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Slope Stability Assessment of Plane Failure along the Road at Sundaridanda, Begnas, Kaski District, Western Nepal

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Abstract
This paper deals with the assessment of rock slope failure along the road at Sundaridanda, Begnas lake which lies in Kaski District of Western region of Nepal. A comprehensive stability assessment was done for rock slope stability. Kinematic analysis was used to analyze the mode of slope failure. Analytical and numerical methods were used for stability analysis. Barton and Bendis's analysis was carried out to determine the frictional properties of the discontinuities. Kinematic analysis using stereographic projection reflected the possibility of plane failure in the research area. The outcome of the analytical analysis reflected that the factor of safety ranged from 0.77 to 2.82 at different locations. The numerical method using SLIDE v.6 software reflected the unstable slopes, critical slopes, and stable slopes at different locations. The support 'the end anchored bolt having capacity 100KN' was provided in critical slope to change into the stable slope.

Keywords
Slope stability, shear strength, plane failure

1. Introduction

About 70% of the strategic road network in Nepal lies in hill and mountain terrain with steep slopes and fragile rocks that are prone to rock slope failure. Nepal is country where landslide occurs every year due to their geomorphology condition which cause devastates society in the local area. many people are killed due to landslide in local society of hilly and Himalayan region which cause effect the local society in the area for example in tinau river induced devastation landslide that causes huge flood downstream. Rock slopes formed either occur naturally or are engineered as the product of excavation to create space for building highways and railway tracks, powerhouses, dams, and mine pits[1].

Decision on what information to collect for defining the potential problem is a very crucial task in rock slope stability analysis. Accurate engineering geological and geotechnical data collection was a key issue at this stage. The collection of such data was done by extensive field mapping of the discontinuities, by analyzing local lithological, structural, hydrological, and by studying photographs of the rock slope. In most cases, the great majority of slides occur along the major geological discontinuities, such as lithological boundaries, bedding/foliation planes, faults, and weakness zones. Mainly plane, wedge, toppling, and rockfall are common modes of failure show in nepal[2, 3, 4]. The stability of rock slopes is controlled by the shear strength, inclination of discontinuity surface of bedding/foliation/ex-foliation, or cross joints of rock mass. The collection of reliable data describing geometrical and geotechnical properties of such discontinuities is used to evaluate the failure mode i.e., plain failure, wedge failure, or toppling failure of the rock slope under question. A stereographic-based kinematic analysis was used to define the possible slope stability failure mode and the geometry of the slope. All rocks slopes consist of significant structural features and a variety of geological parameters. The presence of such variable geometrical and geological parameters in rock slope analysis always complicates the issue, and optimum slope design becomes challenging.

Among these important parameters that influence the rock slope design is the shear strength of the discontinuities, which is governed by different geological and non-geological parameter[5]. Kinematics analysis provides the types of failure.

More detailed stability analyses as analytical method using Barton and Bendis crietria calculated mathematically for factor of saftey and numerical method using slide software required for the design of stabilization measures using strength type as Baton and Bendis criteria. In the Begnas Lake area, the risk of plane failure was seen clearly as the dip of the bedding plane daylights the hill slope. Due to the construction of the road and toe cutting of the rock slope, the risk had even escalated higher.

2. Literature Review

Rock masses consist of intact rock and joints, which may fail due to[6]: (a) yielding and discrete of intact rock; (b) movement of rock block from their parental rocks; (c) combination of the above two failure modes. Jointed rock masses tend to have a behavior dominated by the strength of joints. It is of great importance to ensure that a numerical method is capable of representing the practical rock joint behavior as close as possible when modelling the stabilities of discontinuous rock masses[7, 8]. Different types of slope failure are associated with different geological structures and it is important in slope design to recognize potential stability problems during the early stages of a project. Geological geometrical conditions likely to lead to such failures. There are four types of slope failure. The importance of distinguishing between these four types of slope failure is that there is a specific type of stability analysis for each as shown in Figure 1.

[9] proposed a nonlinear shear strength criterion based on a series of experimental shear tests on rock joints[7]:

$$\tau/\sigma_n = \tan\left(JRC * \log\left(JCS/\sigma_n\right) + \phi_r\right)$$

where σ_n is the normal stress acting on the joint, ϕ_r is the residual friction angle, which equals to the base friction angle ϕ_b in case of unweathered joint surfaces; JRC is the joint roughness coefficient and JCS is the joint compressive strength[9, 7]. Stability of slope is related with driving and resisting force . Governing factors are very important for slope stability analysis of rock slope and for plane modes of failure for their contribution in the driving and resisting forces. The main internal governing factors are; the geometry of the slope, potential failure plane characteristics, surface drainage and groundwater condition whereas the external factors are rainfall, seismicity and man made activities[3, 10].

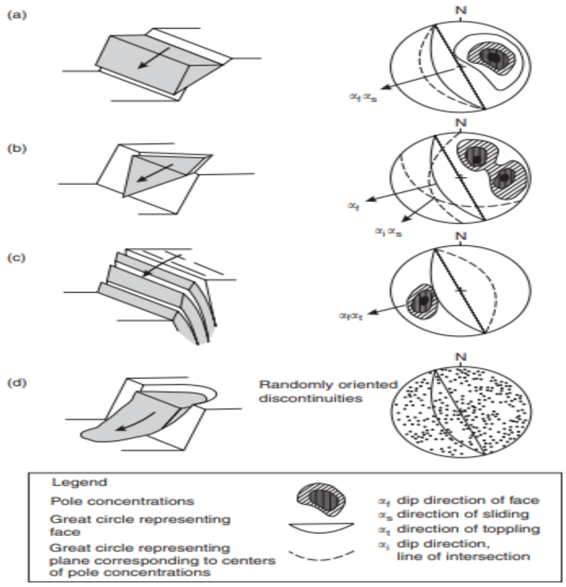

Figure 1: Main types of rock slope failure, and structural geology conditions likely to cause these failures: (a) plane failure in rock containing persistent joints dipping out of the slope face, and striking parallel to the face; (b) wedge failure on two intersecting discontinuities; (c) toppling failure in strong rock containing discontinuities dipping steeply into the face; and (d) circular failure in rock fill, very weak rock or closely fractured rock with randomly oriented discontinuities [11].

Stability analysis for a slope, having plane mode of failure, can be carried out by adopting various techniques. Broadly, these techniques can be classified into; (i) conventional approach; that includes kinematic methods, empirical methods, analytical method and limit equilibrium methods [3, 2, 12, 13] and (ii) numerical methods; includes continuum modeling, discontinuum modeling and hybrid modeling[3, 13].

3. Methodology

Data Collection

Attitudes of the hill slope, orientation of bedding/foliation plane, and joints is measured and value is in a table 1 where DD is dip direction and DA is dip amount of discontinuity plane. Surface irregularities(asperities), effect the stability of the slope which is measured in the field with the help of scale and graph. The value of JRC is obtained by marking measurements of the surface and then comparing with the standard format of roughness profile. Here the value obtained below from measurements on the surface at different locations and calculated and Joint Compressive Strength were analyzed with the help of a Schmidt hammer are in table 2 to calculate the shear strength of the joint using Barton and Bendis criteria.

Table 1: Measured data slope at each location

Location and Hill slope	Average Attitude DD / DA	Orientation of Discontinuity	Remarks
1 and	185° – 190° / 36° – 45°	Foliation	Plane Failure
170° / 45°	90° / 85°	J_1	
	190° – 210° / 55° – 65°	J_2	
2 and	180° – 185° / 40° – 45°	Foliation	Plane Failure
170° / 45°	345° – 350° / 45° – 57°	J_1	
	260° – 265° / 50° – 60°	J_2	
3 and	170° – 202° / 32° – 46°	Foliation	
170° / 50°	250° / 51°	J_1	
	183° / 51°	J_2	
4 and	180° – 205° / 35° – 51°	Foliation	Plane Failure
172° / 52°	90° / 80°	J_1	
	210° / 75°	J_2	
5 and	170° – 215° / 45° – 60°	Foliation	Plane Failure
175° / 52°	58° / 88°	J_1	
6 and	195° – 205° / 58°	Foliation	
173° / 60°	210° – 250° / 39° – 58°	J_1	
7 and	114° – 200° / 51°	Foliation	Plane Failure
175° / 54°	60° / 80°	J_1	
8 and	165° – 210° / 45° – 54°	Foliation	
175° / 50°	150° / 75°	J_1	
9 and	190° – 210° / 55° – 80°	Foliation	
175° / 40°	232° / 85°	J_1	
10 and 175° / 45°	180° – 200° / 55° – 60°	Foliation	
11 and 175° / 45°	162° – 189° / 42° – 65°	Foliation	

Table 2: Measured value of JRC and JCS

Location	JRC	JCS
1	8.30	28
2	16.97	68
3	10.66	89
4	15.13	82
5	4.05	68
6	7.1	96
7	5.5	13
8	10.75	17
9	7.01	13
10	7.835	20
11	7.835	34

Kinematic analysis

The kinematic analys is used for to find the common modes of failures which occurs in rock mass such as plane, wedge, toppling. rThese methods reqires the geometry of the rock mass of discountinuity which cause slope instability without considering the force causing rock slope failure. Kinematics using stereographic projection representation stereonet of the planes and lines. Stereonets are useful for analyzing the discontinuity of rock blocks. stereonet program is use for the analysis which visualize the structural data using geometry of data to determine the kinematic feasibility of rock mass and statistical analysis of the discontinuity properties.[11]. This methods suggest the potential for rock slope failure occurrence. Kinematic analysis is the first step to check and begin for other analytical approaches[3].

Analytical method

This method of stability analysis for plane surface failures requires the resolutions of forces which is perpendicular to and parallel to potential failure surfaces. These include the shear strength of the rock mass along the failure, the influence of force as seismic acceleration, and the effect of pore water pressure surfaces. The condition for planar failure is explained below. In which prediction of pore water pressure is difficult, so U is zero and using an analytical formula for determining the factor of safety for planar rock surface as shown below. The value of the factor of safety in Table 3 is in dry condition of rock slope. Using Barton and Bendis failure criteria to calculate the factor of safety formula used above in the equation.

Factor of safety = (Shear strength)/(Shear stress)

Weight of the unstable block (W) = $\gamma * A$

Normal stress(σ) =$(w\cos\psi_p)/A$

Shear stress (τ) = $(w\sin\psi_p)/A$

For calculation at location 1,

Here, JRC = 8.38

JCS = 28 Mpa

Unit weight(γ) = 25 KN/m^3

Height = 10 m

Area of failure surface = 10.04 m² (the area is calculated by the 2D model of the figure 2 in autocad.

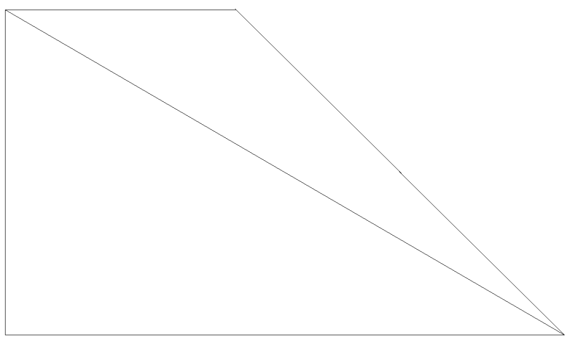

Figure 2: 2D view at loaction 1

Length = 1m (assumed)

Weight of the unstable block (W) = 25* 10.044*1 = 251 KN

Normal stress(σ) = $(W\cos\psi_p)/A = (251 * cos(40))/10.044 = 19.14$ MPa

Shear stress (τ) = $(W\sin\psi_p)/A = (251 * sin(40))/10.044 = 16.06$ MPa

Shear strength (τ) = $\sigma_n * \tan(JRC * \log(JCS/\sigma_n) + \phi_r)$

$\tau = 22.326$ MPa

therefore a factor of safety = (Shear strength)/(Shear stress) = 22.326/ 16.06 =1.39 is nearly equal to 1 which is critical.

Remaining location of factor of saftey obtained by using analytical method is in table 3

Table 3: Calculation of factor of saftey using Barton and Bendis Criteria

Location	H (m)	ψ_f (°)	ψ_p (°)	Area (m²)	Weight (KN)	Normal stress (MPa)
1	10	45	40	10.04	251	19.15
2	10	45	40	10.04	251	19.15
3	10	50	40	18.59	464	19.12
4	12	52	42	24.73	618	18.57
5	10	65	50	18.83	470.9	16.06
6	14	60	58	4.869	121.72	13.24
7	12	54	51	3.95	98.75	15.73
8	10	50	47	17.58	439.65	17.05
11	10	45	42	5.42	135.65	18.57

Table 4

Shear stress (MPa)	Shear Strength (MPa)	Factor of Saftey
16.06	22.326	1.39
16.06	42.7	2.65
16.04	45.263	2.82
16.72	153	9.15
19.14	14.813	0.773
21.2	19.19	0.905
19.42	15.12	0.788
18.28	32.7	1.788
16.72	25.36	1.516

Numerical Analysis

Conventional methods cannot slove accurately insitu stresses, varied geometries,non linear behaviour, material anistrophy , for these problems numerical modelling technique can be suitable solution. Numerical analysis let on for material deformation and faiure, evaluations of effects of parameter variation, dynamic loadingmodelling of pore pressure creep deformation. however numerical analysisis is restricted by some limitation.For example, input parameters are not usually measured and availability of these data is generally poor. Numerical methods used for slope stability analysis can be divided into three main groups: continuum, discontinuum and hybrid modeling[3].

These method used for the plane failure analysis as the application of numerical methods for obtained factor of saftey of rock slopes and data requi the calculation are obtained from the field of the project area and from literature review[2, 4, 14].Each parameter used in the analysis can be direlty obtained in a usable form for analytical equation that have considered different forces for their analytical formulations and each methods have made different assumption as shown in to evaluate the stability condition of slopes with plane modes of failure so that these assumption is necessary, though lateral deviation in slope geometry and geological condition. The stability condition assessed is presumed to be representative for the entire slope[2].

Table 5: Different methods of analytical approches used in slide

Method	Force balance (vertical)	Force balance (horizontal)	Moment balance
Ordinary MS	Yes	No	Yes
Bishop's simplified	Yes	No	Yes
Janbu's simplified	Yes	Yes	No
Janbu's generalized	Yes	Yes	Used to compute interslice shear forces
Spencer	Yes	Yes	Yes
Chugh	Yes	Yes	Yes
Morgenstern-Price	Yes	Yes	Yes
Fredlund-Krahn	Yes	Yes	Yes
Corps of Engineers	Yes	Yes	No
Lowe and Karafiath	Yes	Yes	No
Sarma	Yes	Yes	Yes

Assumption made in the numerical methods of slopes with complex geometries and geological conditions may oversimplify the situation and the results may not be realistic. although experience has shown that the analytical method has provide satisfactory results for engineering applications, the stability analysis of two dimensional slope geometries make simple analytical approaches such as Bishop's method suitable for slope analysis and their risk management. The method used in this paper is

Simplified Bishop's Method of Analysis

A simplified Bishop's method based on the method of slices has been used in the limit equilibrium analysis to calculate the factor of safety at all locations. It is assumed that the total force normal force acts at he center of the base of each piece and derived by summing the total force in the vertical direction. IT gives more accurate results although it does not satisfy the complete limit equilibrium and procedure gives the comparatively accurate factor of saftey[15]. IN this analysis of the rock slope failure Bishop's simplified method is implemented by the slide v.6 software[15]. for shear strength of rock Barton and Bendis method are used which requires joint roughness coefficient, joint compressive strength and friction angle.

4. Scope and Limitations

Scope

Slope stability analysis is used to figure out the stability of earth, rock fill dams, embankments, excavated slope road cut and natural slope in the rock for risk management.

Slope stability analysis is the review of potential slope failure mechanism and is the investigation of potential failure mechanisms and sensitivity to different mechanism.

Limitations

Data were collected from surface mapping only.

5. Research Setting

The Sundaridanda, Begnas

The study area from Begnas Tal bus park to Sundaridanda with latitude (28° 09.878'N) and longitude (84° 05.974'E).The area was 300 m road corridor of Begnas-lake Buspark-Sundaridanda Road. The altitude of the area lies between 760 to 810 m above sea level.Sundaridanda, Begnas tal is located in Gandaki province, western region of Nepal,lekhnath municipality of Kaski district. This road connects the

Figure 3: Project area

tourism sectors as the aesthetic look of Begnas-lake and Rupa-lake view point at Sundaridanda. The road furthermore connects various rural villages of Kaski District and Lamjung District, including Vorletar, the main city of Lamjung.

Geology of the project area

The area where rockslide occurs lies in lesser Himalayan rocks consisting low to medium grade metamorphic represented by alternation meta-sandstone and quartzite of kunncha formation. At this location colour of rocks is mainly greenish grey having fine grain texture with phyllitic cleavage. The structure of rock is foliated and composition of minerals is mica, chlorite, quartz. Mainly phyllite metamorphic rock is found. There is possibility of plane failure from analysis which may impact to the road users. Hill slope is around 172°/50°.

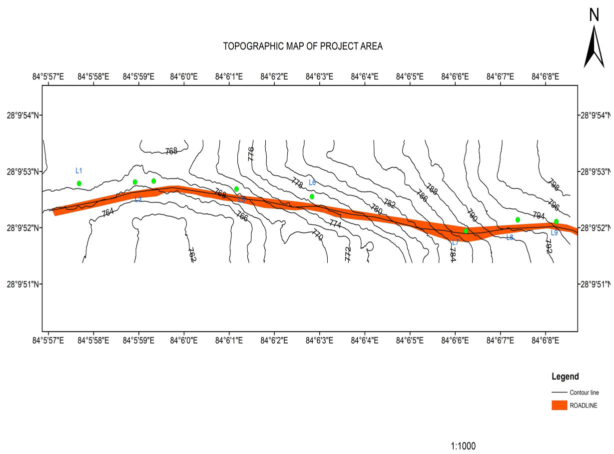

Figure 4: Topographic map at project area

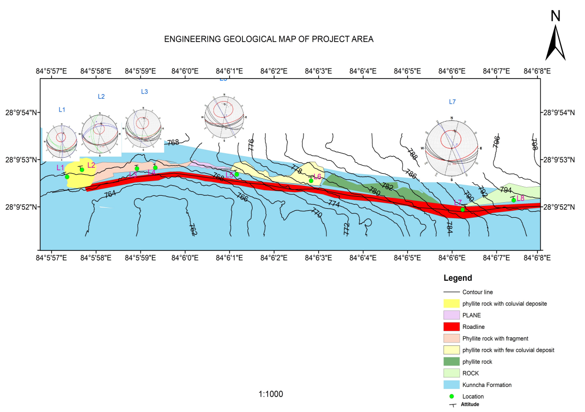

Figure 5: Engineering geological map at project area

6. Discussion

Plane failure in rock slopes is comparatively simple modes of failure than other modes of failure. Although it may involve complex failure mechanism due to complex geometry [16], heterogeneity in rock mass, non planar potential failure plane variation in shear-strength along the potential discontinuity plane, uneven distribution of the water forces surcharge and the dynamic loading conditions slope. Recognizing and assessment of above governing factors is necessary for the rock slope stability analysis.

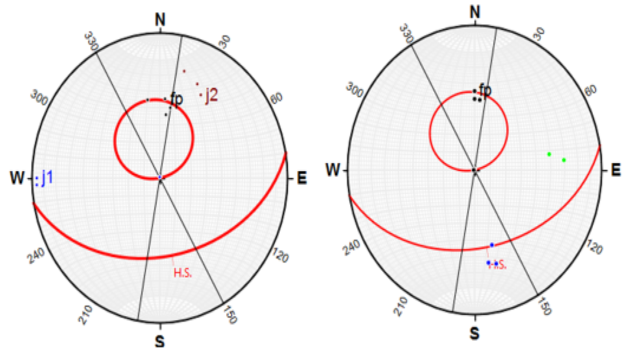

Figure 6: Stereographic projection at location 1 and 2

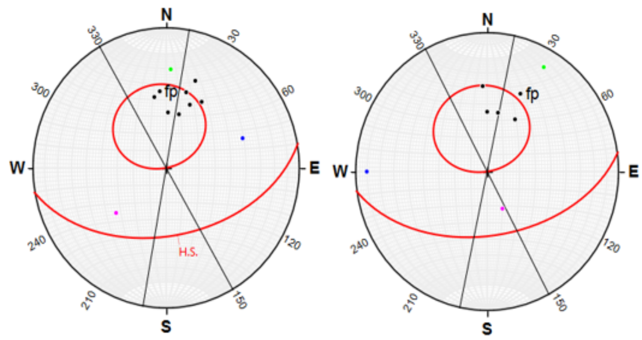

Figure 7: Stereographic projection at location 3 and 4

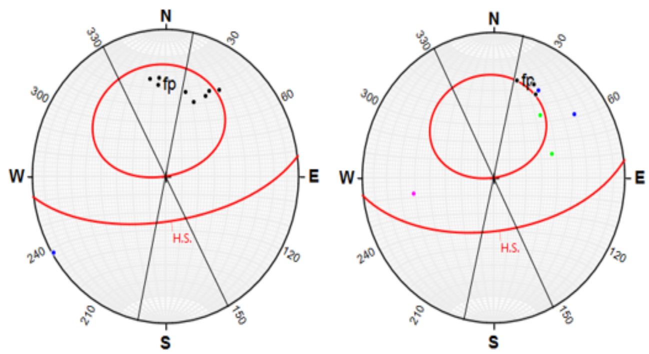

Figure 8: Stereographic projection at location 5 and 6

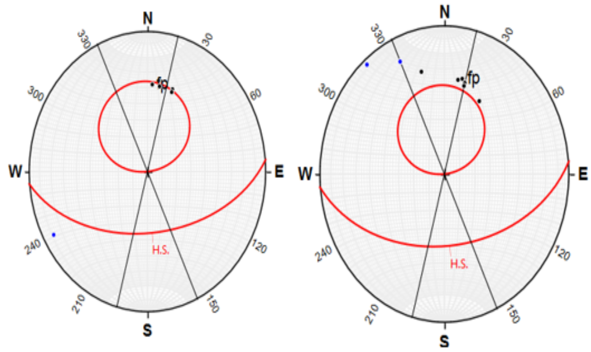

Figure 9: Figure 6.1.4: Stereographic projection at location 7 and 8

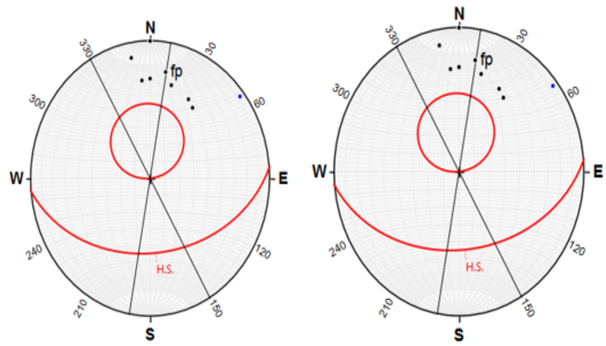

Figure 10: Stereographic projection at location 9 and 10

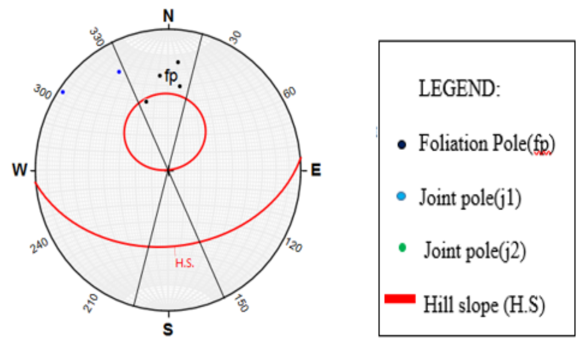

Figure 11: Stereographic projection at location 11

The average hill slope attitude having dip direction and dip amount is 174°/50°. Attitude of foliation plane, joints and hill slope aspects of different location were plotted in stereonet of stereographic projection. At location 1, 2, 3, 4, 5, and 7 as shown in figure below. From plotted stereographic projection, the strike of foliation plane was parallel or nearly parallel (within approximately ±20°) to the strike of slope face and the foliation plane 'daylight' in the slope face, which means that the dip of the plane is less than the dip of the slope face and Joints have minor effect Joints. Possibilities of plane failure at this study area.

The height of the slope is assumed, and the frictional angle is assumed to be 28°. In analytical method calculated of Factor of Safety has been seen that locations 1,2,3,4,6,8 and 11 have a factor of safety greater than one, which means they have a stable slope, and locations 5,6 and 7 have a factor of safety less than one, which means an unstable slope from the analytical method.

JRC, JCS, friction angle plotted in slide software using Barton and Bandis criteria to determine the factor of safety at different locations. Using friction angle 28°. Simplified Bishop method is used for analysis in slide software. Each location of slope is examine by using simplified Bishop's method as implemented by the two dimension slide V.6 software. The factor of saftey at each location were calculated using Bishop's simplified method which shown in figure below.

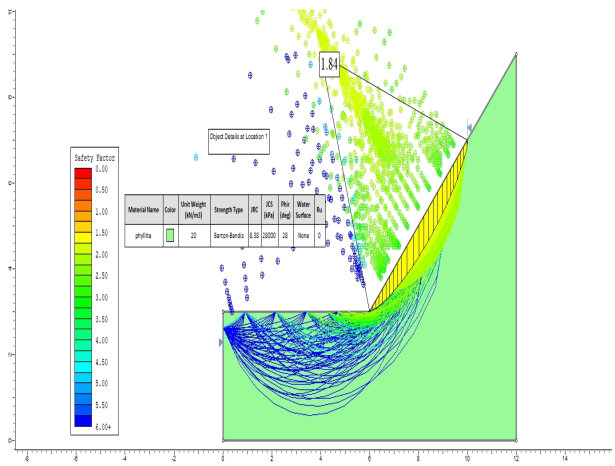

Figure 12: At location 1

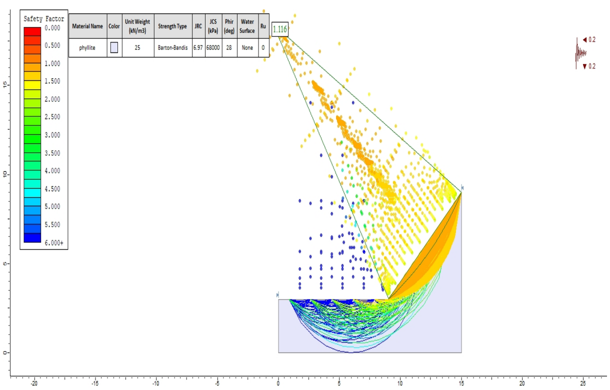

Figure 13: At location 2

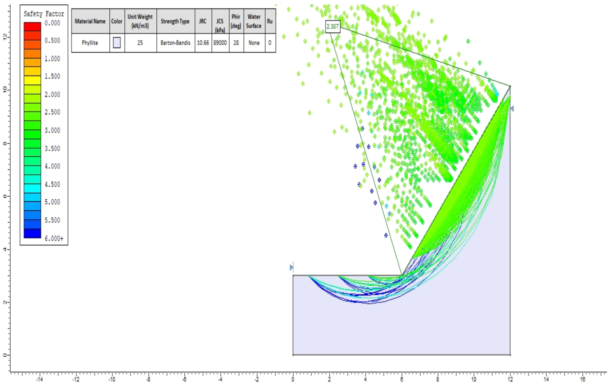

Figure 14: At location 3

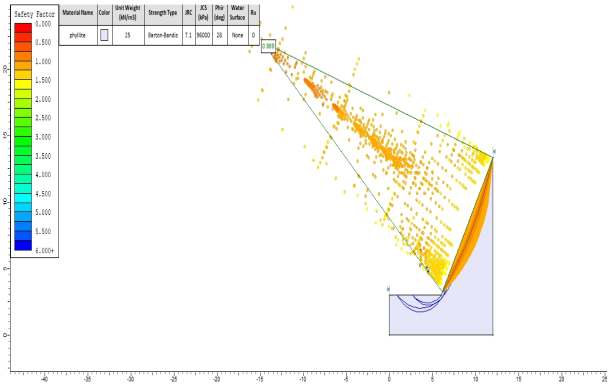

Figure 17: At location 6

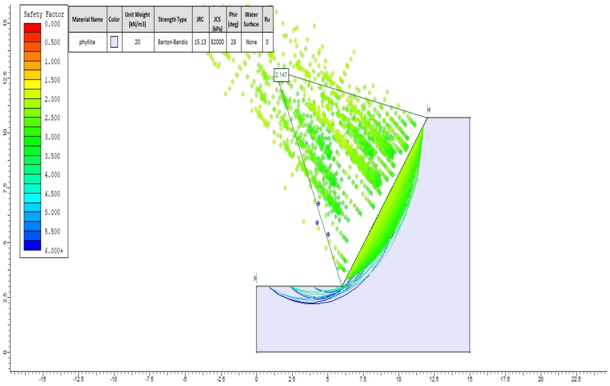

Figure 15: At location 4

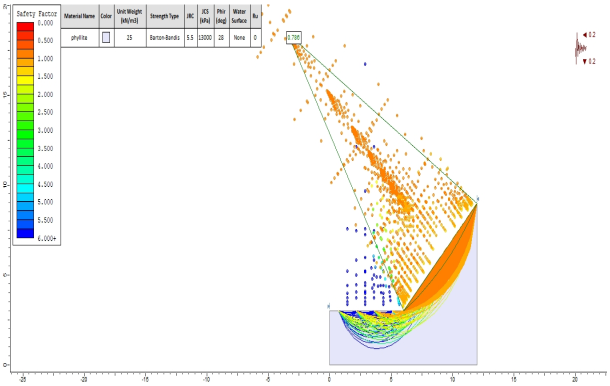

Figure 18: At location 7

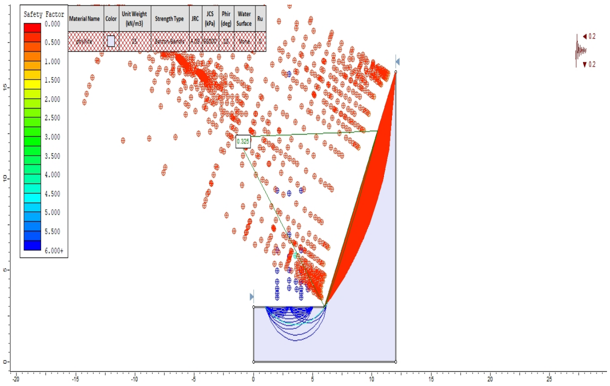

Figure 16: At location 5

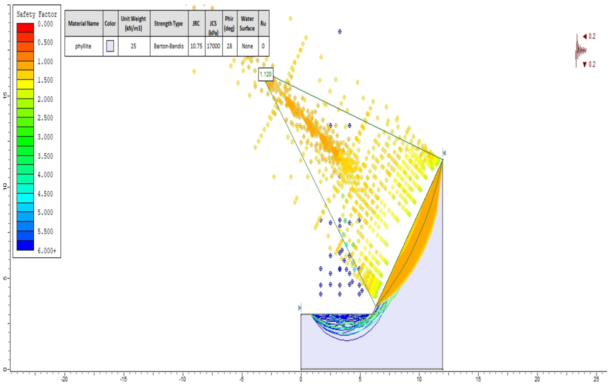

Figure 19: At location 8

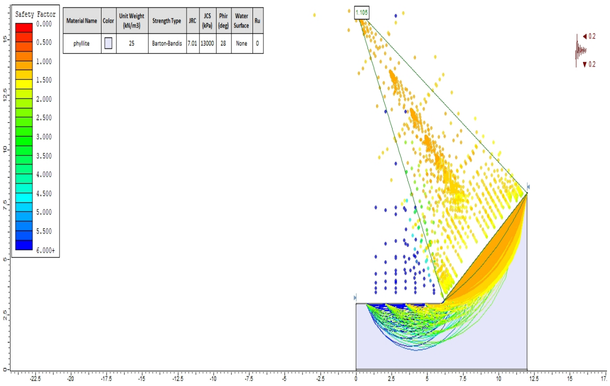

Figure 20: FigureAt location 9

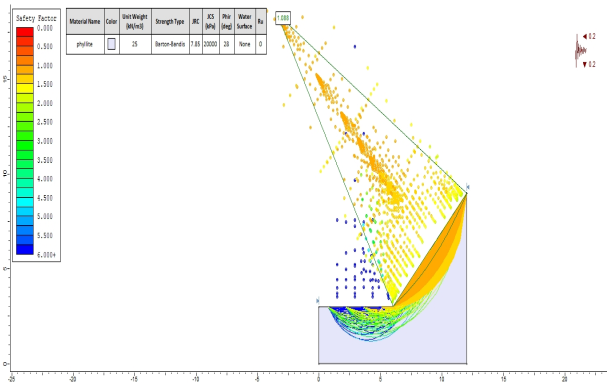

Figure 21: At location 10

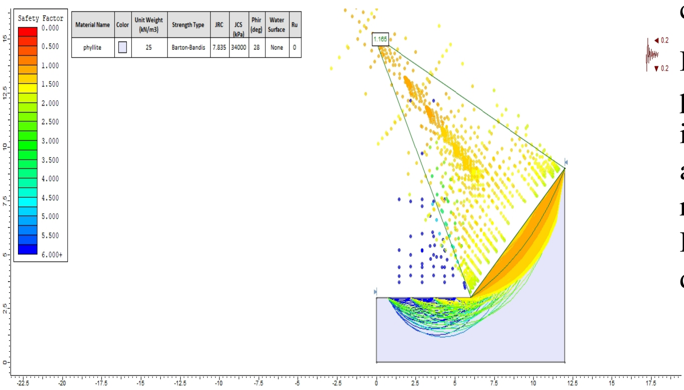

Figure 22: At location 11

The variation in the color of slip surface show the factor of saftey along the slip surface.The FoS values at location 1, 2, 3, 4, 5, 6, 7, 8, 9, 10and 11 are 1.844, 1.116, 2.307, 2.147, 0.325, 0.986, 0.786, 1.120, 1.105, 1.088 respectively, which obtained by the analysis using barton and bendis strength criteria the slip surfaces occurs at he toe of the slope which means failure of sloppe occurs at he toe. This may be due to more overburden stress on the slope.

7. Conclusion

The study focused on the road-cut slopes for stability analysis along Begnas-lake to Sundaridanda Road section, Kaski District. The study area lies in the Lesser Himalayan Zone of Western Nepal. The Phyllite of Kuncha Formation comprised the study area. The study identified that the 300 m plane failure occurred along the road cutting slope. A comprehensive stability assessment was done for rock slope stability. Kinematic analysis was used to analyze the mode of slope failure. Analytical and numerical methods were used for stability analysis. Barton and Bendis's analysis was carried out to determine the frictional properties of the discontinuities. Kinematic analysis using stereographic projection reflected the possibility of plane failure in the research area.

Numerical methods provided the factor of safety 1.844, 2.307, and 2.147 at locations 1, 3, and 4, which reflected stable slope conditions. Similarly, the factor of safety of 0.325, 0.906, and 0.786 at locations 5, 6, and 7 reflected unstable slope conditions. The factor of safety of 1.116, 1.120, 1.105, and 1.165 respectively, at locations 2, 8, 9, 10, and 11 reflected the critical slope condition. The support of "end anchored bolt" having capacity 100KN' was calculated for slope stability in the critical slope.

It was considered that during the analysis, the fracture pattern and groundwater condition of the rock mass increased the risk of rock failure. The outcomes of the analytical analysis reflected that the factor of safety ranged from 0.77 to 2.82 at different locations. However, pore water pressure and seismic loading decrease the factor of safety.

8. Recommendations

It is recommended that the 'End-anchored bolt provided at 1m spacing having 100KN capacity support needs for critical slopes which increase the factor of saftey as shown in figure at location 8 . Unstable slopes of rock mass have weathered phyllite, i.e., locations 5, 6, and 7 need fully grouted rock bolts having 100KN capacity support with wire mesh. The support is provide on the basis of site condition and their applicable treatment.

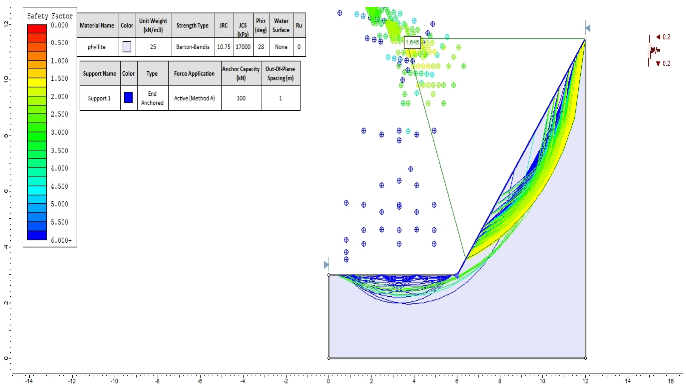

Figure 23: sAt location 8 with support

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