GEOLOGICAL INVESTIGATION & LANDSLIDE RISK ASSESSMENT OF A SECTION NEAR KHARPADA VILLAGE ALONG MUMBAI-GOA HIGHWAY

Submitted in partial fulfilment of the requirements

of the degree of

Bachelor of Engineering

by

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CERTIFICATE

This is to certify that the project entitled **"Geological Investigation & Landslide Risk Assessment Of A Section Near Kharpada Village Along Mumbai-Goa Highway"** is a bonafide work of **Khan Fathima Israr, Maddarki Tahmeena Abbas ali, Shaikh Minaz Yakub & Shaikh Mohammed Arshad** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of "Undergraduate" in "Civil Engineering"

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DECLARATION

We Civil engineering students of Anjuman Islam Kalsekar Technical Campus, hereby declare that we have completed the project titled "**Geological Investigation & Landslide Risk Assessment Of A Section Near Kharpada Village Along Mumbai-Goa Highway"** during the academic year 2018-2019. we declare that this written submission represents ours ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. we also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. we understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

The rocks exposed in the area are compact Basalt belonging to the most famous basaltic lava flows known as Deccan Trap. These rocks are prone to weathering due to presence of cooling joints which are the discontinuities along which water penetrates and expose the fresh rock to alteration. Different degrees of alteration due to weathering, formation of soils and failure due to complex geological conditions together with high-intensity rain fall makes the Basalt prone to landslide. A section near Kharpada Village along the Mumbai- Goa Highway selected for Geological investigation and Landslide risk assessment, show presence of 3 set of joints. The joint set identified as J1, J2 and J3 are striking in the NE-SW, NW-SE and N-S direction respectively. The joint set J1 and J2 are near vertical whereas J3 is perfectly horizontal. These joints have divided the rock into blocks of varying size and altered it to varying degree depending upon the frequency and openness of joints. Kinematic analysis of the slope has revealed that the right-hand side slope of the road from spot no 1-7 and 17-10 is susceptible to wedge failure as the sliding surface daylight in the slope face. The vulnerability to slide along these spots have also increased due to highly weathered nature of the rock. The spot no 8-16 show stable slope as the sliding surface does not daylight in the slope face and the rock has not suffered weathering forming it a stable slope. This study reveals the importance of structural geology and kinematic analysis in slope stability analysis and if incorporated in designing of slope it can prevent loss of lives and property by slope failure.

Keywords— Deccan Trap, Joints, Kinematic analysis, Discontinuity, Stereographic projection.

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ABBREVIATION NOTATION AND NOMENCLATURE

Chapter 1

Introduction

1.1 Deccan Trap Basalt

At the end of the Mesozoic Era of the Geological history, the Indian peninsula witnessed intensive volcanic activity, due to which stupendous masses of lava and pyroclastic materials were ejected out, which covered a larger part of the peninsula in its southern, western and central parts. The most famous basaltic lava flows formed during the late Cretaceous to Tertiary periods (60 to 65 Ma, Duncan & Pyle 1988).) of Mesozoic era are known as **Deccan Trap Basalt** (Fig.1.1)

Fig.1.1 Deccan Trap Basalt between Mumbai and Mahabaleshwar

The lava flows occur in general in the form of beds, obliterating the previous topography, form flat-topped plateau-like features. As the basaltic lava flowed easily out of the fissures the Deccan Traps spread over an area of about 500,000 square Km in Central and Western India (Gupte 2001) Their step-like or terraced appearance is an outcome of intermittent outpouring of lava flows and suggestive of the name Deccan Traps to these volcanic formations.The Deccan Traps are very susceptible to weathering, different degrees of alteration, formation of soils and experiences frequent slope failure due to complex geological conditions and high-intensity rain in the region.

1.2 Nature of Problem

The Deccan Trap Basalts are prone to landslide due to the presence of contraction joints formed during cooling. The compact and non-vesicular basalts which are free from gas cavities are always well jointed and the vesicular and amygdaloidal basalts are not jointed (Gupte 2001). Joints are always to be considered as a source of weakness of the rocks and as pathways for the leakage of water through the rock. Both these properties of joints destroy the inherent soundness of the rock to a great extent.

Joints are a major cause of instability of the rock masses in the hilly regions. Jointed rocks get easily lubricated in the presence of moisture and sliding or falling from the original places of occurrence. Many landslides and slope failures are directly related to the jointed nature of the rocks e.g. BhorGhat on the Mumbai-Pune line of Central Railway are usually troubled by frequent boulder falls . Geological Investigation revealed that the highly jointed compact basalt form blocks which were being dislodged due to vibration of heavy train traffic (Gupte, 2001). Increase in moisture content in joints filled with clay can cause considerable swelling pressure which may lead to rock falls and rock slides.

1.3 Rationale of Study

The complex Geological conditions of the Deccan Trap Basalt lead to slope failure along the highways, road cuts and tunnels in the Maharashtra. The slope failure poses a risk to human lives, property and lead to environmental degradation. The stability of rock slopes is often significantly affected by the discontinuities such as bedding planes, joints and faults. The properties of discontinuities such as persistence, orientation, spacing, openness, roughness etc are important in deciding the slope's stability. As the discontinuities are known as plane of weakness the failure generally occurs along these surfaces. Geological studies play a very important role in the rock slope stability analysis. The rock type under study is compact Basalt which is jointed, and altered to varying degree by weathering. A detailed investigation of the orientation and other characteristics of the discontinuities will certainly help is assessing the risk of the slope failure in the area. It has been observed by literature review that there is a need to address the geological conditions of the site and to carry out Kinematic analysis to analyze the potential for the various modes of rock slope failures (plane, wedge, toppling failures), that occur due to the presence of unfavourably oriented discontinuities.

1.4 Objectives

→ The following objectives are aimed to be attained by the study-

→ Geological Investigation of the area.

→ Stereographic projection of Discontinuities

→ Kinematic analysis

→ Assessment of Risk on geological ground

1.5 Location and Approach:

The study area Kharpada is 24Km from AIKTC Campus, New Panvel and lies at the Latitude 18º49'33.08'' N and Longitude 73º05'28.01''E, showing an altitude of 20m from MSL. A good exposure of compact basalt along the freshly cut road along the SH-104 was found suitable for data collection and slope stability analysis.

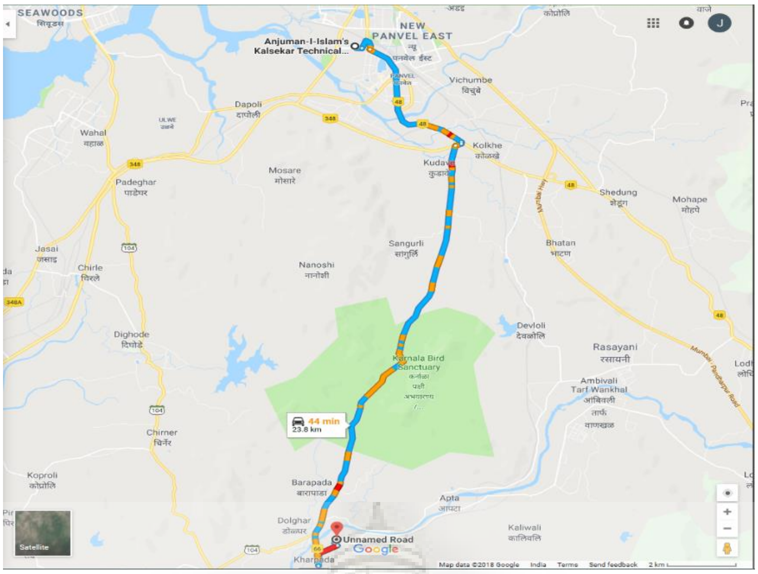


Fig.1.2 Location map of the study Area

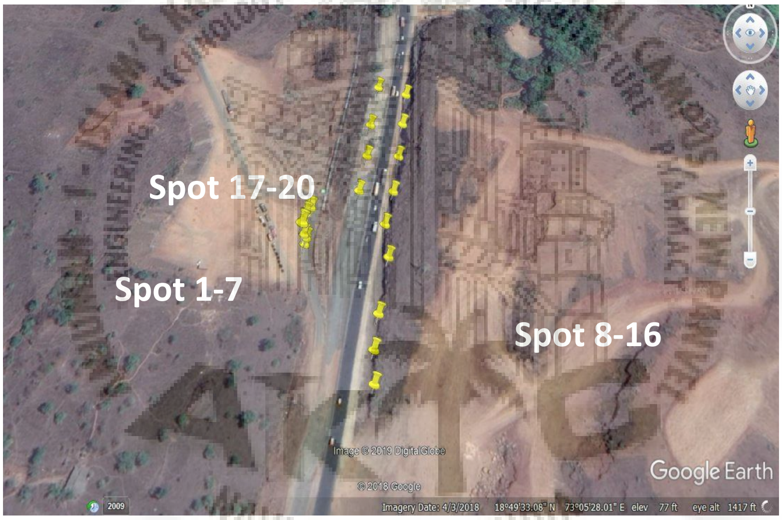


Fig. 1.3 Google map image of the study area

1.6 **Physiography and Climate**

The study area has typical monsoon climate, with hot, rainy and cold weather seasons. Tropical conditions prevail in the area. Rain fall is heavy on an average of 200 centimetres annually. The soil is residual type, reddish in colour, clayey in nature, retains moisture and is also rich in iron with varying thickness. The area comes under the Western Ghat region of Maharashtra and

Chapter 2

Literature Review

2.1 State of the Art

The Deccan Traps which are known as Flood Volcanic Province (DVP) of India consists of Basalt which is a very hard and compact rock. The composition, presence of discontinuity in the form of cooling joints, varying degree of alterations under the tropical climate and other geological factors make these rocks susceptible to landslide problem. All along the highways where compact basalt is exposed and along the Central Railway this problem is encountered regularly. The major landslide of Malin Village, 110 Km from Pune on the 30th July 2014 in which more than 120 people lost their lives is an example of vulnerability of these basaltic slopes.

Slope Failure Studies in Deccan Traps-

Sigh et.al. 2013, studies the stability of road cut cliff face along SH-121, the result of this study shows that the rock face is highly unstable due to steep and jointed rock mass exposed along the highway. Proper preventive measures have also been suggested to arrest the movement of falling rocks before reaching the roads or valleys along the busy Highway.

Ahmad et al. 2015, carried out landslide studies along the SH-72 of Maharashtra a state highway between Poladpur and Mahabaleshwar**.** The paper presented a study of the physical and engineering behaviour of five types of basaltic soils and their usefulness on the stability of slopes of SH-72. The 5 types of soils have been identified based on different parameters and effects of these soils on the slope stability have been worked.

Singh et. al. 2016, carried out field investigations and numerical analyses of the landslide, affecting **Malin village** of Pune district in Maharashtra, India whichoccurred on **July 30, 2014**.Geotechnical properties have been used for numerical modelling of the hill slope that has been performed to calculate factor of safety, maximum displacement, displacement direction and accumulated maximum shear strain with the help of numerical programs based on limit equilibrium method and finite element method approaches, respectively. Thisstudy shows that the hill slope was unstable with FoS.

Gupta et. al. 2017, carried out the study which encompasses the slope stability analysis along six km long bridle path between Janki Chatti and the Yamunotri shrine, located to the north of Main Central Thrust which consists of rocks of the Higher Himalayan Crystallines. **Geomechanical characterisation of the slopes for the assessment of rockfall hazards** through various rockmass classifications has been carried out and different locations were categorized as high, low and moderate hazard locations based on different parameters.

Boshat et. al. 2017, studied the rocks along the Mumbai Pune Expressway and classified the basaltic rocks of the study area in to four types - Compact Basalts, Amygdaloidal Basalts, Tachylitic Basalts and Volcanic Breccias. According to their study Compact and Amygdaloidal basalts are separated by a thin layer of disintegrated material which is formed by weathering. Presence of Tachylitic basalt which on exposure to atmosphere disintegrate forming boles and disturbs the middle layer of compact and amygdaloidal basalt causing rockfalls.

Thigale, S and Umrikar B. 2017 Studied the disastrous landslide episode of July 2005 that killed 190 people and gave rise to hydrothermal anomaly. The data revealed that seismicity of the region has been responsible for developing fissures parallel to N-W to NNW-SSE trending fracture-controlled streams along which majority of landslides occurred following incessant rains. The genesis of hydrothermal anomaly developed at six places has been explained using dilatancy-diffusion model. The symptoms of slope instability observed before the episode at ten places indicate that sliding surfaces had already crossed geological threshold; as a result, landslides occurred without development of hydrothermal anomaly.

Slope Failure Studies in Himalayan Region-

As Himalayas are prone to landslides due to active tectonics some case studies from the Himalayan Landslide were referred which are as follows-

Pant and Luirei 1999, studied **Malpa RockfalIs** of 18 August 1998 in the NortheasternKumaun Himalaya. This paper presents the case history of Malpa rock fall of 18 August 1998, which has claimed a toll of 250 lives, including 60 pilgrims in transit camp, under the shadow of Malpa peak 40 km north of Dharchula. The slope failure which caused the rockfall was aggravated by high angle of hill slope(78°), conducive conditions of bedrock, particularly enlarged joint space and proximity to the Main Central Thrust (MCT).

Pant and Luirei 2005, studies the Amiya Landslide of I1 July 1999. in the southern hills of Kumaun in the proximity of the Main Boundary Thrust (MBT). The slope failure was related to structural conditions of bedrock, particularly five sets of joint spacing and the proximity to the MBT which has been affected by neotectonic movements.

Kumar et. al. 2017 studied Slope stability analysis of Balia Nala landslide, Kumaun Lesser Himalaya, Nainital, This study shows that different kinds of discontinuities (joints, faults and shear zones) and rapid down cutting by the stream due to neotectonic activity affect the stability of the slope. The fragile lithology and deep V-shaped valley further accelerate the mass movement in the study area. In addition, rock mass rating (RMR), factor of safety (FOS) and graphical analysis of the joints indicate the study area as landslide-prone zone.

2.2 **Gaps and Findings**

It has been observed that along with the other geological factors the Kinematic analysis of the discontinuity will be very helpful in assessing the possible mode of failure. Kinematics refers to the motion of bodies without reference to the forces that causes them to move (Goodman, 1989). It is one of the most useful techniques in the recent years to investigate possible failure modes of rock masses which contain discontinuities (Hussain et al., 2015). Therefore a small area in the Kharpada village along the Mumbai-Goa Higway, SH-104 was selected. The kinematic analysis along with other geological investigation of the discontinuity will certainly help in assessing the risk of failure of rock masses along the freshly cut road along the Highway

Chapter-3

Methodology and Data Collection

To attain the said objectives, Geological investigation of the study area was carried out which includes- Lithological characterization of the rocks, identification and orientation of discontinuities, recording uniaxial compressive strength (UCS) (measured using Schmidt hammer according to ISRM (1981, 2007), spacing, openness and frequency of discontinuities and direction and dip of slope. To analyze various modes of rock slope failures (plane, wedge, and toppling failures) the orientation of discontinuities plotted on stereonet and kinematic analysis was done according Duncan & Christopher 2004. The detailed methodology and observation are described as follows-

3.1 Geology of the Area

The area under study comprises a part of the major continental flood basalt province of India commonly known as the Deccan Trap, which is the most extensive geological formation of Peninsular India. GSI carried out systematic Geological Mapping of an area about 150,00 square kms in the western Maharashtra and given a classification based on the presence of megacryst horizons and nature of Flows. Four megacryst marker horizons termed as Ml, M2, M3and M4 have been identified and this succession designated as North Sahyadri Group G.S.I and this entire succession further subdivided into eight different formations (Table 3.1) (Godbole et.al. 1996).

Table 3. 1 Lithostratigraphic succession (Godbole et.al. 1996)

Supergroup	Group	Subgroup	Formation
D		Mahableshwar	Mahableshwar
E			----------M4----------
C		Diveghat	Purandargad
C	NORHT SAHYADRI		Diveghat
A			
N		Lonavla	Karla Indrayani
			----------M3----------
T			
R		Kalsubai	Upper Ratanged
A			----------M2----------
P			Lower Ratangad
			----------M1----------

The lithounits present in the study area are completely aphanitic basalt. These are compact basalts with no gas cavities all along the exposure. The compact basalt of the study area show thick flows with nearly flat top. The rock is altered by weathering giving rock a brown to red colour due to iron oxide mainly along the joints. (Fig. 3.1) Fresh unaltered Basalt showing bluish grey colour is present at the core of jointed blocks and at places where openness of joints is negligible.

Fig. 3.1Compact Basalt exposed in the study area is altered by weathering along the joints

3.2 Identification of Discontinuities

The first step is the identification of set of discontinuities present in the area. A set of parallel joints of common origin is called a joint set. A few joint sets may often intersect forming characteristic patterns. They may intersect perpendicularly or obliquely creating joint systems. Presence of joint systems or joint sets gives a fragmental appearance when they are closely spaced and a blocky appearance when widely spaced. In the present study 3 set of joints J1, J2 and J3 have been identified, where J1 and J2 are near vertical and J3 is horizontal (Fig. 3.2). These joint set devide the rock into blocks of varying size as solutions moving along joints separate the blocks from the intact rock. The joint set J3 has developed in only upper part of the

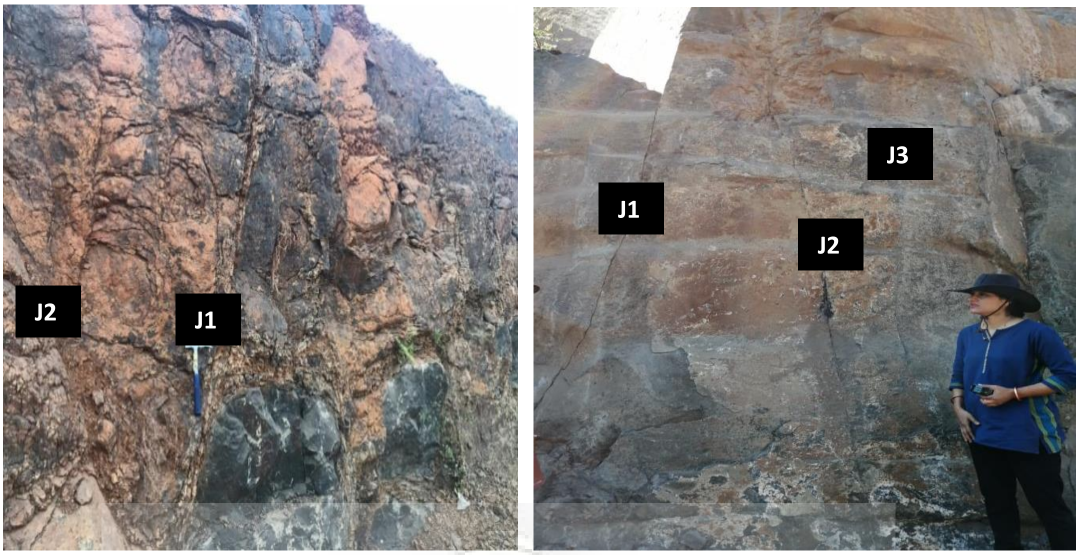


Fig. 3.2Three set of joints J1,J2 and J3 in the study area

3.2.1 Orientation of Discontinuities

The second step is the orientation of discontinuities which is given by the amount of dip (maximum inclination of discontinuity to the horizontal and its direction (the direction towards which the discontinuity is inclined). Strike (the direction of the line formed by the intersection of a rock surface with the horizontal plane) is always perpendicular to the dip. In the present study 3 set of joints have been identified, the first set J1 is showing a near vertical dip 85º -88º (only one joint showing a dip of 75º) and striking NE-SW. Table 3.2 is showing orientation of 3 set of joints in the study area-

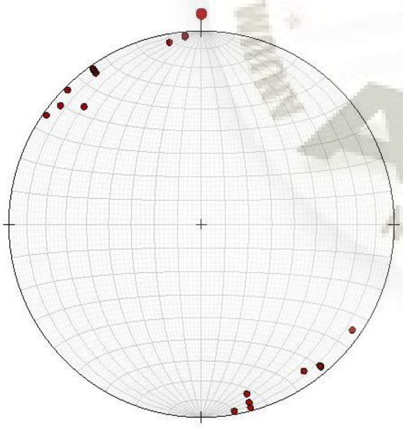
Table 3. 2 Orientation of 3 set of joints in the study area-

Sr no	Landslide type	Slope	Joint Set					
			Strike J1	J1	Strike J2	J2	Strike J3	J3
1	Boulders			75/135		75/46		0/00
2	falling due			85/130		75/20		0/00
3	to spheroidal			87/175		85/10		0/00
4	weathering	85/SE	NE-SW	87/145	NW-SE	70/15	N-S	0/00
5	around the			88/125		78/45		0/00
6	joints			88/135		75/10		0/00
7				85/170		80/15		0/00
8	Loose Blocks			80/345		86/255		0/00
9	are present			85/305		86/200		0/00
10				85/345		85/255		0/00
11	Solid rock,			85/320		88/245		0/00
12	Openness of	82/W	NE-SW	82/325	NW-SE	84/220	N-S	0/00
13	Joins is			86/345		85/245		0/00
14	negligible			86/320		88/230		0/00
15				88/350		85/225		0/00
16				88/345		86/225		0/00
17	Loose blocks develop due to spheroidal weathering			88/175		80/65		0/00
18	Development of blocks ,	80/SE	NE-SW	85/145	NW-SE	85/45		0/00
19	Rocks fall in the			86/145		85/45		0/00
20	upper portion			88/145		86/40		0/00

The pole diagram of this set of joints is showing two clusters on opposite quadrants as some joints dip steeply NW and some steeply SE(Fig. 3.4a). The second set of joint is also steeply dipping (70º -88º) with a strike NW-SE.

Fig. 3.3 Joint set J1 trending NE-SW and J2 trending NW-SE

The pole diagram of this set of joints is also showing two clusters on opposite quadrants as some joints dip steeply NE and some steeply SW(Fig. 3.4b). The third set of joints is horizontal striking N-S. These joints have developed only in the upper part of the formation and may be the result of unloading.



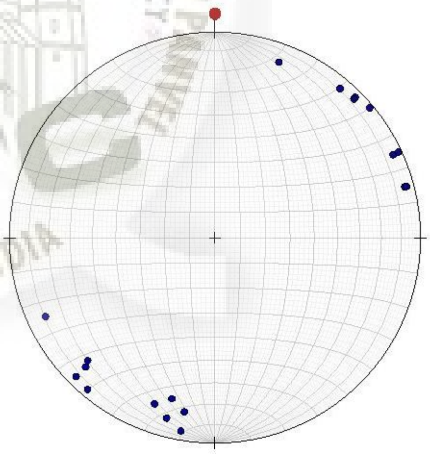


Fig. 3.4.(a) Pole diagram for joint set J1

Fig. 3.4.(b) Pole diagram for joint set J2

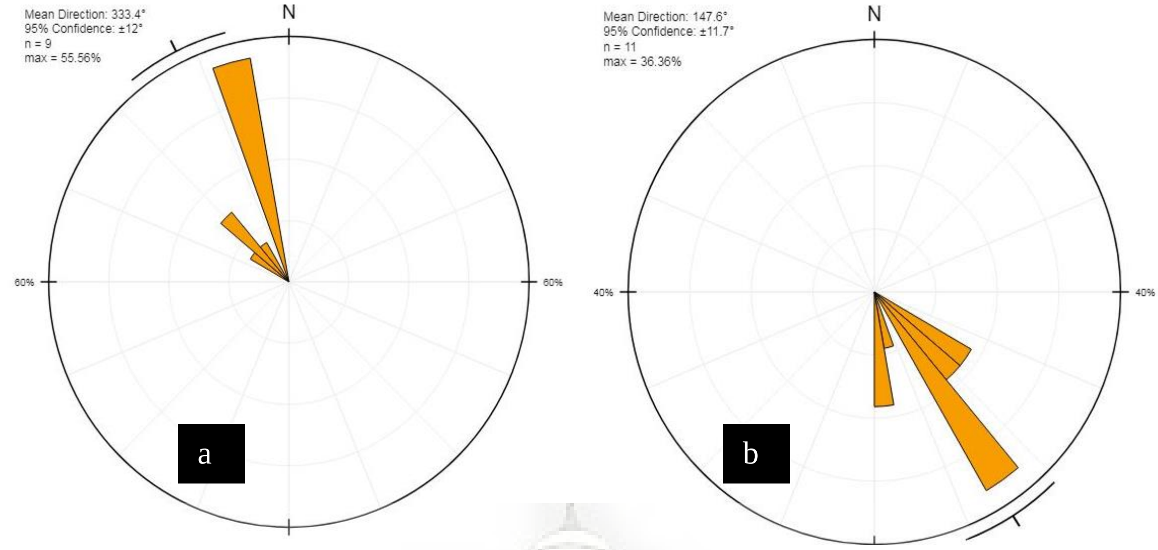


Fig.3.5 Rose Diagram for joint set J1 showing two oppositely diping planes

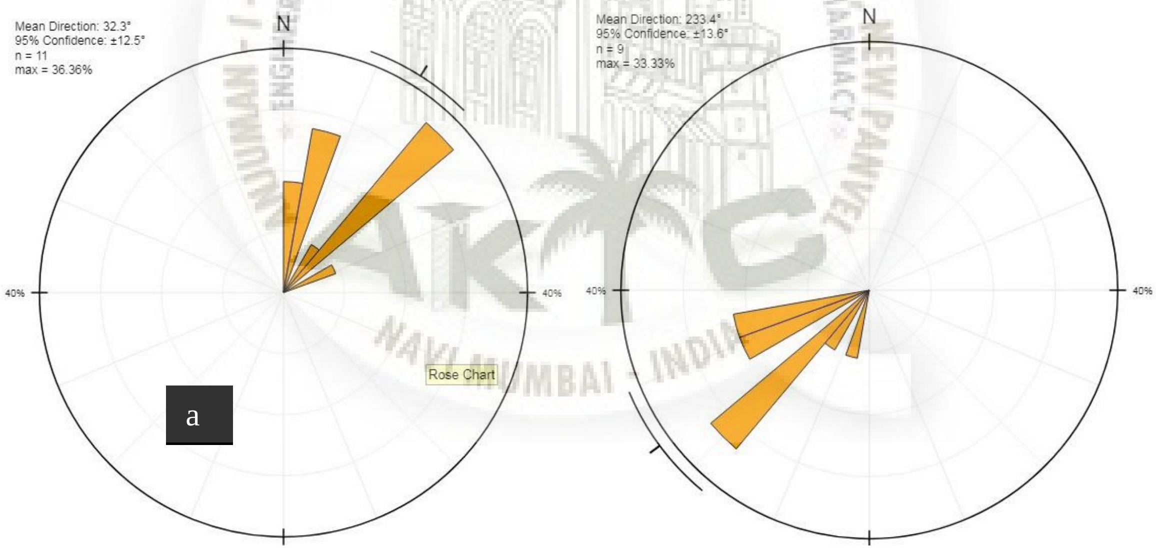


Fig. 3.6 Rose Diagram for joint set J2 showing two oppositely diping planes

3.3 **Description of Discontinuities**

3.3.1 **Joint Density and Joint Frequency**

Fracture density is based on the spacing between all natural fractures in an exposure. In our study for Joint set J1 and J2 from spot 2 to spot 7, the density and frequency increases as the number of joints per m length increases ranging from 1.8 -0.2m for J1 and 0.6m-0.3m for J2 (Table3.3)

Joint set J1 shows irregular density as the spacing is ranging between 1.2-1.95m from spot no 8 to spot no 11 showing less density and hence less frequency, then the spacing is 1.95 to 0.8m between spot no 11 to spot no 15 showing higher density and frequency. Joint set J2 shows irregular variation in density depending upon the spacing ranging between 1.5-3.7m.between spot 8 to spot 10 thereby showing less density and frequency. Spacing of 2-1.3m for spot no 11 to spot no 15 showing higher density and frequency.

For joint set J1 between spot no 17 to spot no 20 the density and frequency is low also the frequency is less. For joint set J2 number of joints reduces with a spacing ranging between 0.8 -2.3m from spot no 17 to spot no 18, therefore density and frequency both reduces.

3.3.2 **Spacing**

Spacing is a required input to several rock mass classification systems, it affects block size and geometry in the rock mass classification systems.For all spots spacing of joint set J1& J2 falls in the range between 0.3 to 1m indicating widely spaced and 1 to 3m very widely spaced. At spot no 10 for joint set J2 the spacing observed is greater than 3m indicating extremely widely spaced (compact rock). At spot 5 the observed spacing of joint set J1 and J2 is between 0.1 to 0.3m indicating moderately spaced (Table 3.3)

Table 3.3 Joint spacing data from the study area

SPOT NO	JOINT	SP1	SP2	SP3	SP4
1.	J1		2.3		
	J2		1.8-2.8		
	J3		1-1.8		
2.	J1		1.8-2		
	J2			0.6-0.8	
	J3		1-1.8		
3.	J1		1.8-2.9		
	J2			0.6-0.8	
	J3		1-1.8		
4.	J1			0.4-1	
	J2			0.7-0.9	
	J3		1-1.8		
5.	J1				0.15-0.2
	J2				0.3
	J3		1-1.8		
6.	J1		1.3		
	J2			0.8	
	J3		1-1.8		
7.	J1		1.35		
	J2		1-1.5		
	J3		1-1.8		
8.	J1		1.2		
	J2		1.5-1.7		
	J3		1-1.7		
9.	J1		1.1		
	J2		2.3		
	J3		1-1.7		
10.	J1		1.3-3		
	J2	3-3.7			
	J3		1-1.7		
11.	J1		1-1.95		
	J2		2-2.4		
	J3		1-1.7		

12.	J1		1.8		
	J2		1.4-2		
	J3		1-1.7		
13.	J1		1.2-2		
	J2		1.9		
	J3		1-1.7		
14.	J1		1.3		
	J2		1.6		
	J3		1-1.7		
15.	J1			0.8	
	J2		1.3		
	J3		1-1.7		
16.	J1		2.5		
	J2		2.3-2.2		
	J3		1-1.7		
17.	J1		1-1.2		
	J2			0.8-0.9	
	J3		1-2		
18.	J1		1.2		
	J2		1.2-2.3		
	J3		1-2		
19.	J1		1.3-1.4		
	J2		1.2.2.2		
	J3		1-2		
20.	J1		1.4-2.8		
	J2		1.3-2		

3.3.3 Continuity

A continuous joint or fracture is weaker and can cause more deformation than a short discontinuous fracture, therefore recording and identification of the more continuous fractures is an important aspect in the slope stability analysis. The descriptor for the continuity is given in the Table 3.4 (Goodman 1976)

Table 3.4 Fracture continuity descriptors

Alphanumeric descriptor	Descriptor	True spacing
C1	Discontinuous	Less than 3 ft (>1 m)
C2	Slightly continuous	3 to 10 ft (1 to 3 m)
C3	Moderately continuous	10 to 30 ft (3 to 10 m)
C4	Highly continuous	30 to 100 ft (10 to 30 m)
C5	Very continuous	Greater than 100 ft (>30 m)

The joints J1 and J2 it is continuous throughout the exposure and may be continued beneath the surface up to some depth and hence can be classified under the category C3 (10 to 30 ft). However joint set J3 is discontinuous.The continuity of the joint surface is in the direction of dip for J1 and J2 and in the direction of strike for joint set J3.Both ends of the joint can not be observed (Fig.3.7) on the exposure for joint set J1 and J2 and hence it is in category E2 according to the table 3.5 (Goodman 1976)

Table 3.5 Descriptor for recording fracture end

Alphanumeric descriptor	Criteria
E0	Zero ends leave the exposure (both ends of the fracture can be seen in the exposure).
E1	One end can be seen (one end of the fracture terminates in the exposure
E2	Both ends cannot be observed (two fracture ends do not terminate in the exposure).

Fig. 3.7 Field photograph showing continuity of joint

3.3.4 **Openness**

The openness is measured normal to the fracture surface. This aperture or openness affects the strength, deformability, and seepage characteristics. The descriptor for the openness is given in the table 3.6 (Goodman 1976)Joint set JI and J2 do not show any visible separation (NVS) from spot no 8-16 (Fig. 3.8a) J1, J2 and J3 are moderately to wide open at spot no. 1-7 and spot no 17 (Fig. 3.8b). The horizontal joint set has developed only in the upper part of the section on the right hand side of the road (spot no. 1-7 & 17-20) and falls in the open category (3 to 10 mm) table 3.7

Table 3.6 Fracture openness descriptors

Alphanumeric descriptor	Descriptor	Opennesss
00	Tight	No visible separaation
01	Slightly Open	Less than 0.003 ft [1/32 inch (in)] (<1 mm)
02	Moderate Open	0.003 to 0.01 ft [1/32 in to 1/8 in] (1 to 3 mm)
03	Open	0.01 to 0.03 ft [1/8 to 3/8 in] (3 to 10 mm)
04	Moderately wide	0.03 ft [3/8 in] to 0.1 ft (10 to 30 mm)
05	Wide	Greater than 0.1 ft (>30 mm) (record actual openness)

Table 3.7 Fracture openness data from the study area

JOINT	O0	O1	O2	O3	O4	O5
J1	NVS Spot no 8-16				0.01	0.05
					0.01	0.1
					0.02	
					0.02	
					0.02	
J2	NVS Spot no 8-16				0.02	
					0.01	
					0.03	
J3	NVS Spot no 8-16					

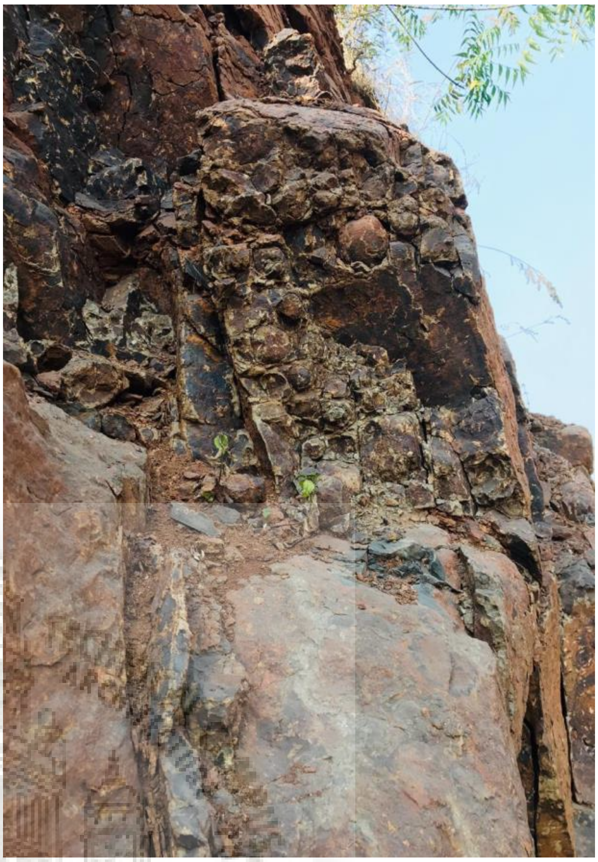


Fig. 3.8(a) Joint sets show negligible openness

Fig. 3.8(b) Widely open joints at spot no 6

3.3.5 **Filling**

Presence or absence of coatings or fillings affects strength and permeability of fractures. It is also necessary to distinguish between types, alteration, weathering, and strength and hardness of the filling material while assessing the role of discontinuity in failure

.

3.3.6 **Thickness**

Table 3.8 Fracture filling thickness descriptors (Goodman 1976)

Alphanumeric descriptor	Descriptor	Thickness
T0	Clean	No film coating
T1	Very thin	Less than 0.003 ft [1/32 inch (in)] (<1 mm)
T2	Moderately thin	0.003 to 0.01 ft [1/32 in to 1/8 in] (1 to 3 mm)
T3	Thin	0.01 to 0.03 ft [1/8 to 3/8 in] (3 to 10 mm)
T4	Moderately thick	0.03 ft [3/8 in] to 0.1 ft (10 to 30 mm)
T5	Thick	Greater than 0.1 ft (>30 mm) (record actual thickness)

The observed thickness of the fillings observed in the area of study falls under T1-T3 i.e. very thin to thin. The joints from spot no 10-16 falls under the T1 category (table 3.8).

3.3.7 **Fracture Filling(mm)**

Table 3.9 Fracture filling data from the study area

JOINT	T1	T2	T3
J1	0.75	1.5	4
	0.75	2	5
	0.8	1	
	0.25	2	
		2.5	
		1	
		1.5	
J2	0.75	1.5	
	0.5	2	
	0.25	1	
	0.9	2.5	

	0.25		
JI & J2	0.8	1.5	3
		1	4
		1	3
		1	
		1	
		2	
		1	
J3	-	1.5	3
		2.5	

From the above data it is clear that the filling in Joints J1,J2 and J3 show very thin to thin filling i.e. from <1 mm to 10 mm(table 3.9).

3.3.8Composition

The mineralogical classification of fillings is important to convey the physical properties of fractures that may be significant criteria for design. The present study show that the joints from spot no 10-17 show quartz filling (Fig. 3.9.(a)) while are other joints show filling by weathered material mainly the oxidized product form by weathering of iron bearing minerals in Basalt(Fig. 3.9.(b)). Clay is also present in small amount as it is clear from the vegetation along the fractures, the clay may swell or cause swelling pressures and cause more opening of joints.

Fig. 3.9.(a) Field photograph showing thin layer of quartz along joints

Fig. 3.9.(b) Field photograph showing weathered material along joints

3.3.9 **Weathering/Alteration along Joints**

Most of the joints wherever the openness is open (O3) to wide (O5) are showing varying degree of alteration and weathering. The iron-rich minerals in Basalt have oxidised to give brown to red colour staining to the rock due to formation of iron oxide (Fig.3.10a) The joint set from spot no 10-17 are showing no staining in the lower part as there is negligible openness along the joints (Fig.3.10b).

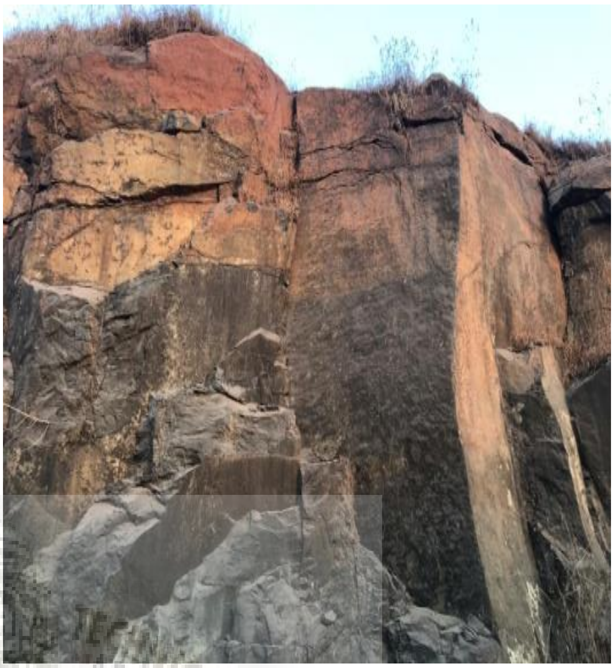


Fig. 3.10 Field photograph showing Weathering/Alteration along Joints

3.3.10 Moisture

The joint surface is generally dry but shows evidence of water flow such as staining, leaching, and vegetation. Some of the joint surfaces show seepage and is wet with occasional drops of water(Fig.3.11).

Fig. 3.11 Flow of water along the joint

3.3.11 **Roughness and Waviness of joint surface**

All the joint set show smooth surfaces, it is not striated or slickensided and falls undear the slightly rough or smooth category of the waviness according to the table 3.10

Table 3.10 Fracture roughness descriptors (Goodman 1976)

Alphanumeric descriptor	Descriptor	Opennesss
R1	Stepped	Near-normal steps and ridges occur on the fracture surface.
R2	Rough	Large, angular asperities can beseen.
R3	Moderately rough	Asperities are clearly visible and fracture surface feels abrasive
R4	Slightly rough	Small asperities on the fracture surface are visible and can be felt
R5	Smooth	No asperities, smooth to the touch.
R6	Polished	Extremely smooth and shiny.)

3.3.12 **Hardness**

Field Index Tests

Schmidt Hammer tests can is used to estimate the hardness/strength of the rock surfaces along a discontinuity by orienting the hammer perpendicular to the surface. Direct testing on rock was done and the reading measured from both the weathered and fresh surfaces (Fig.3.12). Five readings were taken at various locations on each surface. The two lowest values discarded and the remaining three values averaged to get the rebound number. It is clear from the (Fig.3.13) that the compressive strength is very high for the un weathered rock mass whereas it is greatly reduced along the weathered and fractures surfaces.

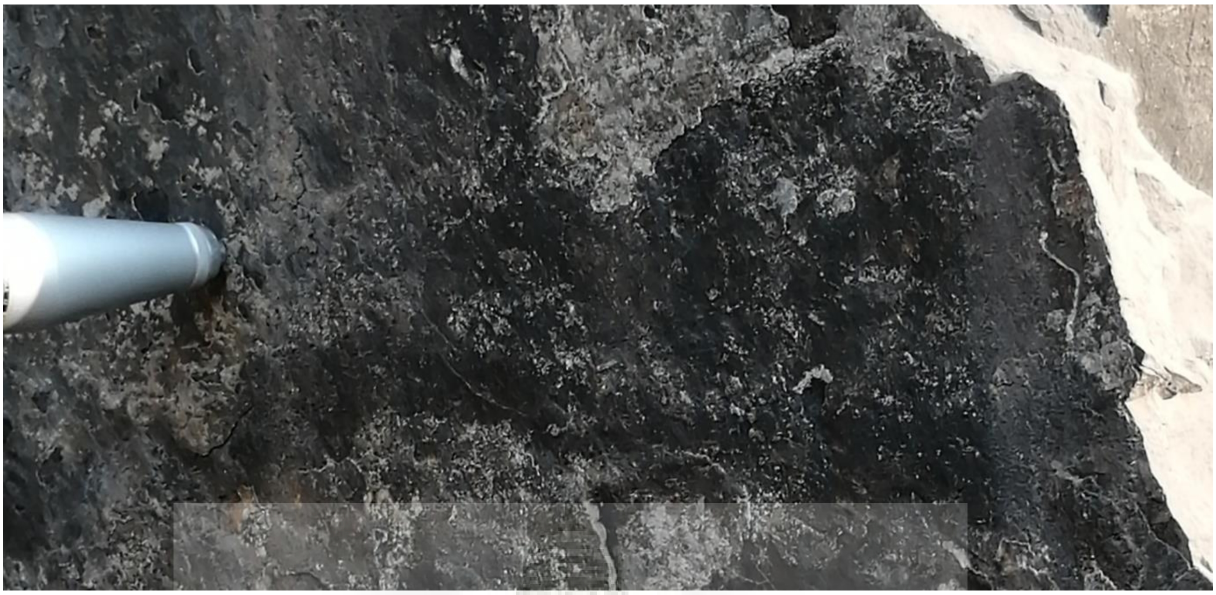


Fig. 3.12 Schmidt Hammer tests at the field

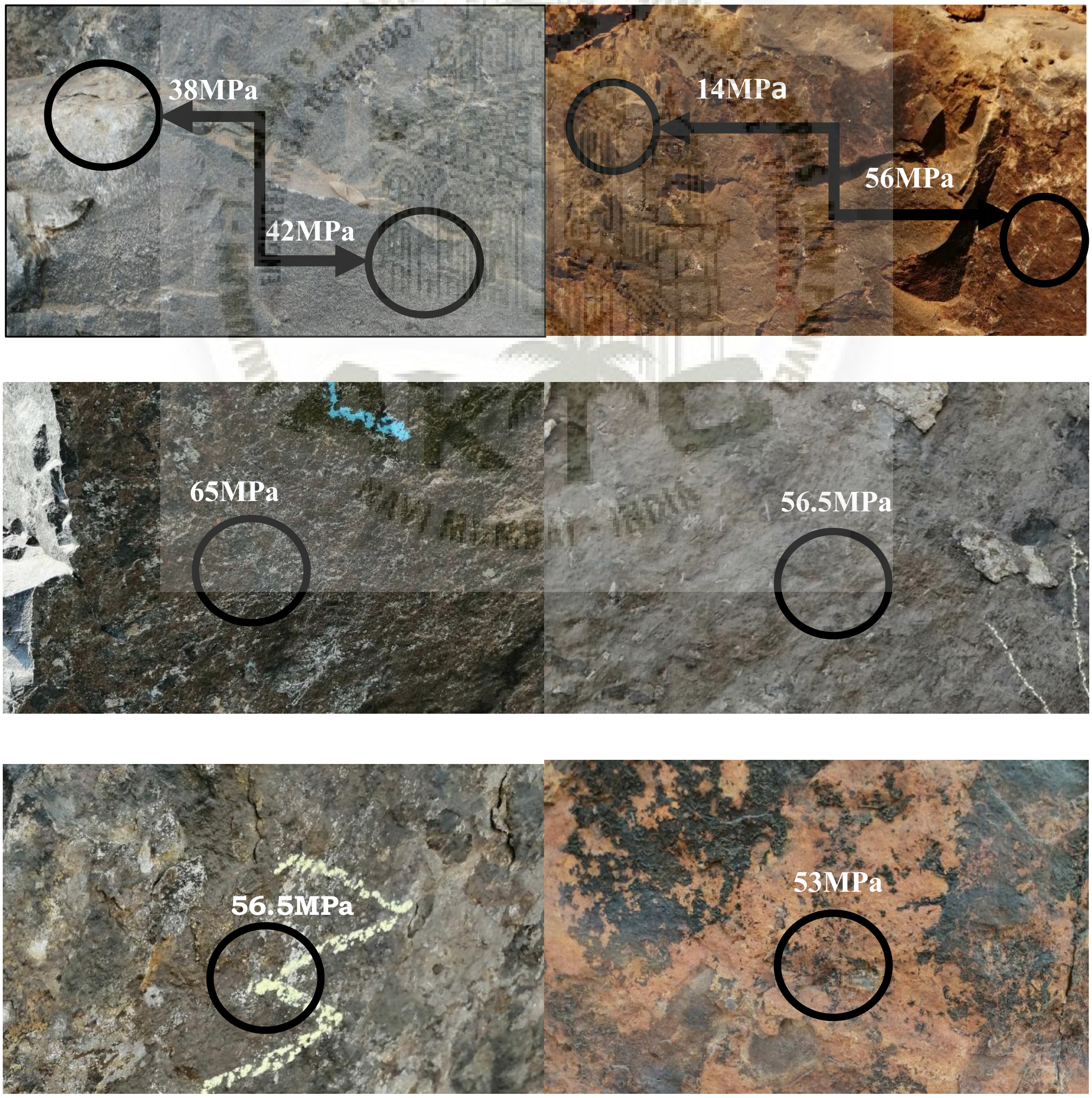


Fig. 3.13 UCS at different locations in the field

3.4 **Spheroidal Weathering of Basalt**

Basalt is prone to weathering due to iron rich minerals which oxidize rapidly in water and air staining the rock in rust colour. As the rock of the study area is traversed by three set of joints which has broken the rock in to blocks. The intersecting joint set that control the slow movement of water along the joints and attack the rock from all sides result in to formation of concentric shells of rock (Fig.3.14). The volume of fresh rock reduces slowly and the shape of the block becomes more spherical leading to the spheroidal weathering. The rounded boulders formed by this progressive decomposition can be seen in the spot no 1-7. The spheroidal weathering indicate extreme weathering resulting into onion skin like morphology of altered layers enveloping a core of fresh rock

Fig.3.14 Spheroidal Weathering

3.5 **Stereographic Projection**

The stereographic projection is a very fast and useful technology for many structural problems. A useful description of the stereonet is given by Senanayke S. 2013 and described it as a methodology used in structural geology and engineering to analyze orientation of lines and planes with respect to each other. The stereonet is a type of standardized mapping system that allows us to represent various angles in 3D space on a 1D paper. They are used for analysis of various field data such as bedding attitudes, joint planes, hinge lines and numerous other structures. In structural geology, we use the bottom half or hemisphere of the spherical projection.

stereonets represents half a sphere where the cross section has 360-degrees. The pole to the plane ("dip pole") is at 90-degrees to the plane. Planes are lines are drawn on stereonets as they intersect at the bottom of the sphere Senanayke S. 2013). (Fig.3.15).

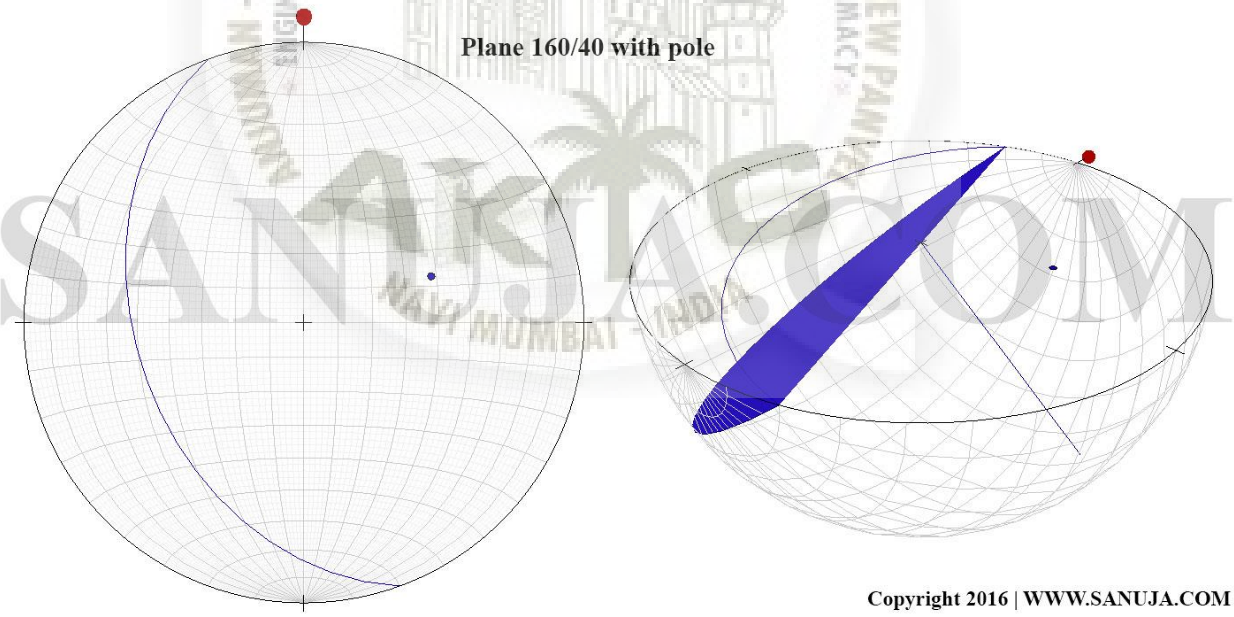


Fig. 3.15 Representation of a plane in stereographic net (Senanayke S. 2013)

3.5.1 **Stereographic Net**

A stereographic net is simply a stereographic projection of the lines of latitude and longitude of a sphere on to a central plane (Fig.3.6). A description of various features of the stereographic net is given by Senanayke S. 2013 as follows-

North: It is the true North which is denoted by the azimuthal angle of 000-degrees on the primitive. All strike angles are measured with respect to the true North.

Primitive: It is the outer most circle is the primitive. It is at 90-degrees from the center of the stereonet. Primitive circle is also a great circle but, it contains N, E, S and W directions at 000, 090, 180 and 270 degrees intervals.

Great circle: A circle on the surface of the sphere made by the intersection with the sphere of a plane that passes through the centre of the sphere. The great circles run North-South (longitudinal) or up-down and bisect the sphere precisely. The great circle is divided in to 360 degrees (like 360 degree protractor).

Small circle: A circle on the surface of a sphere made by the intersections of a plane that does not pass through the centre of the sphere. Small circles run left-right (latitudinal) on the stereonet and are perpendicular to the great circles.

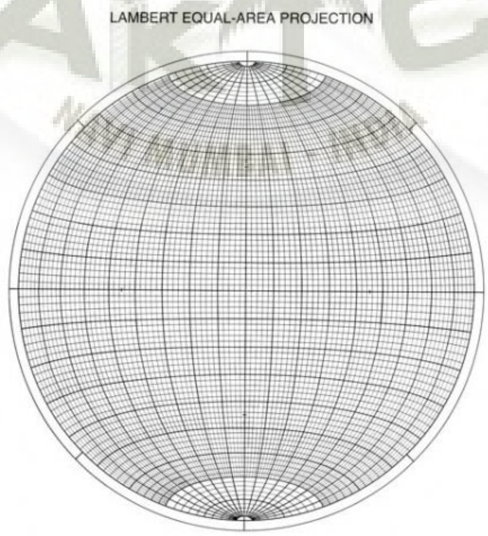


Fig. 6 Stereographic net

3.6 **Interpretation of Field Data**

Duncan & Christopher 2004 has given a detailed account of stability of rock slopes affected by the discontinuities such as bedding planes, joints and faults. The properties of discontinuities such as persistence, orientation, spacing, openness, roughness etc are important in deciding the slope's stability. As the joints are known as plane of weakness, the failure generally occurs along these surfaces. Geological studies play a very important role in the rock slope stability analysis and it involves two steps- (i) Determination of properties of discontinuity, (ii) Determination of influence of discontinuity of slope stability which involves studying the relationship between the orientation of the discontinuity and the face. The objective of this study, which istermed *kinematic analysis*, is to identify possible modes of slope failure (Duncan & Christopher 2004)

Orientation of a line:

The intersection of two planes defines a line in space that is characterized by a trend and plunge. The plunge is the dip of a line and the trend is the direction of the horizontal projection of the line measured clockwise from north, and corresponds to the dip direction of a plane. In the stereographic projection, this line of intersection is defined as the point

where the two great circles cross .The two intersecting planes may form a wedge shaped block as shown in Fig.3.17, and the direction in which this block may slide is determined by the trend of the line of intersection.

If the angle between the planes is small, a narrow, tight wedge will be formed with a higher factor of safety compared to a wide, open wedge in which the angle between the planes is large.

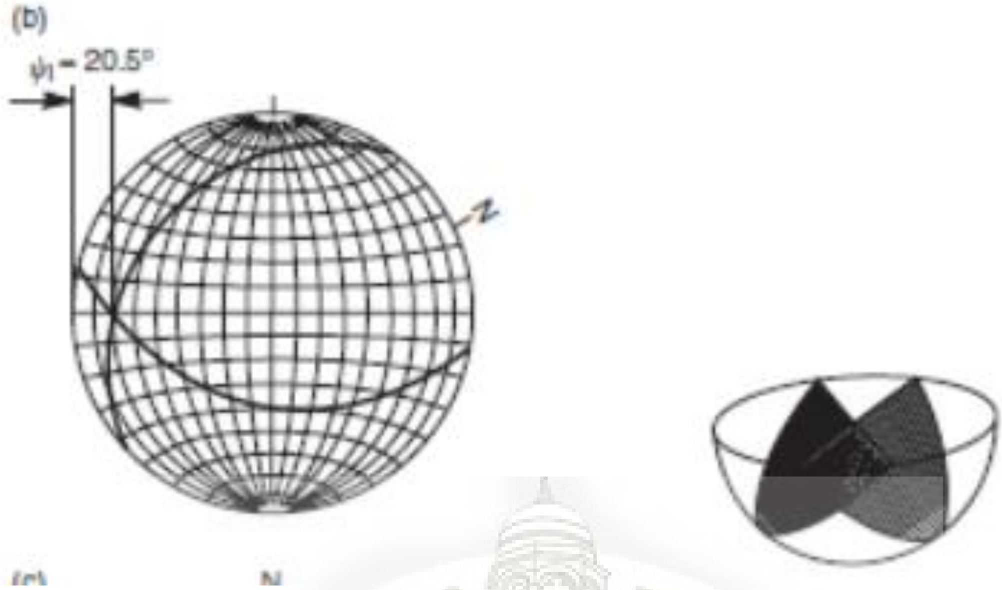


Fig.3.17 Formation of wedge shape by intersection of two planes (Duncan & Christopher 2004)

3.7 **Kinematic Analysis**

Once the data is plotted on the stereo net, it is easy to identify the type of block failure and the plot can be used to give direction of the block slide and stability conditions of the concerned area. The determination of conditions of wedge failure from stereo plots have been given by **Duncan & Christopher 2004.** For either plane or wedge failure to take place, it is fundamental that-

The dip of the sliding plane in the case of plane failure, or the plunge of the line of intersection in the case of wedge failure, be less than the dip of the slope face (i.e. $\psi i<\psi f$) (Fig. 3.18 a&b). That is, the sliding surface "daylights" in the slope face.

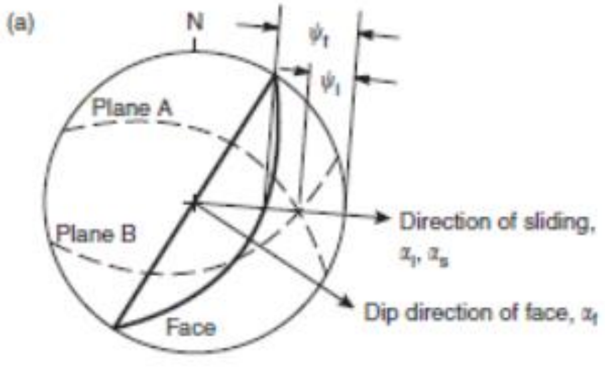


Fig.3.18Conditions of Plane and Wedge Failure (Duncan & Christopher 2004)

From the((Fig.3.5(a&b)) rose diagram the orientation of mean J1 (58/85) and J2 (122/85) plane has been taken and plotted on the stereo net. The angle between J1 and J2 is 54º, the intersection line has a trend 90 and plunge 81º(ψi) and the dip of slope is 85º (ψf) so the joint set J1 and J2 could together form a wedge failure that would slide in the direction of trend. As the slope face is parallel to the direction of sliding and the pole of line of intersection daylights on the face i.e. ψi<ψf (Fig.3.19a)

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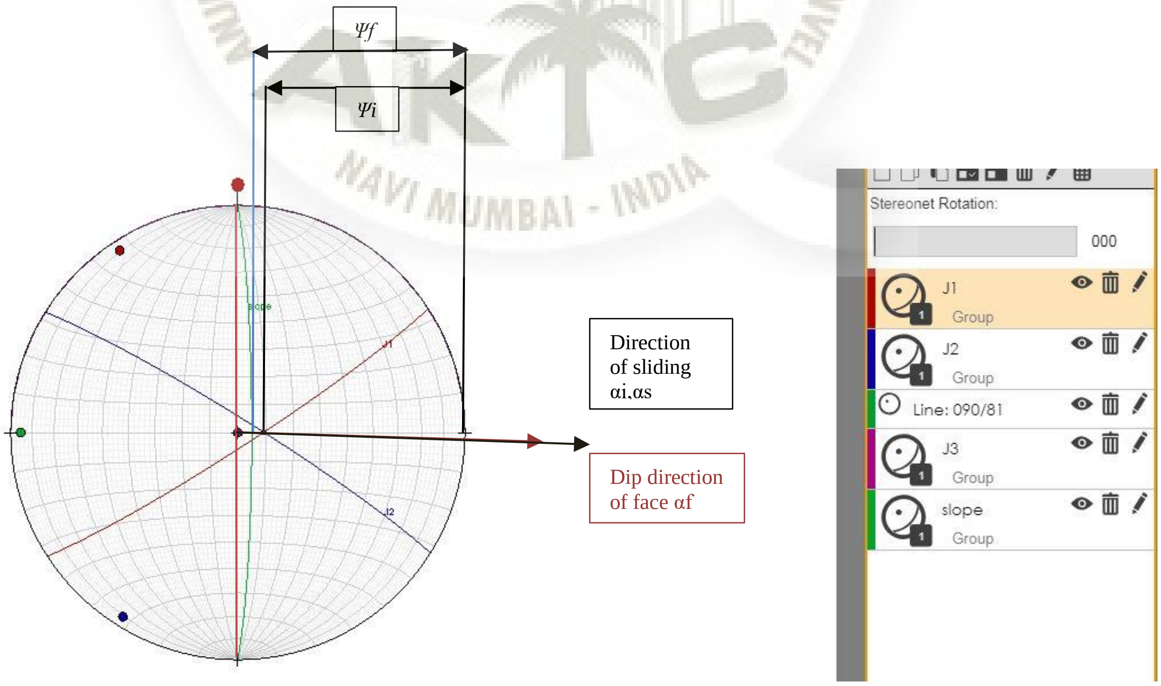

Fig.3.19(a) Wedge failure will occur along the line of intersection (dip direction αi) on slope with dip direction αf as the of sliding daylights on the slope face

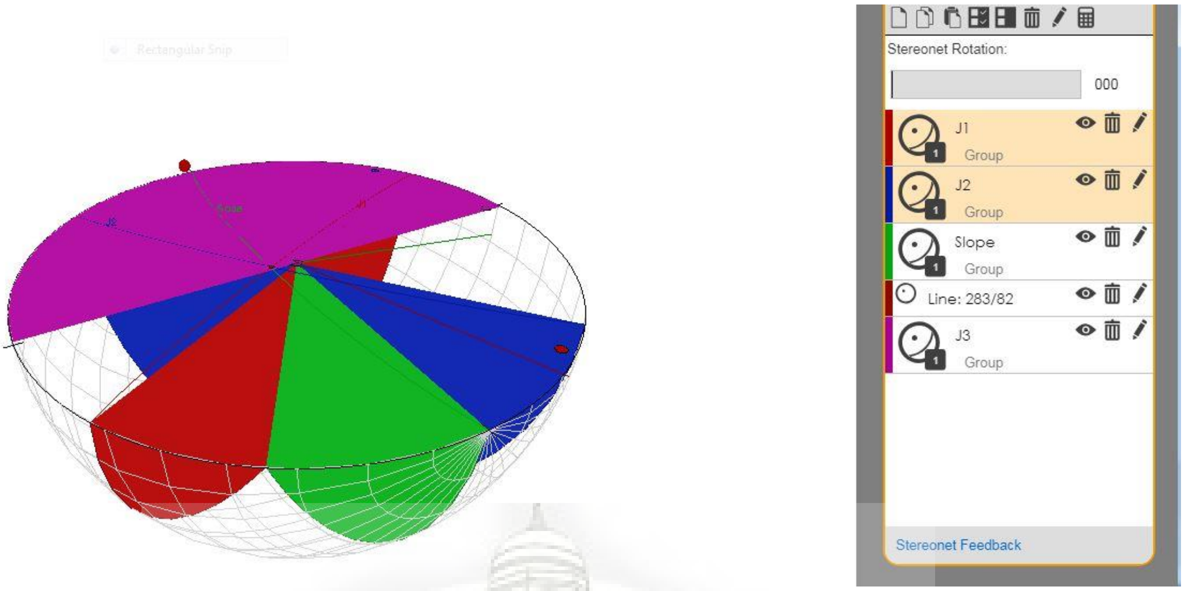

Fig. 3.19 (b) 3D of stereographic projection

Fig. 3.19((c) Wedge shape block formation by intersection of J1 and J2

On the left hand side of the road the J1 and J2 are perpendicular to each other and the intersection line has a trend 283 and plunge 82°(ψi) and the dip of slope is 80° (ψf) so the joint set J1 and J2 could together form a wedge but it would not fail as the pole of line of intersection does not daylights on the face i.e. $\psi i > \psi f$ (Fig.3.20a)

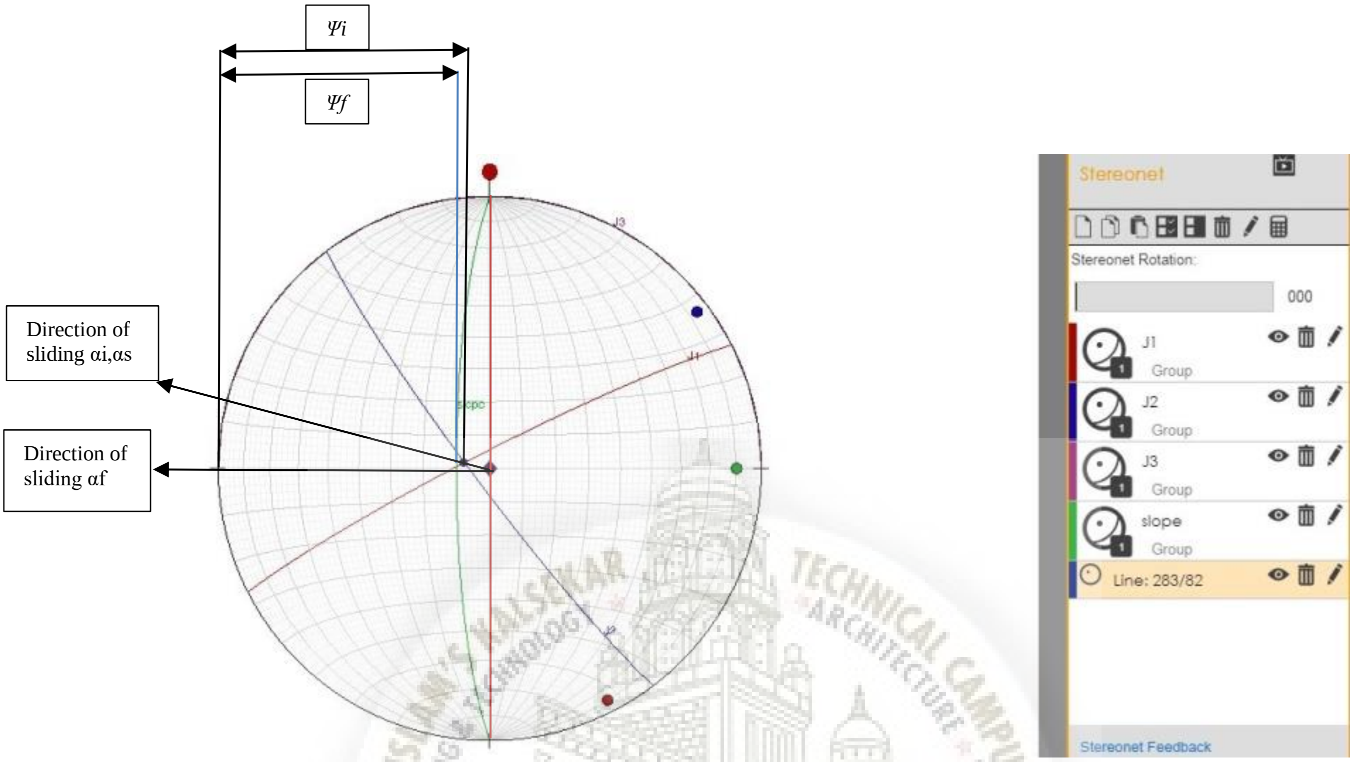

Fig.3.20.(a) Wedge failure will not occur along the line of intersection (dip direction αi) on slope with dip direction αf as the direction of sliding does not daylights on the slope face

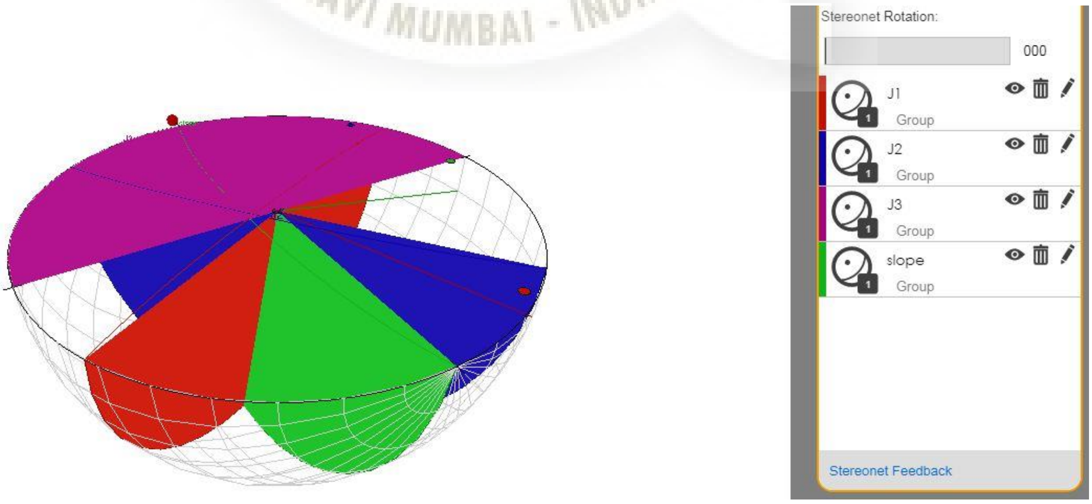

Fig.3.20.(b) 3D of stereographic projection

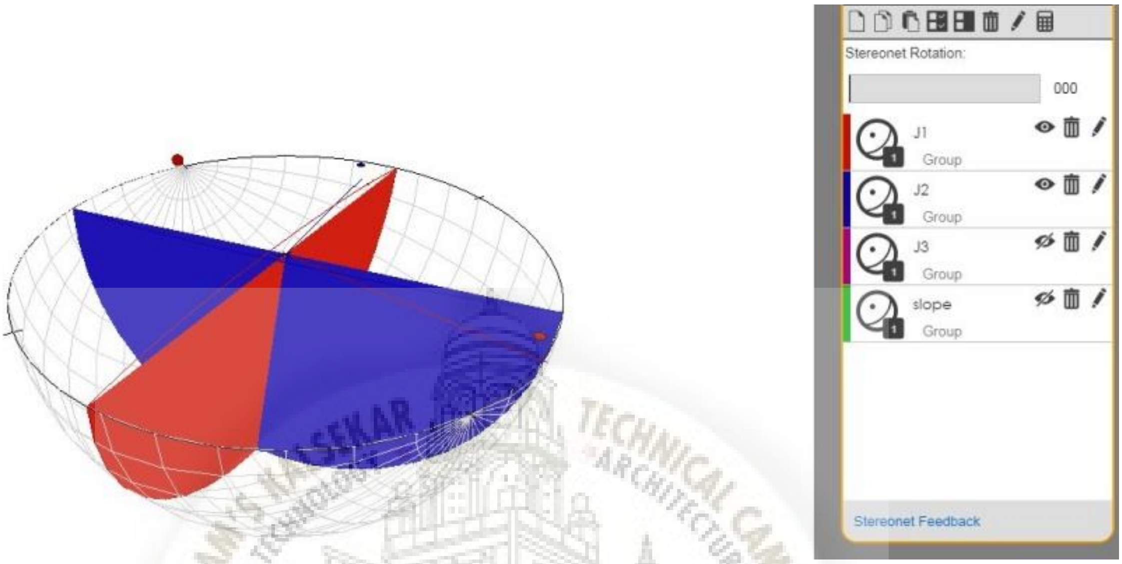

Fig.3.20.(c) Wedge shape block formation by intersection of J1 and J2

CHAPTER 4

Discussion and Conclusion

4.1 Effect of discontinuities on slope stability

Landslides represent a normal geological process associated with weathering, erosion and denudation and contribute to the general process of lowering of the land surface. This natural process however is controlled by underlying geological conditions of a particular area. Orientation of discontinuities with respect to slope is the most important factor however persistence, spacing and openness are the other factors which influence stability. Application of geological data of discontinuities such as bedding planes, faults, identification and characterization of number of discontinuities is very important for slope stability analysis and should be included in the design. In the present case study the rock type under investigation is compact Basalt and is free from gas cavities. It is very fine grained and homogeneous in nature except very thin bands of iron rich material. It is homogeneous and nearly 20m thick from the road cut and is representing a single lava flow. Three set of joints identified in the area are J1, J2 and J3, wherein J1 and J2 are vertical and J3 is perfectly horizontal (Fig.3.2). The joint set J3 has been developed only in the upper part of the formation which indicates that these are the sheet joints which developed by unloading of the overlying rock mass. It is clear from the data that from spot no 1 to 7 the frequency of joint set 2 is high in comparison to the Joint set J1 and J3, whereas from spot no 8-10 all the joints fall in the category to very widely spaced to widely spaced and a few even in the extremely wide spaced. Due to this the rock mass is divided in to more number of blocks from spot no 1-7 in comparison to other spots and hence showing high degree of weathering as the joints are the openings which allow the rain water to percolate downward and cause weathering.

The persistence of the joints is very high, and both the ends of the joints do not terminate in the exposure (Fig. 3.7). This may be an unfavourable condition but except from spot no 1-7 and 17-18 the openness is negligible due to which water can not percolate through joints and cause weathering. The effect of weathering due to joints can be clearly seen in the varying grade of weathering in the left hand side and right hand side rock formation (Fig. 3.9 a&b). Along the right hand side section the joints are closely spaced and Joint set J3 is more developed in the upper part, the rock is highly weathered and showing spheroidal weathering at the spot no 1-7 (Fig. 3.14) The right block show the filling of joints by weathered material whereas the left block show thin film of quartz. This compositional variation itself is making the left block more stable. The moisture is more in the open joints in the right hand side sequence which is clear from seepage of water and presence of vegetation whereas the left hand side sequence is completely dry. The Schmidt Hammer test clearly show high compressive strength for the solid rock mass whereas the strengths is greatly reduced in the areas affected by weathering in the vicinity of joints (Fig. 3.13).

Kinematic analysis of the joints on the left hand side of the road suggest wedge failure as the slope face is parallel to the direction of sliding and the pole of line of intersection daylights on the face i.e. $\psi i < \psi f$ (Fig.3.19a) There is more risk of failure at the spots 1-7 and 17-18 as the joint frequency is high at these spots which has led to the formation of highly weathered rock(Fig.3.14). However the rock is solid despite the presence of joints at the spot no 18 to 20 owing to low frequency and less openness of joints in these spots only a thin film of staining is present along the joints and failure will not take as the plunge of line of intersection (82º) is more than the dip of the slope (80º).The kinematic analysis of the joint data from spot no 8-16 show that J1 and J2 are perpendicular to each other and forming a wedge but this slope is stable as the plunge of line of intersection does not daylights on the face i.e. $\psi i > \psi f$ (Fig.3.20a). The stability of this face is further strengthen by the fact that very little weathering has taken place and restricted only to upper part of the exposure owing to the widely spaced joints and negligible openeness of the joints.

4.2 Conclusion:

The presence of discontinuities in the form of joints have affected the strength of the compact Basalt exposed in the area up to great extent. The detailed investigation of various parameters of joints have led to the conclusion that the rocks have suffered varying degree of alteration and weathering depending upon the spacing, frequency, openness and continuity of joints. It can be concluded that the spots 1-7 which are on the upper right side of the road are susceptible to wedge failure as the rock here is highly weathered. Closely spaced joints have formed a network and increased the rock mass exposed to weathering by providing pathway for the water to move along them. The wide opening of the joints has accommodated more water and formation of clay along the openings has widen the zone of weathering. Kinematic analysis has also revealed unstable conditions due to orientation of joints for the right hand side slope (spot no 1-7 and 17-20) as the sliding surface daylight in the slope face. Whereas the same rock type on the left hand side poses no risk of slide as the sliding surface does not daylight in the slope face. The extremely widely spaced joints and negligible openness has contributed to the strength of the rocks from spot no 8-16. Almost all rock slope stability studies should address the structural geology of the site to assess the cause and mode of failure and if the conditions are unfavorable the slope angle can be modified to make it safe.

It is clear from the above studies that geological conditions and presence of discontinuities play a very important role in the stability of slope. Kinematic analysis is a very useful and quick method in assessing the mode of failure along the slopes and should be included in the design of rock slopes on civil projects to prevent loss of lives and property.

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Submitted in partial fulfilment of the requirements

of the degree of

Bachelor of Engineering

by

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