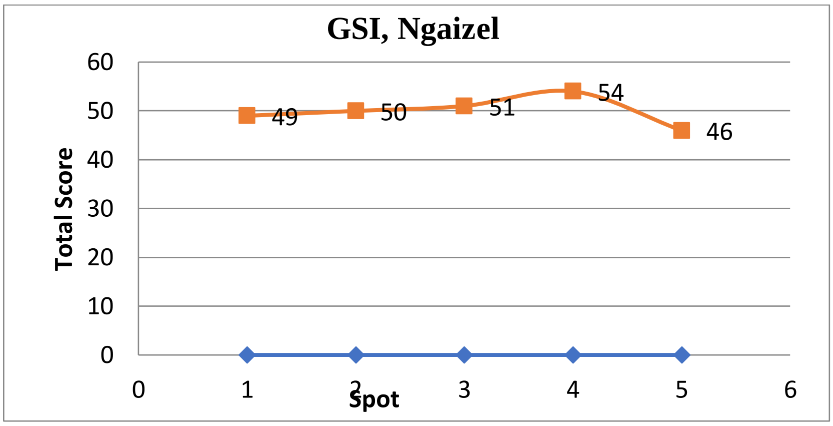

Figure 4. 28: Line chart representing GSI Ngaizel

Table 4. 67: Cumulative GSI Score of Ngaizel

Cumulative result of GSI: Bawngkawn-Edenthar			
Site	*Spot 1*	*Spot 2*	*Spot 3*
Rating	49	50	45

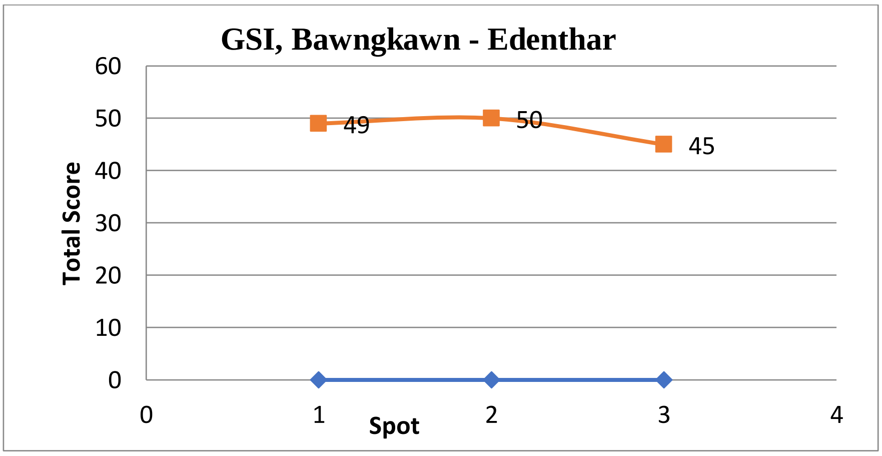

Figure 4. 29: Line chart representing GSI Bawngkawn – Edenthar

4.11 DISCUSSIONS

4.11.1 NH-54 Bawngkawn- Durtlang

The RMR score of Spot 1 (*i.e*. 4), Spot 2 (*i.e*.12) Spot 4 (*i.e*. 15) fall under *Class V* category defined by *Very poor rock*, less than 100Kpa of cohesion of rock mass with friction angle is less than 15 degree. While Spot 3 (*i.e*. 28), spot 5(*i.e*. 22), and Spot 6 (*i.e*. 28) fall under *Class IV* category in the determination of rock mass from total rating which is defined by poor rock, 100-200 Kpa of cohesion of rock mass with friction angle between 15-25 degrees. The average stand-up time is 30 minutes for a 1-meter span which means the period for the rock mass able to withstand without breaking is 30 minutes for a 1(one) meter span.

The SMR score of Spot 1 (*i.e.* 0.25), Spot 3 (*i.e*. 12), Spot 4 (*i.e*. 15), and Spot 5 (*i.e*. 16) falls within *Class Number V* in which the rock mass can be described as *Very bad, completely Unstable, big planer or circular mode of failure and the probability of failure is 0.9*. Two spots such as Spot 2 (*i.e*. 27.1) and Spot 6 (*i.e*. 28) fall within *Class Number IV* in which the rock mass can be described as *Bad, Unstable, planar, or big Wedges of failure, and the probability of failure is 0.6*.

The score result of RHR of Spot 1 (*i.e*. 483.19) and Spot 2 (*i.e*. 429.57) can be categorised as "*Moderate Urgency*" while, Spot 3 (*i.e*. 507.86), Spot 4 (*i.e*. 588.72). Spot 5 (*i.e*. 512.80) and Spot 6 (*i.e*. 508.97) are categorised as "*Higher Urgency*" (After Hoek, 1999).

After plotting the surface condition rating and the structural rating data into the GSI chart, all the data except Spot 3 fall into a region in which the rock mass structure is described as *very blocky- interlocked, partially disturbed mass* with multi-faceted angular blocks formed by 4 or more joint set and the surface condition of the rock mass are described as *good and slightly weathered*. Spot 3 with GSI value 54 falls into a region in which the rock mass structure is described as *blocky, disturbed, steamy* – folded with angular blocks formed by many intersecting discontinuity sets, persistence of bedding planes, or schistosity.

The average UCS of Bawngkawn-Durtlang is 43.16Mpa, which is classed as *a weak rock* (Deere and Miller, 1966). The failure load of the rock sample is determined by using the PLI which gives the uniaxial compressive strength of 24.68kgf/cm^2.

The average RQD is 88.21% which shows that the rock quality is *good*.

The average SDI is 94.8% which indicates the study area possesses *Medium-high durability*.

4.11.2 Ngaizel

The RMR score of Spot 1 (*i.e*.16), Spot 3 (*i.e*.15) Spot 4 (*i.e*. 9), and Spot 5 (*i.e*. 13) fall under *Class V* category defined by *very poor rock*, less than 100Kpa of cohesion of rock mass with friction angle is less than 15 degree. While Spot 2 (*i.e*. 42) falls under *Class III* category in the determination of rock mass from total rating which is defined by *fair rock*, 200-300 Kpa of cohesion of rock mass with friction angle between 25-35 degree. The average stand-up time for three spots 1,3,4, is 30 minutes for a 1-meter span while the average stand-up time for Spot 2,5,6 is 10hours for 2.5m.

The SMR score of Spot 1 (*i.e*.15), Spot 3 (*i.e*. 16), Spot 4 (*i.e*. 3), and Spot 5 (*i.e*. 12.1) falls within *Class Number V* in which the rock mass can be described as *very bad, completely unstable, big planar or circular mode of failure and the probability of failure is 0.9*. Spot 2 (*i.e*. 36) is classified as *Class Number IV* in which the rock mass can be described as *bad, unstable, planar, or big wedge of failure, and the probability of failure is 0.6*.

RHR of Spot 1 (*i.e*. 592.30), Spot 2 (*i.e*. 589.22), Spot 3 (*i.e*.565.11), Spot 4 (*i.e*. 646.29). Spot 5 (*i.e*. 535.01) acquired more than 500 scores, therefore all the spots are categorised as "*Higher Urgency*" (Hoek 1999).

In the GSI chart, Spot1 (*i.e*. 49), Spot 2 (*i.e*. 50), Spot 3 (*i.e*. 51), and Spot 4 (*i.e*. 54) fall into a region in which the rock mass structure is described as *very blocky*-interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint set and the surface condition of the rock mass are described as *good and slightly weathered*. While Spot 5 (*i.e.* 46) falls into a region in which the rock mass structure is described as *blocky, disturbed, steamy* – folded with angular blocks formed by many intersecting discontinuity sets, persistence of bedding planes, or schistosity.

The average UCS of Ngaizel is 56.40Mpa, which is classed as *moderately hard rock* (Deere and Miller, 1966). The failure load of the rock sample is determined by using PLI which gives the UCS of 2.438kgf/cm^2.

The average RQD is 73.1% therefore the rock mass is denoted as *fair quality*.

The average SDI is 96.26% which indicates the study area possesses *high durability*.

4.11.2 Bawngkawn-Edenthar

The RMR of spot 1 (*i.e.*14), Spot 2 (*i.e.*19), Spot 3 (*i.e.* 6) give a rating less than 21 which indicate that the area falls under *Class V* category defined by *very poor rock*, less than 100Kpa of cohesion of rock mass with friction angle less than 15 degrees. The average period for the rock mass able to withstand without breaking is 30 minutes for a 1(one) meter span.

The SMR score of Spot 1 (*i.e.* -6.1), Spot 2 (*i.e.* 15.25), Spot 3(*i.e.* 6) falls within *Class Number V* in which the rock mass can be described as *very bad, completely unstable, big planar, or circular mode of failure and the probability of failure is 0.9*. The negative number of Spot 1 denotes a small RMR value and *very unfavourable condition*.

RHR of Spot 1 (*i.e.* 606.86), Spot 2 (*i.e.* 603.81), acquired higher score which is way higher than score 500 therefore they are categorised as "*Higher Urgency*" (Hoek 1999). On the other hand, Spot 3 (*i.e.* 493.53) can be categorised as "*Moderate Urgency*" as the score is between 300 to 500 (Hoek, 1999)

The surface condition rating and the structural rating data are plotted in the GSI chart. Spot1 (*i.e.* 49) and Spot 2 (*i.e.* 50), fall into a region in which the rock mass structure is described as *very blocky*- interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint set and the surface condition of the rock mass are described as *good and slightly weathered*. While Spot 3 with GSI value 45 falls into a region in which the rock mass structure is described as *blocky, disturbed, steamy* – folded with angular blocks formed by many intersecting discontinuity sets, persistence of bedding planes, or schistosity.

The average UCS of Bawngkawn is 29Mpa, which is classed as a *weak rock* (Deere and Miller, 1966). The failure load of the rock sample is determined by using PLI which gives the uniaxial compressive strength as 0.532 kgf/cm^2.

The average RQD is 83.3% therefore the rock mass is denoted as *good quality*.

The average SDI is 95.75% which indicates the study area possesses *high durability*.

Table 4. 68: Comparision of three different study sites

Parameter	Bawngkawn- Durtlang	Ngaizel	Bawngkawn- Edenthar
Rock/ Bed attitude	*Shale- Sandstone* NW-SE, NE-SW & NNW-SSE Plunge: 15° – 86°	*Siltstone- Shale- Sandstone* NW-SE Plunge: 29° – 42°	*Sandstone- Shale* NE-SW & NNW- SSW Plunge: 19° – 61°
UCS	43.16MPa	56.4MPa	29MPa
RQD	88.21% (Good)	59.5% (Fair)	83.3% (Good)
SDI	94.8% (Medium High)	96.26% (High)	95.75% (High)
PLI	1.12	0.184	0.025
GSI	55 (Avg) Good/ Very Blocky/ Disturb	50 (Avg) Good/ Very Blocky/ Disturb	48 (Avg) Good/ Very Blocky/ Disturb
RMR	**18.17 CLASS- V**	**19 CLASS- V**	**13 CLASS-V**
SMR	**CLASS V (50%) CLASS IV (50%)**	**CLASS V (100%)**	**CLASS III (20%) CLASS V (80%)**
RHRS	**Higher Urgency (67%) Moderate Urgency (33%)**	**Higher Urgency (100%)**	**Higher Urgency (67%) Moderate Urgency (33%)**

The overall comparison of the stydy area reveals that the Uixial compressive strength of Bawngkawn-Edenthar section are quite fair while other area shows a normal range. The RQD of Ngaizel indicate the week rock mass quality due to presence of joint, while other area shows good rock mass.The overall GSI studies indicate blocky structure of rockmass. On the other hand the RMR analysis reveal the poor quality rock mass, as different parameter are incorporated in RMR analysis. From SMR analysic we can conclude that all the area are not so stable. The RHRS studies reveals that all te stydy sites area prone to rockfall and requires immediate action for mitigative measures.

CHAPTER 5

CONCLUSIONS AND MITIGATION SUGGESTIONS

The geology of the research area is mainly composed of shale, siltstone, and sandstone intercalation. This research is based on field investigations, laboratory investigations, and analysis using softwares.

5.1 NH-54 (BAWNGKAWN-DURTLANG)

From the field investigation, Bawngkawn-Durtlang possesses a weak uniaxial compressive strength but acquired good rock quality designation. Whereas the laboratory investigation shows that the study area has medium-high durability to weathering. The PLI test does not produce any significant value which implies soft rock type. Based on the field observation and laboratory investigation we can conclude that the overall quality of the rock mass of the research area is quite fair.

From the GSI, 84% of the study area can be described as 'very blocky structure and slightly weathered surface condition'. 16% obtained blocky structure.

From RMR, the study area can be described as 'poor rock'. Again the SMR data revealed that bad rock mass which is more or less unstable or completely unstable and it gives the probability of failure range from 0.6 to 0.9

Based on the RHRS, 67% of the study area can be categorised as 'High Urgency' and 33% of the study area as 'Moderate Urgency'. Immediate actions regarding mitigation and/ or preventive measures are a must.

Based on the kinematic analysis, the study area exhibits 33.33% possibilities of Planar failure. These concluded that the probability of rockfall is very high in these areas which may end up in blockage of rock and even casualties.

The rockfall analysis revealed that the energy possessed by rockmass during rockfall. Therefore, from the rockfall analysis of NH-54 (Bawngkawn-Durtlang), the maximum bounce height of rockfall in the study area range from 1.77m to 4.8m and the peak or maximum KE range from 1000J to 16000J.

From the overall observations, Bawngkawn - Durtlang can be concluded as poor rock mass, very unstable, high probability of rockfall, and required immediate measures or action to mitigate or minimise the probable rockfall or to stabilise the area.

5.2 NGAIZEL

The UCS data obtained from the field represent ‘moderately hard rock’. Numbers of joints are observed in the area which gives a fair rock quality designation. From the laboratory investigation such as SDI, we observed high durability of weathering. The point load index does produce a very low reading which implies soft rock.

The GSI revealed that 80% of the area embraced a very block structure and rough slightly weathered surface while 20% obtained blocky structure.

Based on RMR studies 80% of the study area can be described as poor rock and 20% are described as fair rock. Slope Mass Rating defined that 80% of the study are possessed very bad rock mass and completely unstable with the probability of failure at 0.09 and 20% are categorised as bad rock mass, unstable with the probability of failure at 0.6.

The scores of RHRS of all the spots fall under ‘Higher urgency’.

The kinematic analysis and rockfall analysis exposed that the possibility of failure mode as 40% of Planar failure. Therefore the probability of rockfall is very high in these areas which may end up in blockage of rock and even casualties.

The rocfall analysis of Ngaizel shows that the maximum bounce height range from .8m to 5.5m. and the peak or maximum KE range from 550J to 2300J.

From the overall studies, the study area Ngaizel can be concluded as poor rock mass, almost completely unstable, high probability of rockfall, and immediate measure should be taken for the stability and safety of the study area.

5.3 BAWNGKAWN- EDENTHAR

Based on the UCS test obtained from the field, the study area Bawngkawn-Edenthar characterised weak rock. Lower number of joint set present in the study area represent good rock quality designation. High durability to weathering obtained from SDI test. The PLI does produce a very low reading which implies soft rock.

The average GSI is 48 about 66% of the area embraced very blocky structure and rough slightly weathered surface while about 33% obtained blocky structure.

Based on RMR and SMR, the entire study area is described as poor rock mass, completely unstable with the probability of failure 0.09. From RHRS, 67% of the study area falls under 'Higher urgency', while 33% falls under 'Moderate urgency'.

The kinematic analysis and rockfall analysis exposed the possibility of failure mode as 67% of Planar failure. Therefore the probability of rockfall is very high in these areas which may end up in blockage of rock and even casualties.

The maximum bounce height obtained from the rocfall analysis of Bawngkawn -Edenthar area range from 0.12m to 7m. The peak or maximum KE range from 290J to 27000J.

From the overall studies the study area Bawngkawn- Edentar can be concluded as poor rock mass, almost completely unstable, high probability of rockfall, and required immediate measures or action to stabilised the area.

5.4 MITIGATION SUGGESTIONS

Since the possibility of a mode of failure is the same for each study area, no separate mitigation is provided. The various mitigative method suggested to minimise the adverse effect of rockfall as well as to stabilise the slope in the research area are as follows.

1. *Trim blasting*: A number of joint sets are encounter in the study area which made the occurrence of unstable rock mass, therefore trim blasting is suggested in some areas.
2. *Re-sloping*: To maintain slope stability some areas with higher slope angles are required to reduce to some extend.
3. *Wire meshing*: Wire meshing will take action to prevent rock boulder and rock debris from falling onto roads. A high-quality steel wire should be used for curtaining meshing the rock faces.

4. *Scale down rock*: A number of overhanging rocks are observed in the study area. In such areas even small vibration or tremor due to vehicles, earthquakes, etc. can easily trigger rockfall. Therefore immediate scaling down using hand or machine is a must. This will avert further catastrophe.
5. *Removal of trees*: The tree root that grows into cracks or joints act as an aiding factor for the occurrence of rockfall. When the wind blows, it creates pressure at the root level which loosens rocks can trigger rockfall. Therefore trees with roots that grow into cracks at the vicinity of the hazard zone should be removed.

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APPENDIX- PHOTO PLATE

Plate 1- Field photographs of Ngaizel

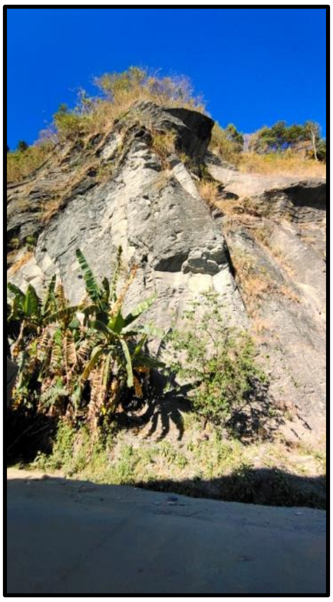

Figure : Spot 1

Figure : Spot 2

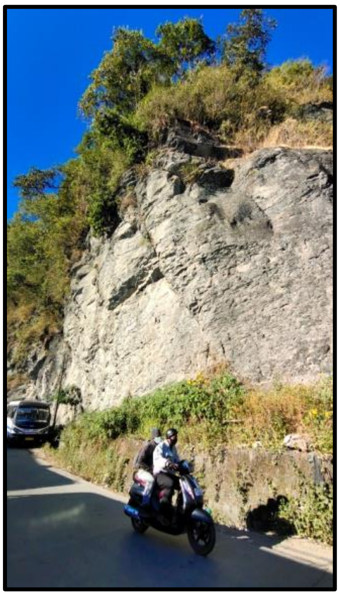

Figure : Spot 3

Figure: Spot 4

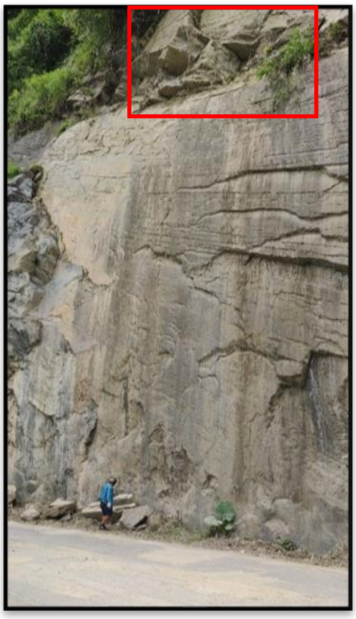

Figure: Spot 5

Figure : Measuring Discontinuities

Figure : Areal view of parts of Ngaizel

Figure : Trees at the top margine of the slope

Figure : Closeup view of rocfall prone area at Ngaizel

Figure : Drone photograph of rockfall at Ngaizel

Plate 2- Field photographs of Bawngkawn -Durtlang

Figure : Spot 1

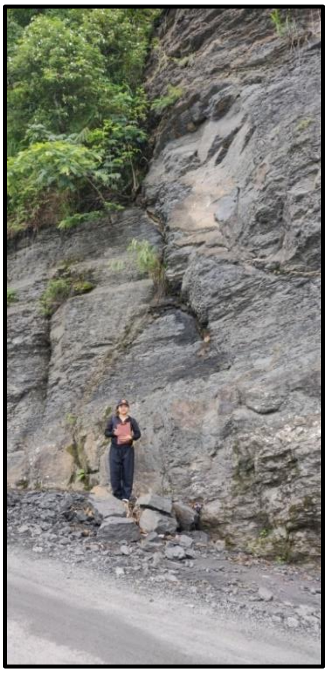

Figure : Spot 2

Figure : Spot 3

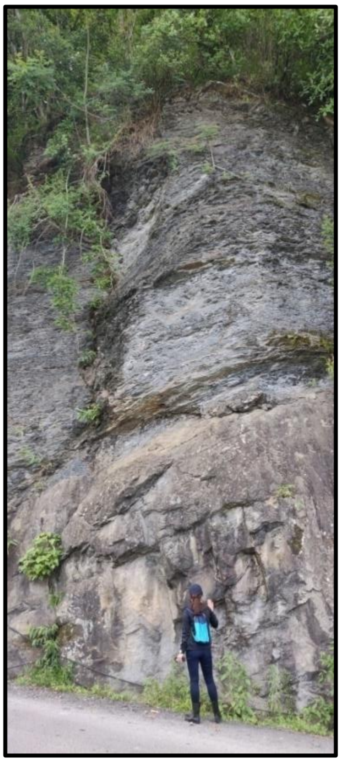

Figure : Spot 4

Figure : Spot 5

Figure : Spot 6

Plate 3- Field photographs of Bawngkawn -Edenthar

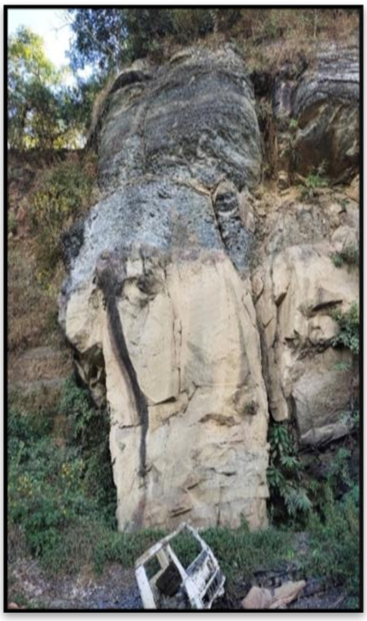

Figure : Spot 1

Figure : Spot 2

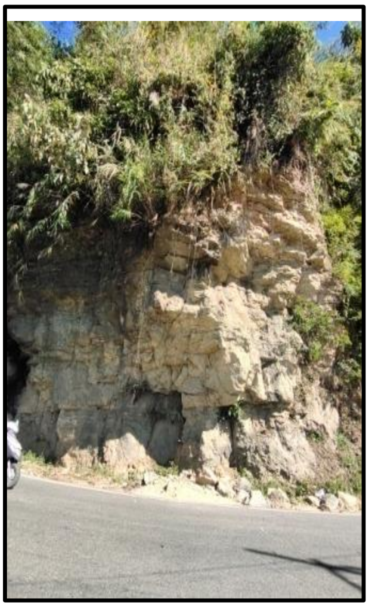

Figure : Spot 3

Figure : Closeup view of Spot 1

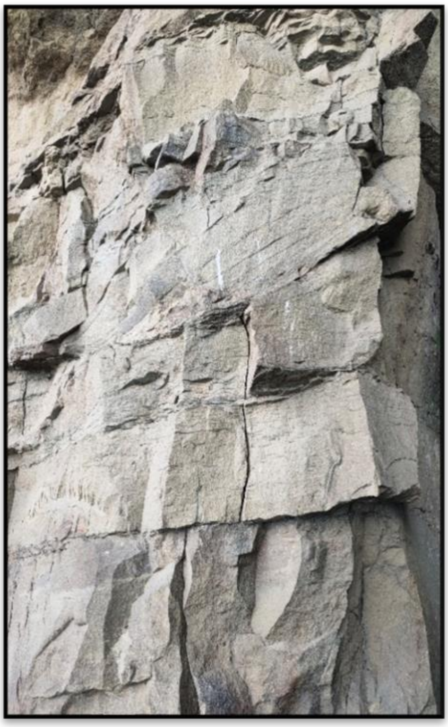

Figure : Closeup view of Spot 2

Plate 4- Rockfalls at the study area

Figure : Ngaizel rokcfall

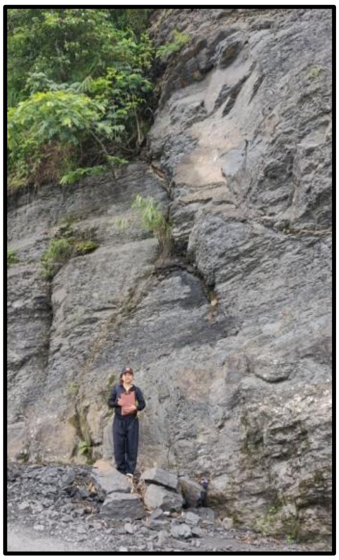

Figure : Bawngkawn-Durtlang rokcfall

Figure : Bawngkawn Edenthar rockfall

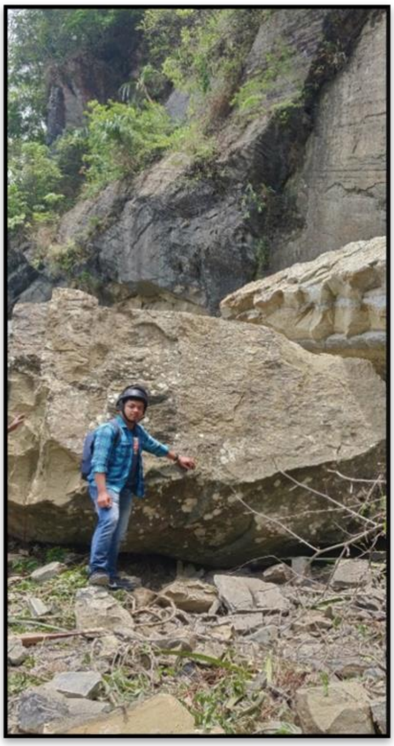

Figure : Ngaizel rockfall

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Father's Name	:	Zothantluanga
Language known	:	Mizo, English
Marital Status	:	Single

EDUCATION

YEAR	INSTITUTION	BOARD	CLASS	SUBJECT	DIVISION	PERCENTAGE
2006	Govt. Mizo High School	MBSE	HSLC	-	I	62.6
2009	Govt. KM Higher Secondary School	MBSE	HSSLC	Science	II	53
2012	Pachhunga University College	MZU	B.Sc.	Geology	I	68.5
2014	Mizoram University	MZU	M.Sc.	Geology	I	74.20
2015	Mizoram University	MZU	Ph.D Course Work	Geology	"O"	7.43 GPA

PERFORMANCE: PUBLICATION, PRESENTATION, TRAINING, WORKSHOP & CONFERENCE PARTICIPATED

1. Published a paper entitled 'Rockfall Analysis of State Highway along the Southern Vicinity of Aizawl, Mizoram' *Science and Technology Journal*, Vol.9 Issue 2, July 2008 ISSN:2321-3388.
2. Published a paper entitled 'RMR and RHRS of Ngaizel road cutting section, Aizawl, Mizoram' *Senhri Journal of Multidisciplinary Studies*, Vol. 4 (2): 7- 20, ISSN: 2456-3757

3. Presented a paper entitled 'Rock Mass Rating along the road cut section of Ngaizel, Aizawl' at Mizoram Science Congress 2018 on 4^{th} October 2018.
4. Presented a paper entitled 'Geological investigation and monitoring of Zuangtui landslide, Aizawl' at Mizoram Science Congress 2018 on 4^{th} -5^{th} October 2018.
5. Presented a paper entitled 'Geotechnical investigation and assessment of Saron veng landslide, Aizawl' at Mizoram Science Congress 2018 on 4^{th} -5^{th} October 2018.
6. Presented a paper entitled 'Rockmass characterization of Bungbangla Quarry, Zemabawk, Aizawl' at NACETER 2019 during 31^{st} October- 2^{nd} November 2019.
7. Presented a paper entitled 'Geotechnical analysis and Rockfall Hazard Rating of Bawngkawn- Durtlang road section, NH-54, Aizawl, Mizoram' at ISRAST2020 on 16^{th}- 18^{th} November 2020.
8. Participated in the Geologic field course on 'Practical Applications of Neotectonics and Quarternary Geolgy in Geolgic Hazard Assessment' during 12^{th} -21th October 2016.
9. Training on 'Application of Numerical Simulation for Slope Stability Risk Mitigation and Management' organised by Dept. of Mining Engineer, IIT (ISM) Dhanbad during 15^{th} to 18^{th} February 2018.
10. Training on 'Geotechnical analysis of rock and soil in laboratory' at CSIR-CIMFR, Dhanbad during 1^{st} to 8^{th} Apri 2019.
11. Landslide Mitigation and Detailed Project Report Preparation organised by NEHU & National Institute of Disaster Management, New Delhi at Shillong during 25^{th} – 29^{th} November 2019.
12. 3 Days National Workshop on 'Landslide Hazard in Southern Mizoram' during 24^{th}- 26^{th} October 2019 at Lunglei organised by MISTIC, DGMR, LGC and GSM
13. Training on 'Application of Remote Sensing and Geographic Information System in Geosciences' organised by North-Eastern Space Application Centre, Meghalaya during 10^{th} – 14^{th} February 2020.
14. 5 Days National Workshop on 'Surveying by Total Station' organised by Department of Civil Engineering, MZU during 7^{th} to 11^{th} May 2018.
15. 3 Days National Workshop on 'Monitoring of Landslide using Total Station' held at PUC Campus during 14^{th} -16^{th} May 2018.
16. Webinar on 'Earthquake versus Landslide with special reference to Mizoram' on 13^{th} August 2020 conducted by Department of Geology, MZU.
17. e-Training on Engineering Geology and Landslide Studies, 21^{st} – 26^{th} September 2020.

18. GEOCHRON- An online Lecture Series on various aspects of Geology org. by Geological Institute, Dept. of Geology, Presidency University, during 22nd Aug. to 27th Sept. 2020.
19. 2 days National workshop on 'Introduction and Demonstration of Advance Equipments in Surveying' Organised by Department of Civil Engineering, MZU during 29th to 30th August, 2019.
20. NRDMS-DST Orientation Programme on Geospatial Technologies during 24th - 26th, July 2019.
21. 2 Days International on 'Landslide Hazard in Mizoram' held at PUC Seminar hall during 23rd – 24th May 2017, organised by DGM, PUC&GSM.
22. Science Academices' Refresher Course in Geology 'Mineralogy, Petrlogy, Ore Geology, Structure Geology and Tectonics' Organised by Department of Geology Mizoram University.
23. Seminar on '2020 Earthquakes in Mizoram' on 15th January 2021, organised by Directorate of Science & Technology, Government of Mizoram.
24. Participated in the Additional Course on 'Interaction Programme for Ph.D Scholars' held from 5th -25th November 2014.
25. Online Webiner on 'Landslide risk reduction and resilience' on 18th August 2020, organised by National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India in collaboration with Geological Survery of India, Ministry of Mines, Govt. of India.
26. Webiner on 'Urban Earthquake Risk Mitigation' organised by National Institute of Disaster Management, Ministry of Home Affairs, on 25th January 2021.
27. Webiner on Earth Day 2021 during 22nd April 2021 organised by Directorate of Science and Technology, Govternment of Mizoram & Geological Society of Mizoram.
28. Resource Person in one day international workshop on 'Geological Research in Indo- Burma Range' during 12 November 2018 organised by Department of Geology Pachhunga University College and Geological Society of Mizoram.

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE	: **H. LALHLIMPUIA**
DEGREE	: **Ph.D. (Geology)**
TITLES OF THESIS	: **GEOTECHNICAL STUDIES OF SELECTED ROCKFALL SITES IN AND AROUND AIZAWL, MIZORAM**
DATE OF ADMISSION	: **5th September 2014**
APPROVAL OF RESEARCH PROPROSAL:-	
1. DRC	: **5th May 2015**
2. BOS	: **8th May 2015**
3. SCHOOL BOARD	: **19th May 2015**
MZU REGISTRATION NO.	: **701 of 2009-10**
Ph. D. REGISTRATION NUMBER & DATE	: **MZU/Ph. D./755 of 19.05.2015**
EXTENSION (IF ANY)	: **19.05.2022**

Head

Department of Geology

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ABSTRACT

As the city grows development of infrastructure began to take place everywhere, Construction or enlargement of highways occur all over the states. Excavation of roadside buildings is ubiquitous. People began to settle not seeking a safe area. These demanding development happens ceaselessly resulting in slope instability and creating a problem and may even lead to fatal disaster. Meanwhile, what has to remember is that take precautions and look at the detailed safety measure before the onset of any construction.

Rockfall is a catastrophe that is frequently encountered in a hilly region, which is disastrous and may cause roadblocks and even casualties to the people that traverse or lived in the vicinity of the area, but the time of occurrence cannot be predicted.

Rockfall usually happens along the highway region. There are many reasons that may cause rockfall, the common problem that triggers rockfall is improper excavation along the highway and construction side. Another important factor is the lack of detailed geotechnical investigation before the implementation of project work.

In this research, we considered three important road-cutting sections around Aizawl such as NH-54 Bawngkawn-Durtlang, Bawngkawn-Edenthar, and Ngaizel. These roads act as an important economic gateway to the entire city as well as a vital trade route to the southern parts of Mizoram.

The geology of the study area is mainly intercalation of shale and sandstone, these intercalation may lead to unequal erosion on the strata itself. Persistence erosion may form overhang rock. Stress applied on the overhanging rock can easily trigger rockfall. Therefore lithology plays an important role in the stability of rock slope. Also, the geological structure such as orientation, spacing, etc, and even groundwater condition is an important factor to consider in the study of rockfall. As mentioned above the occurrence of rockfall depend on the Geological structure. Therefore in areas of complex geological structures like Aizawl, there are certain areas where rockfall might happen. Therefore continuous research is very much required. Since rockfall may occur persistently, monitoring rockfall in a regular basis can reduce its fatal effect. Light detection and ranging (LiDAR), laser scanning, geographical information

systems (GIS), video image recognition etc. are the commonly used technologies for rockfall monitoring.

The main objective of this research is to investigate the characteristic of rock mass concerning the stability condition of the slope. It also aims to identify the hazard region in the study area and suggest mitigation and provide an available protective measure to minimize the adverse effect of rockfall. Detailed geotechnical investigation is carried out in these areas.

The geotechnical investigation performed in the research are Uniaxial Compressive Test, Rock Quality Designation, Rockmass Rating, Slope Mass Rating, Rockfall Hazard Rating System for Indian Landmass, Geological Strength Index, Slake Durability Index Test, and Point Load Index Test. The detailed investigation is carried out through Field and Laboratory analysis. Besides mentioned above analysis using Software such as Kinematic analysis and Rockfall analysis are performed in this research.

The overall result obtained from the studies reveals that the study area possesses bad rock mass, unstable condition, high probability of rockfall, and required immediate measures or action to stabilize the area.

Some of the mitigative measures suggested for the study area are trim blasting, re-sloping, wire meshing, scaling down overhanging rock using hand or machine, and removal of tree roots that traverse the crack or that grow into cracks.