Analysis of Different Slope Features and To Develop Stable Slope Models for Opencast Mine using FLAC slope

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Analysis of Different Slope Features and To Develop Stable Slope Models for Opencast Mine using FLAC slope

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By

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May 30, 2016

Supervisor's Certificate

This is to certify that the work presented in this dissertation entitled "**Analysis of Different Slope Features and to Develop Stable Slope Models for Opencast Mine using FLAC slope**" by "Roshan Khan", Roll Number 711MN1126, is a record of original research carried out by him under my supervision and guidance in partial fulfilments and requirements of the degree of B. Tech and M. Tech Dual degree in Mining Engineering. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

Dr. Hrushikesh Naik
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Abstract

Slope failure is a common problem in opencast mines which occur because of improper design. So it is critical to monitor and analyze the stability of slope on a regular basis. Stability analysis of slopes is associated with the various opencast mining operations throughout the life cycle of the project, and it is very necessary to analyze the slope on a regular basis.

Mining activities involve risk at each working stage and slope stability is an integral part of the open pit or opencast mines as the whole operation process depends on the slope stability. In the mining industry, opencast mines give higher production as compare to underground mine. So it is very important to maintain the stability of the slope in a proper way, and the design of slope should be in such a way so that the slope will be able to bear the different activities going on there.

Slope stability analysis is used in a wide variety of geotechnical engineering issues, including, but not limited to, the following problems:

- To Determine the stable cut and fill slopes,
- To Assess the overall stability of retaining walls, including different stability measures (includes permanent and temporary systems),
- To assess the overall stability of shallow and deep foundations for structures situated on slopes or over potentially unstable soils, and
- Stability assessment of various landslides (mechanisms of failure, and to determine the design properties through back-analysis), and to develop the mitigation techniques to improve stability.

In this present research various software is used for the numerical modelling e.g. – FLAC slope, OASYS to generate the different models to analyze the stability of the slope. Based on different numerical models after using FLAC and OASYS, comparative studies have been carried out for the Factor of safety.

Keywords: Slope Stability Analysis, FLAC Slope, OASYS, Opencast working, Slope Failures, Numerical modelling.

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Chapter 1

Introduction

1.1 Overview

Slope failure is a common problem in opencast mines which occur because of improper design. So it is critical to monitor and analyze the stability of slope on a regular basis. Stability analysis of slopes is associated with the various opencast mining operations throughout the lifecycle of the project, and it is very necessary to analyze the slope on a regular basis.

In India, the quantity of opencast mines which is being worked is consistently expanding when contrasted with underground mines. It is a result of low gestation period, higher efficiency, and brisk rate of speculation. Then again, opencast mining draws in ecological concerns, for example, strong waste administration, degradation of land and financial issues. In disdain to that countless mines, expansive or little, are currently days coming to profound mining profundities. Therefore investigation of slope stability and final pit configuration of slope are turning into a prime concern. Failure of slopes cause loss of life, extra stripping cost for recuperation and treatment of fizzled material, dewatering the pits and some of the time it might prompt mine relinquishment/untimely closure.

So monitoring of slopes stability in open cast mines at various mining stages is very necessary for the economic and safe mining operations. Slopes are normally made based on the availability of geotechnical data and physico-mechanical properties of soil and rock. By using the geotechnical data, the quality of rock mass is analyzed, and from this, properties of rock mass are calculated. Using different properties, the stability of the slopes is calculated from different empirical, analytical as well as numerical techniques.

To solve the problems which are related to stability, numerical modelling software is required. The software which used in this research is FLAC SLOPE and OASYS.

FLAC SLOPE and OASYS were used for slope stability analysis and to calculate the factor of safety. Then results of both of the Software are used for comparison and for the better understanding of slopes.

1.2 Objective of the project

The basic objectives of the project are following –

(a) To Understand the different types and model of slope failure,
(b) Design of stable slope for Opencast mine considering different factors using FLAC slope, and
(c) To consider the different conditions for which the FOS of the slope is maximum, and to give comparisons of FOS by calculating FOS through FLAC and OASYS under same conditions.

1.3 Project Strategies

A broad literature review has been completed for comprehension the distinctive sorts and methods of slope failure. Numerical modelling software such as FLAC/Slope and OASYS were basically checked on for its application to assessment of the stability of slopes in opencast mines. Field examination was done at Belpahar Opencast Mine at Jharsuguda District in Odisha State. Cohesion and angle of internal friction data are used for the analysis purpose.

- Collection of relevant data from mine
- Parametric studies were done through numerical models (FLAC/Slope) to study the effect of cohesion (60-150 KPa) and friction angle (16°-40° at the interval of 4°).
- Pit slope angle was varied from 30° to 65° at an interval of 5°.

1.4 Report Outline

- In chapter-1, the basic definitions, objective of the project are given
- In chapter-2, the details about the different slope failure, and detailed literature review are given to understand the project.
- In chapter-3, project methodology is given. In this chapter, details about the data collected from mine also given.
- In chapter-4, details about the software is provided.
- In chapter-5, results are given. Different model generated by FLAC and OASYS also given.
- In chapter-6, conclusion of the project is provided.

Chapter 2

Literature Review

2.1 Open Pit or Opencast Mines – Introduction [1]

In open pit mining, mineral or ore deposits are mined starting from the earliest stage and descending. Thus, pit slopes are shaped as the mineral is being removed. It is rarely, to say never, Conceivable to keep up steady vertical inclines or pit dividers of considerable stature even in hard and robust rock. The pit slope should in this manner be inclined at some point to anticipate the failure of a rock mass. This slope angle is administered by the geo-mechanical conditions at the particular mine and denotes an upper bound to the general incline edge. The actual points utilized as a part of the pit rely on

(i) the nearness of haulage streets, or inclines, fundamental for the transportation of the impacted metal from the pit,
(ii) conceivable blast damage,
(iii) mineral evaluations, and
(iv) economic limitations.

2.2 Slope Stability [2] [3]

Slope stability monitoring is by and large led to gauge the most feasible safe and economic outlines of the slopes and their adjusting conditions. Slope stability is by and large characterized as the proportion of the resistive forces acting against the main forces or driving forces on the slope surface to failure by falling or sliding. The real concerns of slope stability monitoring is to watch and audit failure systems, finding fundamentally peril slopes, discover the slope stability, ideal plans of slope for safety, financial aspects and configuration of conceivable preventive measures. To decide the steady or unsteady conditions for a slope, alongside the standards of engineering statics, deterministic and probabilistic techniques are likewise used to compute the variable of safety of the slope furthermore its likelihood of failure by quality monitoring. Anytime when the total sliding mass is thought to have structure a tube shaped shape, a unit width nearby the substance of the grade is normally taken for examination, and the slip surface of the incline's cross sectional zone is the fragment of the circle. The strengths following up on the accepted failure mass are resolved which influences the equilibrium and the rotational moments of these forces are figured as for the point speaking to the circular segment's Center. In this technique, the heaviness of the material in sliding mass is considered as the outer burden on the face and the slope's top add to moments which bring about development. The shear quality of the soil gives resistance to the sliding on the expected failure surface. To present if failure happens, a computational strategy is utilized to liken moments that will oppose development to the strengths that causes movement.

The factor of safety against sliding or movement is expressed as:

$$F = \frac{\text{Moments Resisting the Sliding (resisting force)}}{\text{Moments Causing the Sliding (driving force)}}$$

The slope stability problem can be divided into two types:

1. Gross stabilty problem: It refers to large volumes of materials which descend the slopes because of huge rotational type of shear failure and it includes profoundly weathered rock and soil.

2. Local stability problem: This issue which alludes to much smaller volume of material and these sort of failure effect either one or two benches at a time because of shear plane jointing, slope erosion because of surface drainage.

2.3 Factors Affecting Slope Stability [4] [1]

The factors which affect the stability of the slope are:

- Geometry of the Slopes
- Geological Structures
- Lithology
- Ground water

- Method of Mining and Type of Equipment
- Dynamic Forces
- Cohesion
- Angle of Internal Friction

2.3.1 Geometry of the Slopes [4]

The basic geometrical slope design parameters which are height, area of failure surface and overall slope angle. The slope stability decreases, as we increase the height. The overall angle increments upto the conceivable degree of the improvement of the any failure to the rear of the crest increments and it should be considered so that the ground deformation at the mine peripheral territory can be maintained a strategic distance from. Generally slope angle of 45° is thought to be safe by Directorate General of Mines Safety (DGMS). The curvature of the slope has significant impact on the instability and along these lines arched area inclines ought to be kept away from in the slope outline. More extreme and higher the height of slope less is the stability. Figure demonstrating bench, ramp, overall slope and their respective angles is given in Fig.1.

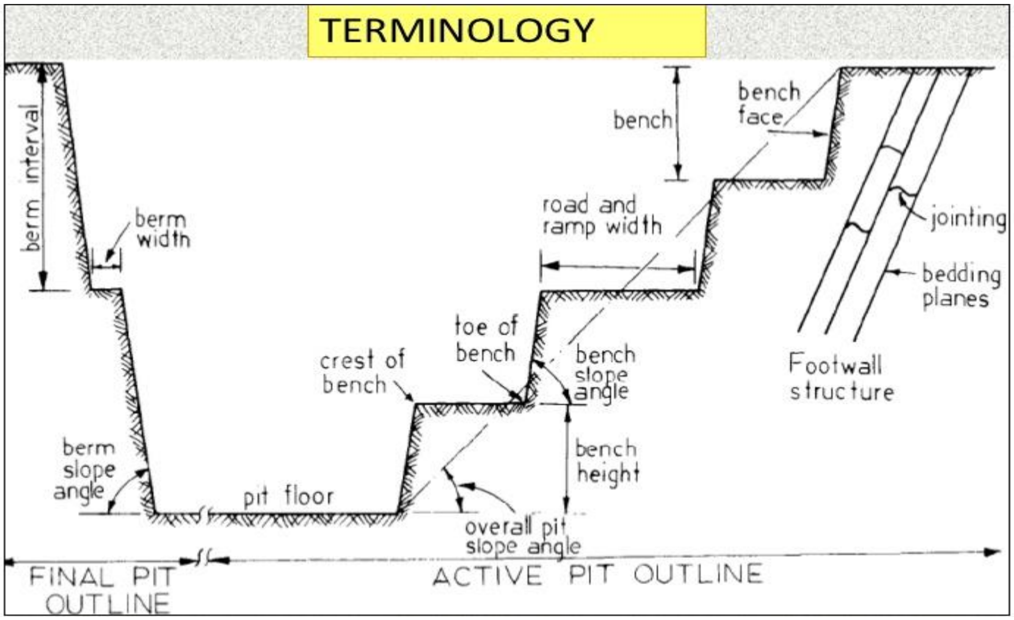


Figure 1 – Diagram showing bench, ramp, overall slope and their respecttive angles (Source – Google Images)

2.3.2 Geological Structures [4]

The main geological structures which affect the stability of the slopes in the open pit mines are:

1. Amount and direction of dip.
2. Intra-formational shear zones.
3. Joints and discontinuities
    a) reduce shear strength,
    b) change permeability, and
    c) act as sub surface drain and plains of failure.
4. Faults
    a) weathering and alternation along the faults,
    b) act as ground water conduits, and
    c) provides a probable plane of failure.

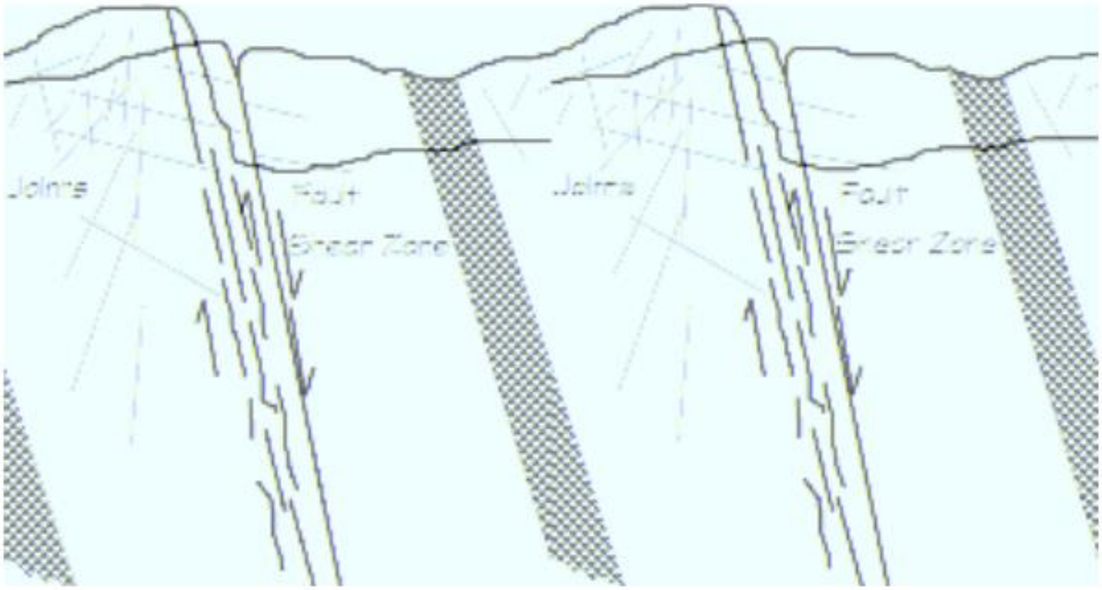


Figure 2 – Different types of joints and faults (partly after Nordlund and Radberg, 1995)

2.3.3 Lithology [4]

The rock materials shaping a pit slope decides the rock mass strength altered by discontinuities, faulting, folding, old workings and weathering. Low rock mass strength is described by circular; raveling and rock fall unsteadiness like the formation of slope in enormous sandstone restrict stability. Pit slopes having alluvium or weathered rocks at the surface have low shearing quality and the quality gets further diminished if water leakage happens through them. These sorts of slopes must be flatter.

2.3.4 Ground water [2]

It causes the following:

- alters the cohesion and frictional parameters and
- reduce the normal effective stress.

Ground water causes expanded up push and driving water compels and has unfavorable impact on the stability of the slopes. Physical and chemical impact of pure water pressure in joints filling material can subsequently adjust the cohesion and friction of the discontinuity surface. Physical impacts of giving uplift on the joint surface, decreases the frictional resistances. This will decrease the shearing resistance along the potential failure plane by lessening the effective normal stress following up on it. Physical and the chemical impact of the water pressure in the pores of the rock cause a decline in the compressive quality especially where confining stress has been decreased.

2.3.5 Method of Mining and Type of Equipment [2] [4]

Generally there are four methods of advance in open cast mines. They are:

- strike cut- advancing down the dip,
- strike cut- advancing up the dip,
- dip cut- along the strike, and
- open pit working.

The utilization of dip cuts with development on the strike reduces the length and time that a face is exposed during excavation. Dip cuts with development angled to strike may frequently use to lessen the strata dip into the excavation. Dip cut for the most part offer the most stable strategy for working however experience the ill effects of confined production potential. Open pit method are used as a part of steeply dipping seams, because of the expanded slope height are more prone to large piece/buckling modes of failure. Mining equipment which heaps on the benches of the open pit mine offers ascend to the expansion in additional charge which thus expands the force which tends to pull the slope face descending and in this manner instability happens. Instances of circular failure in spoil dumps are more pronounced.

2.3.6 Dynamic Forces [4]

Because of impact of blasting and vibration, shear stresses are quickly expanded and as result dynamic speeding up of material and hence increase the stability problems in the slope face. It causes the ground movement and breaking of rocks.

Blasting is an essential factor administering the most extreme achievable bench face angles. The impacts of careless or poorly designed blasting can be exceptionally critical for slope stability, as noted by Sage (1976) and Bauer and Calder (1971). Other than blasting harm and back break which both decrease the bench face angle, vibrations from blasting could possibly bring about failure of the rock mass. For small scale slopes, different sorts of smooth blasting have been proposed to diminish these impacts and the encounters are entirely great (e.g. Hoek and Bray, 1981). For large scale slopes, nonetheless, blasting turns out to be less of issue following back break and blast harm of benches have negligible effects on the general slope angle. Moreover, the high recurrence of the blast speeding up waves preclude them from dislodging substantial rock masses consistently, as pointed out by Bauer and Calder (1971). Blasting impelled failures are in this way a marginal issue for large scale slopes. Seismic events, i.e., low frequency vibrations, could be more risky for large scale slopes and a few seismic-impelled failures of characteristic slopes have been seen in mountainous regions. Together with all these causes external stacking can likewise assumes a critical part when they are available as in case of surcharge because of dumps on the crests of the benches. In high altitude regions, solidifying of water on slopes appearances can results in the development of ground water pressure behind the face which again signifies instability of the slope.

2.3.7 Cohesion [4]

It is the characteristic property of a rock or soil that measures how well it resists being deformed or broken by forces such as gravity. In soils/rocks true cohesion is caused by electrostatic forces in stiff over consoledated clays, cementing by Fe2O3, CaCO3, NaCl, etc.

and root cohesion however the apparent cohesion is caused by negative capillary pressure and pore pressure response during undrained loading. Slopes having rocks/soils with less cohesion tend to be less stable.

The factors that strengthen the cohesive force are as follows:

- Friction,
- Stickiness of particles can hold the soil grains together. However, being too wet or too dry can reduce cohesive strength,
- Cementation of grains by calcite or silica deposition can solidify earth materials into strong rocks, and
- Man-made reinforcements can prevent some movement of material.

The factors that weaken cohesive strength are as follows:

- High water content can weaken cohesion because abundant water both lubricates (overcomeing friction) and adds weight to a mass,
- Alternating expansion by wetting and contraction by drying of water reduces strength of cohesion, just like alternating expansion by freezing and contraction by thawing. This repeated expansion is perpendicular to the surface and contraction vertically by gravity overcomes cohesion resulting with the rock and sediment moving slowly downhill,
- Undercutting in slopes, and
- Vibrations from earthquakes, sonic booms, blasting that create vibrations which overcome cohesion and cause mass movement.

2.3.8 Angle of Internal Friction [4] [2]

Angle of internal friction is the angle (ϕ), measured between the normal force (N) and resultant force (R), that is attained when failure just occurs in response to a shearing stress (S). Its tangent (S/N) is the coefficient of sliding friction. It is a measure of the ability of a unit of rock or soil to withstand a shear stress. This is affected by particle roundness and particle size. Lower roundness or larger median particle size results in larger friction angle. It is also affectted by quartz content. The sands with less quartz contained greater amounts of potassium-feldspar, plagioclase, calcite, and/or dolomite and these minerals generally have higher sliding frictional resistance compared to that of quartz.

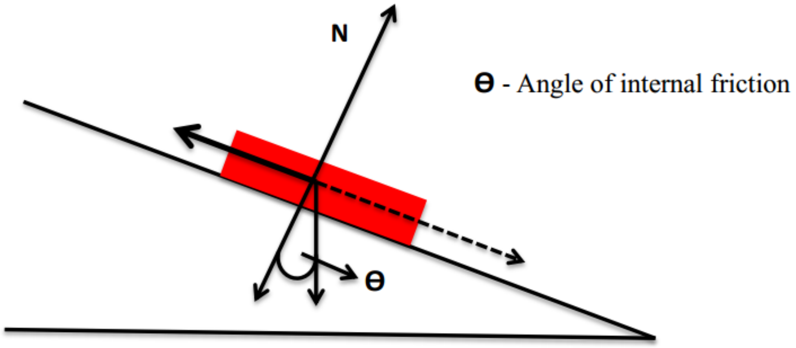


Figure 3 – Diagram showing angle of internal friction (Source: Google image)

2.4 Types of Slope Failure [3]

Slope failures of different types are of the following types:

- Plane Failure
- Wedge Failure
- Circular Failure
- Toppling Failure

2.4.1 Plane Failure

Simple plane failure is the easiest form of rock slope failure to analyze. It occurs when a discontinuity striking approximately parallel to the slope face and dipping at a lower angle intersects the slope face, enabling the material above the discontinuity to slide. Variations on this simple failure mode can occur when the sliding plane is a combination of joint sets which form a straight path.

This means that the solution is never anything more than the analysis of equilibrium of a single block resting on a plane and acted upon by a number of external forces (water pressure, earth quake, etc.) deterministic and probabilistic solution in which parameters are considered as being precisely known may be readily obtained by hand calculation if effect of moment is neglected.

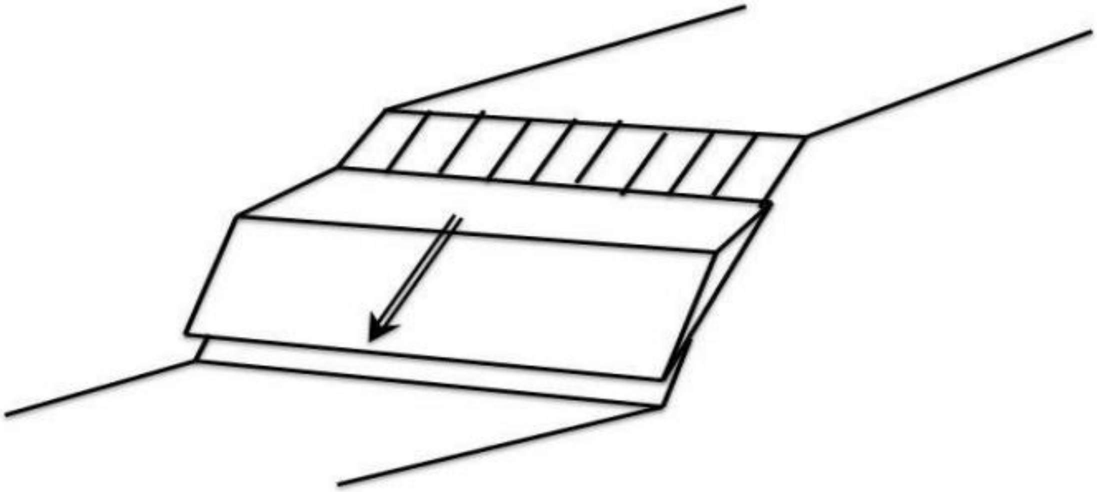


Figure 4 – Plane failure (after Coates, 1977; Call and Savely, 1990)

For a plane failure analysis, the geometry of the slope is very critically studied. In this connection two cases must be considered:-

(a) A slope having tension crack in the upper face, and
(b) A slope with tension crack in the slope face.

2.4.2 Wedge Failure

The three dimensional wedge failures occur when two discontinuities intersects in such a way that the wedge of material, formed above the discontinuities, can slide out in a direction parallel to the line of intersection of the two discontinuities. It is particularly common in the individual bench scale but can also provide the failure mechanism for a large slope where structures are very continuous and extensive. When two discontinuities strike obliquely across the slope face and their line of intersection ‘daylights’ in the slope, the wedge of the rock resting over these discontinuities will slide down along the line of intersection provided the inclination of these line is significantly greater than the angle of friction and the shearing component of the plane of the discontinuities is less than the total downward force.

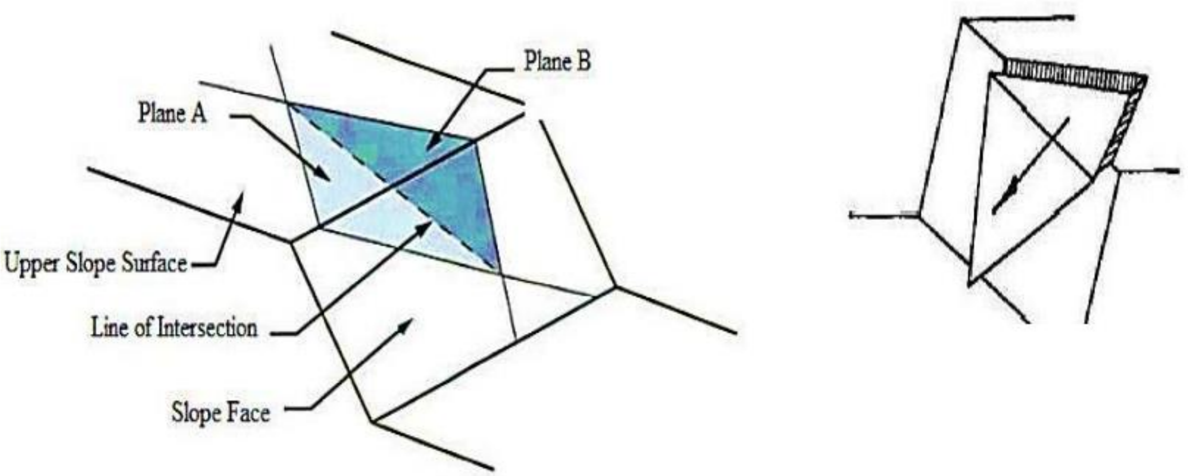


Figure 5 – Wedge failure (after Hoek and Bray, 1981)

The total downward force is the downward component of the weight of the wedge and the external forces (surcharges) acting over the wedge. The wedge failure analysis is based on satisfying the equilibrium conditions of the wedge. If ‘w’ be the weight of the wedge, the vector ‘w’ can be divided into two components in the parallel and normal directions to the joint intersection.

2.4.3 Circular Failure

This failure can occurs in soil slopes, the circular method occurs when the joint sets are not very well defined. When the material of the spoil dump slopes are weak such as soil, heavily jointed or broken rock mass, the failure is defined by a single discontinuity surface but will tend to follow a circular path. The conditions under which circular failure occurs are follows:

- When the individual particles of soil or rock mass, comprising the slopes are small as compared to the slope, and
- When the particles are not locked as a result of their shape and tend to behave as soil.

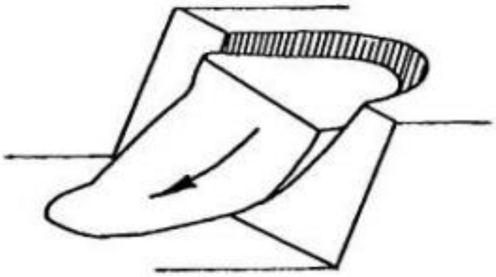


Figure 6 – Three-dimensional failure geometry of a rotationnal failure (after Hoek and Bray, 1981)

Figure 7 – Circular failure in highly weathered, granitic rock (on Highway 1, near Devil's Slide, Pacifica, California).(Source: Rock slope engineeering, 4th edition by Duncan C. Wyllie and Christopher W. Mah,)

Types of circular failure Circular failure are classified in three types depending on the area that is affected by the failure surface. They are:-

a) **Slope failure:** In this type of failure, the arc of the rupture surface meets the slope above the toe of the slope. This happens when the slope angle is very high and the soils close to the toe possess the high strength.
b) **Toe failure:** In this type of failure, the arc of the rupture surface meets the slope at the toe.

c) **Base failure:** In this type of failure, the arc of the failure passes below the toe and in to base of the slope. This happens when the slope angle is low and the soil below the base is softer and more plastic than the soil above the base.

2.4.4 Toppling Failure

Toppling or overturning has been recognized by several investigators as being a mechanism of rock slope failure and has been postulated as the cause of several failures ranging from small to large ones.

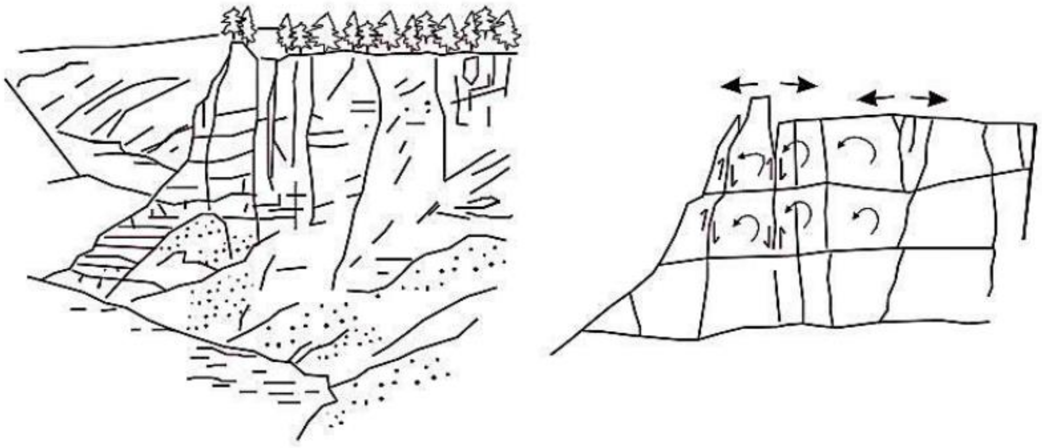


Figure 8 – Toppling mechanism of the north face of Vaiont slide (Muller, 1968)

It occurs in slopes having near vertical joint sets very often the stability depends on the stability of one or two key blocks. Once they are disturbed the system may collapse or this failure has been postulated as the cause of several failures ranging from small to large size. This type of failure involves rotation of blocks of rocks about some fixed base. This type of failure generally occurred when the hill slopes are very steep.

After Hofmann several model studies were carried out by Soto (1974), Ashby (1971) and Whyte (1973), while Cundall (1971), Byrne (1974) and Hammett (1974) who integrated rotational failure modes into computer analysis of rock mass behavior. At the point when the weight vector of block of rock resting on a slanted plane falls outside the base of the block, this prompts toppling failure. This kind of failure may happen in undercutting beds (Fig. 9). When they are bothered the framework may crumple or this failure has been proposed as the reason for a few failures going from little to substantial. This kind of failure by and large happened when the hill slopes are extremely steep.

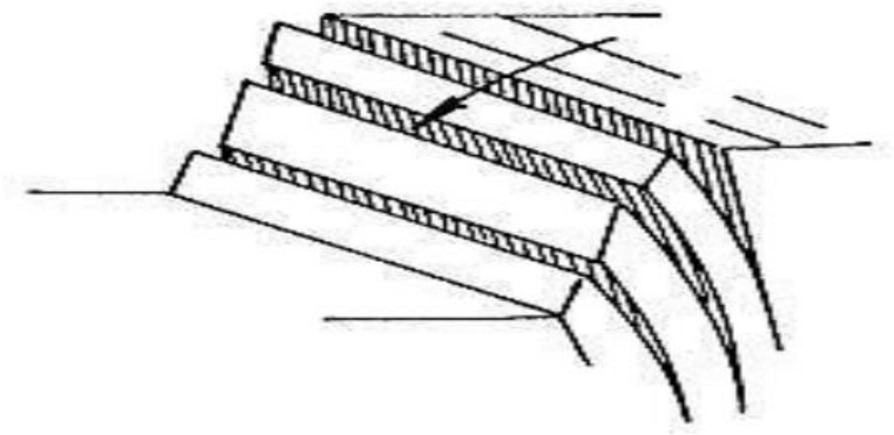


Figure 9 – Toppling Failure (modified after Hoek & Bray, 1981)

(Source:www.dipanalyst.com/Kinematic%20Analysis/Kinematic%20Analysis.html)

2.5 Reasons for Slope Failure in Mines [5]

There are many reasons exist for a bench slope failure. Some of them are:

- Dynamic loading due to blasting, earthquake, and HEMM (heavy earth moving machineries) etc. shear stresses increases instantly in the rock mass as the result of vibration.
- Water pressure in the joint is also liable for frequent slope failure than all other causes taken together.
- Very often the location, orientation and properties of structural discontinuities in the rock mass acts as a major factor for rock slope failure.
- Due to lack of supervision in the high-wall bench.
- Flooding of floor due to existence of aquifers.
- Because of the decrease in the cohesion and friction angle value of dump materials.
- In deep-hole blasting maintenance of slope angle is also very difficult and probability of slope failure becomes very high.

2.6 Factors to be considered in Assessment of Stability [6]

The Factors which should be considered are of following types –

2.6.1 Ground Investigation [6] [7]

Before any further examination of an existing slope, or the ground on which a slope is to be built, essential borehole information must be obtained. This information will give details of the strata, moisture content and the standing water level and shear planes. Piezometer tubes are installed into the ground to measure changes in water level over a period of time. Ground investigations also include:-

- in-situ and laboratory tests,
- aerial photographs,
- study of geological maps and memoirs to indicate probable soil conditions, and
- visiting and observing the slope.

2.6.2 Most Critical Failure Surface [7]

In homogeneous soils relatively unaffected by faults or bedding, deep seated shear failure surfaces tend to form in a circular, rotational manner. The aim is to find the most critical surface using "trial circles".

The method is as follows:

- A series of slip circles of different radii is to be considered but with same centre of rotation. Factor of Safety (FOS) for each of these circles is plotted against radius, and the minimum FOS is found.
- This should be repeated for several circles, each investigated from an array of centers. The simplest way to do this is to form a rectangular grid from the centers.
- Each centre will have a minimum FOS and the overall lowest FOS from all the centre shows that FOS for the whole slope. This assumes that enough circles, with a large spread of radii, and a large grid of centers have been investigated.
- An overall failure surface is found.

Fig. 10 & 11 shows variety of slope failure circles analyzed at varying radii from a single centre and variation of factor of safety with critical circle radius respectively.

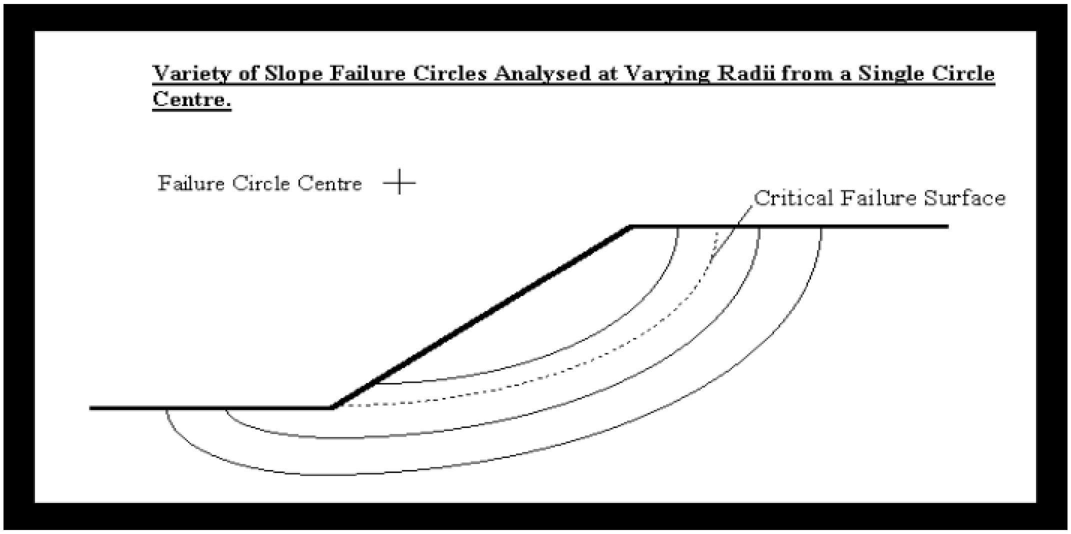


Figure 10 – Variety of slope failure circles analysed at varying radii from a single centre

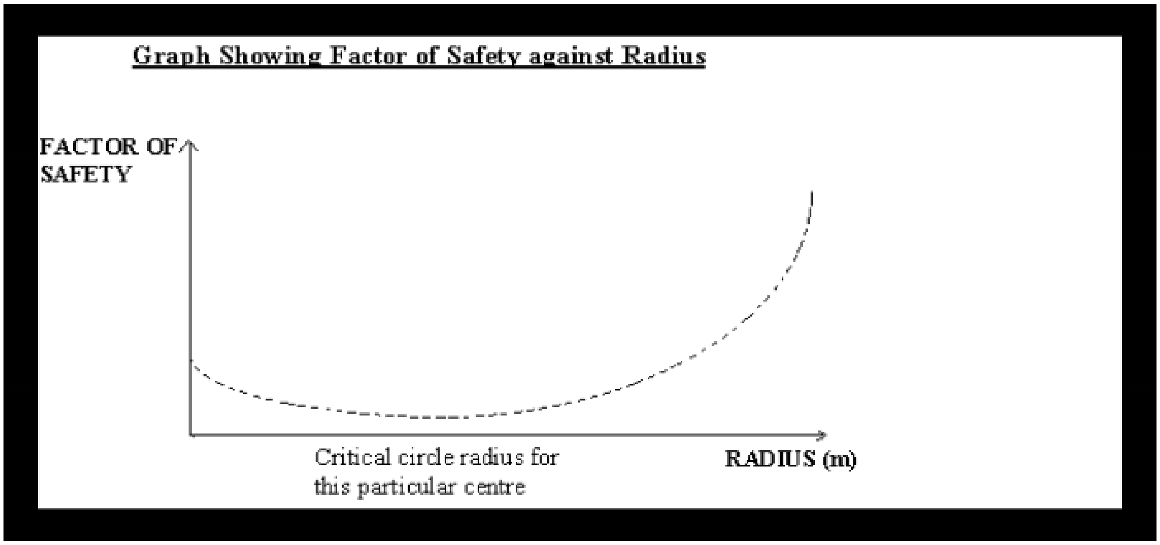


Figure 11 – Variation of factor of safety with critical circle radius

2.6.3 Tension Cracks [7] [6]

A tension crack at the head of a slide suggests strongly that instability is imminent. Tension cracks are sometimes used in slope stability calculations, and sometimes they are considered to be full of water. If this is the case, then hydrostatic forces develop as shown in Fig. 12. Tension cracks are not usually important in stability analysis, but can become so in some special cases. Therefore assume that the cracks don't occur, but take account of them in analyzing a slope which has already cracked.

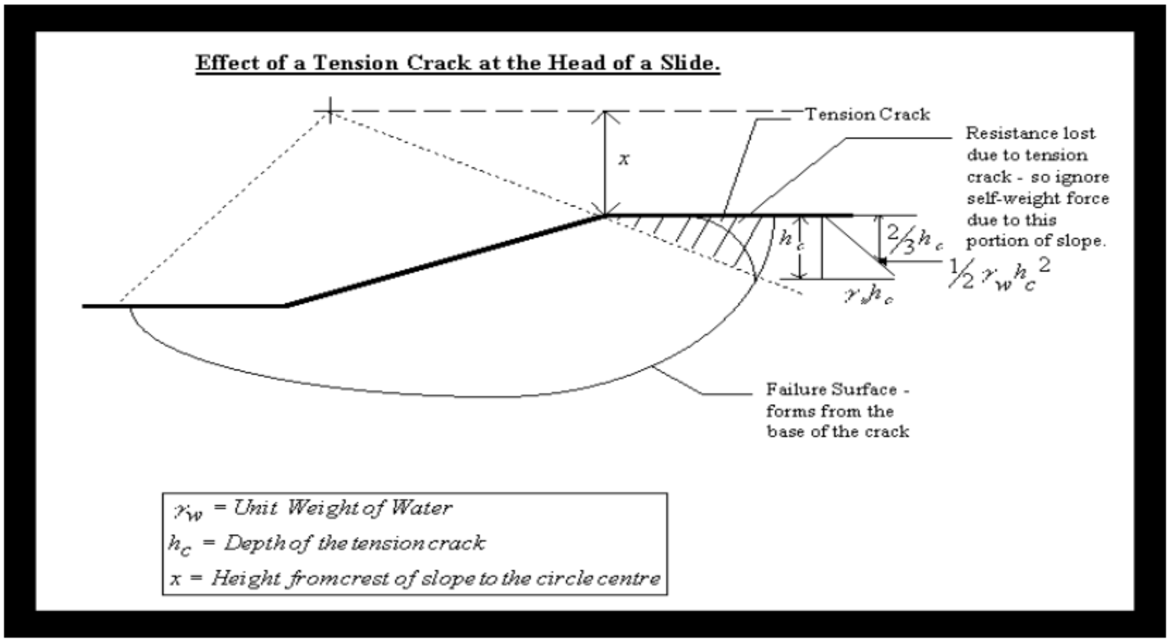


Figure 12 – Effect of tension crack at the head of a slide

2.6.4 Submerged Slopes [7]

When an external water load is applied to a slope, the pressure it exerts tends to have a stabilizing effect on the slope. The vertical and horizontal forces due to the water must be taken into account in analysis of the slope. Thus, allowing for the external water forces by using submerged densities in the slope, and by ignoring water externally.

2.6.5 Factor of Safety (FOS)

The FOS is chosen as a ratio of the available shear strength to that required to keep the slope stable.

Table 1 - Guidelines for equilibrium of a slope

FOS	Slope Type
<1.0	Unsafe to work
1.0 – 1.25	Questionable safety to work
1.25 – 1.4	Satisfactory for routine cuts and fills, Questionable for dams, where failure is expected
>1.4	Satisfactory for Dams

For highly unlikely loading conditions, factors of safety can be as low as 1.2-1.25, even for dams. E.g. situations based on seismic effects, or where there is rapid drawdown of the water level in a reservoir.

2.6.6 Progressive Failure [6] [5]

This is the term describing the condition when different parts of a failure surface reach failure at different times. This often occurs if a potential failure surface passes through a foundation material which is fissured or has joints or pre-existing failure surfaces. Where these fissures occur there will be large strain values, so the peak shear strength is reached before other places.

2.6.7 Pre-Existing Failure Surfaces [7] [5]

If the foundation on which a slope sits contains pre-existing failure surfaces, there is a large possibility that progressive failure will take place if another failure surface were to cut through them. The way to deal with this situation is to assume that sufficient movement has previously taken place for the ultimate state to develop in the soil and then using the ultimate state parameters. If failure has not taken place, then a decision has to be made on which parameters to be used.

2.7 Analysis of different Slope Feature (Analytically) [5]

Generally Slope failure occurs when the downward movements of material due to gravity and shear stress exceeds. There are four types of slope failure observe in opencast mine –

- Plane Failure
- Wedge Failure

- Circular Failure
- Toppling Failure

2.7.1 Plane Failure Analysis

Plane Failure generally occurs because of two reasons –

- A slope having tension crack in the upper face,
- A slope with tension crack in the slope face.

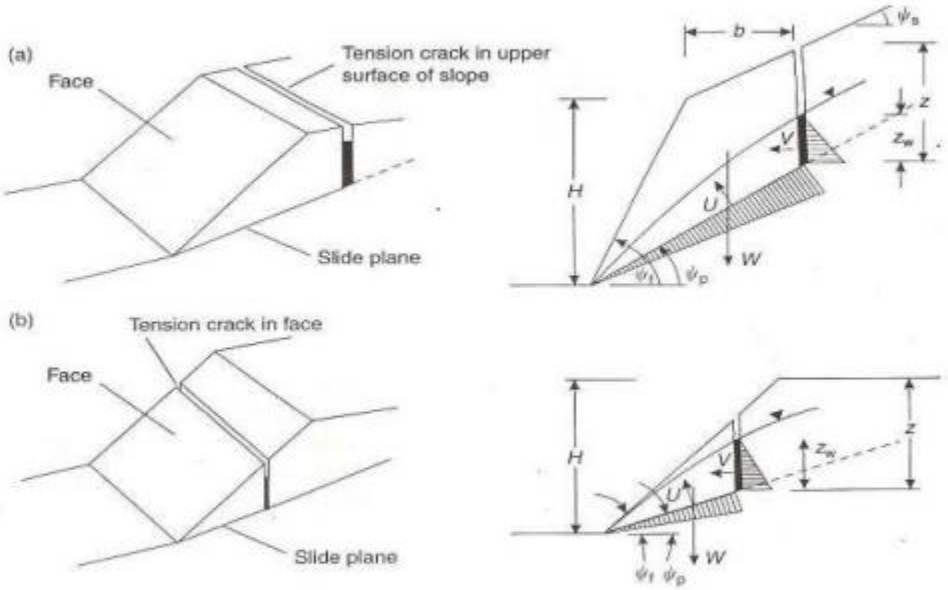


Figure 13 – plane slope failure: (a) tension crack in the upper slope; (b) tension crack in the face

For the analysis, the following assumptions are to be made:-

- The tension crack is vertical and is filled with water.
- The shear strength of the sliding surface is defined by cohesion ‘c’ and the friction angle ‘φ ’ that are related by the equation

$$\tau = c + \sigma \tan \varphi$$

- The forces which are acting are

i. W –unit weight of sliding block

ii. U –uplift force due to water

iii. V –Force in tension crack horizontally due to water

- Tension Crack co-incudes with the crest, when

$$z/H = (1- \cot \varphi_{s\,.}\ \mathrm{Tan}\ \phi_p)$$

Where z = depth of tension crack, H = Height of slope,

ϕs =slope angle, ϕ_p =sliding plane angle

The Factor of Safety can be calculated in the following way

$$\mathrm{FOS} = \frac{\text{Resisting force}}{\text{Driving force}}$$

$$\mathrm{FOS} = \frac{C.A + \Sigma N\ .\mathrm{Tan}\ \phi}{\Sigma P}$$

$$\mathrm{FOS} = \frac{C.A + (W \cos \phi_s - U - V\, sin\phi_p\,)\ .\ \tan\phi}{W\ .sin\phi_s + V.\cos \phi_p}$$

Where area of the sliding plane A is given by

$$A = (H + b \tan \phi_s - z) \operatorname{cosec} \phi_p$$

Where b= distance behind the slope crest

U and V is given by

$$U = \frac{1}{2}\, \gamma_w\, z_w\, (H + b \tan \phi_s - z) \operatorname{cosec} \phi_p$$

$$V = \frac{1}{2}\, \gamma_w\, z_w^2$$

Where γ_w is the unit weight of water

From the above calculations conclusion can be made –

- To increase the FOS, we need to vanish the U, and V force due to water and that can be achieved by pumping out the water and giving proper reinforcement
- By increasing area and keeping slope angle optimum, driving force can be reduced and as a result

2.7.2 Wedge Failure Analysis

The three dimensional wedge failures occur when two discontinuities intersects in such a way that the wedge of material, formed above the discontinuities, can slide out in a direction parallel to the line of intersection of the two discontinuities.

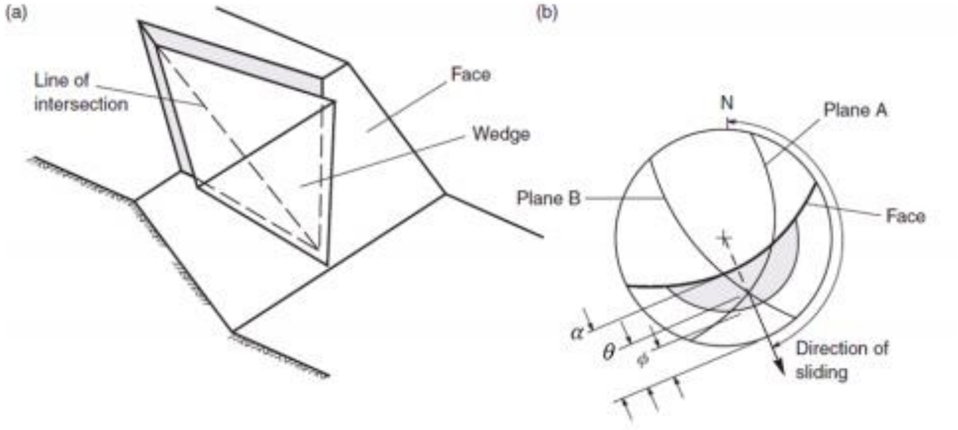


Figure 14 – Geometric conditions of wedge failure: (a) pictorial view of wedge failure; (b) stereo plot showing the orientation of the line of intersection

- For the analysis purpose, the weight, W of the wedge can be divided into two forces, normal direction forces and parallel direction forces.

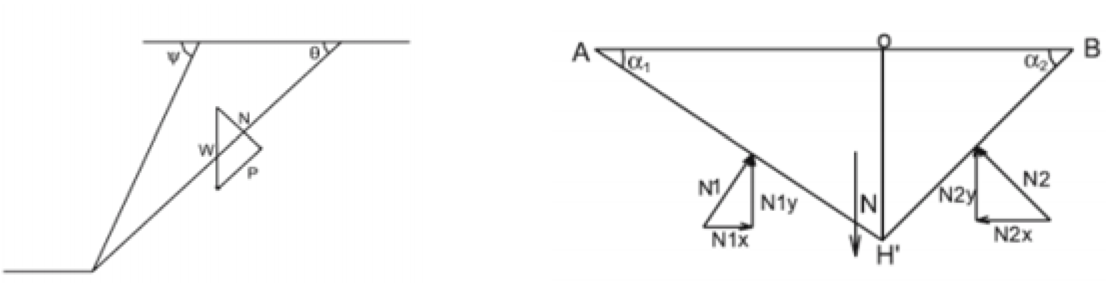


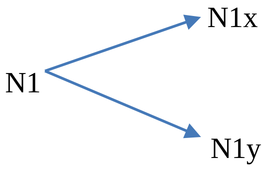
Figure 15 - Figure showing different forces acting on slope during tension

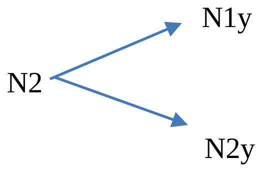
So $N = W \cos\theta$

$P = W \sin\theta$

Further normal direction force, N can be divided in two direction N_1 and N_2 at two surfaces.

Further these N1 and N2 forces can be divided into two component in x-direction and y-direction





So

$N1x = N2x$ and $N1x = N2x = N1 \sin\alpha1 = N2 \sin\alpha2$

And $N1y = N1 \cos\alpha1$, $N2 = N2 \cos\alpha2$ and

$$N1y + N2y = N$$

So finally

$$N1y + N2y = N = W \cos\theta$$

So

$$N1 = \frac{N \sin\alpha2}{\sin(\alpha1+\alpha2)}, \quad N2 = \frac{N \sin\alpha1}{\sin(\alpha1+\alpha2)}$$

So the FOS of the slope will be

$$\text{FOS} = \frac{\text{Resisting force}}{\text{Driving force}}$$

$$\text{FOS} = \frac{T1+T2}{\text{W sin}\theta}$$

Where T1, T2 are the resisting forces at tow surfaces.

$$T1 = N1 \tan \varphi + C.\ A1$$

$$T2 = N2 \tan \varphi + C.\ A2$$

Where C = cohesion, and φ = internal friction angle

A1 and A2 = area of two different sides

- So by above calculations, it can be calculated if the angle of internal friction angle is more than FOS is more and to reduce driving force slope angle should be less.

2.7.3 Circular Failure Analysis

- Circular failure is generally observed in slope of soil, mine dump, weak rock and highly jointed rock mass.
- It is very important to identify the position of most critical circle in analysis of such failure. Various slip circles may be analysed and the one yielding the minimum factor of safety can eventually be obtained.
- Generally , in circular failure , FOS is given by

$$\text{FOS} = \frac{Shear\ Stress}{Shear\ Strain}$$

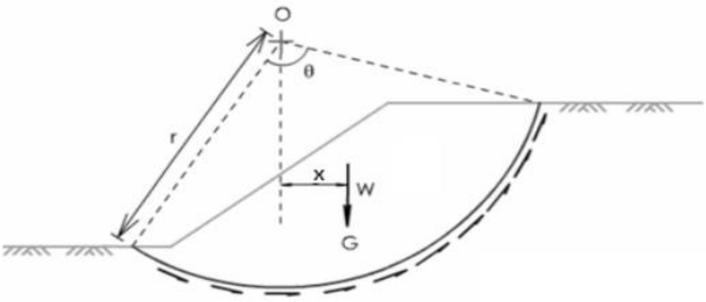


Figure 16 - Analysis of a trial slip circle

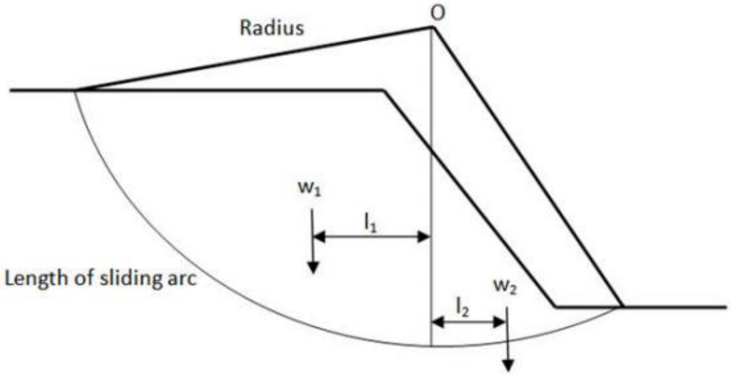


Figure 17 - Failure analysis by slip circle method

The shear strength will acting along the length of the sliding arc at moment arm length r. the slope is stable when

$$W_1. l_1 < W_2. l_2 + \tau .L.r$$

Where $\tau = C.A + \sigma_n .\tan \phi$

If the saturated conditions are exist then C =0 and ϕ =0

Then

$$W_1. l_1 > W_2. l_2$$

So

$$\frac{W_2. l_2}{W_1. l_1} < 1$$

So to pretend the circular failure, it is very important to keep the safety factor greater than 1 i.e.

$$\text{FOS} = \frac{W_2. l_2 + \tau L.r}{W_1. l_1}$$

Will be higher. So it should be concluded that if the material is saturated then it is more prone to circular failure as water reduces cohesion and internal friction angle.

2.7.4 Toppling failure Analysis

Toppling failure of rock blocks along the slope occurs when there are formed by closely spaced and steeply inclined discontinuity system dipping into the excavation. For analysis of slope stability against toppling failure, a kinematic analysis of the structural geology is first carried out to identify potential toppling conditions. If failure condition exists, a stability analysis specific to toppling failure is conducted.

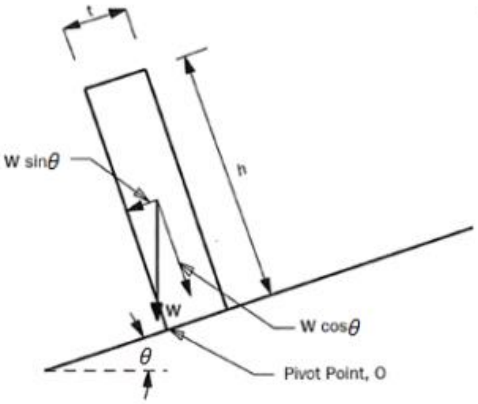


Figure 18 - Basic model for toppling failure and force acting on toppling block

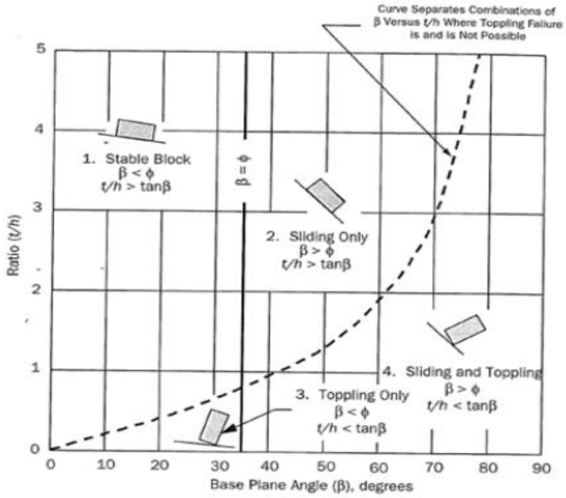


Figure 19 – Conditions for sliding and toppling of a block on an inclined plane (Hoek and Bray, 1977)

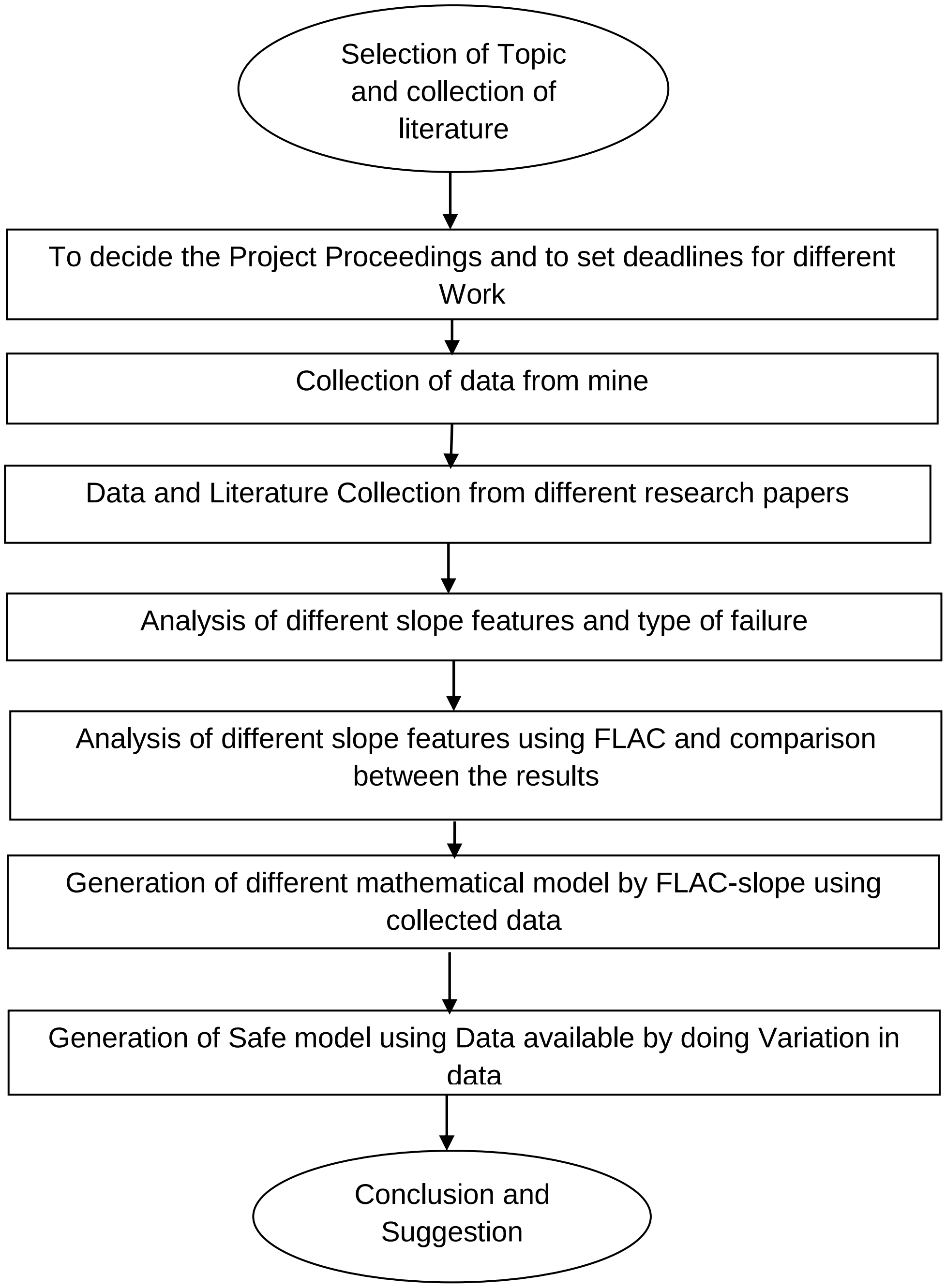
Conclusion can be made for stable block-

- Internal friction angle should be more i.e. the slope should be design in such a way that the slope angle remain less than internal friction angle.
- t/h ratio should be more than tangent value of slope angle.

Chapter 3

Materials and Method

3.1 Project Methodology



3.2 Research Strategies

- Many literatures were studied for understanding the various modes of failures in slope.
- Numerical modelling software OASYS & FLAC/Slope was reviewed for its utilization in evaluating the slope stability in the open pit mine.
- Field study was performed in the Belpahar Opencast Mine having 50 m ultimate pit depth at Jharsuguda district in the state of Odisha .
- Parametric studies were carried out by numerical models (FLAC/Slope & OASYS) to investigate consequences of cohesion (60-150 KPa) and friction angle (16°-40° at the interval of 4°). Also the effect was studied by varying slope angle of the pit from 30° to 65° at an interval of 5°.

3.3 Study Area and Data Collection

Data is collected from Belpahar Open Cast Mine. Belpahar open cast mine is one of the oldest open cast coal projects of Mahanadi Coalfields Limited (MCL). It is situated in the IB Valley Coalfields in Jharsuguda district of Orissa.

The mine is situated between 21^{0}43’45” to 21^{0}48’00” Latitude and 83^{0}49’00” to 83^{0}53’00” longitude. The minimum and maximum elevation range is in between 194m and 232m respectively.

The lease hold area of the mine is 1444.053 Ha.

Total deposits having 6 Kms along strike and 400m to 1300m along dip rise is divided into four quarries, considering the local geological in between viz. quarry no. 1 to 3s. There are two seams in Belpahar open cast mine, namely, Rampur and IB seam. The thickness of Rampur seam is 18-20 m and that of IB seam is 7 m.

3.4 Location of Belpahar OCP

Belpahar Opencast Mine is one of the ***oldest & leading*** opencast coal projects of MAHANADI COALFIELDS LIMITED. It is situated in the IB Valley coalfields in Jharsuguda District of Orissa. The mine is situated between 21^{0}-43’-45” to 21^{0}-48’-00” North Latitude and 83^{0}-49’-00” to 83^{0}-53’-00” Longitudes. It is 12 kms south of both Belpahar and Brajarajnagar Railway Station (S.E. Rly). The area is generally undulating. The minimum and maximum elevation range is between 194 mtrs. and 232 mtrs. Mine Area is bounded at

Southside by Kushraloi Village and at North & West Side by OPGC Railway line. Towards east it is bounded by the Village Kirarama and Bandhbahal Village. Total Lease hold area of the Mine is 1444.053 Ha**.**

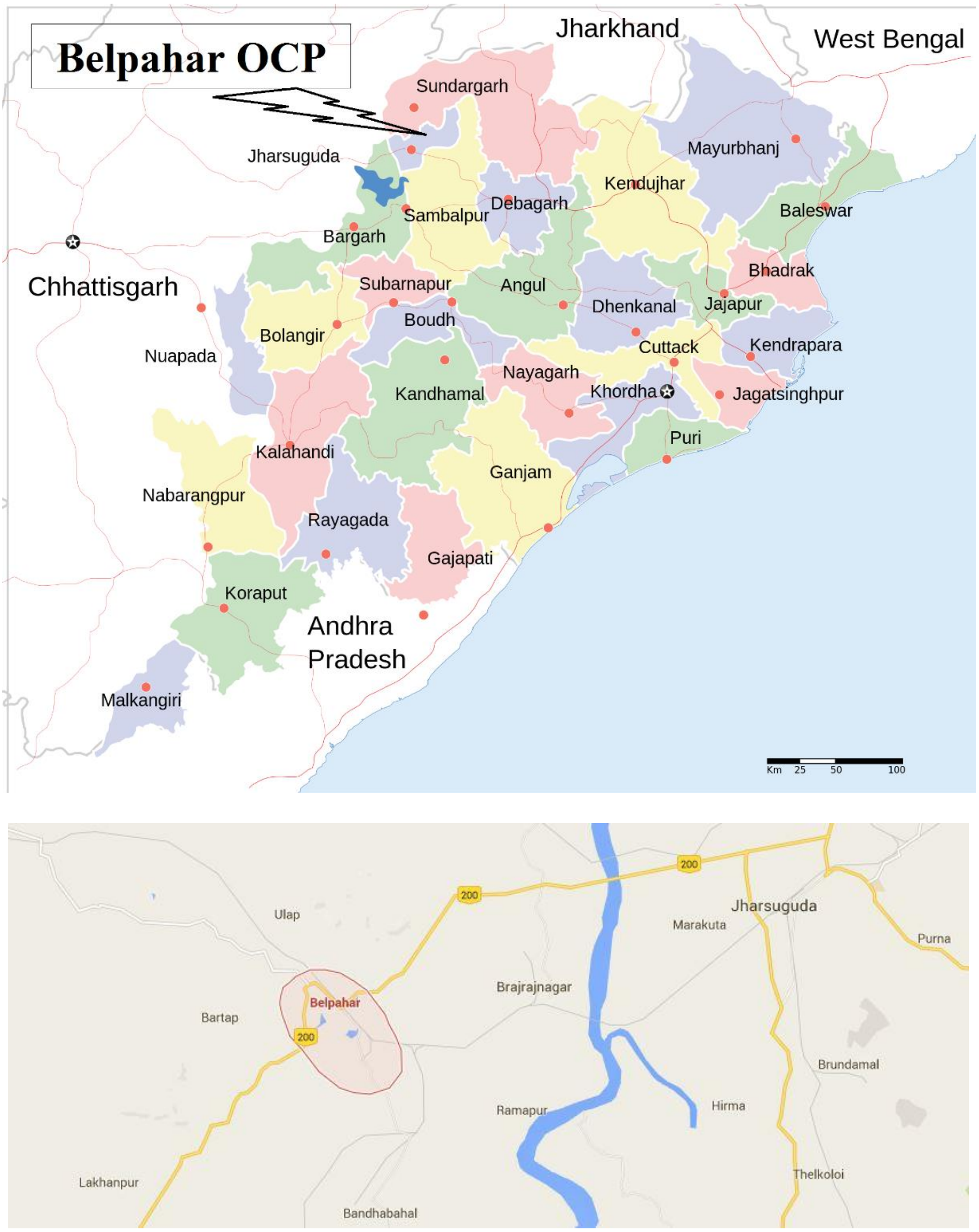


Figure 20 - Location of Belpahar OCP (Image source – Google Images and Google Maps)

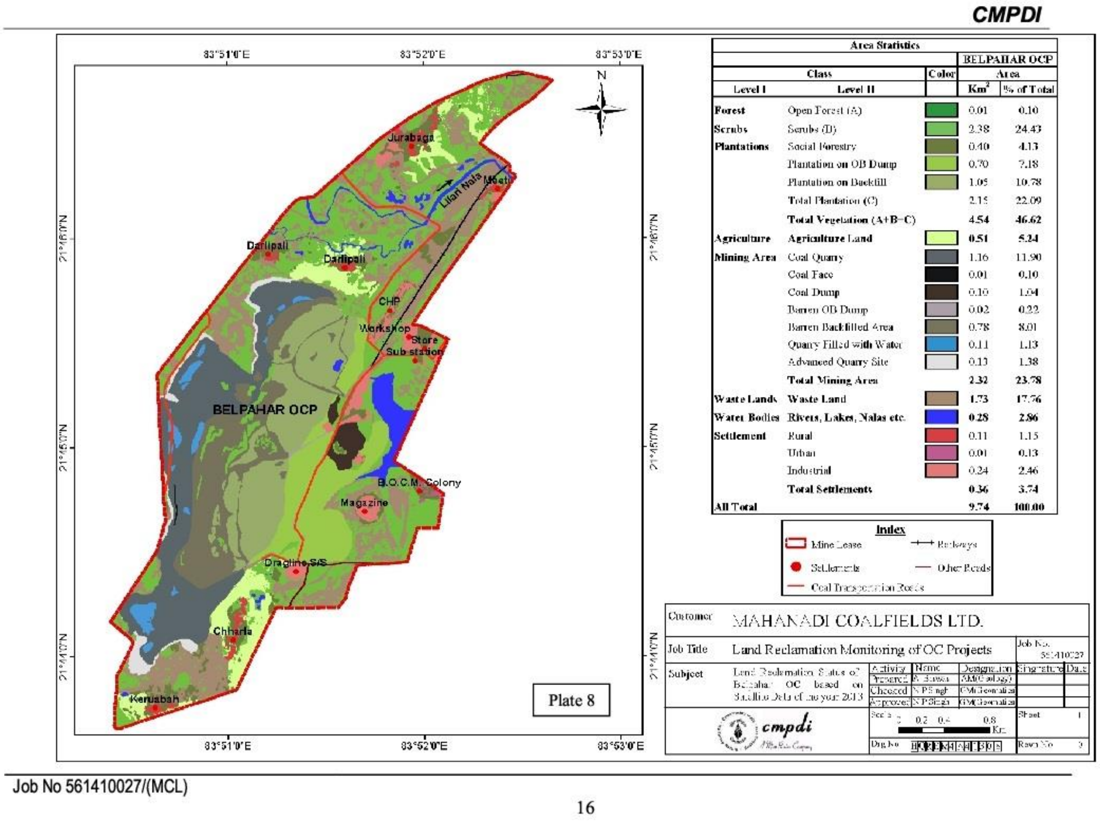
3.5 Geology of Belpahar OCP

The total deposit having 6 kms. along strike and 400m. to 1300m. along dip-rise, is divided into four quarries, considering the local geological faults in between, viz; Quarry No.1 to 3S. Presently Quarry No. 2, 3N & 3S is in operation. There are two seams in Belpahar Opencast Mine, namely, Rampur Seam and IB Seam. Rampur Seam is divided into Rampur Top & Bottom.

The *thickness of Rampur Seam* is 18-20m and that of *IB Seam* is 7m. Over Burden over Rampur Seam is being removed by *Shovel-Dumper* combination and the O.B. parting between Rampur & IB Seam is being removed by *10/70 Dragline*. The coal is being extracted by *Departmental Surface Miner & Contractual Surface Miner* in addition to conventional drilling & blasting. Contractual tippers (ESM) and (PAP) are engaged for transportation of coal from faces to CHP, sidings no 06 & 07 & UTLS which is within mine premises.

Sr. No.	Description		6.0MTY
1	Date of Approval	**:**	MCL/SAMB/GM(P&P)/11/4407 dated 11.02.2011
2	Date of opening of the Mine	**:**	11/09/1983
3	Total leasehold Area.	**:**	1444.053Ha
4	Mine Strike Length	**:**	6414m along floor ; 6494m along surface
5	Dip-rise Length	**:**	989m along floor ; 1087m along surface
6	No. of quarries	**:**	4
7	Present area of working	**:**	Quarry No.2,3 North & 3 South
8	Coal seam being worked	**:**	IB & Rampur
9	Thickness of seam	**:**	IB seam - 7 m & Rampur Seam-20-22M
10	General seam gradient	**:**	1 in 15
11	Stripping ratio	**:**	1 : 1.43
12	Quality of coal	**:**	G-13
13	Annual Production Target	**:**	6.0 MTY
14	Balance Mineable Reserve(as on 01.01.14)	**:**	33.56MT
15	Balance Overburden(as on 01.01.14)	**:**	113.527M.Cum.
16	Balance life(as on 01.01.2014)	**:**	06Years
17	Total area to be excavated	**:**	624.62 Ha.
18	Area already excavated(as on 01.01.115)	**:**	360.859 Ha

19	Total de coaled area(as on 01.01.15)	**:**	191.000Ha
20	Total backfilled area.(01.01.15)	**:**	164.889 Ha
21	Total plantation area		
	a) Over backfilling	**:**	93.80 Ha
	b) Over external Overburden dump	**:**	55.33 Ha
22	Production performance (2013-14)		
	a) COAL	**:**	59.99 Lakh Te.
	b) OB	**:**	73.47 Lakh m^3.
23	Production performance (2014-15)		Upto 31.12.2013
	a) COAL (Up to 31st Dec. 13)	**:**	57.71 Lakh Te.
	b) OB (Up to 31st Dec. 13)	**:**	76.56 Lakh m^3.
24	Coal Exposure (as on 01.01.2015)		
	a) Total	**:**	17.42 Lakh Te.
	b) Mineable.	**:**	10.83 Lakh Te.



Area Statistics

Class		Color	BELPAHAR OCP Area	
Level I	Level II		Km²	% of Total
Forest	Open Forest (A)	🟩	0.01	0.10
Scrubs	Scrubs (B)	🟩	2.38	24.43
Plantations	Social Forestry	🟩	0.40	4.13
	Plantation on OB Dump	🟩	0.70	7.18
	Plantation on Backfill	🟩	1.05	10.78
	Total Plantation (C)		2.15	22.09
	Total Vegetation (A+B+C)		**4.54**	**46.62**
Agriculture	**Agriculture Land**	🟩	**0.51**	**5.24**
Mining Area	Coal Quarry	⬛	1.16	11.90
	Coal Face	⬛	0.01	0.10
	Coal Dump	🟫	0.10	1.04
	Barren OB Dump	⬜	0.02	0.22
	Barren Backfilled Area	🟫	0.78	8.01
	Quarry Filled with Water	🟦	0.11	1.13
	Advanced Quarry Site	⬜	0.13	1.38
	Total Mining Area		**2.32**	**23.78**
Waste Lands	**Waste Land**	🟫	**1.73**	**17.76**
Water Bodies	**Rivers, Lakes, Nalas etc.**	🟦	**0.28**	**2.86**
Settlement	Rural	🟥	0.11	1.15
	Urban	🟪	0.01	0.13
	Industrial	🟥	0.24	2.46
	Total Settlements		**0.36**	**3.74**
All Total			**9.74**	**100.00**

Customer MAHANADI COALFIELDS LTD.
Job Title Land Reclamation Monitoring of OC Projects
Job No. 561410027
Subject Land Reclamation Status of Belpahar OC based on Satellite Data of the year 2013

Activity	Name	Designation	Signature	Date
Prepared	A. Biswas	AM(Geology)		
Checked	N P Singh	GM(Geomatics)		
Approved	N P Singh	GM(Geomatics)		

Sheet 1
Drg No [illegible]
Revn No 0

Job No 561410027/(MCL)

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Figure 21 - Details about Belpahar OCP (Image Source - CMPDI)

3.6 Overview of Belpahar OCP

Figure 22 - Overview of Belpahar OCP (1)

Figure 23 - Overview of Belpahar OCP (2)

Figure 24 - Overview of Belpahar OCP (3)

3.7 Major Machineries Used at Belpahar OCP

Figure 25 - Surface Miner used at Belpahar OCP

Figure 26 - Working of Shovel and Dumper

Figure 27 - Working of Rope Shovel and Dumper

3.8 Data Used

For analysis purpose using FLAC software data of different mines is collected and used.

Data of Belpahar open cast mine -

The data of Belpahar open cast mine which used for analysis purpose are cohesion and angle of internal friction.

1.	Cohesion (C)	0.082 MPa = 82 KPa
	Angle of internal friction (ϕ)	24.5^0

The above data is for main analysis purpose and other MCL open cast mines data (IB Valley area Mines) used for comparison purpose.

The data’s of IB Valley opencast Mines are following –

S. No.	Cohesion (C) KPa	Angle of Internal Friction (ϕ) (degrees)
2.	85	16^0
3.	60	22^0
4.	70	34^0
5.	47.50	25.71^0
6.	50	21^0

Chapter 4

Numerical Modelling

4.1 Numerical Modelling

Numerous kind of rock slope stability issues include complexities identifying with geometry, material anisotropy, non-linear conduct, in situ stresses and the nearness of other coupled procedures (e.g. pore Pressures, seismic stacking, and so on.).

As a rule the majority of the slope instability related with complexities related to material anisotropy, non-linear conduct, geometry, in situ stresses and the nearness of a few coupled procedures (e.g. pore weights, seismic stacking, and so on.). Numerical Modelling strategy is a fitting technique for those issues which can't be controlled by conventional strategies. Numerical methods of analysis which used for rock slope stability may be divided into three approaches:

- Continuum Modelling,
- Discontinuum Modelling and
- Hybrid Modelling.

4.1.1 Continuum Modelling

Continuum modelling is most appropriate for the examination of slopes that are involved massively, intact rock, feeble shakes, and soil-like or intensely broke rock masses. Most continuum codes demonstrate a facility for including discrete cracks, for example, faults and bedding planes however are unseemly for the investigation of blocky mediums. The continuum approaches utilized as a part of rock slope dependability incorporate the finite-difference and finite-element strategies. Recently by far most of distributed continuum rock slope analyses have utilized the 2-D finite element code, FLAC. This code permits a wide decision of constitutive models to describe the rock mass and fuses time subordinate conduct, coupled hydro-mechanical and dynamic demonstrating.

Continuum modelling is most appropriate for the investigation of slopes that are included huge, Two-dimensional continuum codes accept plane strain conditions, which are often not legitimate in in homogeneous rock inclines with shifting structure, lithology and geography.

The late appearance of 3-D continuum codes, for example, FLAC 3D and VISAGE empowers the designer to embrace 3-D investigations of rock inclines on a desktop PC. Despite the fact that 2-D and 3-D continuum codes are greatly helpful in describing rock slope failure instruments it is the obligation of the specialist to check whether they are illustrative of the rock mass under thought. Where a rock slope contains various joint sets, which control the system of failure, then a discontinuum displaying approach might be viewed as more suitable.

4.1.2 Discontinuum Modelling

Discontinuum strategies regard the rock slope as an irregular rock mass by considering it as a gathering of inflexible or deformable pieces. The examination incorporates sliding along and opening/conclusion of rock discontinuities controlled primarily by the joint typical and joint shear solidness. Discontinuum modelling constitutes the most normally connected numerical way to deal with rock slope investigation, the most well known technique being the distinct-element method. Distinct element codes, for example, UDEC utilize a power uprooting law indicating association between the deformable joint limited pieces and Newton's second law of movement, giving relocations affected inside the stone slant. UDEC is especially appropriate to issues including jointed media and has been utilized broadly as a part of the analysis of both landslide and surface mine slopes. The impact of outer variables, for example, underground mining, seismic tremors and groundwater weight on square sliding and twisting can likewise be reproduced.

4.1.3 Hybrid Modelling

Hybrid methods are progressively being embraced in rock incline examination. This may incorporate joined examinations utilizing limit equilibrium stability investigation and finite-element groundwater stream and stretch investigation, for example, received in the GEO-SLOPE suite of programming. Hybrid numerical models have been utilized for an impressive time as a part of underground rock designing including coupled limit/finite element and coupled limit/distinct component arrangements. Recent advances incorporate coupled molecule stream and finite difference investigation utilizing FLAC3D and PFC3D. These crossover systems as of now show huge potential in the examination of such marvels as channeling slope failures, and the impact of high groundwater weights on the failure of weak rock slants. Coupled limited/distinct component codes are currently accessible which join versatile remeshing. These techniques utilize a limited component cross section to speak to either the rock slope or joint bounded piece. This is combined with a discrete - component model ready to model twisting including joints. In the event that the stress inside the rock incline surpass the failure criteria inside the limited component display a break is started. Remeshing permits the proliferation of the splits through the finite element lattice to be reproduced. Hybrid codes with versatile remeshing schedules, for example, ELFEN, have been effectively connected to the reproduction of extreme cracking connected with surface mine impacting, mineral pounding, holding wall failure and underground caving.

4.2 Why Numerical Modelling?

Numerical Analysis is one of the important analyses as it gives the basic idea for the slope development. Numerical analysis should be done because of following reason –

- Numerical analysis helps to explain the observed physical behavior of rock.
- Numerical analysis additionally assesses numerous potential outcomes of geographical models, design choices and failure modes.
- Numerical analysis may consolidate key geologic components, for example, faults and ground water giving more sensible approximations of conduct of genuine slope than systematic models.

4.3 Different programs which can be used for slope stability analysis

- FLAC SLOPE
- GEO-STUDIO
- OASYS
- ROCFALL
- UDEC
- SLIDE
- SLOPE/W
- CLARA-W
- DIPS
- PFC2D/3D
- UDEC
- SVOFFICE
- FLAC 3D
- ELFEN
- 3DEC
- GALENA

4.4 Fast Lagrangian Analysis of Continua (FLAC)

FLAC, Fast Lagrangian Analysis of Continua, is numerical modelling software for advanced geotechnical analysis of soil, rock, groundwater, and ground support in two dimensions. *FLAC* is used for analysis, testing, and design by geotechnical, civil, and mining engineers. It is designed to accommodate any kind of geotechnical engineering project that requires continuum analysis.

FLAC utilizes an explicit finite difference formulation that can model complex behaviors, such as problems that consist of several stages, large displacements and strains, non-linear material behaviour, or unstable systems (even cases of yield/failure over large areas, or total collapse).

4.5 General approach of FLAC

The demonstrating of geo-engineering forms includes uncommon contemplations and a configuration rationality not quite the same as that took after for outline with fabricated materials. Examinations and plans for structures and excavations in rocks or soils must be accomplished with moderately little site-particular information, and a mindfulness that deformability and quality properties may change significantly. It is difficult to get complete field information at a rock or soil site. Since the information fundamental for outline forecasts are restricted, a numerical model in Geo-mechanics ought to be utilized principally to comprehend the overwhelming mechanism influencing the conduct of the framework. Once the conduct of the framework is comprehended, it is then suitable to create straightforward counts for a designprocedure.

It is conceivable to utilize FLAC specifically in outline if adequate information, and also a comprehension of material behavior are accessible. The outcomes created in a FLAC investigation will be exact when the project is supplied with suitable information.

The steps suggested performing a fruitful numerical investigation –

Step-1	To define targets for the model examination
Step-2	To create a reasonable photo of the physical framework
Step-3	To develop and run straightforward idealize models
Step-4	To gather problem particular information
Step-5	To set up a progression of point by point model runs
Step-6	To perform the model computations
Step-7	To Present results for elucidation

Table 2 - Table Showing different steps which used in FLAC

4.5.1 To define targets for the model examination

The level of subtle element to be incorporated into a model frequently relies on upon the reason for the analysis. For instance, if the goal is to settle on two clashing components that are proposed to clarify the conduct of a framework, then a rough model might be developed, given that it permits the systems to happen. It is enticing to incorporate many-sided quality in a model since it exists truly. Notwithstanding, muddling components ought to be discarded on the off chance that they are prone to have little impact on the reaction of the model, or on the off chance that they are superfluous to the model's motivation. Begin with a worldwide view and include refinement if necessary.

4.5.2 To create a reasonable photo of the physical framework

It is essential to have a calculated photo of the issue to give an underlying assessment of the expected conduct under the forced conditions. A few inquiries ought to be asked when setting this up picture. For instance, is it expected that the framework could get to be shaky? Is the transcendent mechanical reaction direct or non-linear? Are developments anticipated that would be huge or little in examination with the sizes of articles inside the issue district? Are there very much characterized discontinuities that may influence the conduct, or does the material carry on basically as a continuum? Is there an impact from groundwater communication? Is the framework limited by physical structures, or do its limits reach out to endlessness? Is there any geometric symmetry in the physical structure of the framework? These contemplations will direct the gross qualities of the numerical model, for example, the outline of the model geometry, the sorts of material models, the limit conditions, and the underlying balance state for the investigation. They will figure out if a three-dimensional model is required, or if a two-dimensional model can be utilized to exploit geometric conditions in the physical framework.

4.5.3 To develop and run straightforward idealize models

While making a physical framework for numerical monitoring, it is more proficient to develop and run straightforward test models in the first place, before building the nitty gritty model. Basic models ought to be made at the most punctual conceivable stage in a venture to produce both information and comprehension. The outcomes can give further understanding into the applied photo of the framework; Step 2 may should be rehashed after straightforward models are run.

Straightforward models can uncover inadequacies that can be helped before any huge exertion is put resources into the investigation. For instance, do the chose material models adequately speak to the normal conduct? Are the limit conditions affecting the model reaction? The outcomes from the straightforward models can likewise manage the arrangement for information accumulation by distinguishing which factors have the most impact on the analysis.

4.5.4 To gather problem particular information

The data which is required for a model analysis are of following:

- Points of interest of the geometry (e.g., profile of underground openings, surface geology, dam profile, rock/soil structure);
- Positions of geologic structure (e.g. - bedding planes, faults, joint sets etc.);
- Material behavior (e.g. - post-failure behavior, elastic/plastic type of properties);
- Different primary conditions (e.g., in-situ state of stress, saturation, pore pressures); and
- External loading (e.g. - pressurized cavern, explosive loading).

Since, regularly, there are substantial vulnerabilities connected with particular conditions (specifically, condition of stress, deformability and quality properties), a sensible scope of parameters must be chosen for the examination. The outcomes from the basic model keeps running (in Step 3) can regularly demonstrate accommodating in deciding this extent, and in giving knowledge to the configuration of research center and field tests to gather the required information.

4.5.5 To set up a progression of point by point model runs

Regularly, the numerical examination will include a progression of PC simulation that incorporate the distinctive systems under scrutiny and traverse the scope of parameters got from the amassed database. While setting up an arrangement of model keeps running for count, a few viewpoints, for example, those recorded underneath, ought to be considered -

- How much time is required to perform every model estimation? It can be troublesome to acquire adequate data to touch base at a helpful conclusion if model runtimes are intemperate. Thought ought to be given to performing parameter varieties on different PCs to abbreviate the aggregate calculation time.
- The condition of the model ought to be saved at a many stages so that the whole run does not need to be rehashed for every parameter variety. For instance, if the analysis includes a few stacking/emptying stages, the client ought to have the capacity to come back to any stage, change a parameter and proceed with the monitoring from that stage.
- Are there an adequate number of checking areas in the model to accommodate a reasonable elucidation of model results and for correlation with physical information?

It is useful to find a few focuses in the model at which a record of the change of a parameter, (for example, displacement) can be checked amid the computation.

4.5.6 To perform the model computations

It is best to first make maybe a couple model runs split into particular areas before dispatching a progression of complete runs. The runs ought to be checked at every phase to guarantee that the response is of course. Once there is confirmation that the model is performing accurately, a few information records can be connected together to run a complete figuring succession. Whenever amid an arrangement of runs, it ought to be conceivable to intrude on the count, see the outcomes, and after that proceed or change the model as fitting.

4.5.7 To Present results for elucidation

The last phase is the presentation of the outcomes for a clear elucidation of the investigation. This is best expert by showing the outcomes graphically, either specifically on the PC screen, or as yield to a printed copy plotting gadget. The graphical results ought to be introduced in an arrangement that can be specifically contrasted with field estimations and perceptions. Plots ought to plainly distinguish regions which are required from the monitoring, for example, areas of figured stress focuses, or ranges of stable development versus shaky development in the model. The numeric estimations of any variable in the model ought to likewise be promptly accessible for more definite understanding by the modeler.

4.6 Flow Chart for Factor of Safety calculation for FLAC

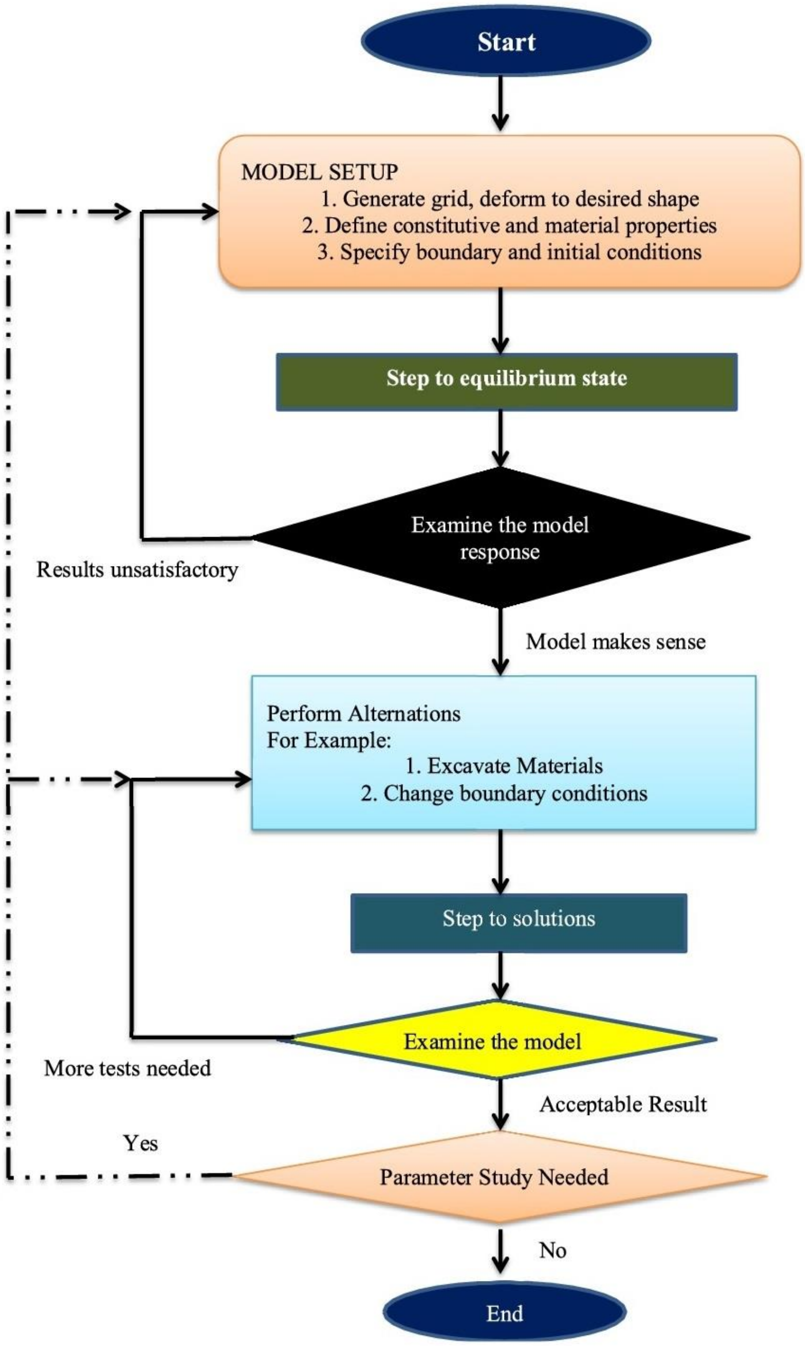


Figure 28 - Flow chart for factor of safety calculation using FLAC (User's Guide, 2002)

4.7 Steps to find FOS using FLAC

There are 4 stages involved for calculating of factor of safety. They are of following types –

- Models Stage
- Build Stage
- Solve Stage
- Plot Stage

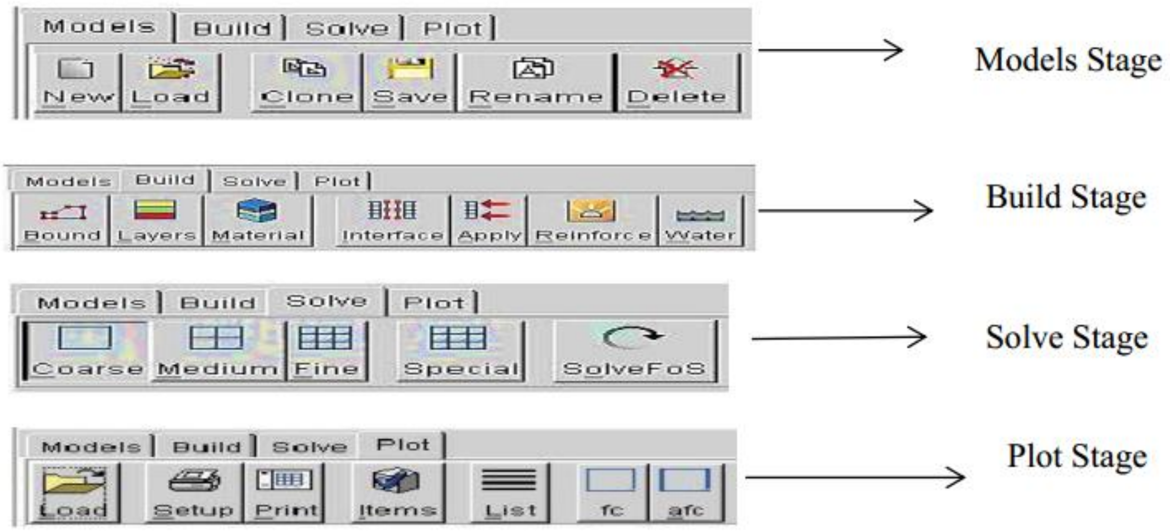


Figure 29 - Modelling-stage tools bars for every stage (User's Guide, 2002)

4.7.1 Models Stage

Every model in a task is named and recorded in a tabbed bar in the Models stage. This permits simple access to any model and results in a task. New models can be added to the tabbed bar or erased from it whenever in the study. Models can likewise be re-established (stacked) from past activities and added to the present venture. The slope limit is additionally characterized for every model at this stage.

4.7.2 Build Stage

For a particular model, the slope conditions are characterized in the Build stage. This incorporates: changes to the incline geometry, expansion of layers, particular of materials and feeble plane, utilization of surface stacking, situating of a water table and establishment of fortification. Likewise, spatial locales of the model can be avoided from the variable of FOS computation. The manufacture stage conditions can be included, erased and changed whenever amid this stage.

4.7.3 Solve Stage

In the Solve stage, the FOS is computed. The determination of the numerical cross section is chosen first (coarse, medium and fine), and afterward the FOS computation is performed. Distinctive quality parameters can be chosen for incorporation in the quality diminishment way to deal with ascertain the security variable. As a matter of course, the material cohesion and angle of friction are utilized.

4.7.4 Plot Stage

After the arrangement is finished, a few outcomes determinations are accessible in the Plot stage for showing the failure surface and recording the outcomes. Model results are accessible for ensuing access and correlation with different models in the venture. All demonstrates made inside a venture, alongside their answers, can be saved, the task documents can be effortlessly re-established and comes about saw at a later time.

4.8 OASYS

OASYS programming can likewise be utilized for the determination of FOS by giving the geotechnical information. Slope has been basically intended to examine the slope solidness, with a choice to fuse soil support. It can likewise be utilized to study pore pressure and issues identified with bearing limit. The system can analyze both circular as well as non-circular failure, in this manner calculations to be done for soil and rock slopes.

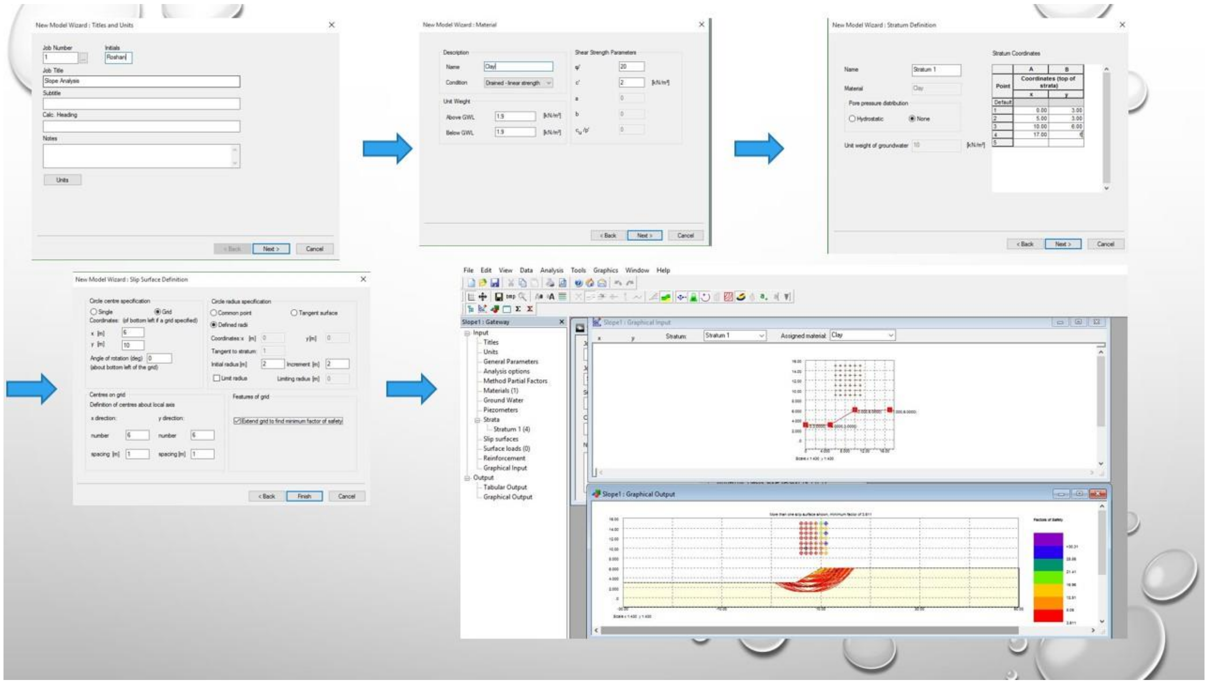
OASYS uses the following types of analysis methods:

- Bishop's Method
- Janbu's method
- Swedish circle (Fellenius) method.

4.8.1 Steps to find FOS using OASYS

The steps involved in finding the factor of safety are following –

- Create new file
- Define material
- Giving Stratum definition
- Giving slip circle parameters
- Adding of multiple layer through gateway tool
- Analyse the result
- Present graphical outcome or tabular outcome



New Model Wizard : Titles and Units

Job Number: 1
Initials: Roshan
Job Title: Slope Analysis
Subtitle:
Calc. Heading:
Notes:

New Model Wizard : Material

Description
Name: Clay
Condition: Drained - linear strength
Unit Weight
Above GWL: 1.9 [kN/m³]
Below GWL: 1.9 [kN/m³]
Shear Strength Parameters
φ': 20
c': 2 [kN/m²]
a: 0
b: 0
c_u/p': 0

New Model Wizard : Stratum Definition

Name: Stratum 1
Material: Clay
Pore pressure distribution: ○ Hydrostatic ● None
Unit weight of groundwater: 10 [kN/m³]

Stratum Coordinates

	A	B
Point	Coordinates (top of strata)	
	x	y
Default		
1	0.00	3.00
2	5.00	3.00
3	10.00	6.00
4	17.00	6
5		

New Model Wizard : Slip Surface Definition

Circle centre specification
○ Single ● Grid
Coordinates: (of bottom left if a grid specified)
x [m]: 6
y [m]: 10
Angle of rotation (deg): 0
(about bottom left of the grid)

Circle radius specification
○ Common point ○ Tangent surface
● Defined radii
Coordinates: x [m]: 0 y [m]: 0
Tangent to stratum: 1
Initial radius [m]: 2 Increment [m]: 2
☐ Limit radius Limiting radius [m]: 0

Centres on grid
Definition of centres about local axis
x direction: number: 6 spacing [m]: 1
y direction: number: 6 spacing [m]: 1

Features of grid
☑ Extend grid to find minimum factor of safety

Slope1 : Graphical Input
Stratum: Stratum 1 Assigned material: Clay

Figure 30 - Steps to Find FOS using OASYS

Chapter 5

Results and Discussion

5.1 Parametric Studies (Results)

Parametric studies were performed via numerical models (OASYS & FLAC/Slope) to investigate the variation of the angle of internal friction (16°-40° at an interval of 4°) & Cohesion (60-150kPa at an interval of 20kPa) on FOS. Also, Pit slope angle was varied from 30° to 65° at an interval of 5°.

5.1.1 Calculation of Factor of Safety for Belpahar Open Cast Mine and to generate different Models by varying parameters

Cohesion = 82 KPa

Angle of internal Friction (ϕ) = 24.5^0

At different slope angle values, the factor of safety results is following –

Sr. No.	Slope Angle	FOS using FLAC Slope	FOS using OASYS
1.	30	3.76	3.98
2.	35	3.38	3.57
3.	40	3.09	3.10
4.	45	2.87	2.99
5.	50	2.67	2.54
6.	55	2.51	2.08
7.	60	2.34	1.77
8.	65	2.17	1.43

Table 3 - FOS calculation using FLAC and OASYS

5.1.2 Models Generated through FLAC and OASYS at different slope angle

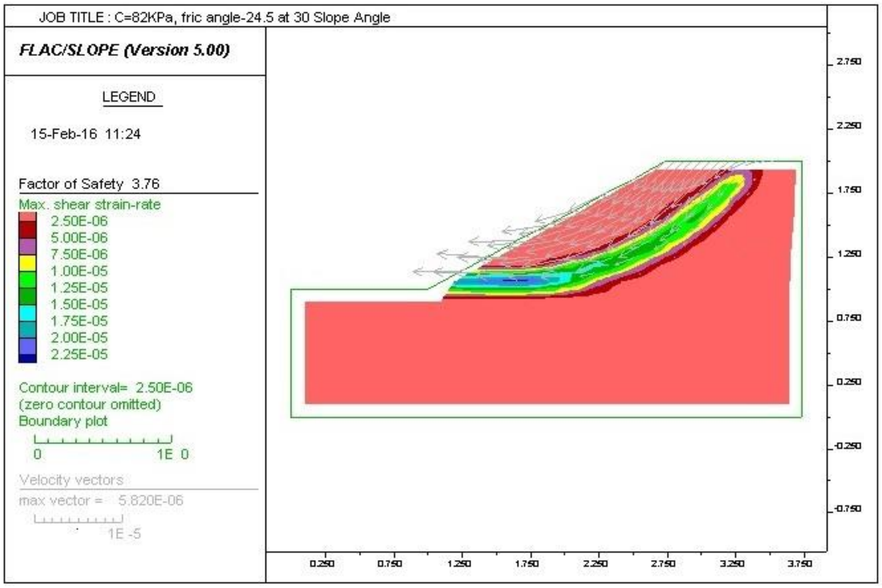


Figure 31 - Model at 30 deg Slope angle with FOS = 3.76 using FLAC

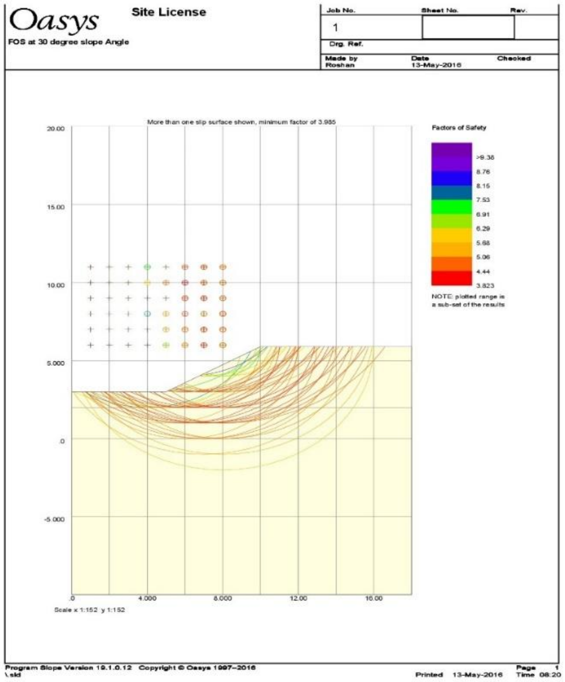
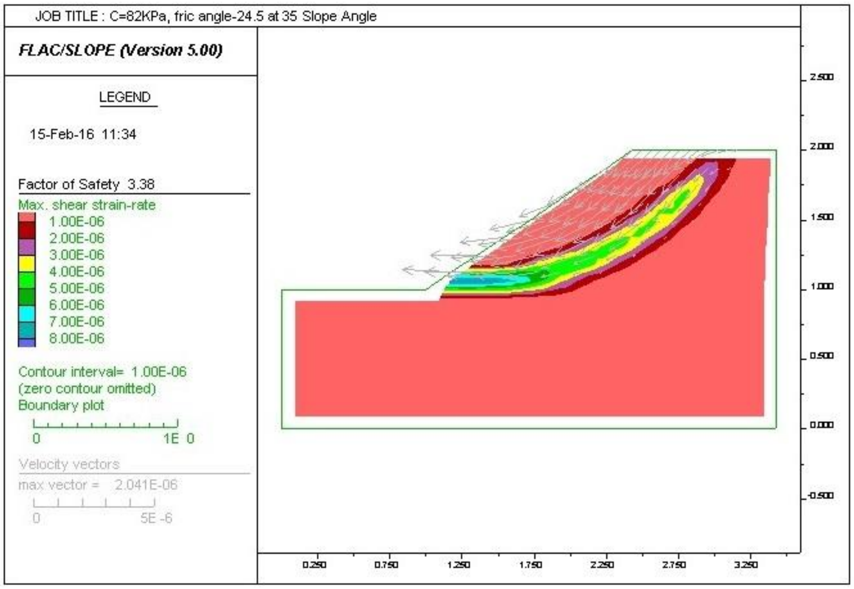


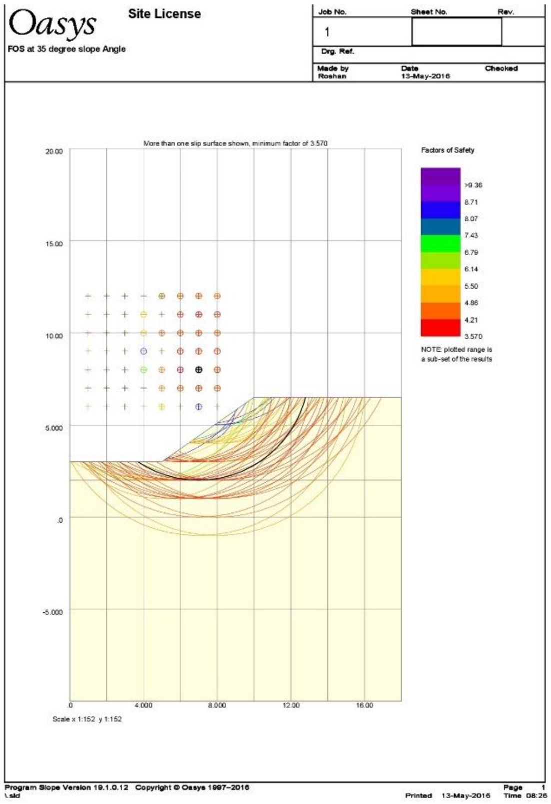
Figure 32 - Model at 30 deg Slope angle with FOS = 3.98 using OASYS



JOB TITLE : C=82KPa, fric angle-24.5 at 35 Slope Angle

FLAC/SLOPE (Version 5.00)

Figure 33 - Model at 35 deg Slope angle with FOS = 3.38 using FLAC



Oasys Site License

FOS at 35 degree slope Angle

Job No. 1

Sheet No.

Rev.

Drg. Ref.

Made by Roshan

Date 13-May-2016

Checked

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Figure 34 - Model at 35 deg Slope angle with FOS = 3.57 using OASYS

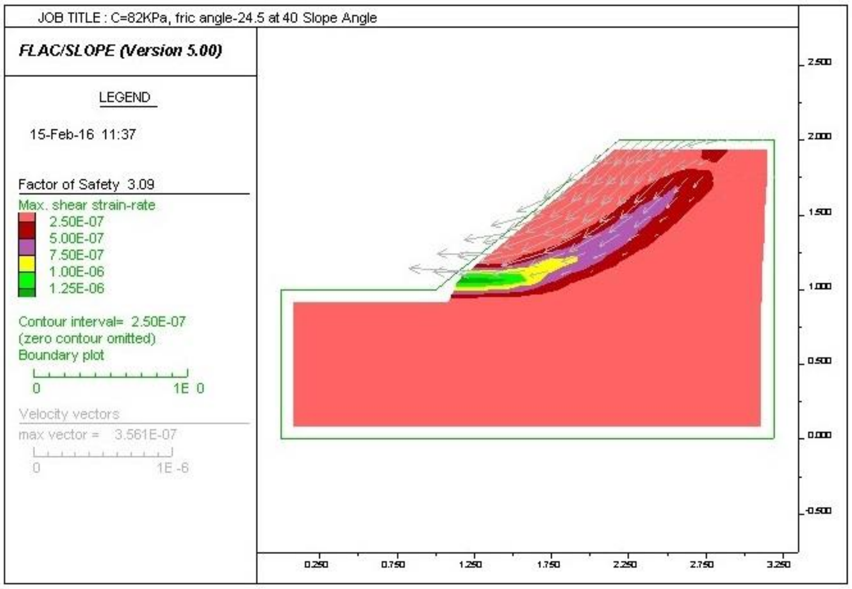


Figure 35 - Model at 40 deg Slope angle with FOS = 3.09 using FLAC

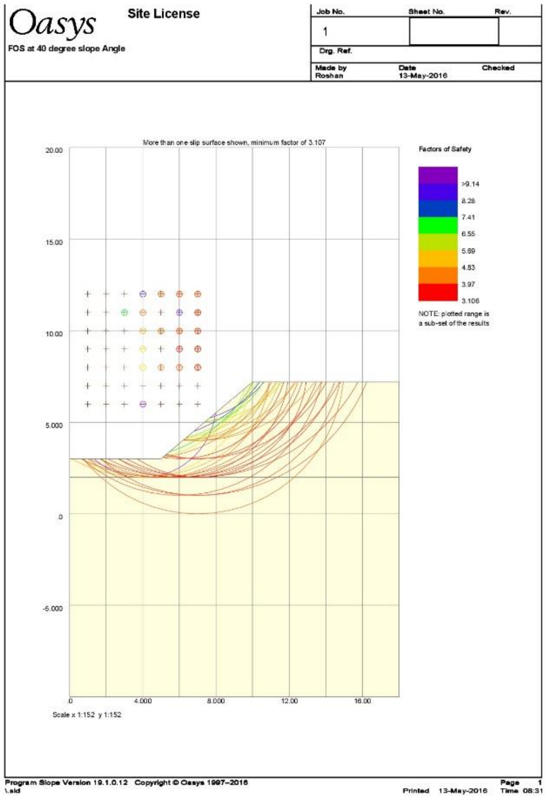


Figure 36 - Model at 40 deg Slope angle with FOS = 3.1 using OASYS

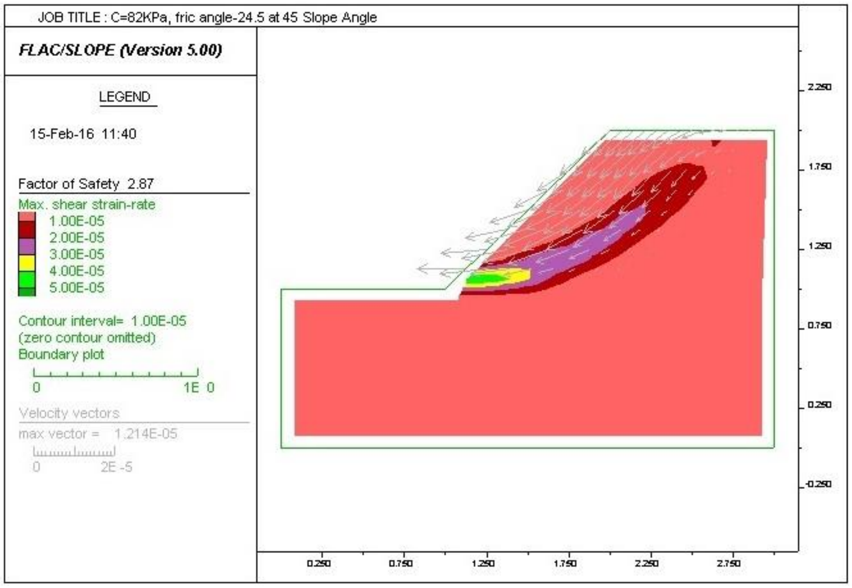


Figure 37 - Model at 45 deg Slope angle with FOS = 2.87 using FLAC

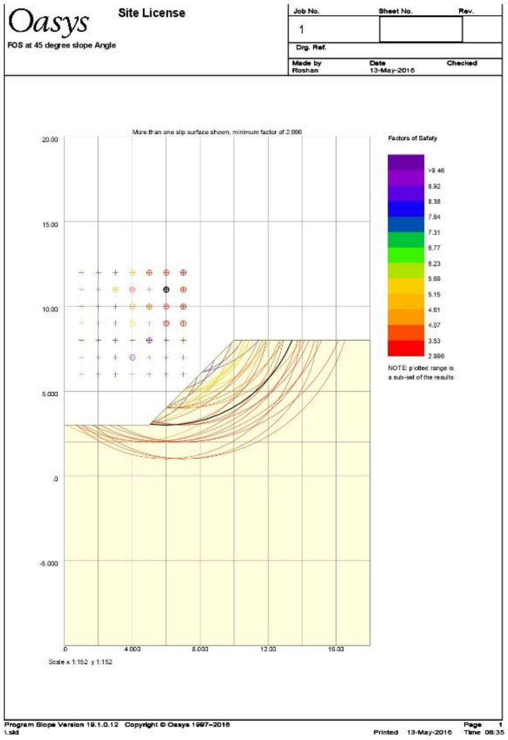


Figure 38 - Model at 45 deg Slope angle with FOS = 2.99 using OASYS

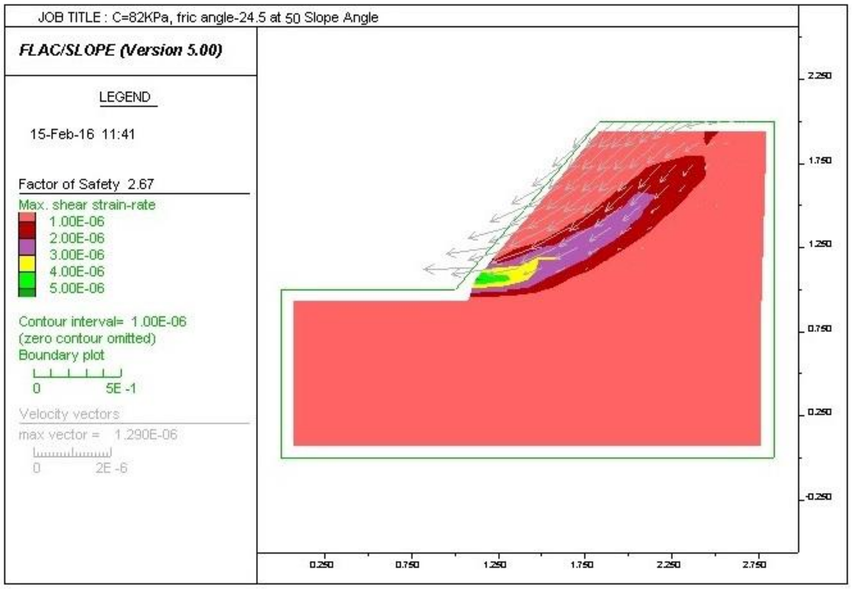


Figure 39 - Model at 50 deg Slope angle with FOS = 2.67 using FLAC

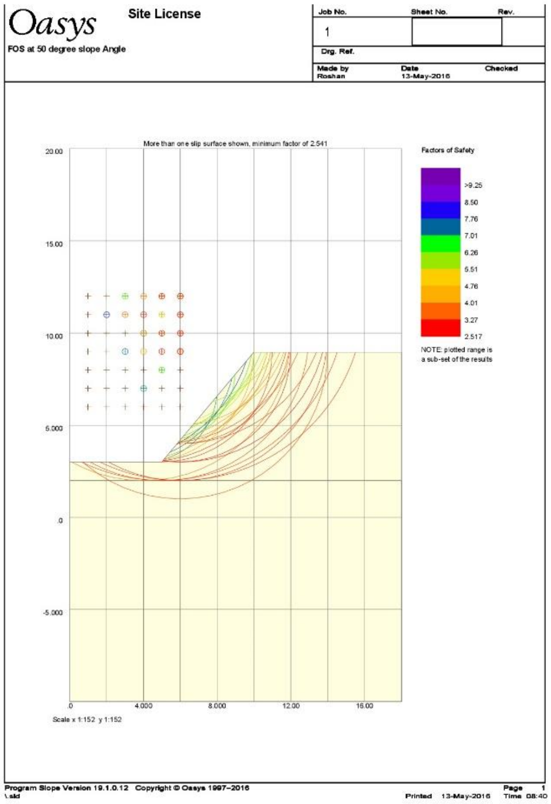


Figure 40 - Model at 50 deg Slope angle with FOS = 2.54 using OASYS

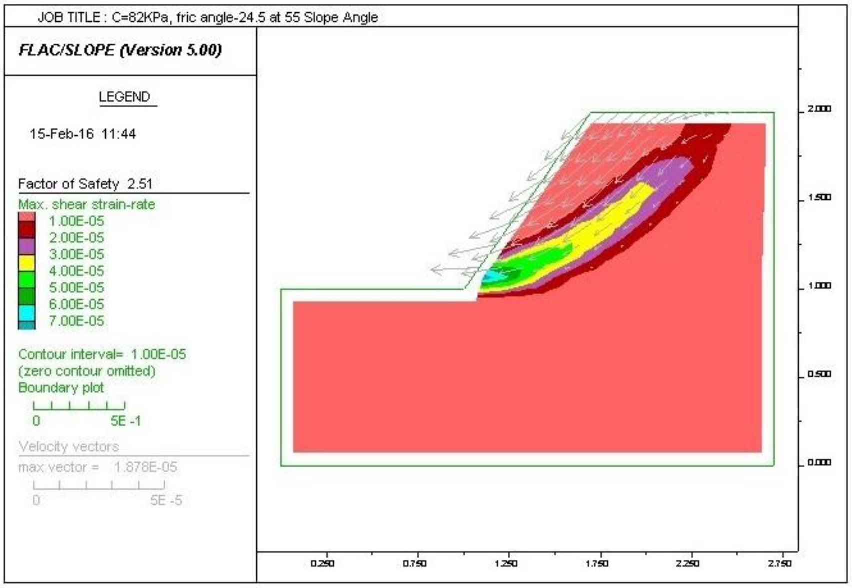


Figure 41 - Model at 55 deg Slope angle with FOS = 2.51 using FLAC

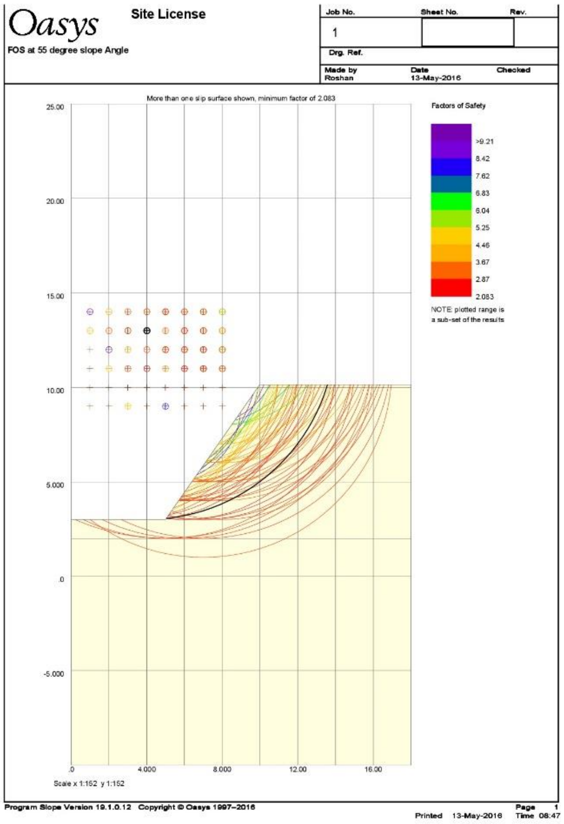
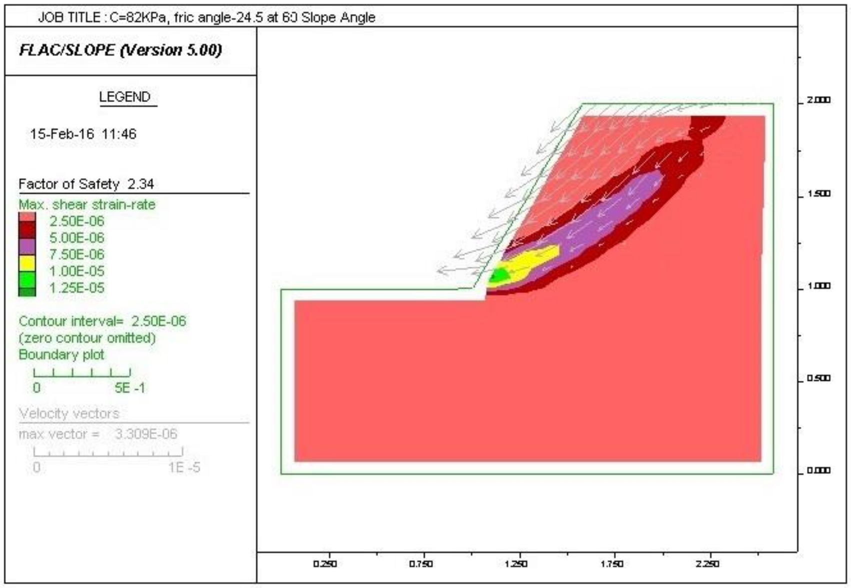


Figure 42 - Model at 55 deg Slope angle with FOS = 2.08 using OASYS


JOB TITLE : C=82KPa, fric angle-24.5 at 60 Slope Angle

FLAC/SLOPE (Version 5.00)

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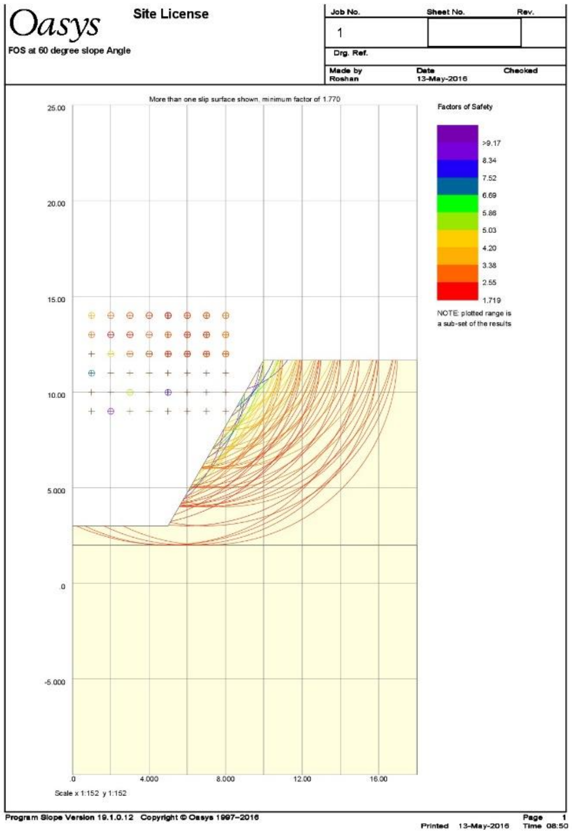
Factor of Safety 2.34

Figure 43 - Model at 60 deg Slope angle with FOS = 2.34 using FLAC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FOS at 60 degree slope Angle

Job No. 1

Sheet No.

Rev.

Drg. Ref.

Made by Roshan

Date 13-May-2016

Checked

More than one slip surface shown, minimum factor of 1.770

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Figure 44 - Model at 60 deg Slope angle with FOS = 1.77 using OASYS

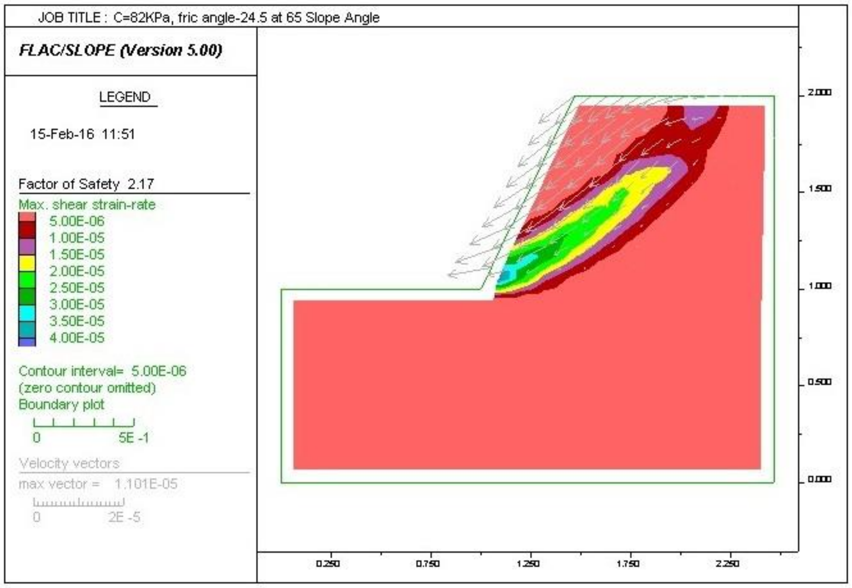

Figure 45 - Model at 65 deg Slope angle with FOS = 2.17 using FLAC

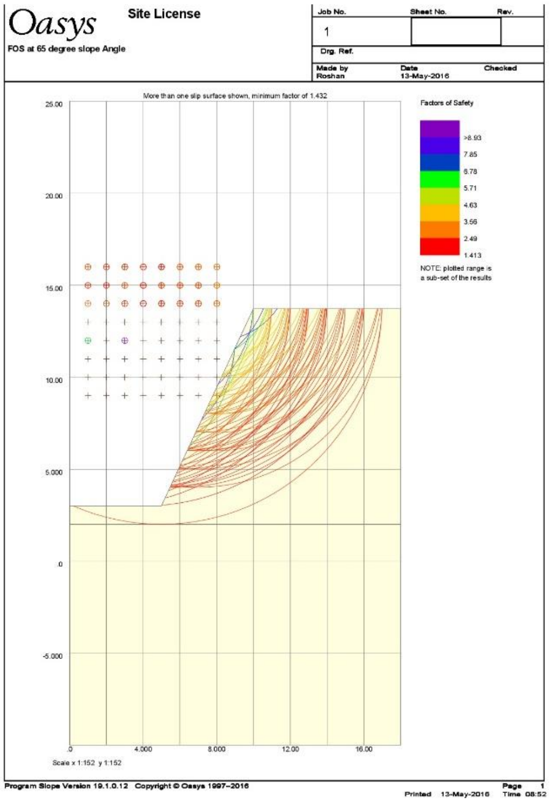

Figure 46 - Model at 65 deg Slope angle with FOS = 1.43 using OASYS

5.1.3 Graph showing variation of FOS for FLAC

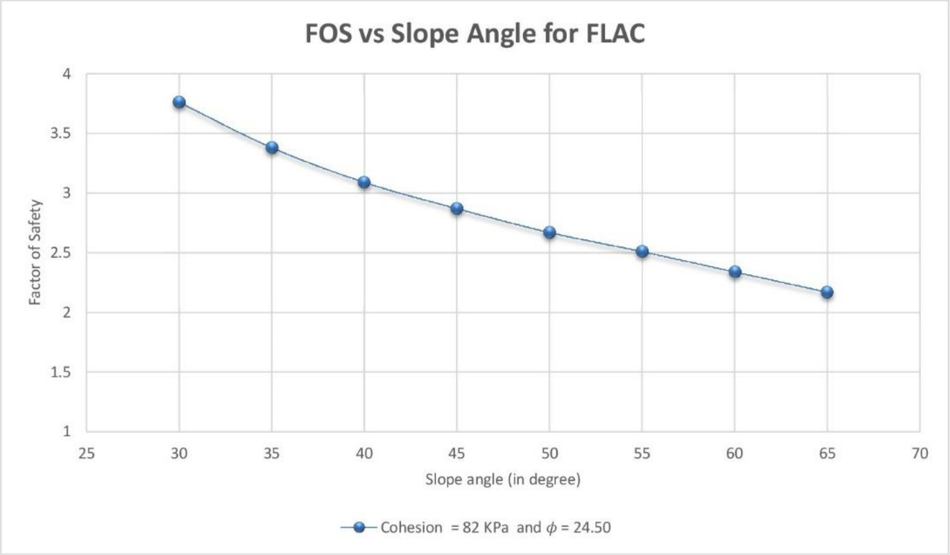

Figure 47 - Graph showing variation of FOS for FLAC

5.1.4 Graph showing variation of FOS for OASYS

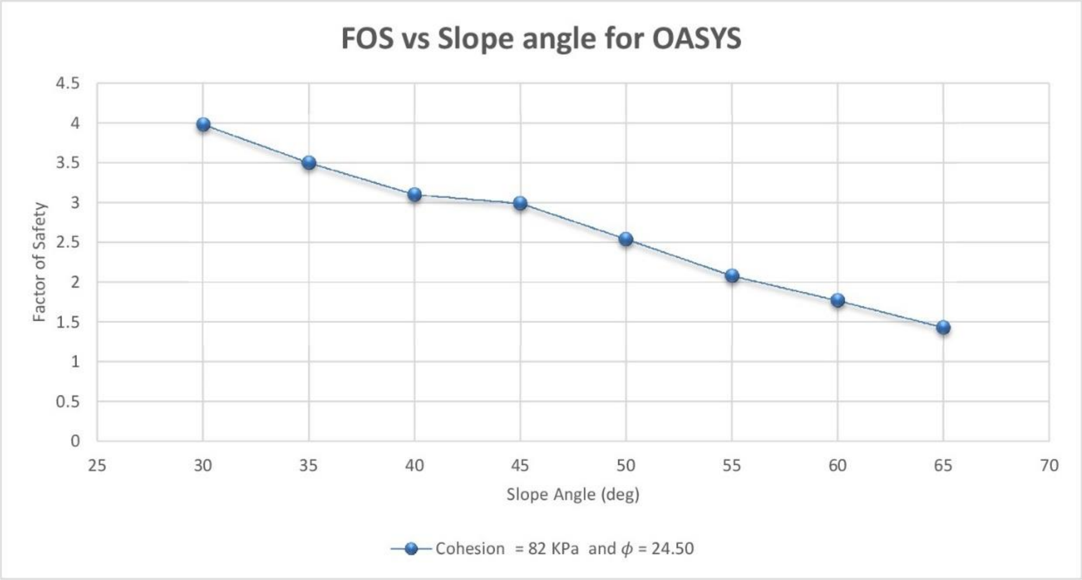

Figure 48 - Graph showing variation of FOS for OASYS

5.1.5 Graph showing comparison of FOS in between FLAC & OASYS

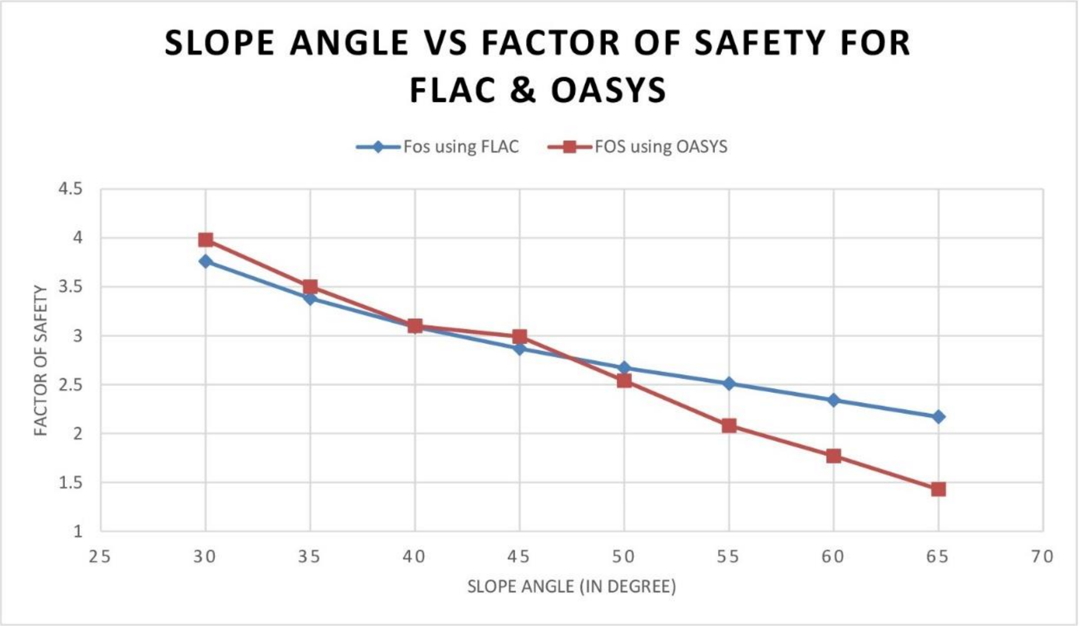

Figure 49 - Graph showing comparison of FOS in between FLAC & OASYS

5.2 Factor of safety for various Cohesion and Angle of internal friction

The factor of safety calculated for the same slope angle by varying Cohesion from 6o KPa to 150 KPa and at different internal friction angle by using both FLAC and OASYS for comparative studies.

Slope Angle = 45^0

Cohesion (C), KPa	Internal Friction Angle, ϕ (deg)	Factor of Safety using FLAC	Factor of Safety using OASYS
C = 60 KPa	16	1.14	1.87
	20	1.37	2.03
	24	1.56	2.17
	28	1.73	2.32
	32	1.89	2.49
	36	2.03	2.66
	40	2.17	2.83

C = 80 KPa	16	1.15	2.08
	20	1.37	2.22
	24	1.57	2.37
	28	1.74	2.53
	32	1.89	2.71
	36	2.04	2.89
	40	2.18	3.39
C = 100 KPa	16	1.16	2.19
	20	1.38	2.35
	24	1.57	2.50
	28	1.75	2.70
	32	1.90	2.90
	36	2.05	3.10
	40	2.18	3.30
C = 120 KPa	16	1.17	2.38
	20	1.39	2.54
	24	1.58	2.70
	28	1.75	2.86
	32	1.91	3.03
	36	2.05	3.22
	40	2.19	3.43
C = 150 KPa	16	1.19	2.64
	20	1.40	2.83
	24	1.59	2.97
	28	1.76	3.13
	32	1.92	3.30
	36	2.06	3.53
	40	2.20	3.70

Table 4 - Factor of safety for various Cohesion and Angle of internal friction for FLAC and OASYS

5.2.1 Graph showing Factor of Safety Vs Frictional Angle for FLAC SLOPE

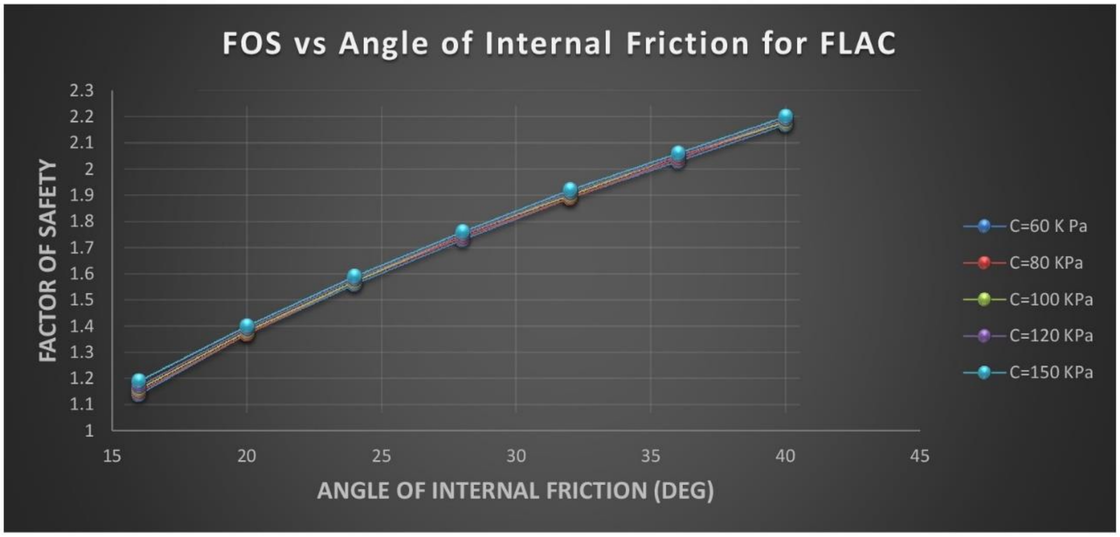

Figure 50 - FOS vs angle of internal friction for FLAC

5.2.2 Graph showing Factor of Safety Vs Frictional Angle for OASYS

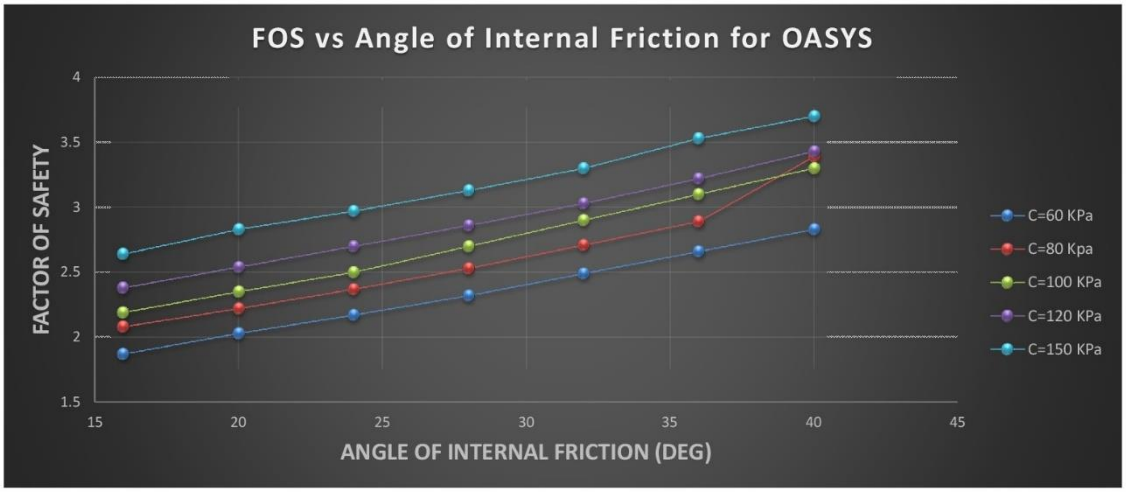

Figure 51 - FOS Vs Angle of Internal Friction for OASYS

5.3 Calculation of factor of Safety for IB Valley area mines at different slope angles (For comparison purpose)

1. C=82 KPa, ϕ = 24.5^0 (Belpahar OCP) 2. C =85 KPa, ϕ = 16^0

3. C =60 KPa, ϕ = 22^0 4. C =70 KPa, ϕ = 34^0

5. C =47.5 KPa, ϕ = 25.71^0 6. C =50 KPa, ϕ = 21^0

Sr. No.	Slope Angle (deg)	C =82 KPa, ϕ = 24.5^0	C =85 KPa, ϕ = 16^0	C =60 KPa, ϕ = 22^0	C =70 KPa, ϕ = 34^0	C =47.5 KPa, ϕ = 25.71^0	C =50 KPa, ϕ = 21^0
			Factor Of Safety				
1.	30	3.76	3.63	4.42	4.47	4.06	4.26
2.	35	3.38	3.28	3.99	4.03	3.65	3.84
3.	40	3.09	3.00	3.67	3.69	3.35	3.53
4.	45	2.87	2.79	3.41	3.42	3.10	3.27
5.	50	2.67	2.60	3.19	3.21	2.90	3.06
6.	55	2.51	2.42	2.99	3.00	2.72	2.86
7.	60	2.34	2.26	2.79	2.80	2.53	2.66
8.	65	2.17	2.10	2.60	2.61	2.35	2.44

5.3.1 Graph showing comparison of FOS for different Mines

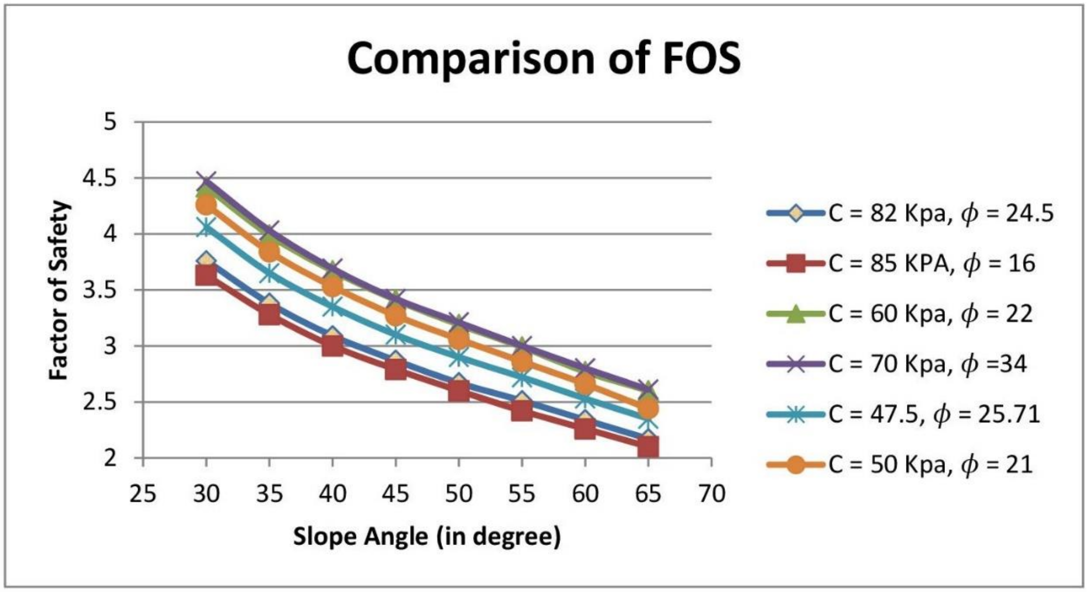

Figure 52 - Graph for comparison of FOS for different Mines

5.4 Discussion

The various models generated using FLAC slope software and the FOS calculated through FLAC slope software also compared with the FOS calculated through OASYS software. Based on above results following thing can be addressed –

- Based on Table 3, it can be seen that the factor of safety is continuously decreasing as the slope angle increases. Theoretically it is said that the slopes generally be safe at 45^0. Here, at 45^0 the FOS was 2.87 for FLAC and 2.16 for OASYS.
- By doing changes in slope angle from 30^0 to 65^0, the FOS through FLAC are in the range of 3.76 to 2.17 and for OASYS are in the range of 4.0 to 0.896.

- Further, by doing variation in Cohesion and in angle of internal friction, different models generated with the help of FLAC and OASYS and the results compared.
- It is seen that at a higher cohesion values, the FOS calculated by FLAC and OASYS was more than the previous one.
- It is also observed that factor of safety calculated by both of the software i.e. FLAC and OASYS, was little bit different for the same conditions. The results are different as both software use different analysis methods.
- FLAC uses finite element analysis method for the evaluation of factor of safety, while OASYS uses slip circle method for the analysis of factor of safety.
- Other data from nearby mine which are of same seam are also collected and analysed to see the variation of FOS with FOS of Belpahar OCP.

Chapter -6

Conclusion

On the basis of above research and different results generated by different software such as – FLAC, OASYS; the conclusion which can be made are of following types –

- From the analysis it can be seen that FOS varies accordingly as we change different parameters such as slope angle, angle of internal friction, cohesion.
- Factor of safety is a calculation of resisting force divided by driving force. So if any change in resisting force occur due to any activity FOS increases or decreases as the case may be.
- It can be seen that the results are different for both of the software under same conditions. The reason behind different results is that both used different analysis techniques for the slope monitoring.
- OASYS uses slip circle method while FLAC uses finite element method to calculate the FOS.
- In OASYS, by varying the slip circle radius i.e. the failure line the result will also vary but in FLAC by varying the meshing size i.e. coarse, medium or fine or special during solve stage FOS will also vary.
- When Cohesion and internal friction vary simultaneously then it is accordingly changed FOS result in both of the software i.e. FLAC and OASYS.
- By doing changes in slope angle from 30^0 to 65^0, the FOS through FLAC are in the range of 3.76 to 2.17 and for OASYS are in the range of 3.98 to 1.43.

Scope of Future Work

In spite of many research on slope stability, there is requirement of wide analysis of slopes as major hazards in opencast mines are associated with slope failure. In future, other modelling software may be used such as UDEC, Galena, and ANSYS for modelling and designing purpose of slopes other than FLAC and OASYS. Regression analysis and ANN can also be used for prediction of slope failure.

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