STABILITY ANALYSIS OF CUT SLOPE ALONG THE ROAD ALIGNMENT

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IN

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Submitted by:

KM Sakshi

2K20/GTE/11

Under the Supervision of

Prof. KONGAN ARYAN

DEPARTMENT OF CIVIL ENGINEERING

DELHI TEHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering**)**

Bawana Road, Delhi-110042

May 2022

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering**)**

Bawana Road, Delhi-110042

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I, **KM SAKSHI, 2K20/GTE/11**, student of M. Tech (Geotechnical Engineering), hereby declare that the project dissertation titled **"Stability Analysis of Cut Slope Along the Road Alignment"** is submitted to the Department of Civil Engineering, Delhi Technological University, Delhi, by me in partial fulfillment of requirement for the award of degree of **Master of Technology (Geotechnical Engineering)**. This thesis is original work done by me and not obtained from any source without proper citation. This project work has not previously formed the basis for award of any degree, diploma, fellowship or other similar title or recognition.

Place: Delhi **KM SAKSHI**

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DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering**)**

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that project dissertation titled **“Stability Analysis of Cut Slope Along the Road Alignment”** submitted by **KM SAKSHI, 2K20/GTE/11,** Department of Civil Engineering, Delhi Technological University, Delhi, in partial fulfillment for the award of degree of Master of Technology, is a project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

Supervisor

Prof. KONGAN ARYAN

CIVIL ENGINEERING DEPARTMENT

Delhi Technological University,

Delhi-110042

ABSTRACT

The current study used several geotechnical parameters of rock slope sections to analyse the stability of cut slope along the road alignment. The project's goal is to conduct a rock mass slope stability analysis. Four different heights of open cut slopes in rock are mentioned throughout the study. It comes across (Overburden and Weathered Rock). To ensure that the entire cut slopes are stable, FoS will be obtain. If the unsupported slope's FOS is less than desirable, suitable support system shall be used and it will be reanalyzed to achieve desired FOS. SLIDE 6.0 is a two-dimensional programme used for slope stability and assesses the safety factor of circular and non-circular slope failure in soil and rock slopes. This project includes critical sections for cut heights of 8m, 16m, 24m, and 32m. Roclab software was used to compute the Mohr Coulomb fit rock mass for both Overburden and Weathered Rock.

Keywords: Cut slope stability. Factor of safety (FOS). SLIDE 6.0 software. Roclab software. Hoek Brown criteria

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TABLE OF CONTENTS

LIST OF TABLES

PAGE NO.

LIST OF FIGURES

PAGE NO.

List of Graph

CHAPTER-1
INTRODUCTION

1.1 General

Slope failure is a common calamity in several countries, particularly when incline slopes are drastically reduced for development area. The majority of man-made slope failures are the result of poor design such as geometric design problems like slope inclination and height, as well as an inability to anticipate load and soil resistance. On natural slopes, excavation activities can cause the slope face to bend, decreasing shear strength and increasing the risk of slope failure. If no improvements are performed on the cut slope, the movement may continue. Slope stability has become one of the most difficult challenges in the construction industry due to the geography and climatic circumstances. Earthworks, hill roadways, railway lines, embankments, dams, open-cut mining, reservoirs, and coast slope stability are only a few examples of slope engineering uses. Failure of slope is the most common natural disaster that causes substantial property and life loss.

The slope's stability is greatly influenced since the resisting force, is weaker than the driving force. The major objective of the present work is to evaluate slope stability of cut slopes at various heights using the SLIDE 6.0 software. A soil wedge that has been strengthened with a structural element such as a soil nail, geo-fabric, a pre-stressed anchor, or the other material can be tested using SLIDE 6.0. Because of the extensively fractured characteristics of rock mass, the investigation used the curvilinear generalized Hoek-Brown (GHB) failure criterion. Using Bishops and Janbu methods, the critical factor of safety (FoS) for each slope was established, and correction actions were recommended as needed.

The direction of the discontinuity in the rock mass has an impact on slope stability. Due to randomly positioned discontinuities in the rock mass, failure of slopes along the road cut may occur. As a result, determining the direction of the adversely oriented discontinuity is crucial. According to oriented discontinuities such as joints, faults, shear zones and bedding planes, the mode of slope failure might be planer, wedge, or topple.

1.2 Types of slope failure in geotechnical engineering

1.2.1 Rotational failure

When failure occurs due to rotation of soil mass, the failing slip surface will start to move outwards and downwards. When the slope surface curves as a result of rotation by a slip surface. Face, base, and toe failures are all possible scenarios. Toe failure occurs whenever the collapsing surface passes through the slope's toe.

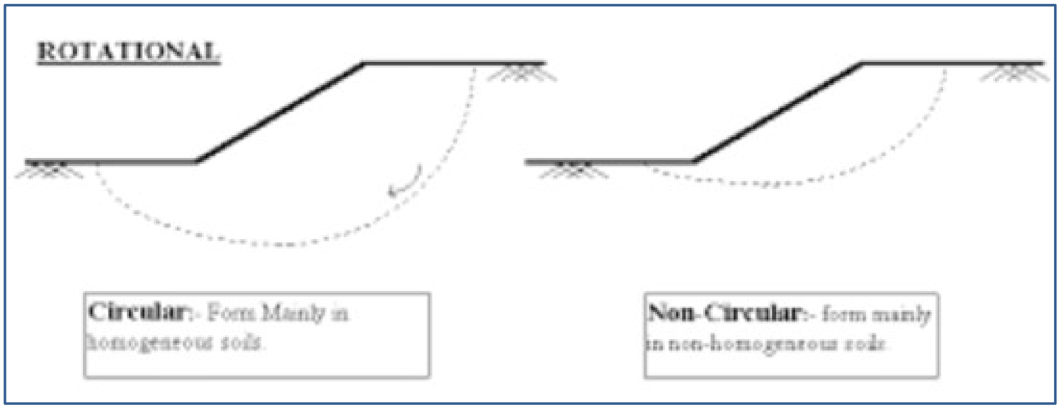


Figure-1: Circular and Non-Circular failure

Rotational failure can take place in three different modes. However, this happen with the loose sand of soft medium to soft strata and might be with pore water pressure and excessive stress induced in the material.

- Failure of base
- Failure of toe
- Failure of face or slope

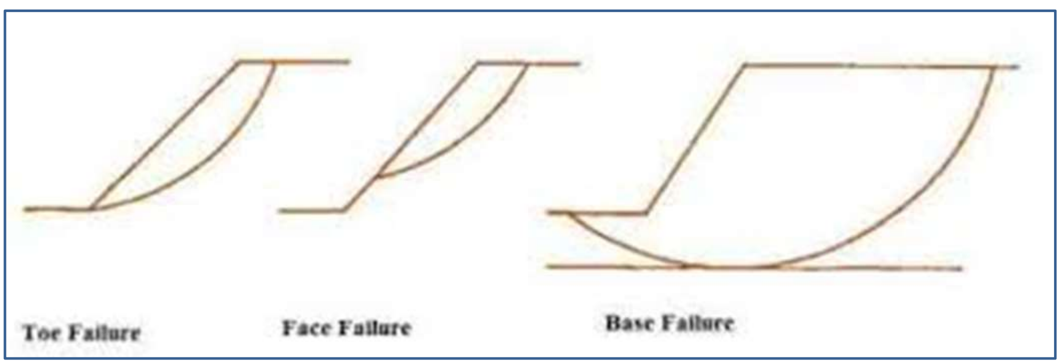


Figure-2: Three Different Rotational Failure

1.2.2 Translational failure

An infinite slope or semi-infinite slope has no specified boundaries/limitations and assumes that the soil beneath the free surface has the same properties and depth as the slope. An infinite slope's top layer will form an uniform slip surface, which is called as a transverse failure. Translational failure can be detected using layers of slope materials.

1.2.3 Compound failure

Compound failure is formed due to a combination of rotation and translation sliding failures. As the name implies, failure occurs when the slip surfaces curves both at ends but has a uniform or flat center point. When a firm soil grade develops from a sufficient depth from the toe, the slip surface may become flat.

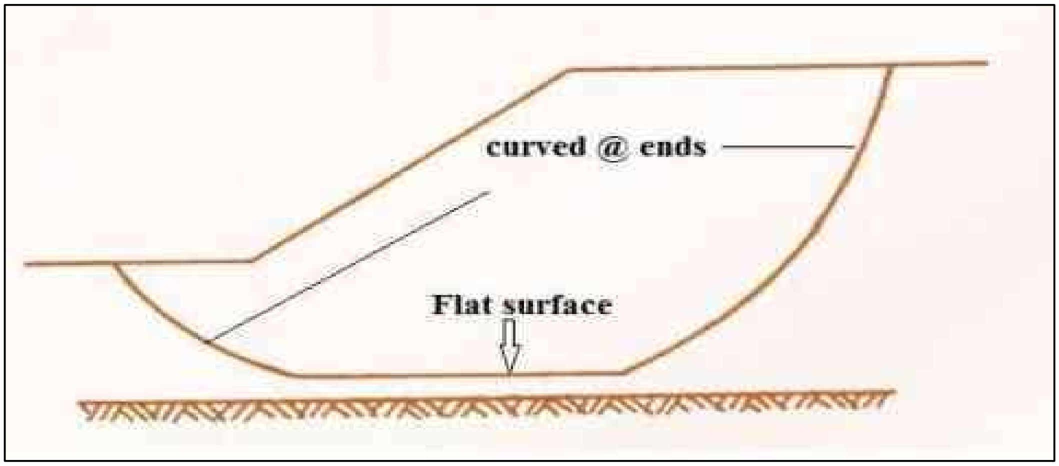


Figure-3: Compound failure

1.2.4 Wedge failure

When a plane is inclined wedge failure is also known as planes or blocks failure, occurs. When the soil has unstable layers or joints that arise as the slope is formed from two non-compatible materials, for example, the slope can collapse.

The main difference between a wedge and a translation collapse is that a wedge can happen on infinite or finite slopes.

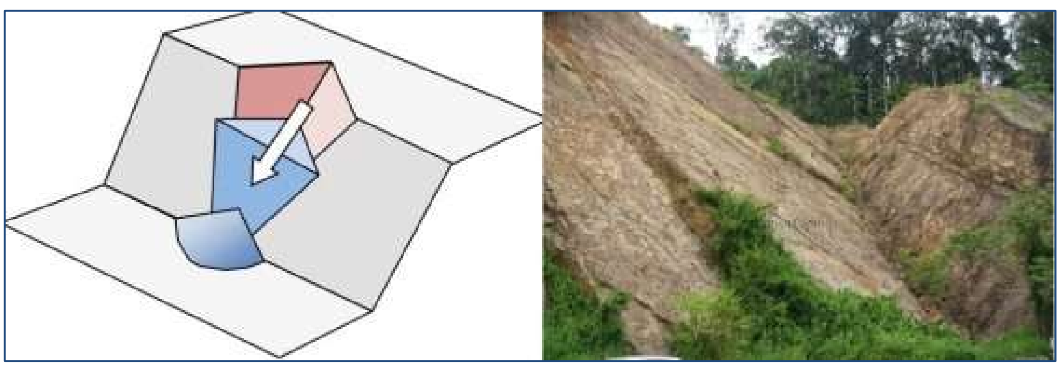


Figure-4: Wedge Failure correspondence to the slope

1.3 Global Stability Check for Slopes

SLIDE 6.0 software will be used to perform a global stress analysis of cut slope in critical sections. Any support systems will be the most important section. The findings of the analysis are presented as a safety factor, which is defined as ratio of effective shear strength to sliding plane shear stresses.

$$FOS = \frac{\tau}{\sigma}$$

If FOS of without supported slope is less than desired, suitable support system shall be used and it will be reanalyzed to achieve desired FOS analyzed without.

1.4 Study area

The research area lies in district of Rudraprayag, which is having land area of approximately 25000 km and comes between latitude 30° 19′ 00″ and 30° 49′ N and longitude 78° 49′ and 79° 21′ 13″ E. This location can be reached from Rishikesh and Dehradun via transit. Whereas, railway are constructing railway line and tunnel to Badrinath Dham. However, this public transport is undergoing project. The research road cut slopes exciting along NH-58 from Kaliyasaur to Rudraprayag in Alaknanda valley. This road is extremely important for getting from one location to another. The geology of the examined area is located on the Garhwal Syncline's northeastern flank. Google imagery was used to indicate the study locations from S1 through S7 (Figure-5).

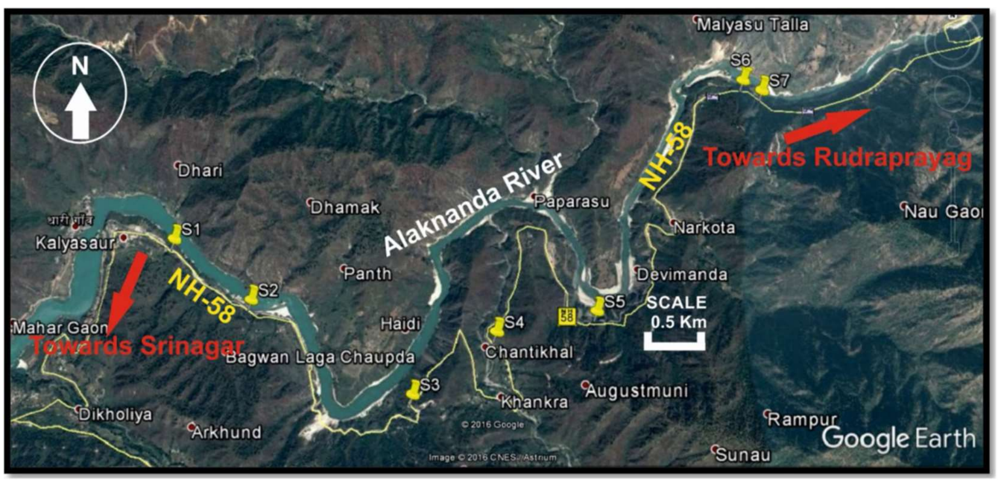


Figure-5: Google imagery representing the research area along NH-58 from Srinagar to Rudraprayag

1.5 Objective of the Study

- To check the stability of selected rock cut slope along Road Kaliyasaur to Rudraprayag in Alakhnanda Valley section NH-58 Uttarakhand at four different heights of 8m 16m 24m and 32m in overburden and weathered rock along long term stabilization.

- Analysis the adequate Berm width, Slope height, and Slope angle which provide the sustainability to cut slope.
- Provide Economical design and long-lasting support system.
- Optimization of cut height
- To assess the stability of selected cut slope for seismic loading.
- To determine the stability of rock cut slope subjected to rock bolting with static and seismic conditions.

CHAPTER-2
REVIEW OF LITERATURE

- **Singh et al., (2008)** investigated that the degree of weathering has a substantial impact on the slope's stability. Although all of the slopes evaluated were made of the same material, some collapsed slopes were found in areas that had experienced extensive weathering, demonstrating that even a tiny degree of weathering can drastically diminish a slope's stability. Dewatering occurs quickly in the Himalayan highlands due to the steep gradient, yet still water causes rock saturation. The strength of saturated samples was employed as an input parameter, with the joint reduction method being applied to get the input parameter closer to the insitu state.

- **Sarkar et al., (2012)** detailed measurements were taken on road cuts slope sides in the Garhwal Himalayas to collect information for rock mass categorization using Rock Mass Rating (RMR) and Geological Strength Index (GSI) (GSI). 50 data pairs were used to analyse the relationship between RMR and GSI. The Himalayas have been thoroughly investigated for the purpose of determining slope mass by using SRM and RMR techniques. Six slopes are fully unstable, 17 slopes are unsteady, other six slopes are mostly stable, nine slopes are steady, and only one hill is completely stable, according to the data.

- **Singh et al., (2014)** carried out 2-D basic limit equilibrium method and a numerical method based on finite element were used to investigate the cut slopes. The 2-D limit equilibrium method follows by Slide v.6 and Plaxis v.8 which follows method of finite element, used to investigate the stability of each hill-cut slope. The latest results on slope heights and displacement patterns point to the presence of zone of strain rate and displacement vectors. The toe region of higher slopes showed displacement. The highest shear strain zones were found around the slopes' toes. Tension cracks were also discovered near the tops of the slopes, posing a serious threat to their stability.

- **Sarkar et al., (2015)** researched those slopes in the Sikkim Himalayas that are prone to failure. They inflict significant harm to neighboring infrastructure. The Generalized Hoek Brown method was utilized to acquire input data such as shear strength using a deterministic methodology. The factor of safety was calculated using these estimated values to determine the slopes' stability state.

- **Vishal et al., (2015)** investigated slope having highly jointed rock mass along NH- 109. It was indicated that most of places consists weak phyllitic and schistose rock with same jointed and at few locations weathered quartzitic rock mass. Two-dimensional finite element methods were used to study slope stability. And found that despite the steep slope angle, the hill cut stay stable due to its material properties.

- **Tiwari and Latha (2016)** studied that the continuum with joints approach was used to capture failures in certain slope section, which was confirmed with wedge failure analysis. Depending on slope deformations and failure patterns discovered through computational simulations, rock bolt were devised to achieve the requisite factors of safety against failure while preserving deformations within authorized limits. The authors present a design of rock bolts as well as a comparison of slope stability with and without strengthening.

- **Anbazhagan et al.,(2016)** studied the LEM-based slope stability conditions were similar with the SRF-FEM and indicated that the slopes with the maximum height and dip angle are critically strong with a strength decrease factor smaller than 1. The Slope Mass Rating and Rock Mass Rating basic (RMRbasic) classification systems were used to analyses the rock slope stability. The FOS was estimated for soil slopes using the and Limit Equilibrium and Circular Failure Chart approaches. Two sections of Kolli Hills Ghat Road were designated as highly hazardous zones, while the remaining three were designated as moderate hazard zones. To ensure the slopes' stability, certain sections required landslide mitigation measures.

- **Sharma et al., (2016)** investigated geotechnical properties of Malshej Ghat basaltic soil in Maharashtra, India, as well as their utilization as key input criteria for evaluating road cut hill slope stability along National Highway-222. It is proposed that basaltic soils have a high degree of variability and complex geotechnical activity, and that geotechnical information collected from a single point may not be sufficient for analyzing and characterizing the complete road cut hill slope section. The slip surface at one research location indicates that the slope may have failed near the toe due to overburden stress. To avoid toe erosion, these soil slopes require mechanical structures such as retaining walls and a good drainage system.

- **Pradhan and Siddique (2019)** used Phase2D finite element modelling simulator, 20 vulnerable road cut slopes were delineated for comprehensive slope stability investigation. For stability assessments, the generalized Hoek-Brown criterion was used. Five of the twenty slopes are unstable, with a safety factor of less than or equal to one, requiring immediate attention. Four slopes have FoS values between 1 and 1.3, indicating marginal stability, whereas the others are stable. To compare slope stability study with GHB criterion, the Mohr-Coulomb criterion was used. It was established that heavy rain during monsoon season significantly lowers the stability of cut slopes.

- **Ready and Krishna (2019)** studied that the weakest zones in a rock mass are discontinuities. The characteristics of discontinuities play a major role in the failure mechanism of a rock slope. Anisotropy is created in the rock mass by discontinuities such as faults, bedding planes, and joints. PHASE2, a finite element process shear strength reduction tool, is used to analyze the rock slope's stability. Rock bolts were proposed for strengthening the slope sections, and the reinforcement scheme was determined by experimental analysis. The addition of reinforcement enhanced the slope section's safety factor or strength reduction factor.

- **Siddique and Khan (2019)** investigated the safety of road cut slopes along Uttarakhand's National Highway 58 (NH-58) between Kaliyasaur and Rudraprayag. During the field survey, vulnerable slopes were found. In addition, a bivariate plot revealed a linear association between quantified GSI and basic RMR. The likelihood of structurally controlled breakdowns due to negatively oriented discontinuities was also determined using kinematic analysis**.** The initial or input data for estimating the stiffness and deformability of rocks is GSI and RMR.

- **Sardana et al., (2019)** studied the area between Kulikawn and Saikhamakawn in Aizawl at which the road has been cut. Using kinematic analysis, the road cut slopes that have the potential to collapse were detected, and there were basically two types of failures discovered: Topple and wedge failure. In this study, the Geological Strength Index, continuous slope mass rating (CoSMR) and slope mass rating (SMR), were used to assess the stability of road cut slopes. Numerical modelling was also used to examine the road cut slope's stability. To maximize slope stability, the slope dip has to be 10°–15° more than the perpendicular to the ground, according to the research.

- **Sharma et al., (2019)** selected six sites of from Srinagar to Sirobagarh, for comprehensive geology and geotechnical research and slope stability evaluation using various methodologies. These sites were chosen based on rock properties, slope morphology, and failure mode differences, and their potential degree of stability was analyzed by slope stability assessment techniques. The results reveal that computed Continuously Slope Mass Rating values give a more realistic picture of slope stability assessment can be used to assess the stability of rock mass in Himalayan terrain. The main causes of intense deformation include tectonic stress, climatic conditions, and anthropogenic factors.

- **Komadja et al., (2021)** studied clay mineral activity, the slope structure (total slope angle and height) has the greatest effect on the parameters of the investigated slopes excavations at the slope's crown, the construction of retaining and wire mesh walls at the toe, and grass growing on the slope's surface.

CHAPTER-3
DESIGN DATA FOR CUTSLOPE

3.1 General

Only the stability of the cut-slope made in weathered rock is investigated. Safety factors adopted for failure with various load cases is shown in Table-1. The adopted safety factors is taken based on guidelines of Federal Highway of America (FHWA).

Table-1: Adopted FoS for different load cases

Load Case	Description	Required Minimum FOS
Dead Load + Water	Static Loading	1.5
Dead Load + Water + Seismicity	Dynamic Loading	1.0

3.2 Seismic Coefficient Calculation

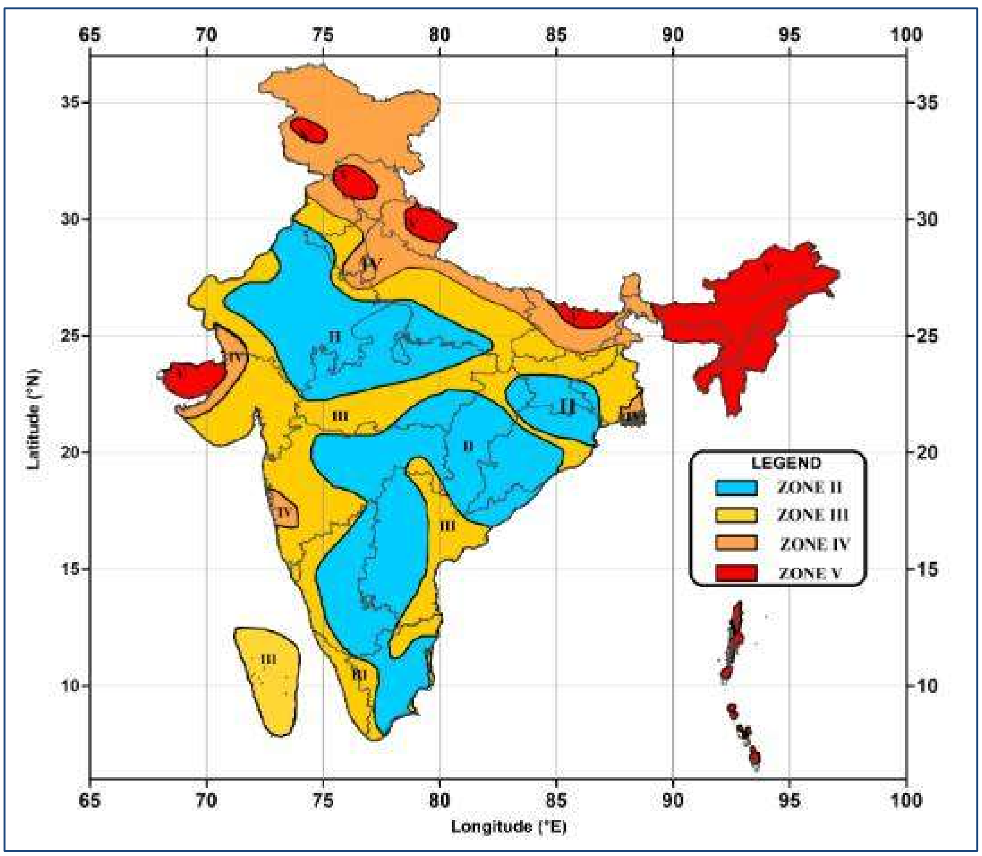


Figure-6: Seismic zoning map of India (Source: IS1893-2002)

The project site lies in Zone IV of seismic. The place is surrounded by multiple active faults, which have previously been the site of several large earthquakes. According to IS:1893-2002, the zone-IV factor is Z=0.24. The following formulas are used to calculate the horizontal and vertical seismic coefficients.

3.2.1 Design Horizontal Seismic Coefficient, A_h

$$A_h = \left(\frac{z}{2}\right) * \left(\frac{l}{R}\right) * \left(\frac{Sa}{g}\right)$$

Where,

Seismic zone	=	Zone IV
Seismic zone factor, Z	=	0.24 As per IS 1893 2002
Important factor, I	=	1.5
Sa/g	=	2.5
Response reduction factor, R	=	2.5
Horizontal seismic coefficient, A_h	=	$\left(\frac{z}{2}\right) * \left(\frac{l}{R}\right) * \left(\frac{Sa}{g}\right)$
	=	0.18

3.2.2 Design Vertical Seismic Coefficient, Av

$$A_v = \frac{2}{3} * A_h$$

Vertical seismic coefficient, Av	=	2/3*A_hAs per clause 6.4.5 of IS:1893 2002
	=	0.12

Therefore

Horizontal seismic coefficient, Ah	=	0.18
Vertical seismic coefficient, Av	=	0.12

According to IRC 75: 2015, the safety factor for a mountainous terrain slice slope can be limited to 1.4 for static conditions, for the safe side or in extreme situations, a safety factor of greater than 1.5 should be targeted while designing any construction.

Loads from Earthquakes: Based on the project region being in seismic zone IV, In the analysis, a horizontal seismic value of 0.18 and then a vertical stress coefficient of 0.12 were employed.

3.3 Material Description and Properties

3.3.1 Self-Weight of Rock Mass

From laboratory test it is interpreted that self-weight of rock mass (saturated unit weight) in Overburden is around 20.5 kN/m^3 and in weathered rock is around $22 kN/m^3$.

Table-2: Physical and Mechanical Properties of Rock Mass for Overburden and Weathered Rock (Phyllite)

Intact Rock Properties			
Description	**Unit**	**Overburden**	**Weathered Rock (Phyllite)**
Unit Weight	kN/m^2	20.5	22
UCS Intact	MPa	3000	15000
GSI	-	21	36
Intact Rock Constant	-	5	17
Disturbance Factor	-	0.7	0.7

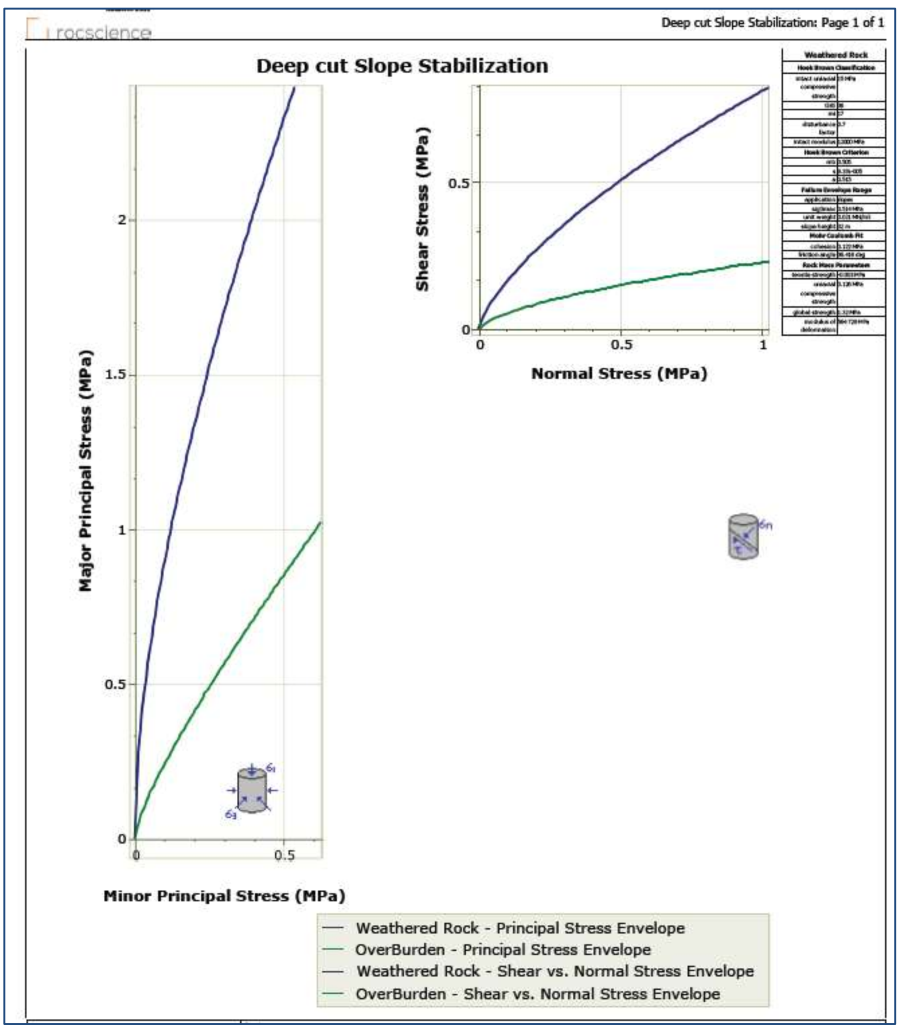


Figure-7: Weathered/ Phyllite Rock Mass Properties

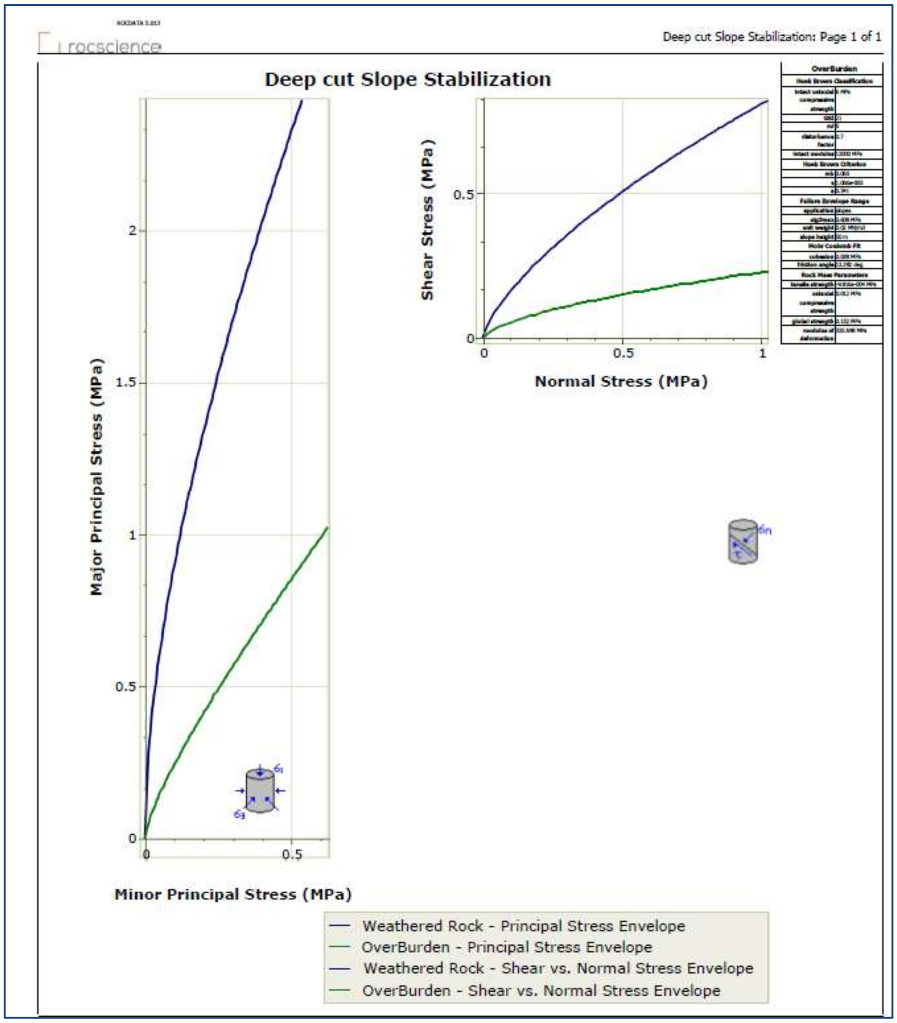


Figure-8: Overburden/Disintegrated Properties of Rock Mass

3.3.2 Support/Reinforcement Properties for Cut slopes

Slopes will require support in terms of systematic rock bolts and shotcrete. For the shotcrete and rock bolt, the following support parameters are taken into account.

3.3.3 Shotcrete (FRS)

The shotcrete is modelled as plastic standard beam element, so if the shotcrete yield at any point the extra forces are passed to the nearby rock mass and support element. Shotcrete reinforcement (100mmx100mm x5mm) will be used at face of the slope and on overburden. We will use shotcrete deep cut slope stability, which is equivalent to M35grade concrete as per Indian Standard.

Table-3: Shotcrete Properties used for Cut Slopes

Description	Unit	Value	Reference Code
Characteristic Compressive strength(fck)	MPa	35	IS 456:2000
Residual Compressive Strength	MPa	9	IS 456:2000
Mean Tensile strength= $0.3xf_{ck}^{2/3}$	MPa	3.7	Euro Code EN 1991
Allowable Shear Strength	MPa	5.5	1S15026:2002
Young's Modulus	MPa	34000	IS 456:2000

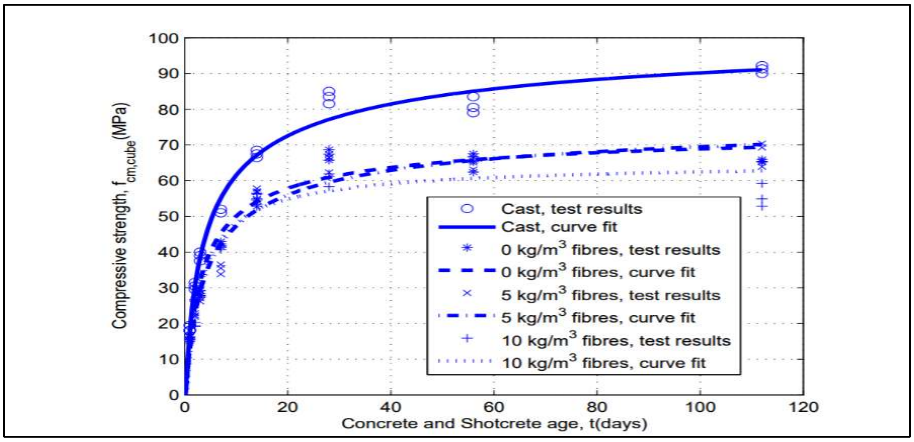


Figure-9: Shotcrete Compressive Strength

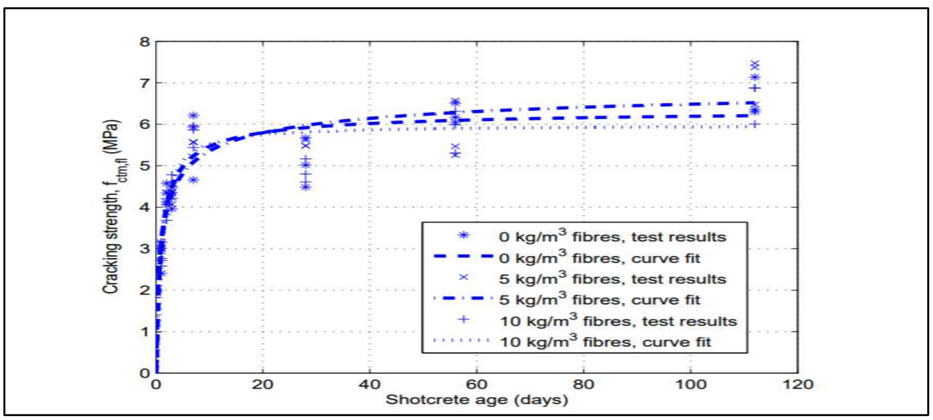


Figure-10: Shotcrete Cracking Strength

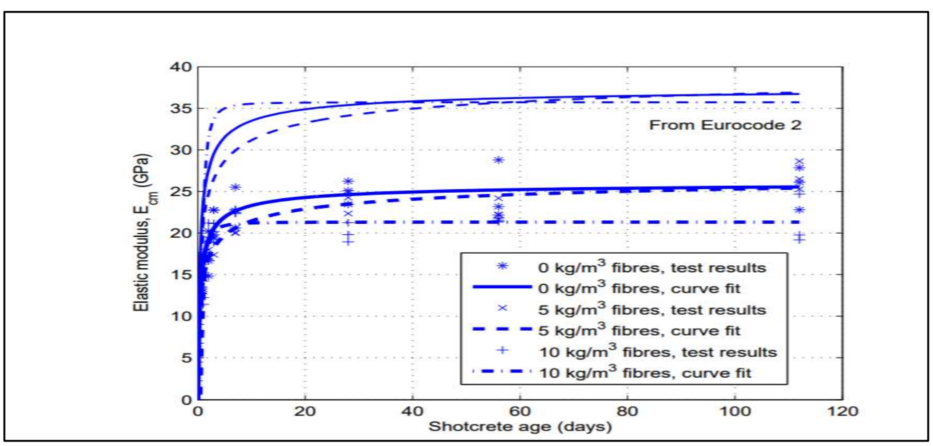


Figure-11: Shotcrete Elastic Modulus

Above Figures, (Figure-9, Figure-10 and Figure-11) shows the short-term property of shotcrete for 1hour and 24 Hour. It is clear that short term property of shotcrete (SFRS) such as Elastic Modulus, cracking strength and compressive strength are 80%, 60% and 40% of design capacity respectively.

3.4 Wire Mesh

For 24m and 32 m Slope region wire mesh will be used to protect falling of small chunks of rock mass during slope excavation. This will be used along with shotcrete of adequate thickness. Grade thickness and grid to grid spacing of wire mesh will be Fe500, 5 mm and 100 mm x100 mmx5mm respectively.

3.5 Anchor Plate

Rock bolt anchor plates should be made of mild steel Fe 500, with dimensions of 150 mm x 150 mm x 8 mm and a diameter of 25 mm.

3.6 Fully Grouted Rock Bolt

Rock bolt at deep cut slope will be deformed bar of Grade Fe500, whose characteristic curve with reference to IS 456:2000 is attached as Table-4.

Table-4: Properties of support system (Rock Bolt)

Rock bolt diameter	mm	25
Hole of minimum diameter	mm	45
Yield shear strength	MPa	500
Yield strength	KN	245.93
Cross-sectional area	mm^2	491
Strength at Elastic limit (0.80x yield)	KN	196
Design strength considered (approx.)	KN	190
Rock bolt length	m	4/5/6/8

3.7 Justification of Bond Length

Calculation of bond length of anchored bolt

Grade of steel = Fe500

Dia. of bar use =25mm

Maximum service load on 1 anchored, P = 190kN

As per clause 6.4.2n of IS 1448:1997

Assuming characteristics strength of the grout, fck = 25.00 N/mm^2

Allowing bond stress, (fck/10) = 25.00/10 =2.50 N/mm^2

Maximum Permissible allowable bond stress of deform bars = 2.50 N/mm^2

As per clause 6.4.2.3 of IS 1448:1997

Anchorage length shall be obtained from following expression:

$$L = \frac{P.F}{\pi d \tau a}$$

L = Effective anchor length

P = Pull out force per anchor

F = FoS taken as 3

D = dia. of bar

$$L = \frac{190*1000*3}{3.14*25*2.5}$$

L = 6000mm/6m

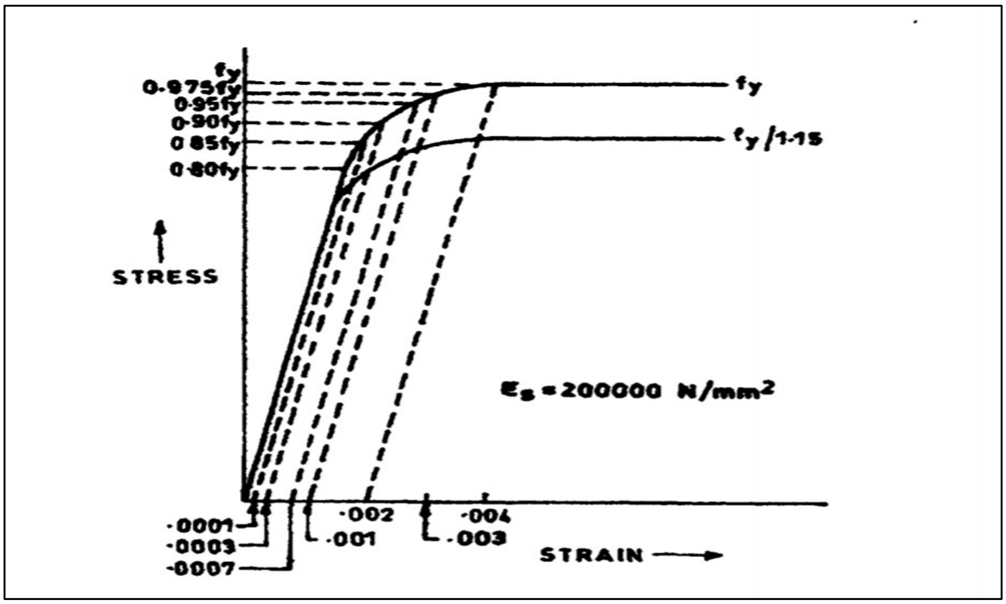


Figure-12: Characteristic Curve of Fe500D

The rock bolt used for Cut Slopes is a basic deformed bar of Grade Fe500, whose characteristic curve is shown in Figure-12 with reference to IS 456:2000.

CHAPTER-4
METHODOLOGY

4.1 Design Methodology for cut Slope

The impact on each activity and condition on the slope's stability was investigated further in this study. The Simplified Bishop and Janbu) As in Limit Equilibrium Analysis, approaches were applied. (LEA) performed by SLIDE 6.0. The rock slope's stability Bishop's modified method for calculating the lowest possible Safety factor (FOS) against rotating failure within probable slip circles was used to assess the slopes' stability.

4.2 Global Stability Check for Cut Slopes

The stage wise global stability analysis for cut slope will be carried out for critical section using Rocscience Slide 6.0 software. First the critical section will be evaluated without any support system. The observations are described in terms of a factor of safety, which is described as the ratio of available shear strength to shear stresses induced on the sliding plane. If the unsupported slope's FOS is less than desirable, suitable support system shall be used and it will be reanalyzed to achieve desired FOS. In global stability analysis of slope, stage wise analysis first up to tunnel heading excavation level shall be carried out after that analysis for final excavation up to invert level will be carried out, although support requirement for analysis of final stage will govern but we will include the stage analysis in design report pertaining to hill cut slopes.

Shear Strength Reduction is used in Slide 6.0 software to achieve global stability. Slide-6.0's Shear Strength Reduction tool automates a finite element slope stability and a crucial strength reduction factor of strength computed for the model. The critical strength reduction factor is equivalent to the "safety factor" of the slope.

4.3 Design Results of Slope Stability Analysis

The cut slope failure is phenomenon which is exhibited when accumulated stresses, lateral earth pressure is released and cause mass movement downward to valley side. Although cut slopes are commonly associated with hilly terrain, also they can occur in places with little relief. Lateral spreading unstable, and a wide variety of slope failures associated with foreign material. Now days, along with conventional techniques like limit equilibrium method, several advanced numerical techniques (discontinue, continuum and hybrid methods) are available and being widely used in rock slope stability analysis. In the present work, limit equilibrium method (Simplified Bishop Method), has been chosen to analyze the behavior of rock mass on cut slope. The better understanding of the failure mechanism involved and predicting the chances of the failure of the cut slope. Also, an attempt has been made to perform a comparative analysis of result obtained from above analysis methods. SLIDE 6.0 software used to perform numerical simulation work.

4.3.1 Limit Equilibrium Method (LEM)

In the limit equilibrium approach, the stability of slopes in soils is defined as the ratio between available shear resist along the failure point surface and the shear on the surface. A safety factor can be defined as ratio of available shearing resistance(τ) to the failure plane and to shear stress (σ):

$$\text{FoS} = \frac{\tau}{\sigma}$$

The sum of all shear loads along the slip surface matches the soil's available strengths when the slip surface breaks and the safety factor is one.

4.3.2 Hoek-Brown model

Mostly in case of rock with such a high shear modulus, the Hoek-Brown materials model is recommended. The Hoek Brown criteria is frequently used in deep cut excavation for analysis rock. It is based on the assessment of the interconnecting of solid rock and the surface conditions between these blocks. The Hoek & Brown method has a total of eight parameters:

Table-5: Notations and Description of Geological Data

σ_{ci}	UCS of the intact rock (>0), kPa
mi	Intact rock parameter
GSI	Geological Strength Index
E	Young's modulus of rock mass, kPa
μ	Poisson's ratio
D	Disturbance factor
c'	Drained cohesion
Φ'	Drained friction angle
σ_{ψ}	Absolute value of confining pressure σ'_3 at which $\psi = 0°$, kPa
ψ_{max}	Dilatancy angle (at $\sigma'_3=0$)

As shown below, the non-linear relationship between the major and minor effective principal stresses can be used to create the generalized Hoek-Brown failure criterion.

$$\sigma'_1 = \sigma'_3 + \sigma_{ci}\left(m_b\frac{\sigma'_3}{\sigma_{ci}} + s\right)^a$$

mb is a reduced value of the intact rock parameter mi as calculated by;

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right)$$

The auxiliary material constants s and an are obtained by the following relationships for the rock mass;

$$s = \exp\left(\frac{GSI-1}{9-3D}\right) \text{ and } a = \frac{1}{2} + \frac{1}{6}\left[\exp\left(\frac{-GSI}{15}\right) - \exp\left(\frac{-20}{3}\right)\right]$$

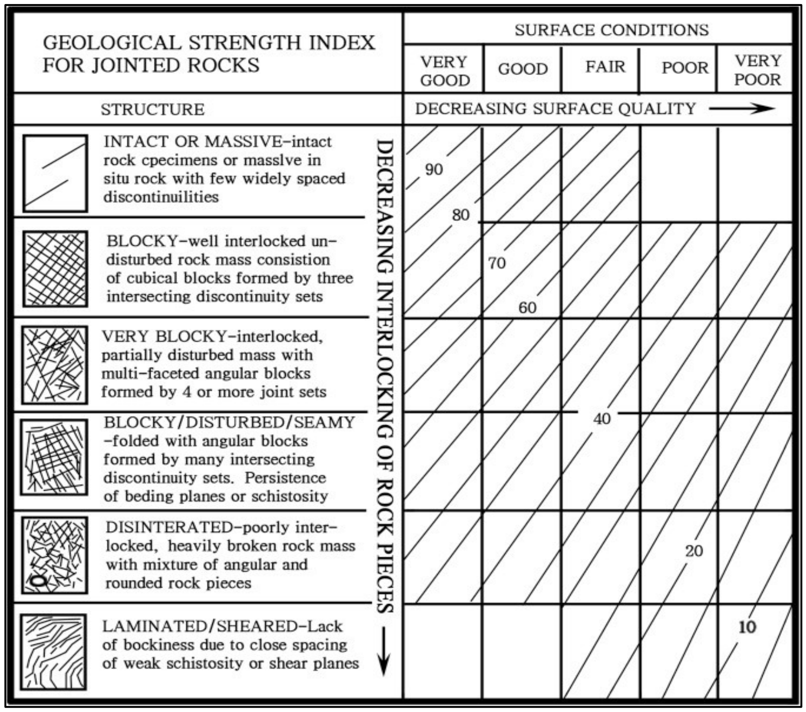
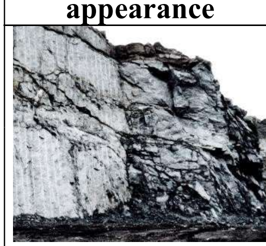


Figure-13: GSI values depending on rock structure (Hoek, 2002)

Based on Hoek & Brown, the Geological Strength Index (GSI), Disturbance factor (D), and Intact rock parameter (mi) are calculated (2002).

Table-6: Guidelines used for estimating disturbance factor D

Rock mass appearance	Rock mass Description	Value suggested for D
	Blasting used on small scale in civil engineering slopes causes only minor rock mass damage, especially when controlled blasting is utilized, as illustrated on the left side of the photo. Stress alleviation, on the other hand, causes some disruption.	D = 0.7 Good blasting D = 1.0 Poor blasting
	Heavy blasting production, as well as stress reduction through overburden removal, cause severe disturbance to very huge open pit mine slopes. In some soft rocks excavation can be carried out by dozing and ripping and the degree of damage to the slopes is less.	D = 1.0 Production blasting D = 0.7 Mechanical excavation

The rock mass's properties (Table-7) were determined using Roc Lab (Rocscience software). Rock mass strength analysis, which is based on the Generalized Hoek-Brown failure criterion. These values are calculated using estimated parameters such as the intact UCS, GSI, and the Hoek Brown parameter for intact rock, i.e., mi. Table 7 shows the material parameters that were determined as a result.

Table-7: Rock Mass Parameter of Overburden/Disintegrated rock and Weathered Rock

Material Properties	Units	Overburden/ Disintegrated rock	Weathered Rock
Hoek-Brown Classification			
Intact UCS (sigci)	MPa	3	15
GSI		21	36
mi		5	17
Disturbance factor		0.7	0.7
Intact modulus (Ei)	MPa	12000	12000
Modulus ratio (MR)		4000	800
Hoek- Brown Criterion			
Mb		0.065	0.505
s		1.07e-5	0.0001
a		0.541	0.515
Mohr-coulomb Fit			
Cohesion C	MPa	0.033	0.453
Friction angle Φ	-	8.72°	21.00°
Rock Mass parameters			
Tensile strength	MPa	-0.0005	-0.003
Uniaxial compressive strength	MPa	0.006	0.126
Overall strength	MPa	0.076	1.320
Modulus of deformation	MPa	325.70	564.73

4.3.3 The Bishop Method of Slices

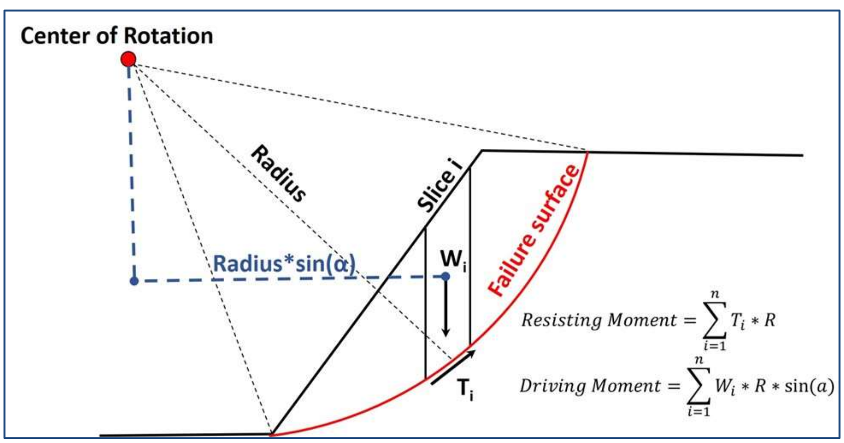


Figure-14: Graphical Representation of Failure Surface with respect to center of Rotation by Bishop Method of Slice

Bishop devised the Simplified Bishop Method (1955). This approach is predicated on the premise that forces on inter slice are horizontal. The Simplified Bishop Method also assumes a circular slip surface.

A typical circular failure surface's FoS will be calculated. The failure surface is considered to be within a single type of soil that performs in compliance with the Mohr-Coulomb failure criterion:

$$\tau = c + \sigma\text{n} \tan(\varphi)$$

T is shear force acting at the base of every slice (Figure -14) which depends on the cohesion, the friction angle, the effective normal force N' and the FoS as:

$$\text{T} = \frac{\text{C} * \text{L} + \text{N}' \tan \varphi}{\text{FoS}}$$

In the vertical direction, forces are added.

$$\Sigma F_{\text{vertical}} = 0 \Leftrightarrow (\text{N}' + \text{U}) * \cos(\alpha) + \frac{1}{\text{FoS}} * [(\text{cl} + \text{Ntan}(\varphi)) * \sin(\alpha)] - \text{W} = 0$$

The forces on the slice's base are calculated using the equilibrium equation, the Mohr-Coulomb equation, and the determination of the factor of safety.

$$\text{FoS} = \sum \left\{ \frac{[(\text{c} * \text{B} + \text{W}(1 - \text{r}_\text{u}) * \tan(\varphi))]\sec(\alpha)}{1 + \left[\frac{\tan(\text{a})\tan(\varphi)}{\text{FoS}}\right]} \right\} \frac{1}{\sum W * \sin(\alpha)}$$

4.3.4 Janbu's simplified method

The FOS is computed by equilibrium horizontal force, and Janbu's simplified method (JSM) is based on a composite SS (i.e. noncircular). Interslice normal forces (E) are considered, as in BSM, but shear forces are ignored (T). The base normal force (N) is calculated in the same pattern that it is in BSM, and calculated FOS as follows:

$$F_f = \frac{\sum(c'l + (N - ul)\tan \phi')\sec \alpha}{\sum W\tan \alpha + \sum \Delta E}$$

where,

$\Sigma\Delta E = E2 - E1$ = normal forces of total interslice

CHAPTER-5
MODELING PREPARATION

5.1 Introduction

SLIDE 6.0 is a two-dimensional programme used for slope stability and assesses the safety factor of circular and non-circular slope failure in soil and rock slopes. SLIDE 6.0 is easy to use, yet it allows you to develop and analyses complex models fast and effortlessly. External loads, support and groundwater can all be modelled in a number of different ways. To examine the stability of slip surfaces, SLIDE 6.0 employs vertically slice limit equilibrium methods. Individual slip surfaces can be evaluated, or search algorithms can be employed to locate the most important slip surface for a certain slope.

Multiple limit equilibrium approaches can be used with SLIDE6.0. For illustration purposes, the Bishop and Spencer methods (e.g., Spencer Bishop, Ordinary, Morgenstern-Price, Janbu) will be used.

For Stability analysis, modeling cut slope at different heights 8m ,16m ,24m in overburden and weathered rock in SLIDE 6.0 software. Also, we have to check the stability for normal and critical condition when seismic loads are applied. As per IS 1893 2002 seismic loading applied. For stabilization the cut slope rock bolt provided in SLIDE 6.0 software and FoS obtained by Bishop and Janbu methods.

5.1.1 Slide Model and Analysis Result of Cut Slope of 8m Height

Slide Model and analysis result of cut slope of 8 m height are given in below figures.

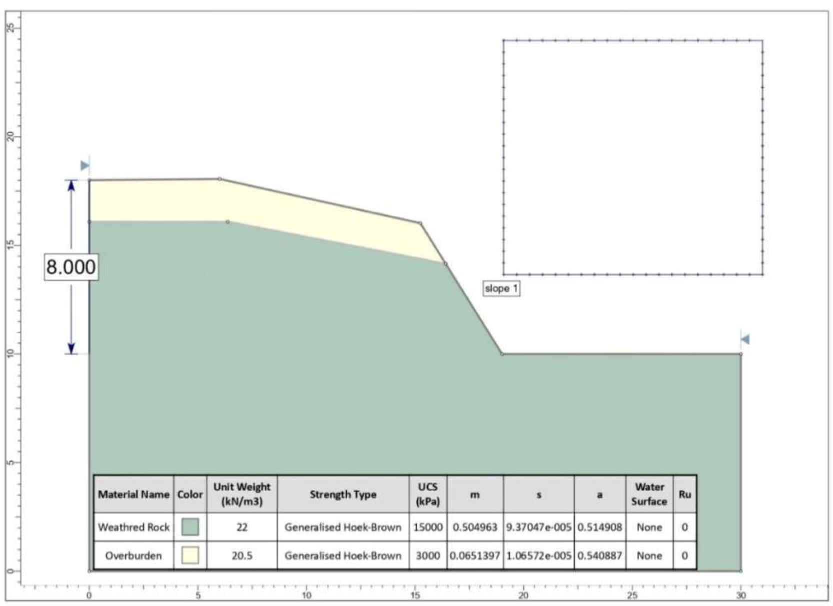


Figure-15: Model of cut slope of 8m height consisting2-3m overburden and highly to moderate weathered Phyllite Rock

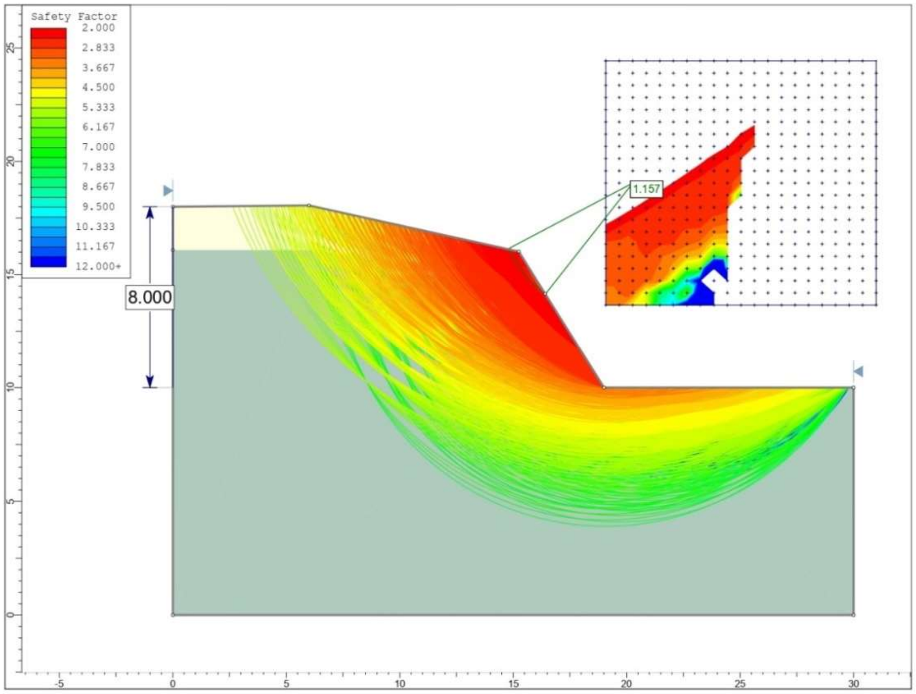


Figure-16: FOS Contours of hill slope analysis in Static condition obtained FOS 1.157>1.5 (stable)

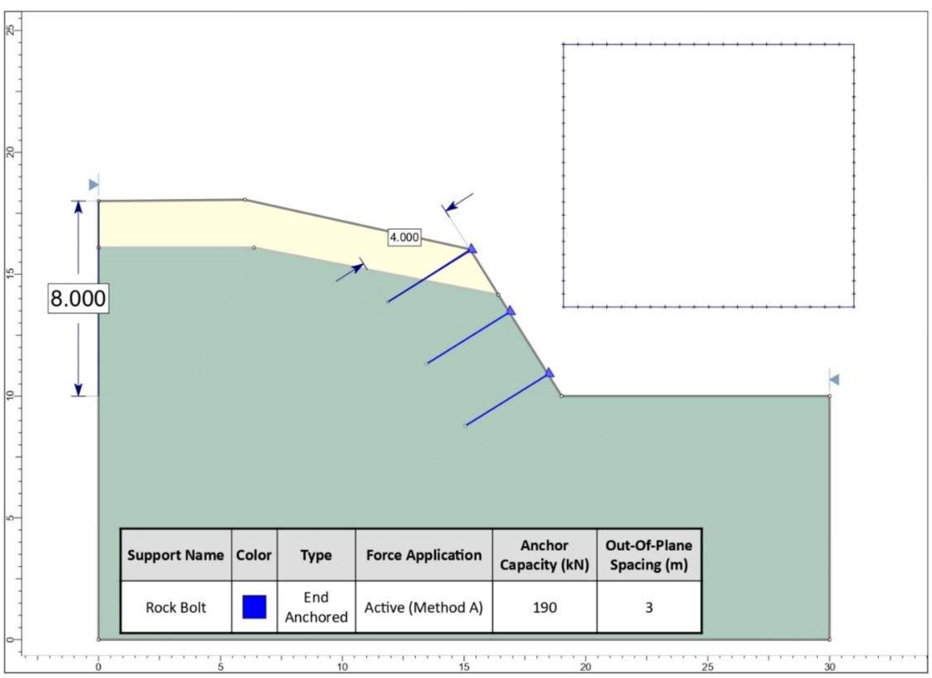


Figure-17: Model of cut slope with support of 8m height consisting2-3m overburden and highly to moderate weathered Phyllite Rock

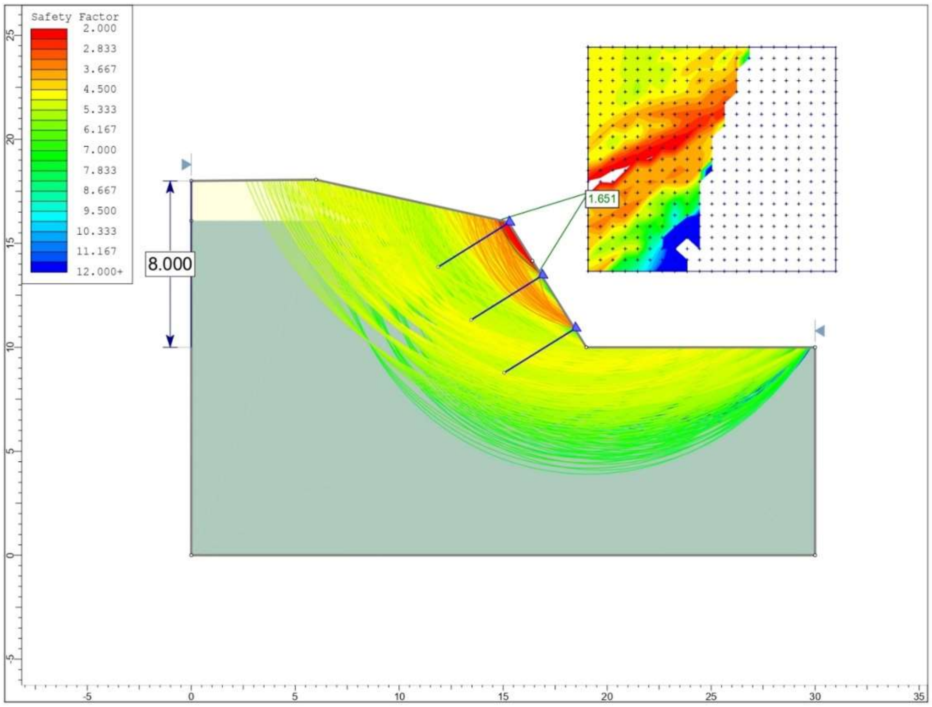


Figure-18: FOS Contours of hill slope analysis with support system in Static condition obtained FOS 1.651>1.5 (stable)

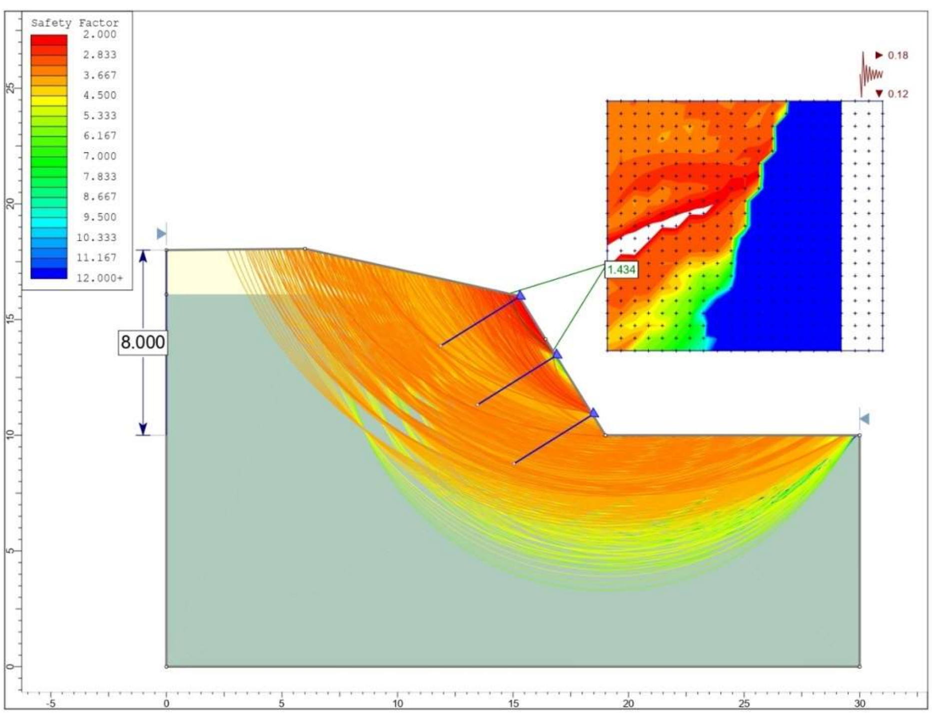


Figure-19: FOS Contours of rock mass in seismic condition with support system on hill slope obtained FOS 1.434>1.0 (Stable) in Overburden and highly to moderate weathered Phyllite Rock

5.1.2 Slide Model and Analysis Result of Cut Slope of 16m Height

Slide Model and analysis result of cut slope of 16 m height are given in below figures.

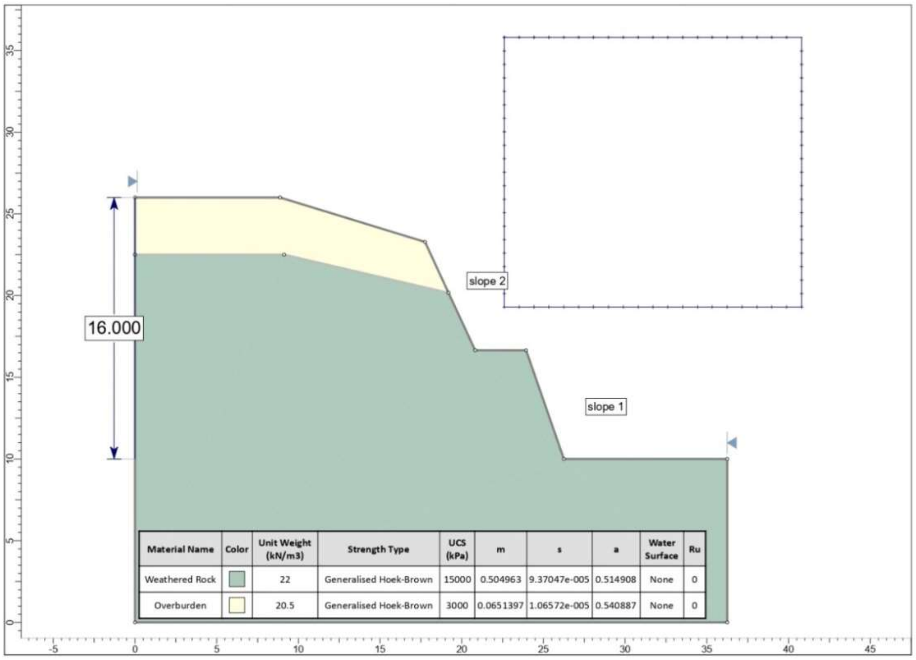


Figure-20: Model of cut slope of 16m height consisting3-4m overburden and highly to moderate weathered Phyllite Rock

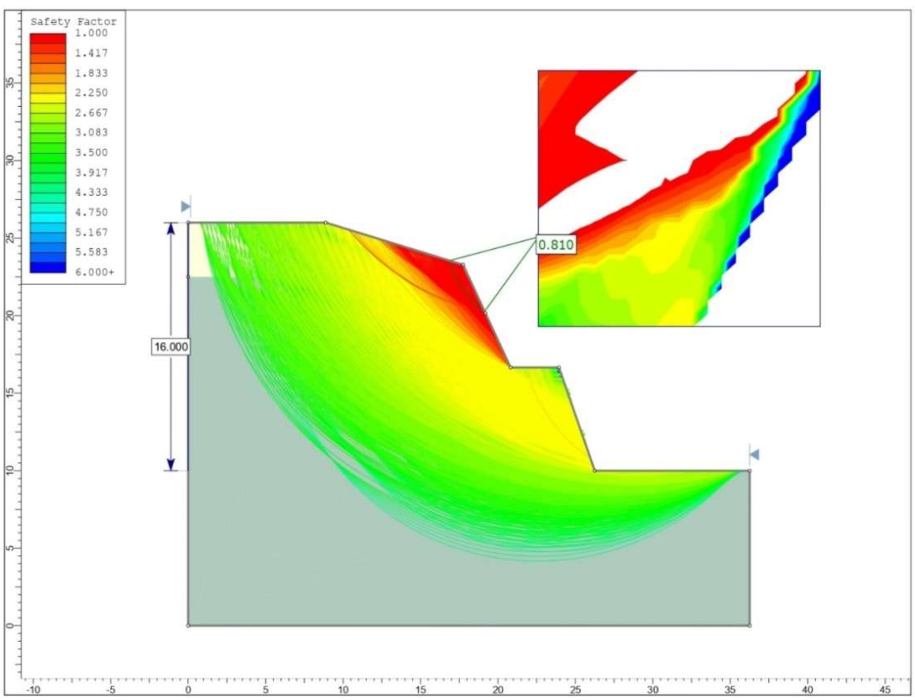


Figure-21: FOS Contours of hill slope analysis without support system in Static condition obtained FOS 0.810<1.5 (unstable)

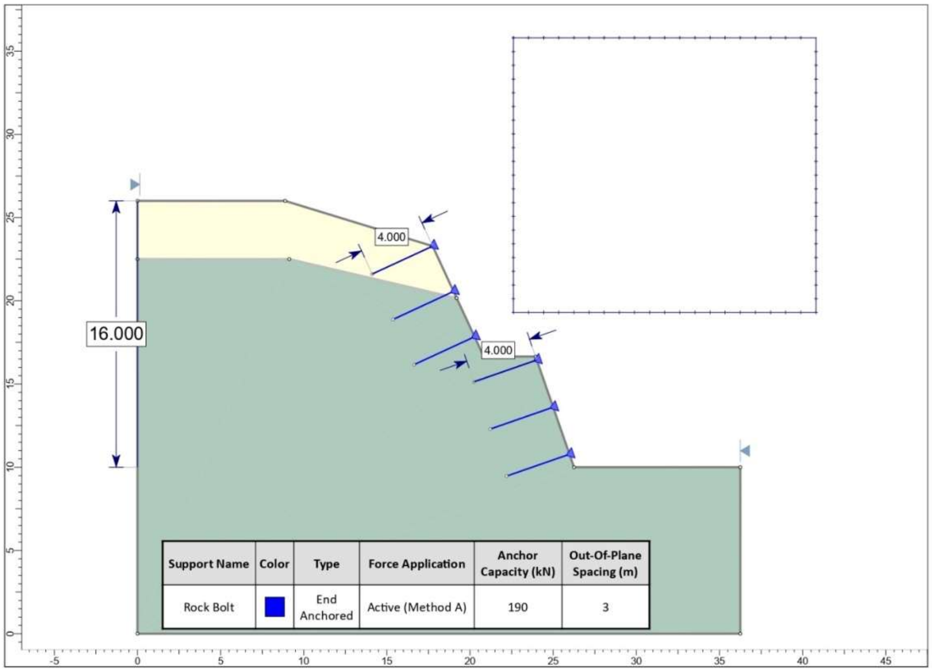


Figure-22: Model of cut slope with support of 16m height consisting2-3m overburden and highly to moderate weathered Phyllite Rock

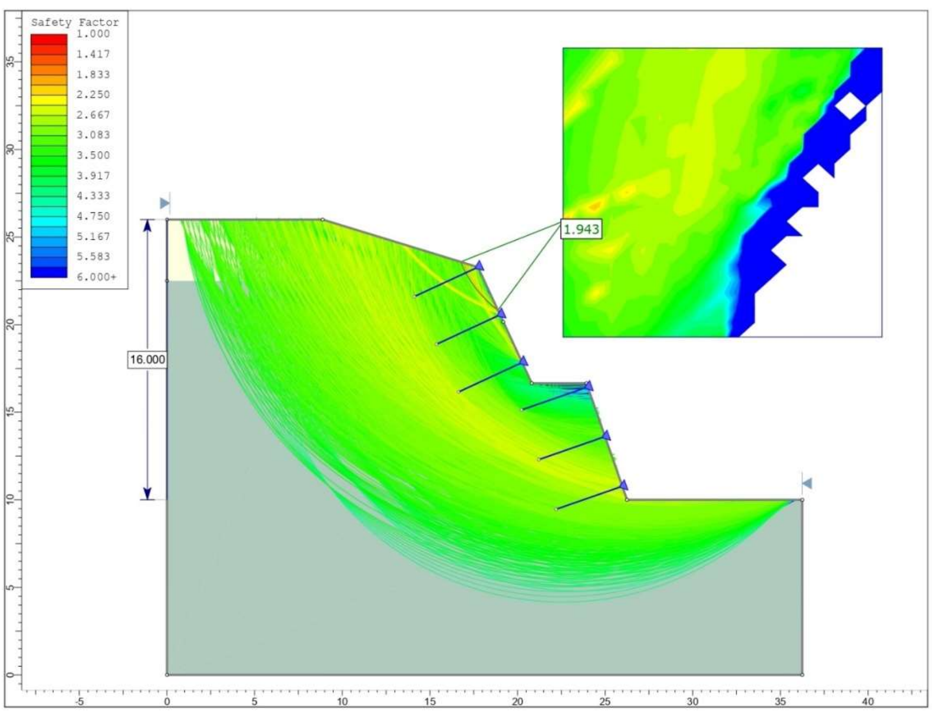


Figure-23: FOS Contours of hill slope analysis with support system in Static condition obtained FOS 1.943>1.5 (stable)

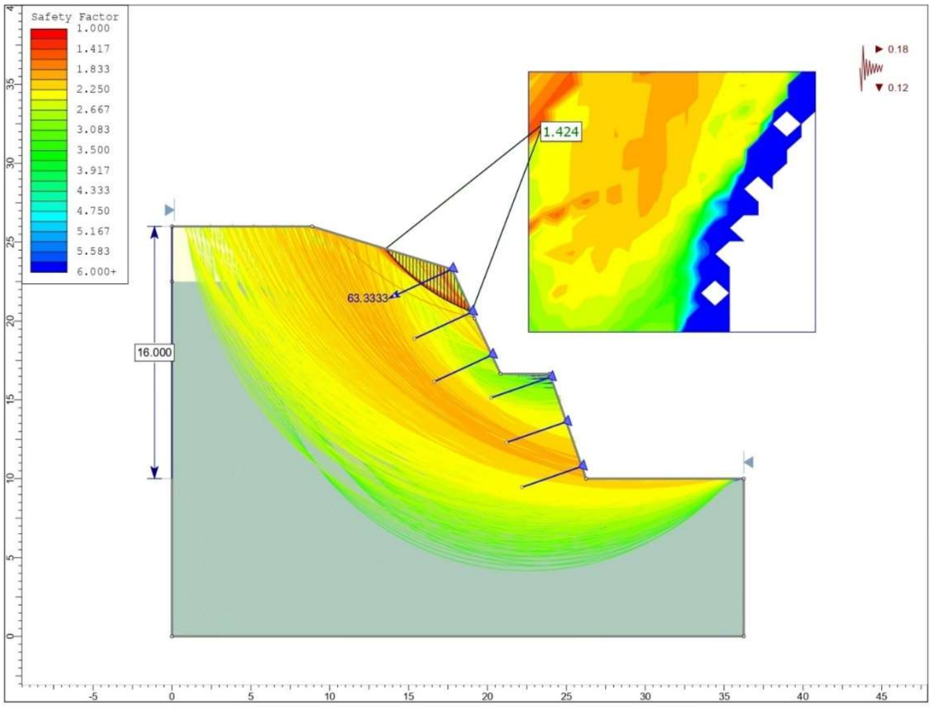


Figure-24: FOS Contours of rock mass in seismic condition with support system on hill slope obtained FoS 1.424>1.0 (Stable) in Overburden and highly to moderate weathered Phyllite Rock

5.1.3 Slide Model and Analysis Result of Cut Slope of 24m Height

Slide Model and analysis result of cut slope of 24 m height are given in below figures.

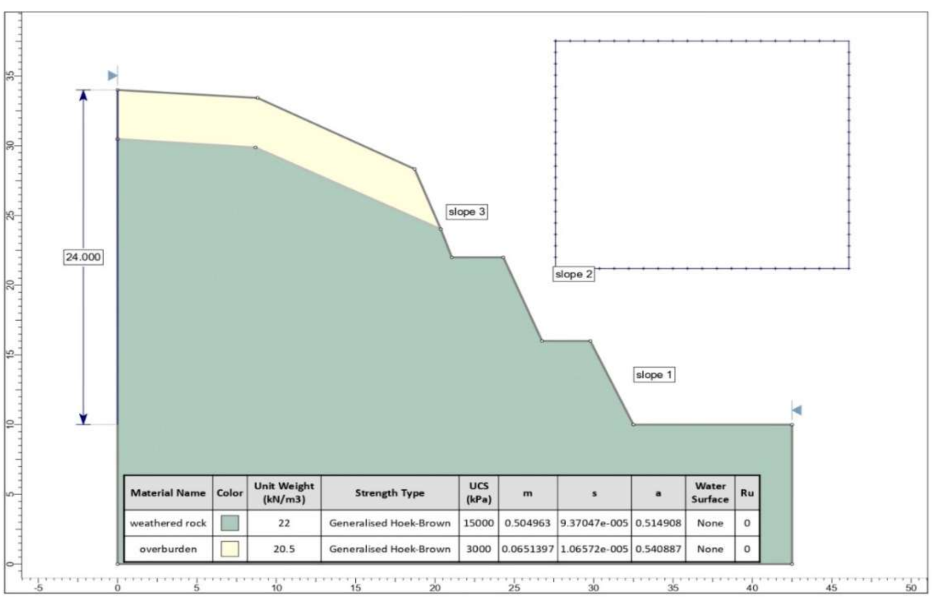


Figure-25: Model of cut slope of 24m height consisting3-4m overburden and highly to moderate weathered Phyllite Rock

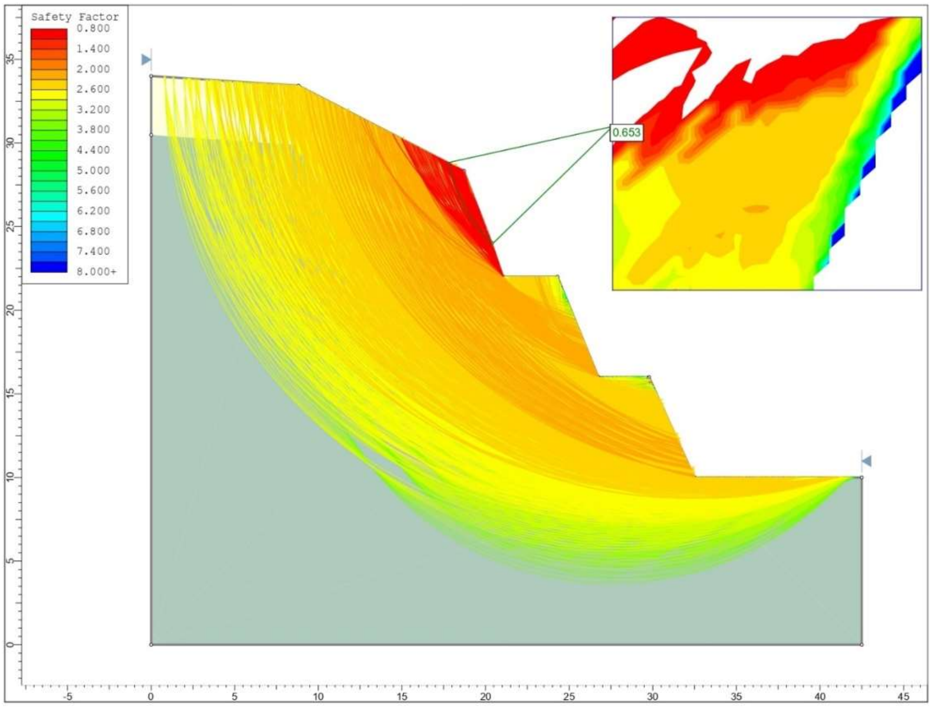


Figure-26: FOS Contours of hill slope analysis without support system in Static condition obtained FOS 0.663 <1.5 (unstable)

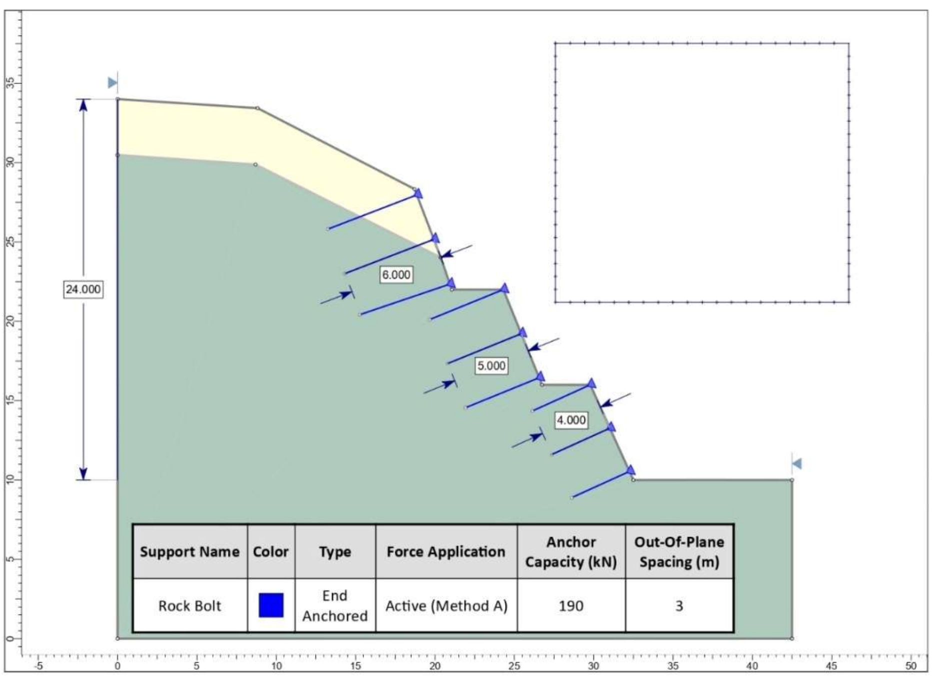


Figure-27: Model of cut slope with support of 32m height consisting2-3m overburden and highly to moderate weathered Phyllite Rock

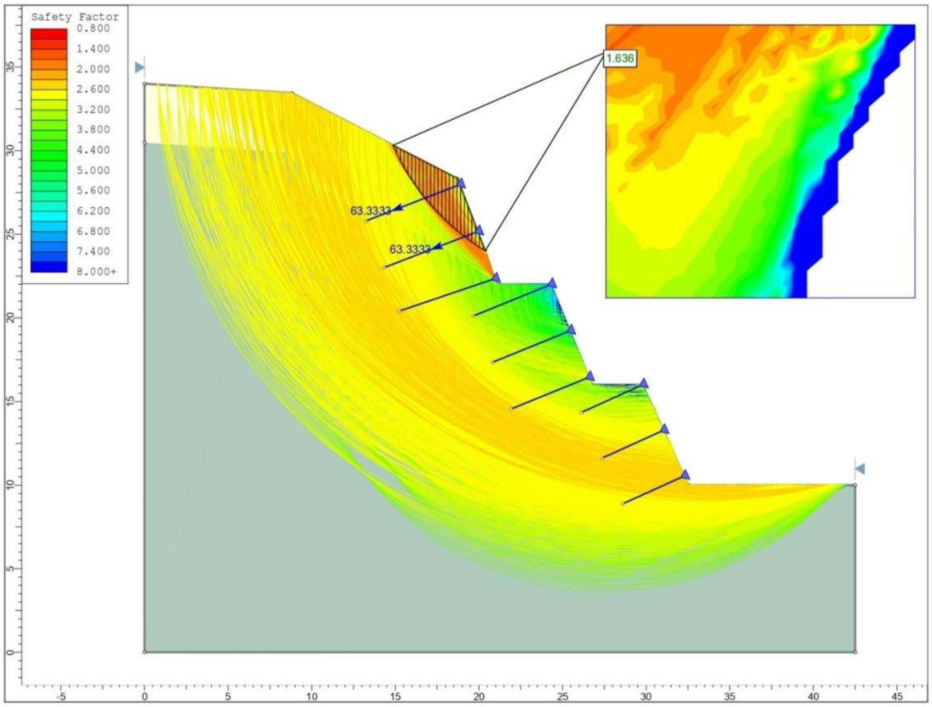


Figure-28: FOS Contours of hill slope analysis with support system in Static condition obtained FOS 1.636>1.5 (stable)

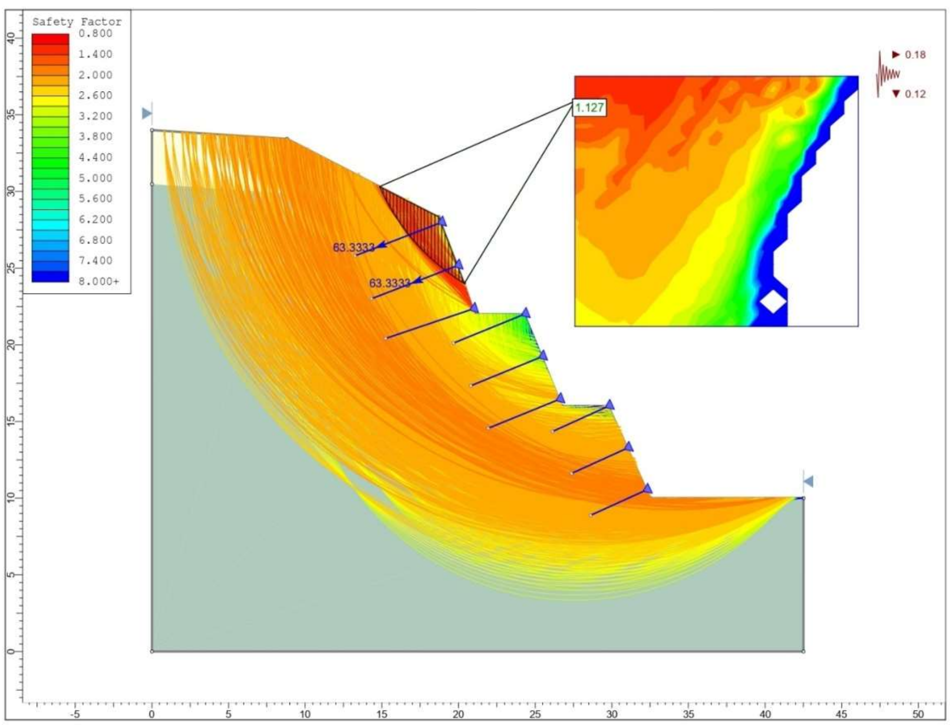
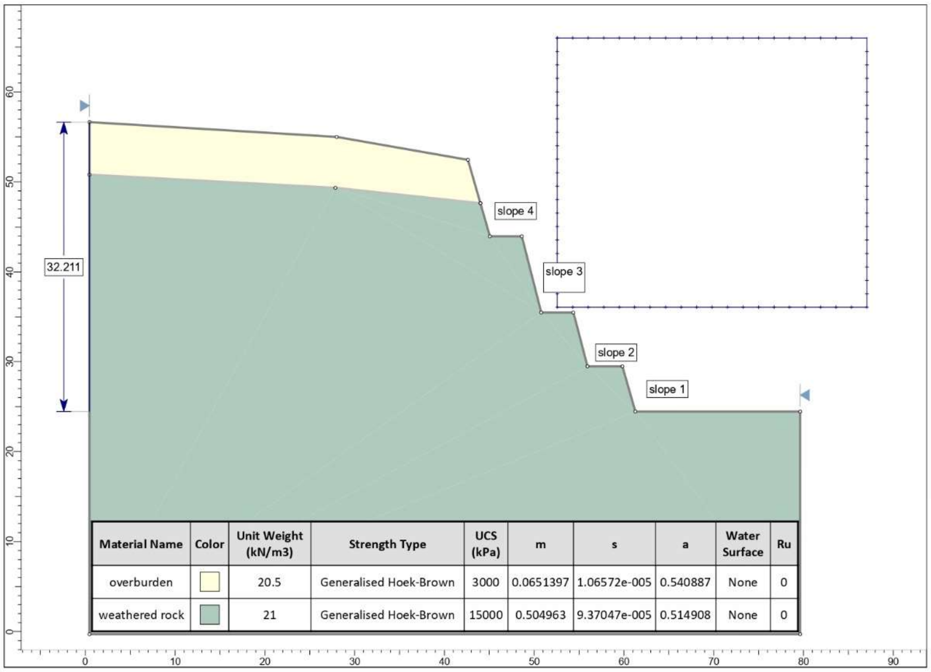


Figure-29: FOS Contours of rock mass in seismic condition with support system on hill slope obtained FoS 1.127>1.0 (Stable) in Overburden and highly to moderate weathered Phyllite Rock

5.1.4 Slide Model and Analysis Result of Cut Slope of 32m Height

Slide Model and analysis result of cut slope of 32 m height are given in below figures and Data Analysis under Seismic given in **Annexure-4.**



Material Name	Color	Unit Weight (kN/m3)	Strength Type	UCS (kPa)	m	s	a	Water Surface	Ru
overburden		20.5	Generalised Hoek-Brown	3000	0.0651397	1.06572e-005	0.540887	None	0
weathered rock		21	Generalised Hoek-Brown	15000	0.504963	9.37047e-005	0.514908	None	0

Figure-30: Model of cut slope of 32m height consisting3-4m overburden and highly to moderate weathered Phyllite Rock

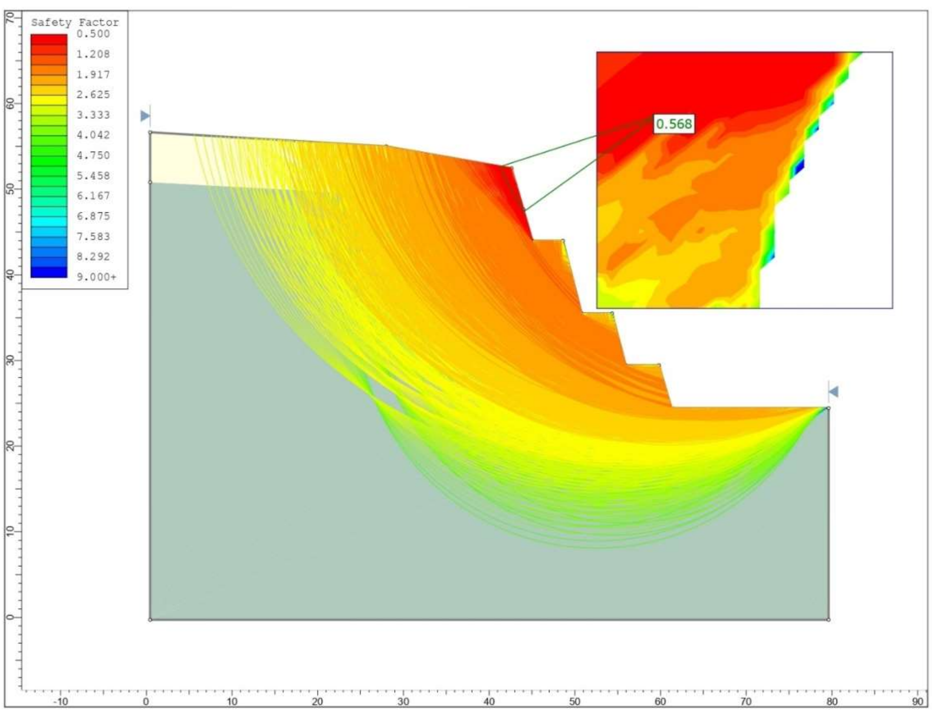


Figure-31: FOS Contours of hill slope analysis without support system in Static condition obtained FOS 0.568 <1.5 (unstable)

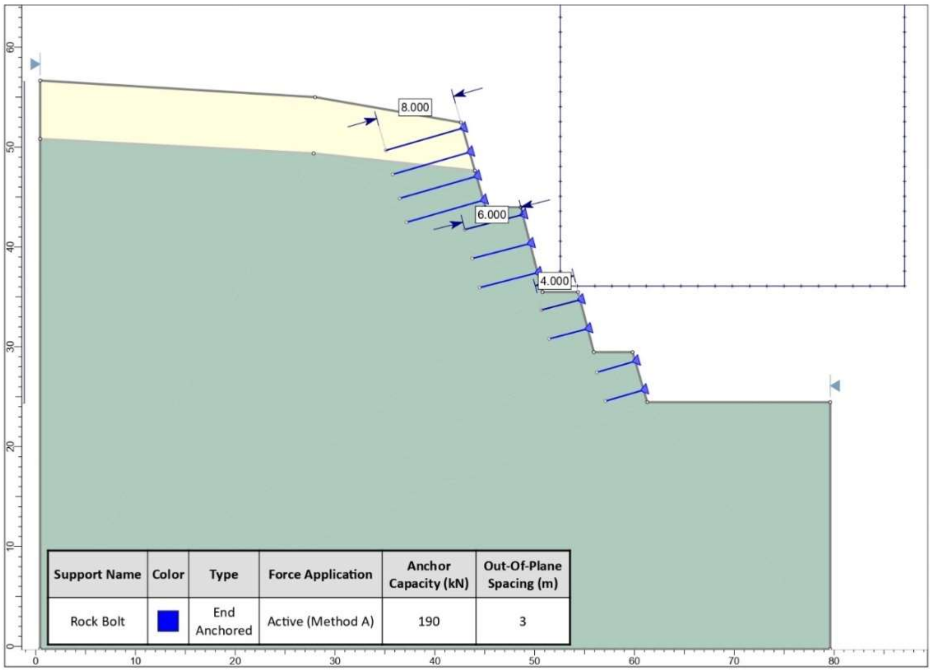


Figure-32: Model of cut slope with support of 32m height consisting2-3m overburden and highly to moderate weathered Phyllite Rock

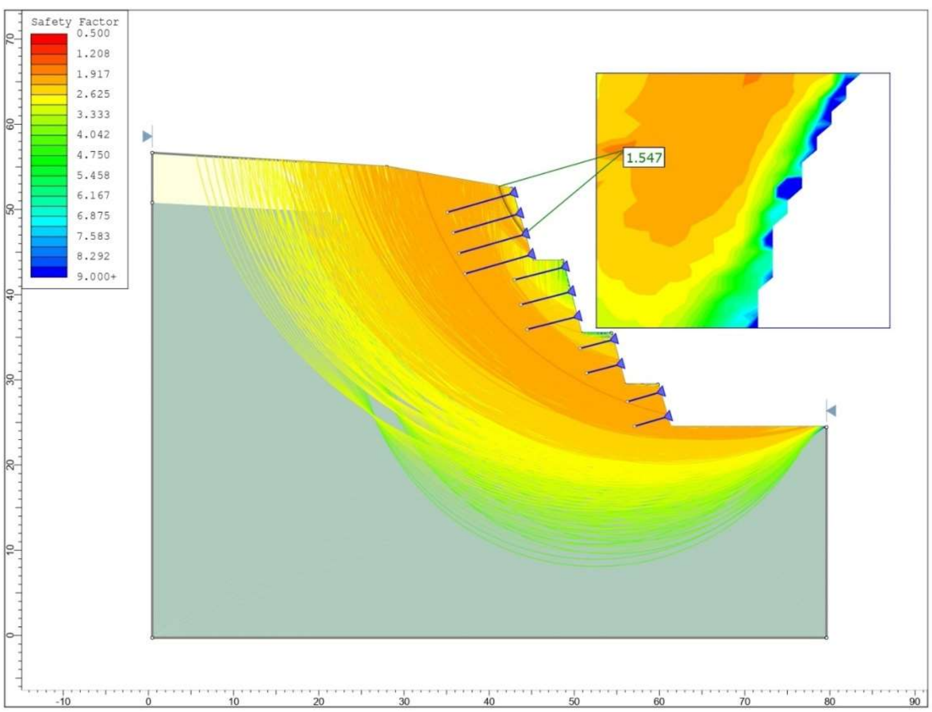


Figure-33: FOS Contours of hill slope analysis with support system in Static condition obtained FOS 1.547 >1.5 (stable)

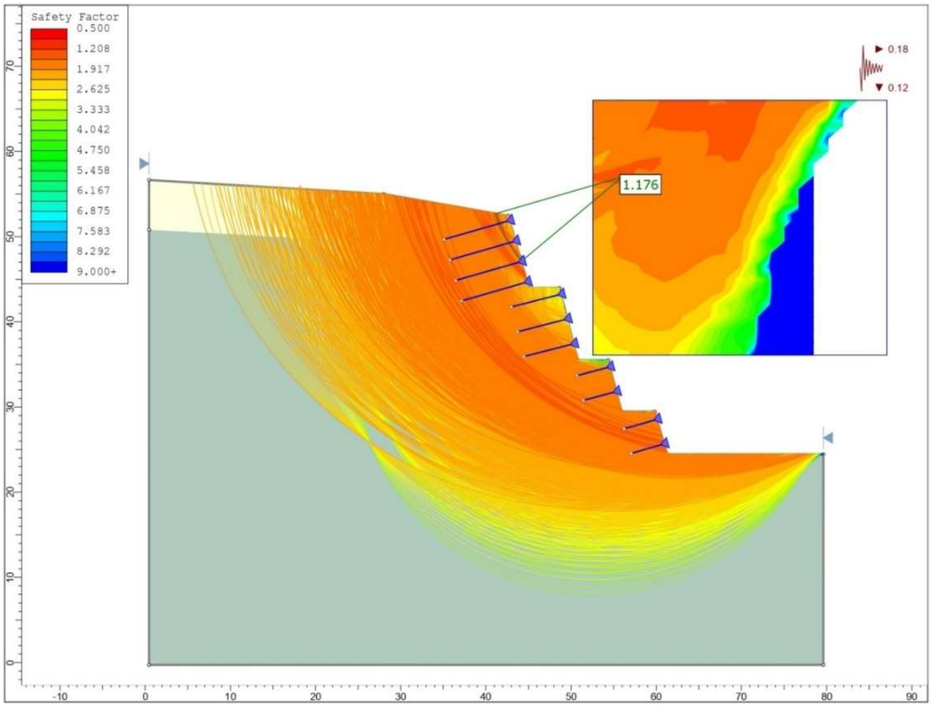


Figure-34: FOS Contours of rock mass in seismic condition with support system on hill slope obtained FoS 1.76>1.0 (Stable) in Overburden and highly to moderate weathered Phyllite Rock

CHAPTER-6
RESULTS AND DISCUSSION

- We concluded that almost all the cases have been failed in both the loading condition static and dynamic, Hoverer, after installing adequate support system on the slope we can considered as a safe slope.
- In 32m height slope having 4 berms consist each 7-8m height which is adequate to adopt proper FoS. Whereas, if we increase the height of slope the overall FoS decreases.

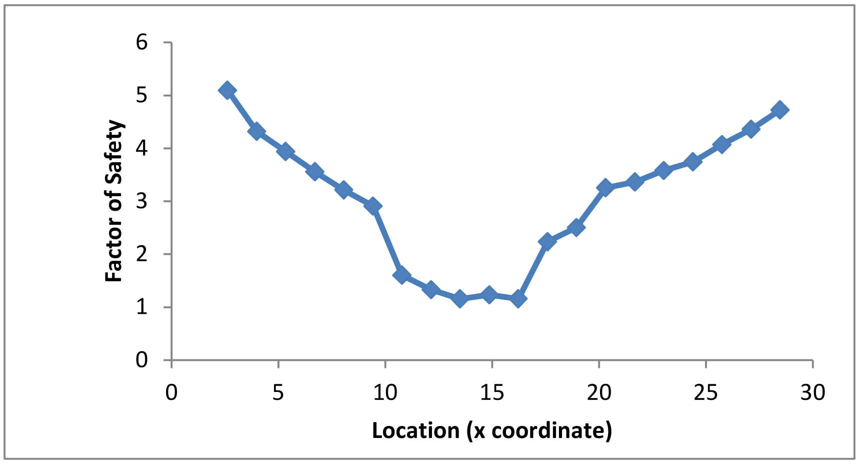
Table-8: Results for Global Stability analysis for Cut Slope in overburden and weathered rock

Cases:		Load Cases	FoS Obtained	FoS Required	Remarks
8 m Height Cut Slope	Case A	Cut Slope in Unsupported	1.157	1.5	Un-Safe
	Case B	Cut Slope -Supported with Bolt -Normal Case	1.651	1.5	Safe
	Case C	Cut Slope Supported with Bolt Seismic Case	1.434	1.0	Safe
16 m Height Cut Slope	Case A	Cut Slope - Unsupported	0.810	1.5	Un-Safe
	Case B	Cut Slope -Supported with Bolt -Normal Case	1.943	1.5	Safe
	Case C	Cut Slope Supported with Bolt -Seismic Case	1.424	1.0	Safe
24 m Height Cut Slope	Case A	Cut Slope in Unsupported	0.653	1.5	Un -Safe
	Case B	Cut Slope -Supported with Bolt -Normal Case	1.636	1.5	Safe
	Case C	Cut Slope Supported with Bolt -Seismic Case	1.127	1.0	Safe
32 m Height Cut Slope	Case A	Cut Slope in Unsupported	0.568	1.5	Un -Safe
	Case B	Cut Slope -Supported with Bolt -Normal Case	1.547	1.5	Safe
	Case C	Cut Slope Supported with Bolt -Seismic Case	1.176	1.0	Safe

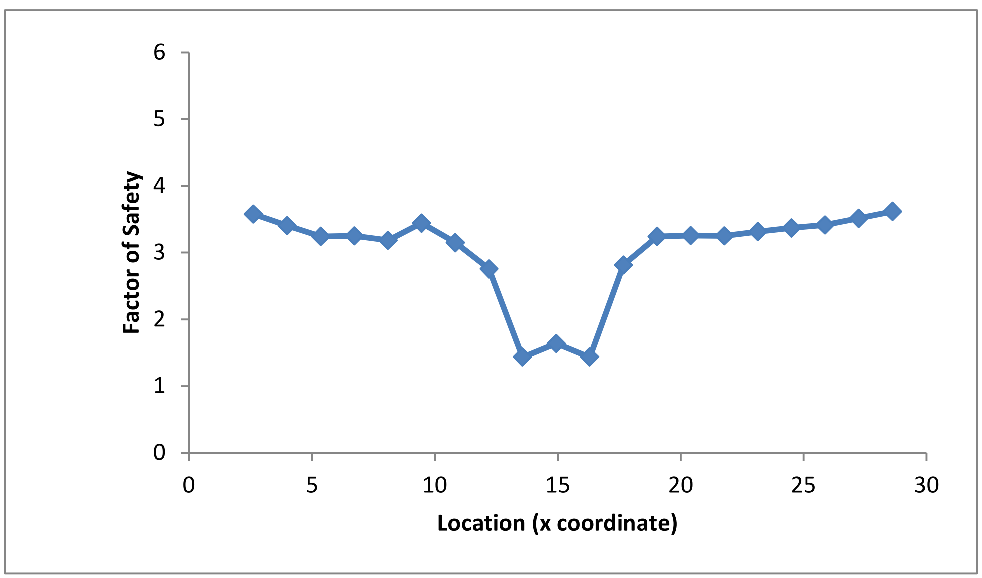
Table-9: Required Support System after Analysis of the Cut Slope

Cut Slope-8m	
Slope-1	190 kN, 4 m long Rock Bolt at 3m x 3m c/c Spacing.
Cut Slope-16m	
Slope-1	190 kN, 4 m long Rock Bolt at 3m x 3m c/c Spacing.
Slope-2	190 kN, 4 m long Rock Bolt at 3m x 3m c/c Spacing.
Cut Slope-24m	
Slope-1	190 kN, 4 m long Rock Bolt at 3m x 3m c/c Spacing.
Slope-2	190 kN, 5 m long Rock Bolt at 3m x 3m c/c Spacing.
Slope-3	190 kN, 6 m long Rock Bolt at 3m x 3m c/c Spacing.
Cut Slope-32m	
Slope-1	190 kN, 4 m long Rock Bolt at 3m x 3m c/c Spacing.
Slope-2	190 kN, 5 m long Rock Bolt at 3m x 3m c/c Spacing.
Slope-3	190 kN, 6 m long Rock Bolt at 3m x 3m c/c Spacing.
Slope-4	190 kN, 8 m long Rock Bolt at 3m x 3m c/c Spacing.

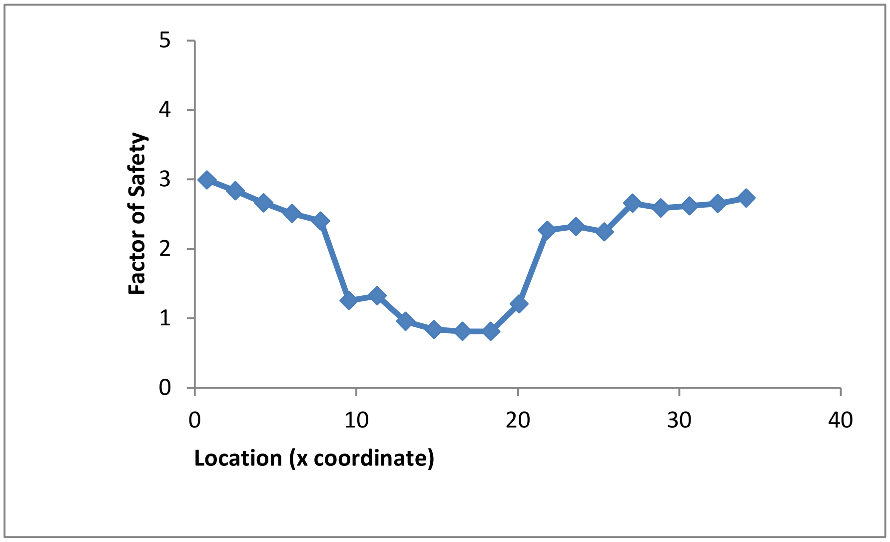
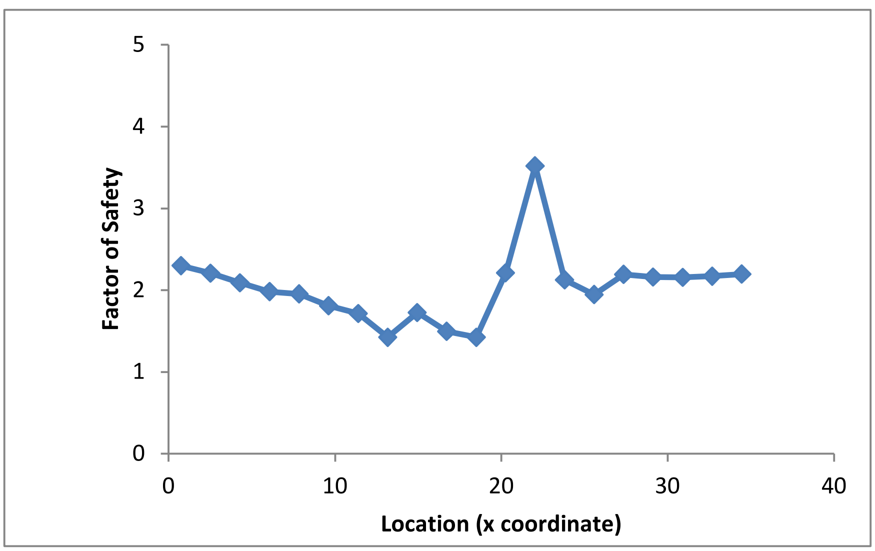
For 8m Height



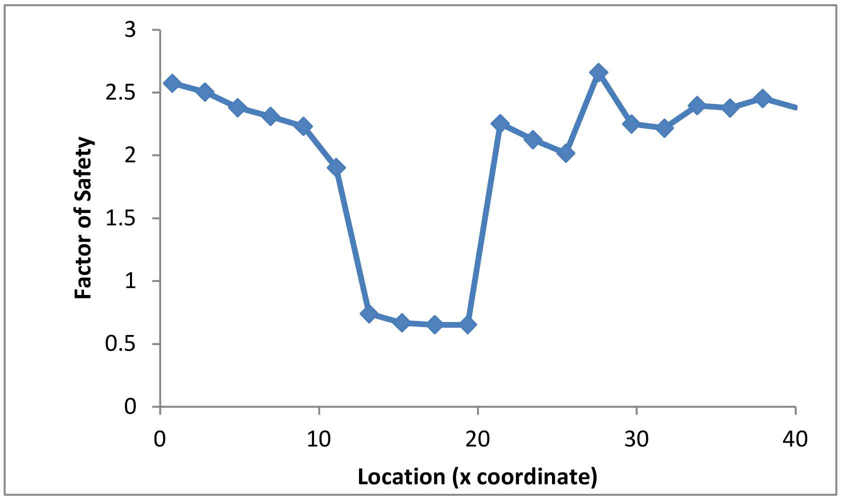
GRAPH 1: Variation of FoS for different coordinates towards Cut slope surface (unsupported 8m)



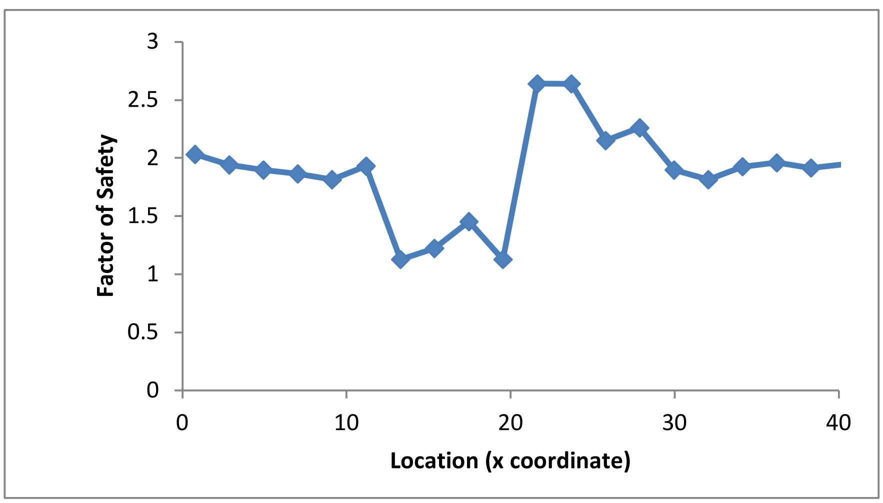
GRAPH 2:Variation of FoS for different coordinates towards Cut slope surface (supported-seismic 8m)

For 16m Height
 **GRAPH 3:Variation of FoS for different coordinates towards Cut towards Cut slope surface (unsupported 16m)**
 **GRAPH 4:Variation of FoS for different coordinates towards Cut slope surface (supported -seismic 16m)**

For 24m Height

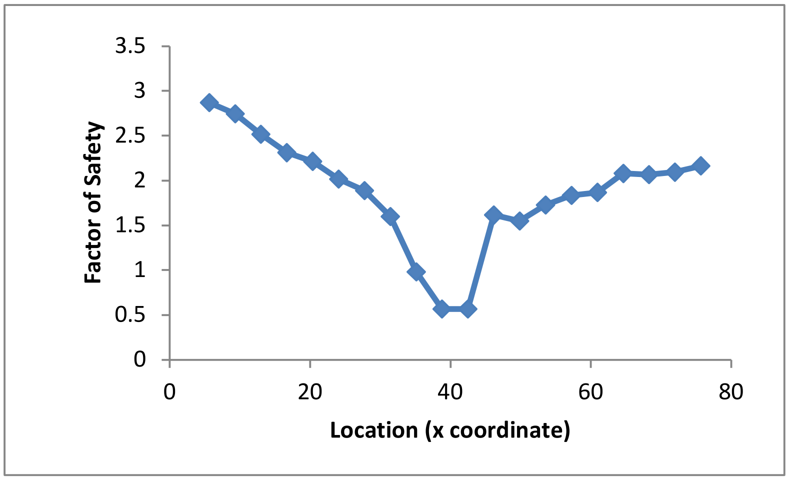


GRAPH 5:Variation of FoS for different coordinates towards Cut slope surface (unsupported 24)

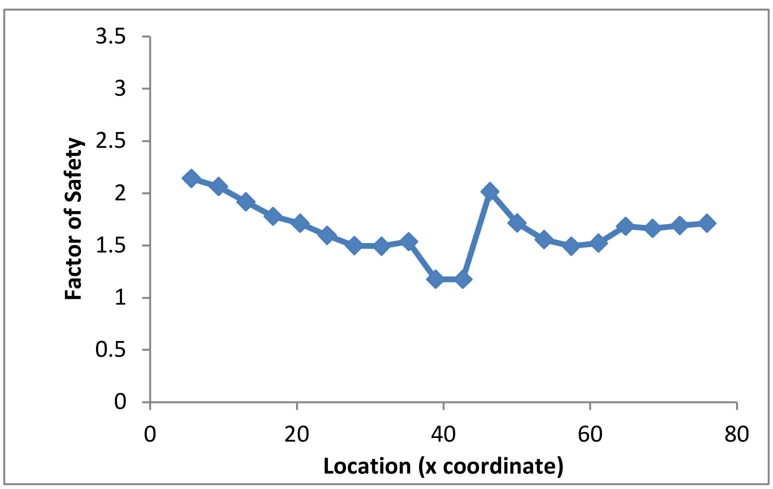


GRAPH 6:Variation of FoS for different coordinates towards Cut slope surface (supported -seismic 24m)

For 32m Height



GRAPH 7:Variation of FoS for different coordinates towards Cut slope surface (unsupported 32m)



GRAPH 8:Variation of FoS for different coordinates towards Cut slope surface (supported-seismic 32m)

CHAPTER-7
CONCLUSION

- Geometry of the slope has a major influence on factor of safety. From the results we can say that there is a considerable reduction in factor of safety with an increase in inclination angle and height of the slope.
- Stability analysis of four different height (8m, 16m,24m,32m) of slope is carried out in Slide 6.0 software for long term stability under normal and extreme loading conditions. The FoS obtained in the analysis for these unsupported slopes under static conditions is 0.81 to 1.4. However, after installing rock bolting as a support system there is a considerable increment of more than 40%in FoS of the analyzed slope in static condition making it safe.
- Factory of safety has decreased with increase in the height of cut slope and making the upper part of the slope unstable.
- After performing all the method analysis on SLIDE 6.0 software it is conclude that FoS obtained from the Bishop method is higher than calculated FoS by Janbu method.
- In general, at the time of slope Cutting/excavation, the overburden could be disturbed and may lead to the hazardous consequences. To overcome this, proper monitoring is required.

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