Analysis of the slope stability of the overburden dumps mixed with fly ash and various stabilization techniques for slope stability

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

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Under the Guidance of: **Prof. H. K Naik**

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C E R T I F I C A T E

This is to certify that the thesis entitled "**Analysis of the slope stability of the overburden dumps mixed with fly ash and various stabilization techniques for slope stability**" submitted by RAVIKANT KUMAR and AYUSH TIWARI in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Prof. H.K. Naik

Dept. of Mining Engineering

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ABSTRACT

Slope stability is the major issues associated with the overburden dumps in the opencast mining scenario. Statistical data reveals that more than half of the accidents occurring in the opencast working are due to the failure of the slope and reason behind this is the improper design of the benches and insufficient works on finding the geo- technical parameters. *The most effective and simple way to cope with the slope failure are precise determination of the geo-technical parameters of the overburden dump and then* ***proper designing of the benches using numerical modeling***, ***water pressure simulation, Limit Equilibrium Method*** etc.

The most influencing factors that contribute to the enhanced slope stability are: ***cohesion and angle of internal friction.*** In recent year a new trend has come i.e. using of fly ash mixed with the overburden dump. There are few reasons and advantages associated with this, like huge amount of the fly ash being generated from the thermal power plants raise a serious question about their disposal besides creating adverse effects on the local environment. According to Ministry of Environment and Forest i.e. MoEF's guidelines, any mine situated within 50 km from a power plant must use at least 25% fly ash as its backfill material. In this project the stability of overburden dumps mixed with fly ash at KTK opencast mine of SCCL was studied. Coming to advantage with it is that optimum mixing of the fly ash with the dump raises the cohesion which imparts a better factor of safety than the conventional method of dumping. The reason for the increase in the cohesion of the fly ash and overburden dump mixture is fly ash has ability to bind the particles strongly.

This project work exhibits the extensive study of the factors contributing to the slope stability, various stabilization techniques for slope stability, laboratory oriented works regarding finding the geo-technical parameters of the overburden and fly ash, and finally then optimum design of the bench of the overburden dump mixed with fly ash using the geotechnical parameters. For designing the bench numerical modeling software FLAC SLOPE is used. Dumps of 30 m height were modeled in FLAC SLOPE to find out the safe slope angle i.e. angles for which the factor of safety > 1.2.

Key words: Fly ash dumping; slope stability, geotechnical parameters; stabilization techniques

LIST OF TABLES

LIST OF FIGURES

Table of Contents

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Slopes either happen commonly or are built by people. A comprehension of geography, hydrology, and soil properties is key to applying slant strength standards appropriately.

Investigation must be based upon a model that precisely speaks to site sub surface conditions, ground conduct, and connected burdens. Time of Analysis, Safe and monetary outline of unearthing's, dikes, earth dams, landfills, and ruin stores are real field of fascination of works.

Slope stability problem is greatest problem faced by the open pit mining industry. The scale of slope stability problem is divided in to two types:

Gross stability problem:

It allude to extensive volumes of materials which descend the inclines because of huge rotational sort of shear disappointment and it includes profoundly weathered shake and soil.

Local stability problem:

This issue which alludes to much little volume of material and this kind of disappointment impact maybe a couple seats at once because of shear plane jointing, slant disintegration because of surface waste.

Coal has been the foundation of the Indian power area. Indian coal ordinarily is of second rate having a fiery remains substance of 40% in examination to imported coals which have a slag substance of 10-15%. Huge amounts of slag are created by the warm power stations in the nation, which dirties nature. Notwithstanding that, the accessibility of area for transfer of fly slag in slurry frame in fiery debris lakes is extremely troublesome.

Remembering this, the Ministry of Environment and Forests (MoEF) has issued warnings stipulating focuses for 100% usage of fly cinder in a staged way. For the mining business it has coordinated the mines existing in 50 km of a warm power plant (by street) to use no less than 25% of the inlay material as fly slag on a weight to weight premise subject to the regard of DGMS Proper exploratory studies are important to assess the soundness of such dumps.

Issues of incline precariousness happen habitually and are a wellspring of real concern in the mining business. These are brought on either because of ill-advised configuration of inclines or a mistaken evaluation of the current ones and represent a peril to the security of individuals, gear and other property. Geographical structure, point of the incline, weight following up on the slant, water substance are a portion of the components that influence slant dependability and must be considered while investigating the strength of a slope.

Keeping this in mind, the Ministry of Environment and Forests (MoEF) has issued notifications stipulating targets for 100% utilization of fly ash in a phased manner. For the mining industry it has directed the mines lying within 50 km of a thermal power plant (by road) to use at least 25% of the backfill material as fly ash on a weight to weight basis subject to the approval of DGMS Proper scientific studies are necessary to evaluate the stability of such dumps.

Problems of slope instability occur frequently and are a source of major concern in the mining industry. These are caused either due to improper design of slopes or an incorrect assessment of the existing ones and pose a danger to the safety of people, equipment and other property. Geological structure, angle of the slope, weight acting on the slope, water content are some of the factors that affect slope stability and must be considered while analyzing the stability of a slope.

In this context the purpose of this project is to study the stability of overburden dumps mixed with fly ash at Kakatiya Khani Opencast (KTK OC) mine of Singareni Collieries Company Ltd. (SCCL) located in Bhupalpalli, Andhra Pradesh. The thermal power plant of APGENCO, situated around 15 km from the mine at Chelpur, supplies the fly ash.

Objectives of the Project:

This project work comprises of the following phases:

1. Detailed study of the experimental methods employed in determining the geo-technical parameters of three different mixtures i.e. OB, OB+30% fly ash.
2. Modeling of the dump slopes in FLAC SLOPE to evaluate the factor of safety (FOS) for different slope angles.
3. Obtaining the optimum dump slope angle i.e. angle at which the Factor of Safety > 1.2.
4. Study of the various stabilization techniques for slope stability.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

Slope Stability:

Slope stability is the stability of the benches of the working face or it may be the overburden dump lying at certain angle with the horizontal. The stability of the slope comes from the fact that when the resisting forces like cohesion exceeds the driving forces like presence of water, seismic activities, and many more, then bench is said to be stable otherwise slope failure occurs.

The practical approach to slope stability is guided by various geo-technical parameters and a good measure of engineering judgment. Judicious planning and implementation of an appropriate slope monitoring program can help in identifying the vulnerable slope sections, predict instabilities, evolve control strategies and even mining under unstable conditions.

2.1 Aim of slope stability:

I. To develop and construct the natural and man-made slopes and the processes leading to such changes in the slopes.

II. To get access to the stability of slopes under different conditions.

III. To assess the possibility of slope failure for both the naturally build up slopes and man-made.

IV. To analyze stability of the slope and to understand the different mechanisms behind this failure.

V. To assess different influencing factors like environmental factors, technical, geo-mining conditions.

VI. To redesign the failed slopes and the proper planning and designing for the prevention and thorough exposure to the effective remedy measures.

VII. To study the effect of seismic loadings on slopes and embankments.

Excessive steepening of the slope may lead to following:

- Slope failure
- Loss of production,
- Extra stripping costs to remove failure material,
- DGMS may close the mine

2.2 TYPES OF ROCK SLOPE FAILURES

Failure in Earth and Rock mass

1. Plane Failure
2. Wedge Failure
3. Circular Failure
4. Toppling Failure
5. Rock fall

Failure in Earth, rock fill and spoil dumps and Embankments

1. Circular
2. Non-circular semi-infinite slope
3. Multiple block plane wedge
4. Log spiral (bearing capacity of foundations)
5. Flow slides and Mud flow
6. Cracking
7. Gulling
8. Erosion
9. Slide or Slump

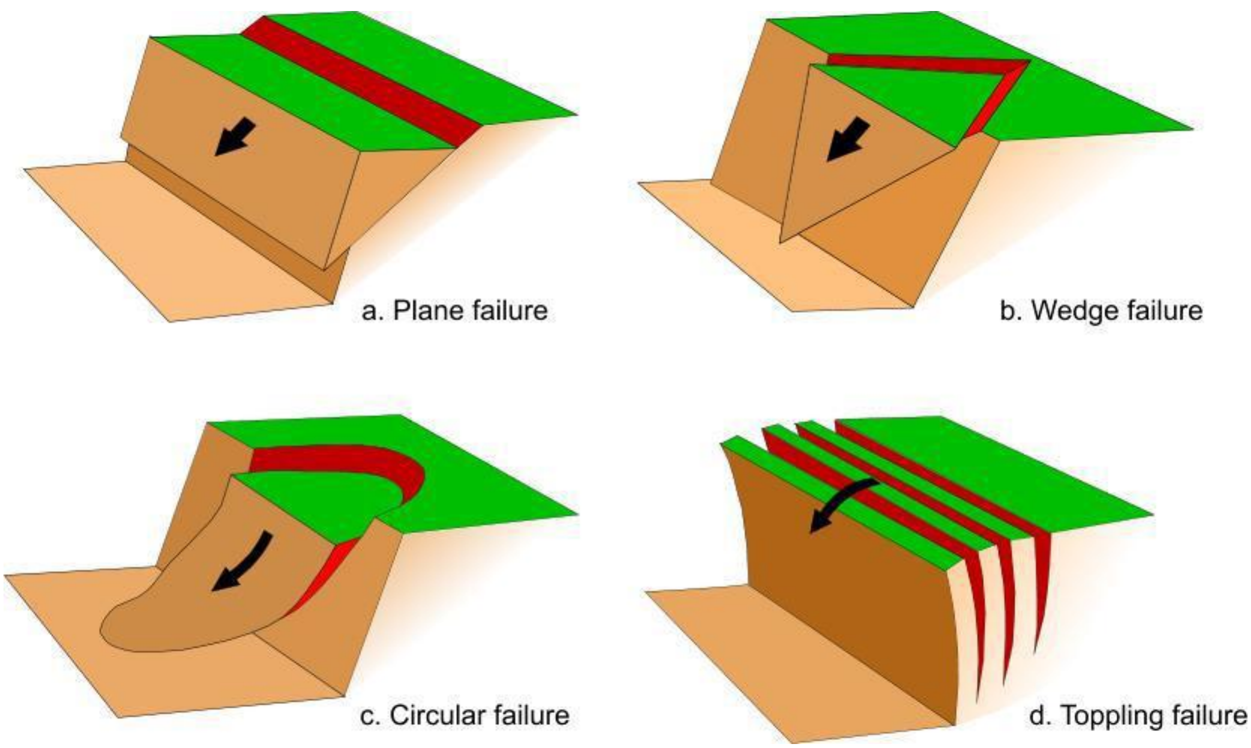


Figure 1: Simplified illustrations of most common slope failure modes

Failure mechanisms for the sliding failure mode

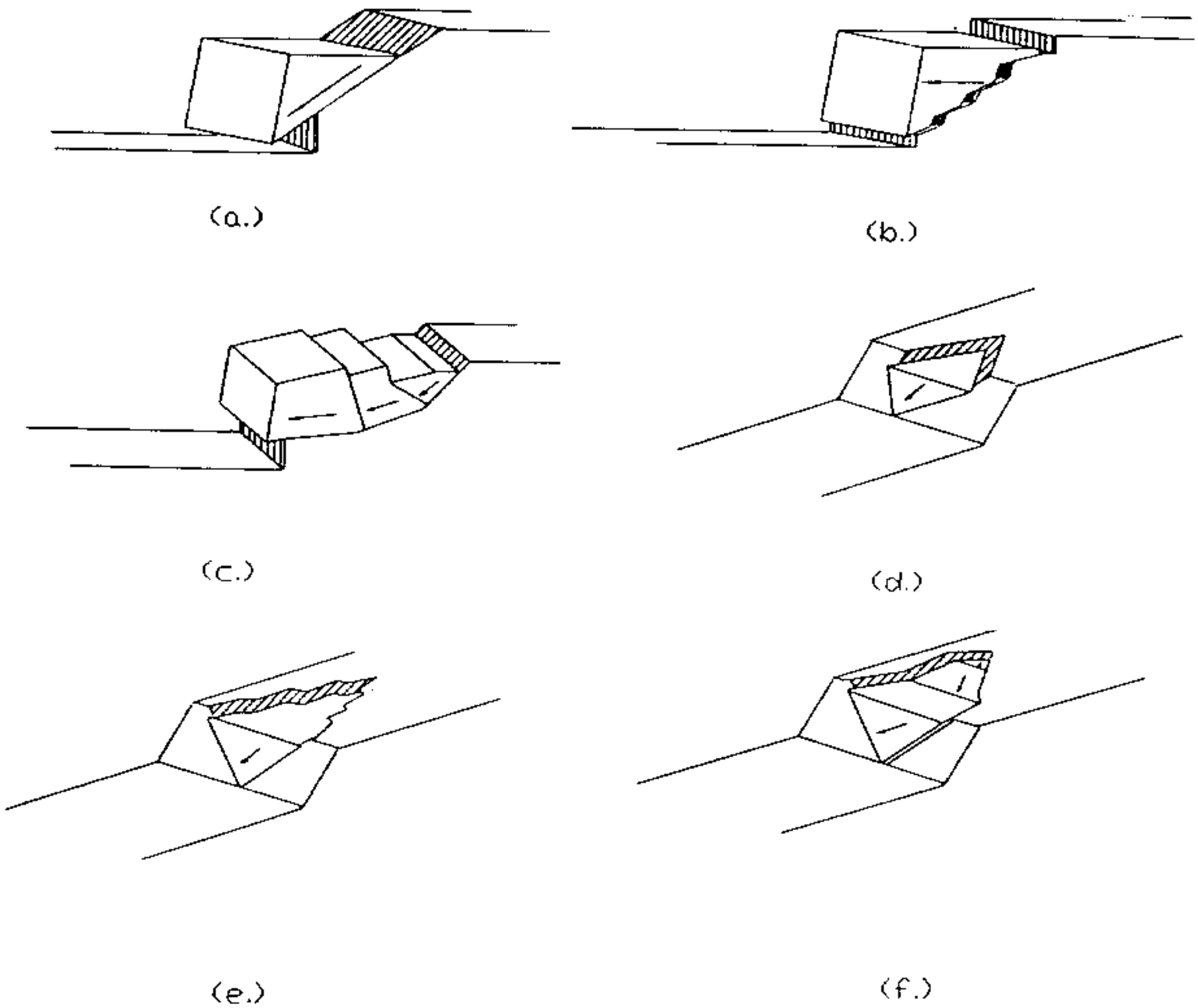


Figure 2: Failure mechanisms for the sliding failure mode (After Brown, 1994):

a. single block with single plane;
b. single block with stepped planes;
c. multiple blocks with multiple planes;
d. single wedge with two intersecting planes;
e. single wedge with multiple intersecting planes;
f. multiple wedges with multiple intersecting planes; and
g. single block with circular slip path

2.2.1 Plane Failure

Generally slopes are found very less prone to this type of failure because the geometric conditions which triggered it to the failure are rarely satisfied.

Geometrical Conditions for the occurrence of Plane failure:

- Sliding plane should be parallel to the face of slope.
- Sliding plane should be "Daylights" on face which means its dip must be smaller than the dip of the slope face.
- Sliding plane dips should exceed the angle of internal friction.
- Release surfaces which provide negligible resistance to sliding must be present.

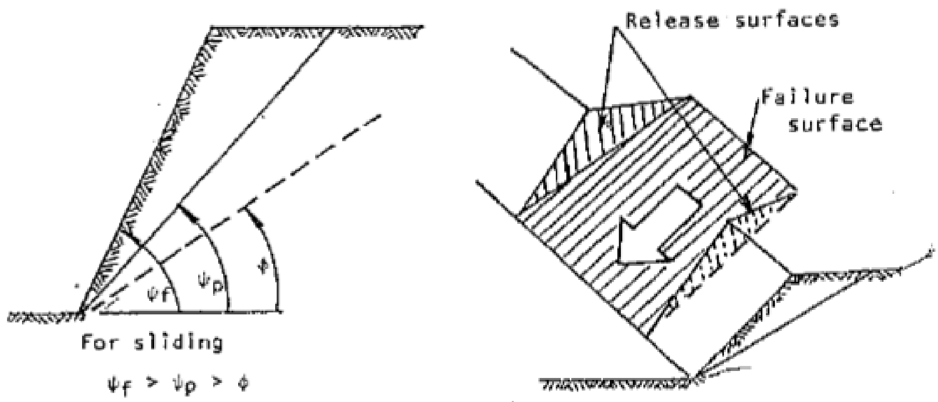


Figure 3: Geometric View of Planar Failure

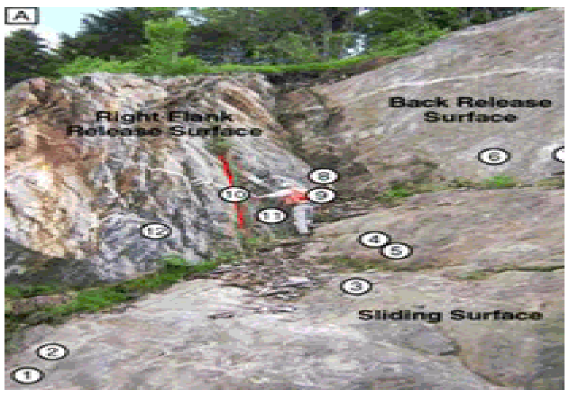


Figure 4: Natural View of Plain failure

2.2.2 Wedge failure

Wedge failure may happen in rock mass if there happens two or more arrangements of discontinuities having lines of convergence are almost opposite to the strike of the incline and plunge toward the plane of the slope.

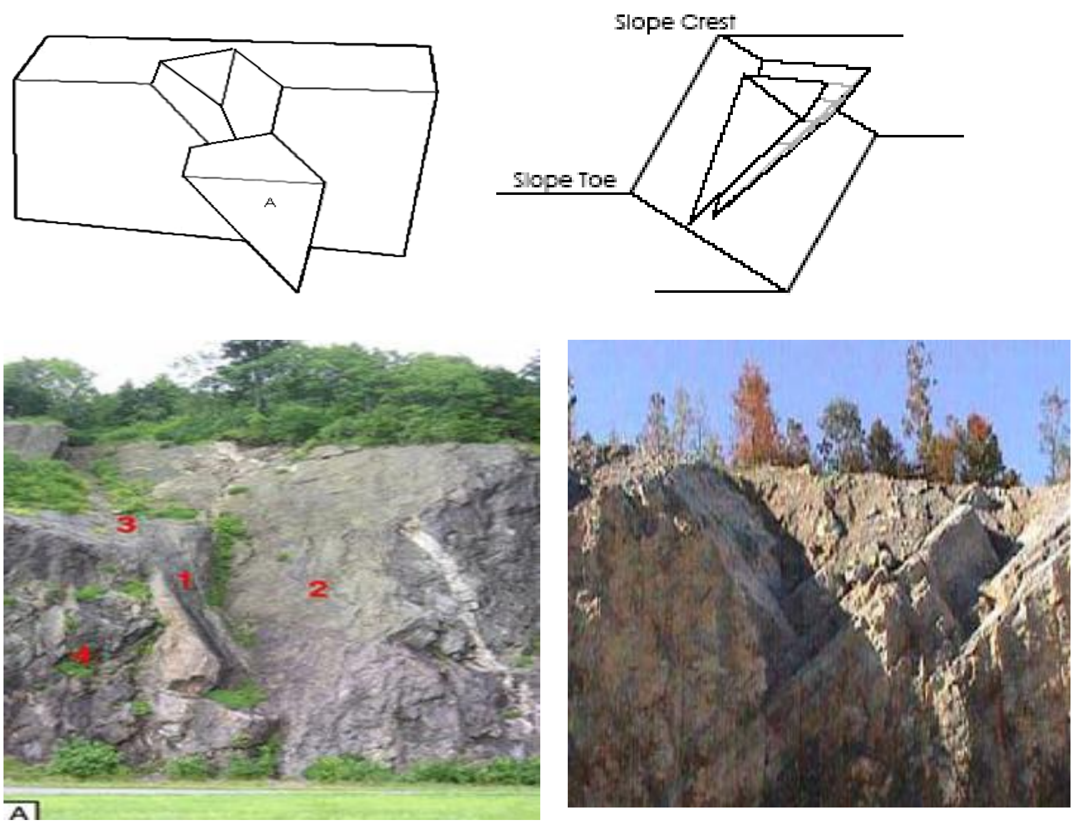


Figure 5: Wedge failure

2.2.3 Toppling Failure

Toppling failures are the most generally happening failures in rock masses which are subdivided into a progression of segments framed by an arrangement of breaks that strike more or less parallel to the slope face and dip steeply into the face?

In a toppling failure the turn of the stone section or piece about an altered point at or close to the base of the incline happens and while slippage happens between the layers. Columnar basalts and sedimentary and transformative rocks with very much characterized sheet material planes are most vulnerable to this method of failures.

There are different sorts of toppling failures happens in the stone mass including flexural, piece, or a blend of square and flexural toppling. At some point toppling can likewise happen as an auxiliary failures mode connected with other failures systems, for example, square sliding.

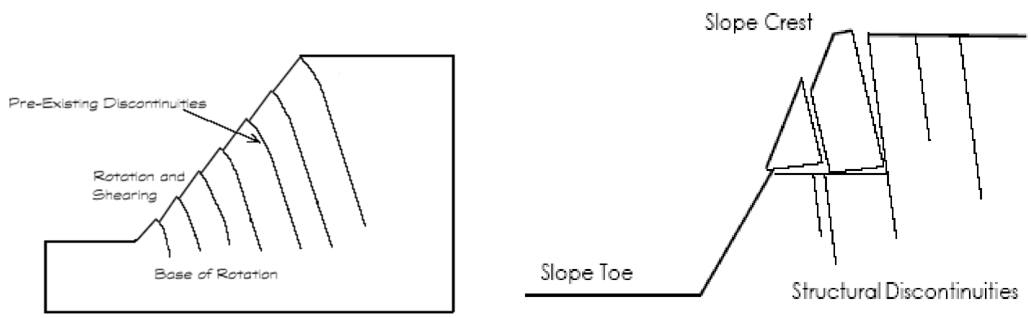


Figure 6: Toppling failure

2.2.4 Circular Failure

- Circular failures generally occur in weak rock or soil slopes.
- This type of failure does not occur necessarily along a purely circular arc, some form of curved failure surface is normally apparent.
- Circular shear failures are influenced by the size and mechanical properties of the particles in the soil or rock mass.

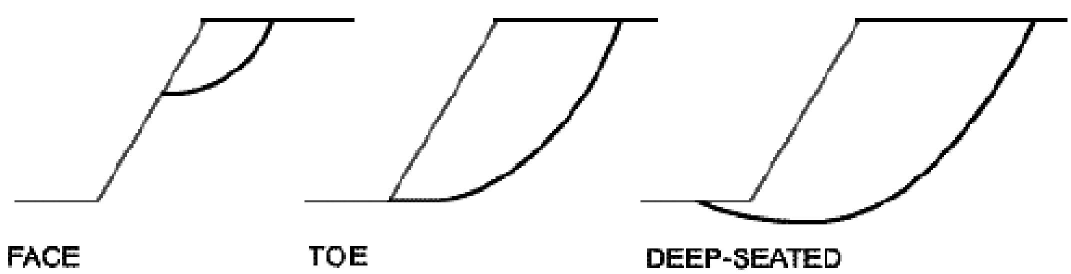


Figure 7: Circular Failure

Types of circular failure

Circular failure is grouped in three sorts relying upon the region that is influenced by the failure surface. They are:-

I. **Slope failure**: In this sort of failure, the circular segment of the break surface meets the incline over the toe of the slant. It is on the grounds that when the incline point is high and the dirt near to the toe has the high quality.

II. **Toe failure:** In this sort of failure, the circular segment of the break surface meets the incline at the toe.

III. **Base failure**: In this sort of failure, the circular segment of the failure goes underneath the toe and into base of the incline. It happens when the incline edge is low and the dirt underneath the base is gentler and more plastic than the dirt over the base.

2.2.5 Rock-Fall

In rock falls, a mass of any size gets confined from a more extreme slant or bluff, along a surface on which little or there happens no shear uprooting, and slips generally through the air by free fall, jumping, ricocheting, or rolling.

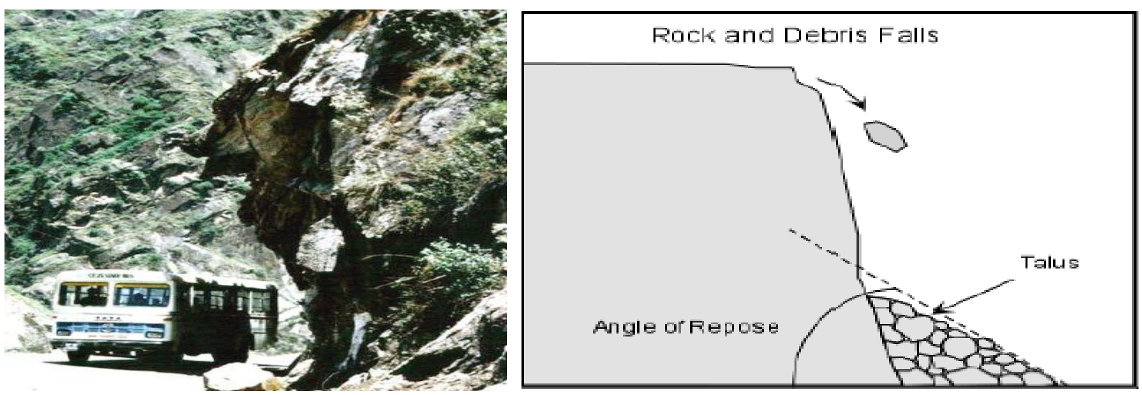


Figure 8: Rock Fall

2.2.6 Cracking

- It is because of the differential settlement of the mine waste and suction level, surpassing the rigidity, is come to.
- Due to further drying, or in resulting dry periods, splits can develop until at long last, the complete thickness of the fixing layer is infiltrated

2.2.7 Gulling

- Gulling is seen in numerous dumps and it is truly prevailing disintegration instrument.
- Gullies include entry point to the profundities frequently well in overabundance of a meter, and it in this way evacuate substantial amounts.

Figure 9: Gulling

2.3 FACTORS AFFECTING SLOPE STABILITY

- Geological discontinuities of Rock Mass
- Geo-technical Properties of slope
- Groundwater and Rainfall
- Slope's Geometry
- State of stress
- Surface erosion due to flow of the water
- Seismic effect i.e forces due to earthquakes
- Dynamic Forces due to Blasting
- Movement of the Heavy Earth Moving Machinery
- Modification in the Slope like Under cutting
- Temperature and Spontaneous Heating
- Presence of underground galleries

2.3.1 Geological discontinuities of rock -mass may be any one of the following

- Joints
- Bedding Joints
- Joint spacing
- Joint direction and dipping
- Faults

2.3.2 Geotechnical Properties of slope "AFFECTING SLOPE STABILITY"

There are following important geo-technical factors which affect the slope stability:

- Shear strength of rock mass
- Cohesion (C)
- Angle of Internal friction (Ø)
- Density
- Permeability
- Moisture Content
- Particle size distribution
- Angle of Repose

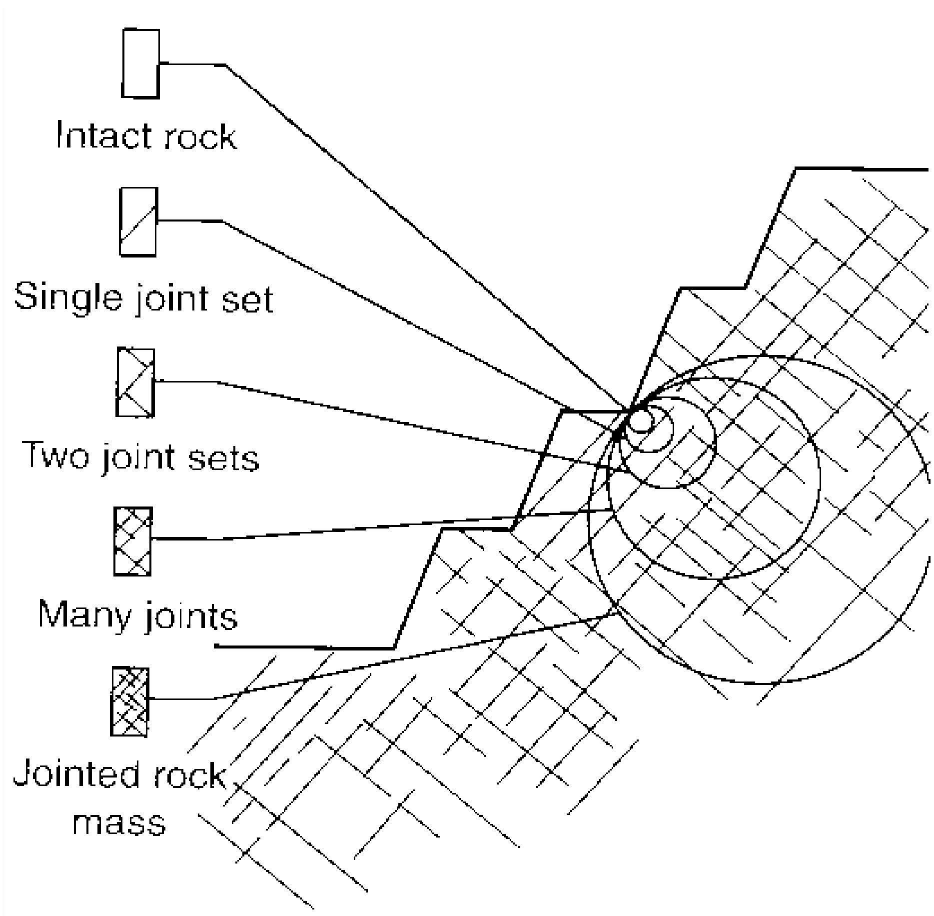


Figure 10: Idealized diagram showing transition from intact rock to jointed rock mass with increasing sample size

2.3.3 Geological Structure:

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

- amount and direction of dip
- intra-formational shear zones
- joints and discontinuities
  - Reduce shear strength
  - Change permeability
  - Act as sub surface drain
  - Planes of failure
- faults
  - weathering and alternation along the faults
  - act as ground water conduits
  - provides a probable plane of failure

2.3.4 Cohesion

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 consolidated clays, cementing by Fe_2O_3, $CaCO_3$, NaCl, etc and root cohesion.

The resistance force per unit area is termed as cohesion, and is measured in Pascal (Pa). In natural soils, cohesion arises from electrostatic bonds between clay and silt particles. Thus, soils empty of clay or silt are not cohesive but for capillary forces arising when little water forms bridges between sand grains, causing negative pore pressure (or “suction”). Values of soil cohesion usually are of the order of some kPa. Rocks typically display much greater cohesion, thousands of times higher than soils. At finite normal stresses, soils and rocks normally display both cohesive and frictional behavior. The shear strength of a soil is thus the sum of the cohesive and frictional contributions. Higher is the cohesion value, more stable will be the slope

However the apparent cohesion is caused by negative capillary pressure and pore pressure response during un-drained loading. Slopes having rocks/soils with less cohesion tend to be less stable.

2.3.5 Angle of Internal Friction

Angle of internal friction is the angle (Ø), measured between the normal force (N) and resultant force (R), that is attained when failure just occurs in response

Angle of internal friction, can be determined in the laboratory by the Direct Shear Test or the Tri-axial Shear Test.

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 affected by quartz content.

2.3.6 Geometry of the slope

The basic geometrical slope design parameters are height, overall slope angle and area of failure surface.

- With increase in height the slope stability decreases.
- The overall angle increases the possible extent of the development of the any failure to the rear of the crests increases and it should be considered so that the ground deformation at the mine peripheral area can be avoided.
- Generally overall slope angle of 45° is considered to be safe by Directorate General of Mines Safety (DGMS).
- Steeper and higher the height of slope less is the stability.

2.3.7 Lithology

- The rock materials forming a pit slope determines the rock mass strength modified by discontinuities, faulting, folding, old workings and weathering.
- Low rock mass strength is characterized by circular raveling and rock fall instability like the formation of slope in massive sandstone restricts stability.
- Pit slopes having alluvium or weathered rocks at the surface have low shearing strength
- The strength may get further reduced if water seepage takes place through them. These types of slopes must be flatter.

2.3.8 Ground Water

It causes the following:

- It may alter the cohesion and frictional parameters
- It can reduce the normal effective stress.
- Physical and chemical effect of pure water pressure in joints filling material can thus alter the cohesion and friction of the discontinuity surface.
- Water pressure in the pores of the rock may cause a decrease in the compressive strength particularly where confining stress has been reduced**.**

2.3.9 Mining Method and Equipment

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
- open pit working
- The use of dip cuts with advance on the strike reduces the length and time that a face is exposed during excavation
- Dip cut generally offers the most stable method of working but suffer from restricted production potential.
- Open pit method are used in steeply dipping seams, due to the increased slope height are more prone to large slab/buckling modes of failure.
- Mining equipment which piles on the benches of the open pit mine gives rise to the increase in surcharge.

2.3.10 State of stress:

In a few areas, there may be high in-situ anxieties display inside the nation rock. High level stress acting generally opposite to a slice incline may bring about pieces to move outward because of the stress help gave by the cut. High level burdens might likewise bring about spalling of the surface of a cut slope.

2.3.11 Erosion (disintegration):

Erosion includes impressive impact the slope solidness. There are essentially two parts of disintegration that ought to be given due thought. The main is expansive scale disintegration, for example, waterway disintegration at the base of a precipice. The second is generally restricted disintegration brought on by groundwater or surface overflow.

2.3.12 Seismic effect:

- Seismic waves going through rock include stress which could bring about breaking..
- Friction is lessened in unconsolidated masses as they are jolted separated.
- Liquefaction may be prompted.
- One of the real perils of seismic tremors is the danger of landslide.
- This is especially so in light of the fact that the most insecure parts of the earth are at the plate limits and it is additionally here that youthful fold mountain belts are framed and there are high alleviation and steep slope.
- Most open pit operators are familiar back break form blast, but most people only consider the visible breakage behind the row of holes of the blast.

2.3.13 Dynamic Forces

- Blasting has a significant influence upon stability of slopes.
- There are following adverse effect of an Uncontrolled blasting
  - Over-breaks, overhangs and extension of tension cracks.
  - Opening & loss of cohesion between weak planes.
  - shattering of slope mass and
  - allowing easier infiltration of surface water
  - Un-favorable groundwater pressures.

Because of impact of blasting and vibration, shear stresses are quickly expanded and as a result dynamic acceleration of the material and therefore builds the security issue in the slope face. It causes the ground movement and cracking of rocks.

2.3.14 Slope Modification –

Modification of a slope either by humans or by natural causes can result in changing the slope angle so that it is no longer at the angle of repose. A mass-wasting event can then restore the slope to its angle of repose.

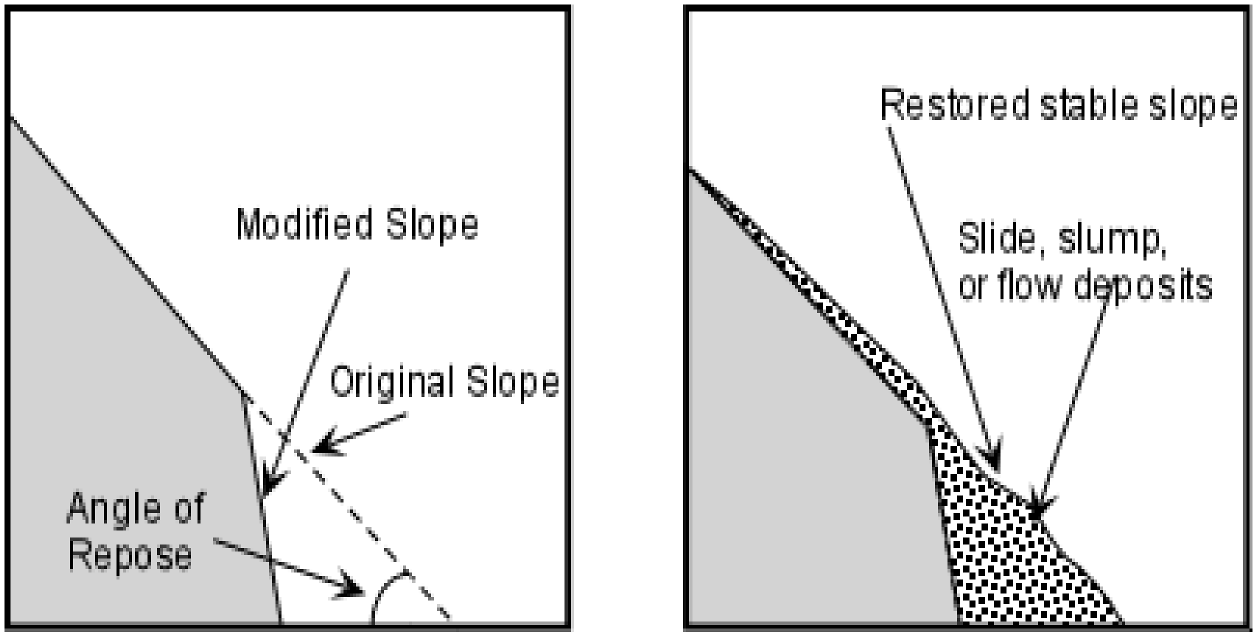


Figure 11: Slope Modification

2.3.15 Undercutting

Streams eroding their banks or surf action along a coast can undercut a slope making it unstable.

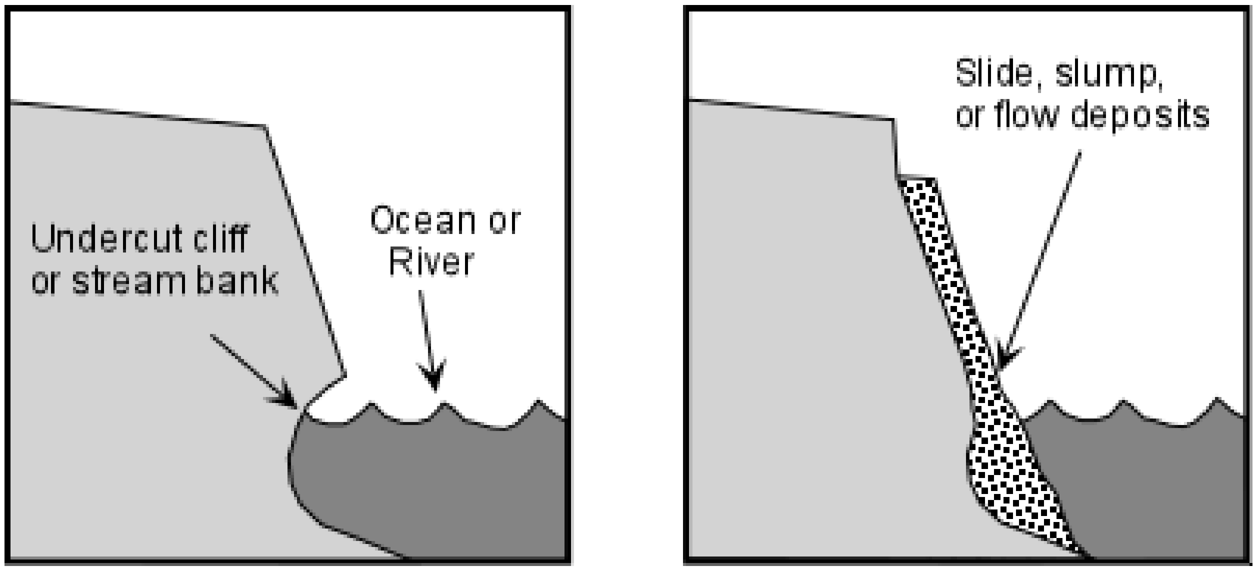


Figure 12: Undercutting

2.4 DGMS Guidelines for Benches or slopes design

2.4.1 Manual or Conventional Opencast Mines

In alluvial soil, morum gravel, clay, debris or other similar ground –

- The sides shall be sloped at an angle of safety not exceeding 45 degrees from the horizontal or such other angle as permitted by Regional Inspector of mines
- The height of any bench shall not exceed 1.5 m and the breadth thereof shall not be less than the height.
- In coal, the sides shall either be kept sloped at an angle of safety not exceeding 45 degree from the horizontal, or the sides shall be kept benched and the height of any bench shall not exceed 3m and the width thereof shall not be less than the height.
- In an excavation in any hard and compact ground or in prospecting trenches or pits, the sides shall be adequately benched, sloped or secured so as to prevent danger from fall of sides. However the height of the bench shall not exceed 6 m.
- No person shall undercut any face or side or cause or permit such undercutting as to cause any overhanging.

2.4.2 Mechanized opencast working.-

- Before starting a mechanized opencast working, design of the pit, including method of working and ultimate pit slope shall be planned and designed as determined by a scientific study.
- The height of the benches in overburden consisting of alluvium or other soft soil shall not exceed 5 m and the width thereof shall not be less than three times the height of the bench
- The height of the benches in overburden of other rock formation shall not be more than the designed reach of the excavation machine in use for digging, excavation or removal.
- The width of any bench shall not be less than –
    a. the width of the widest machine plying on the bench plus 2m, or
    b. if dumpers ply on the bench, three times the width of the dumper, or
    c. The height of the bench, whichever is more.

2.4.3 DGMS Guidelines for Formation of Spoil Banks and Dumps

1. The top soil shall be stacked at a separate place, so that, the same is used to cover the reclaimed area.
2. The slope of a spoil bank shall be determined by the natural angle of repose of the material being deposited, and it should not exceed 37.5 degrees from the horizontal.
3. Loose overburden and other such material from opencast workings or other rejects from washeries or from other source shall be dumped in such a manner that there is no possibility of dumped material sliding.
4. Any spoil bank exceeding 30m in height shall be benched so that no bench exceeds 30m in height and the overall slope shall not exceed 1 vertical to 1.5 horizontal.
5. The toe of a spoil-bank shall not be extended to any point within 45m of a mine opening, railway or other public works, public road or building or other permanent structure not belonging to the owner.

2.5 Methods for Slope Stability Analysis

- Limit equilibrium -
  - Analytical (software),
  - Chart methods
- Kinematic analysis, to determine the types of above mentioned failure.
- Sensitivity analysis
- Classification method –SMR
- Probabilistic method, and
- Numerical modeling method.

2.5.1 Limit Equilibrium Method

- It is the most widely accepted and commonly performed design tool in slope engineering.
- Sliding occurs when a limit equilibrium condition is reached, i.e., when the resisting forces balance the driving forces.

- These methods are the most widely accepted and commonly used design methods and they permit a quantification of slope performance with the variations in all the parameters involved in the slope design.
- The basic idea behind the limit equilibrium approach is to find a state of stress along the critical surface so that the free body, within the slip surface and the free ground surface, is in static equilibrium.
- This state of stress is known as the mobilized stress, which may not be necessarily the actual state along this surface.
- This state of stress is then compared with the available strength, i.e. the stress necessary to cause failure along the slip surface.

Guidelines for the Equilibrium of a Slope

To represent the slope performance other than the equilibrium condition, it is necessary to have an index and the widely used index used to be factor of safety.

- Factor of safety is calculated as the ratio of the resisting force to the driving force.
- It is constant throughout the potentially sliding mass. To ensure the safety of the operation it is required that the Factor of safety should be more than 1.2.

Table 1: Guideline for the Factor of Safety for different aspects

Factor of Safety	Details of Slope
<1.0	Unsafe
1.0-1.25	Questionable safety
1.25-1.4	Satisfactory for routine cuts and fills, Questionable for dams, or where failure would be catastrophic
>1.4	Satisfactory for dams

2.5.2 Planar failure Analysis

1. With no tension crack and no water pressure

Factor of safety = $\dfrac{c + \dfrac{w\cos\theta}{A}\tan\phi}{\dfrac{w\sin\theta}{A}}$ = $\dfrac{cA + w\cos\theta\tan\phi}{w\sin\theta}$

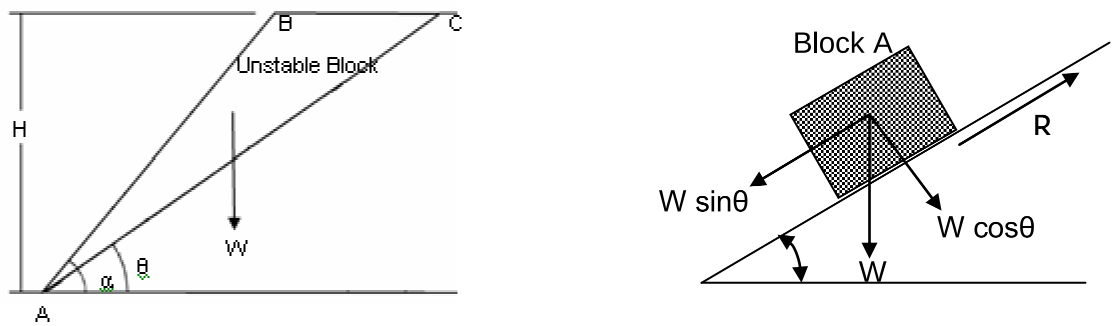


Figure 13: Planar Failure without Tension Crack

2. Tension crack present in upper slope surface

Depth of tension $Z = H + b\tan\alpha_c - (b + H\cot\alpha)\tan\theta$

Weight of unstable $W = \frac{1}{2}(H^2\cot\alpha X + bHX + bZ)$

$X = (1 - \tan\theta\cot\alpha)$

Area of failure surface; $A = (H\cot\alpha + b)\sec\theta$

Driving water force; $V = \frac{1}{2}\gamma_w Z_w^2$

Uplift water force; $U = \frac{1}{2}\gamma_w Z_w A$

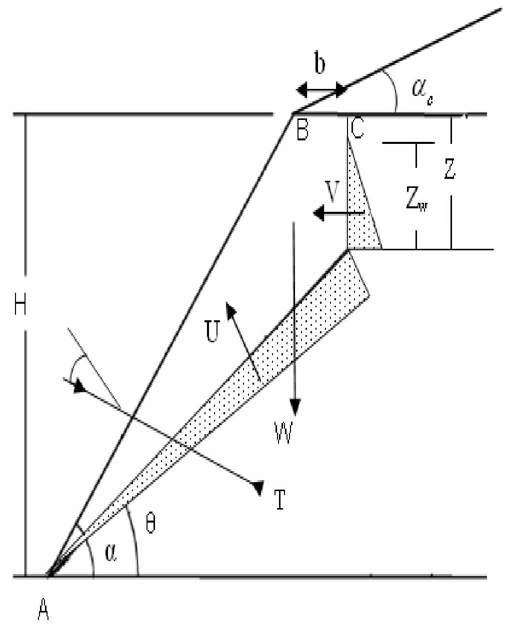


Figure 14: Planar Failure with Tension Crack

3. **Tension crack present in slope face**

Depth of tension crack; $Z = (H \cot\alpha - b)(\tan\alpha - \tan\theta)$

Weight of unstable block; $w = \frac{1}{2}\gamma H^2 \left[\left(1 - \frac{Z}{H}\right)^2 \cot\theta(\cot\theta \tan\alpha - 1) \right]$

Area of failure surface; $A = (H \cot\alpha_c - b)\sec\theta$

Driving water force; $V = \frac{1}{2}\gamma_w Z_w^2$

Uplift water force; $U = \frac{1}{2}\gamma_w Z_w A$

Factor of safety = $\frac{cA + (w\cos\theta - U - V\sin\theta + T\cos\beta)\tan\phi}{W\sin\theta + V\cos\theta - T\sin\beta}$

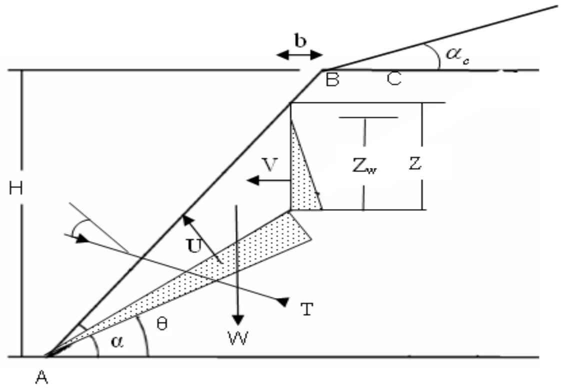


Figure 15: Tension Crack in Slope Face

2.5.3 Circular Failure Analysis:

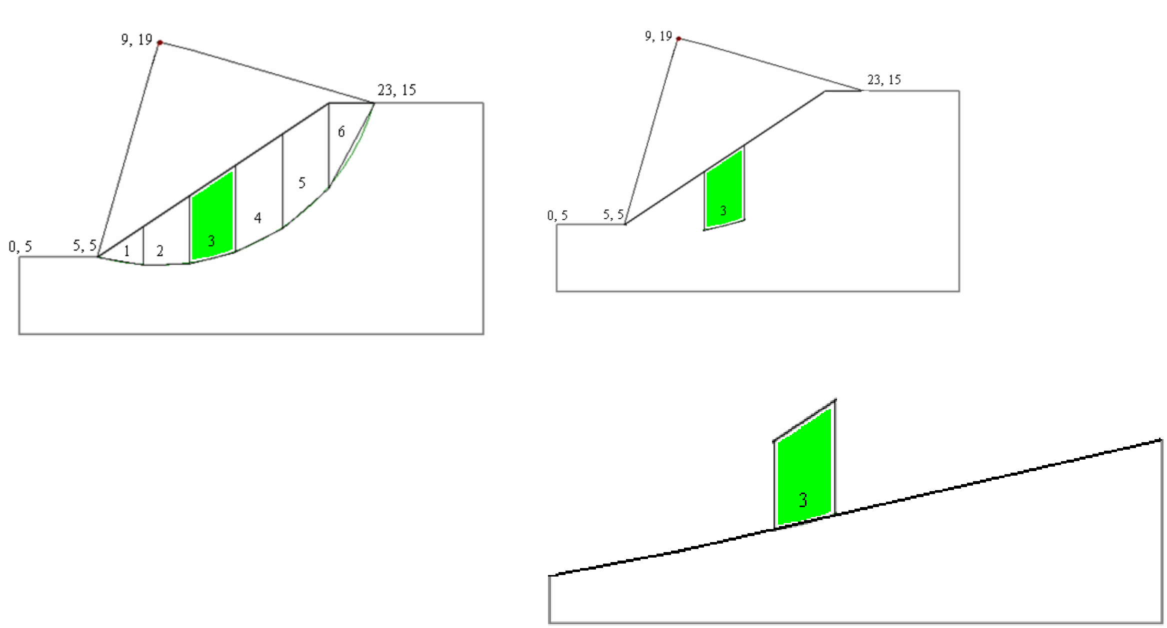


Figure 16: Circular Failure

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

$$\text{FOS} = \frac{c + \sigma \tan\phi}{\tau_s}$$

SOFTWARES being used for the slope stability analysis

Software based on Limit equilibrium Method

SLIDE

GALENA

GEO-SLOPE

GEO5

GGU

SOILVISION

Software for water pressure simulation

HYDRUAS

GEOSLOPE/ SEEP (GEOSTUDIO)

SOILVISION /Water

GMS

FEFLOW

Software based on Numerical modeling

PHASES2

PLAXIS

FLAC-SLOPE / UDEC / PPF

ANSYS

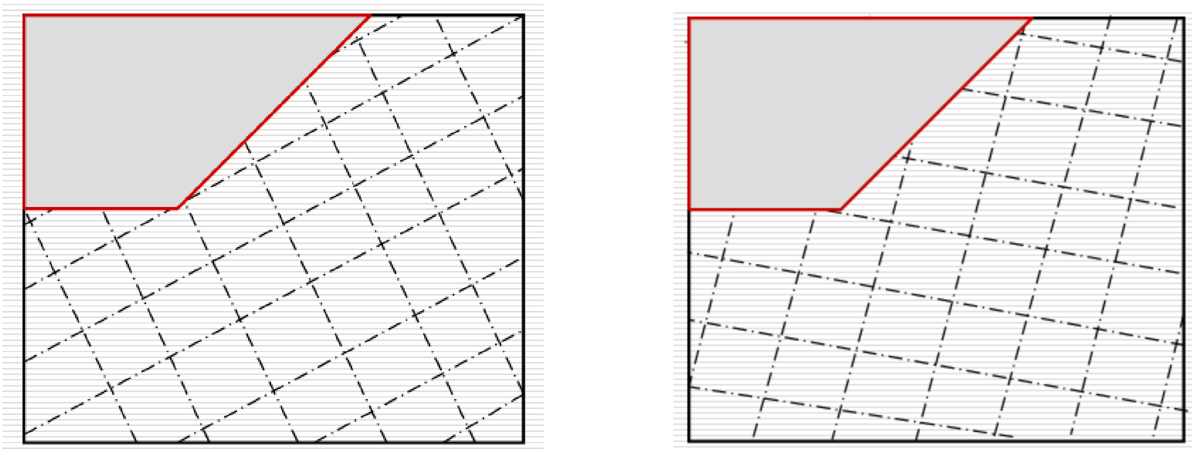
FEFLOW

GEOSLOPE/SIGMA

SOIL-VISION

2.5.4 Kinematic Analysis

The average orientations of the discontinuity sets determined from the geotechnical mapping were analyzed to assess kinematical possible failure modes involving structural discontinuities.



Slope Unfavorable **Slope favorable**

Figure 17: Kinematic Analysis

2.5.5 Sensitivity analysis:

- The sensitivity analysis is to be done to know the influence of water on the factor of safety.
- This study is highly beneficial to choose the best method of remedial measure for any critical slope.
- The influence of groundwater on factor of safety is remarkable.
- The stability analyses of high-wall slope. It is evident that the high-wall slopes are stable in drained condition with cut-off safety factor of 1.3 is unstable, if the slopes are subjected to un-drained condition with safety factor less than 1.3.
- In order to avoid un-drained condition, attention must be paid to avoid entry of rain/ surface water in the slope by providing suitable drainage in and around the quarry, failing which the slope can become unstable. It should be taken up well before the onset of monsoon.

2.6 Stabilization Techniques for the slope stability

"STABILIZATION OF SLOPE" is done by following ways:

- Drainage System
- Removal and repair
- Stabilization through Support
- Geo-synthetic reinforcement
- Retaining walls

2.6.1 Drainage System:

Types:

1. Surface drainage
2. Subsurface Drainage

Surface Drainage Systems: Surface drains and landscape design are used to direct water away from the head and toe of cut slopes and potential landslides, and to reduce infiltration and erosion in and along a potentially unstable mass

Sub-Surface: The main functions of sub-drains are to remove subsurface water directly from an unstable slope, to redirect adjacent groundwater sources away from the subject property and to reduce hydrostatic pressures beneath and adjacent to engineered structures

Objective of the drainage:

- To decrease water pressure
- Effective garland drain, directed away from excavated pit.
- To prove proper and effective drainage which may lead to decrease of 5 to 10 deg. increase in slope angle.

95% slide triggered by poor water management**.**

2.6.2 Removal and repair

When the slope is too steep and the toe is very close to the highway or railway, there will be very less or no space to excavate a catch ditch or construct a barrier. Therefore, alternative stabilization measures may be to remove loose rock, securing it in place with some bolts, or to drape mesh on the slope.

It is generally more preferable to remove loose rock and eliminate the hazard, provided it form a stable face and not undermine other potentially loose rock on the face**.**

Following operations fall under this techniques:

- Excavation & repair
- Catchment & Wire Netting
- Grading & Serrating
- Benching
- Re-sloping and unloading
- Lightweight Fill
- Counter berms
- Trimming
- Shear Keys
- Scaling

2.6.3 Stabilization through Support

- Ground Inclusions
- Ground anchor
- Soil Nailing
- Rock Bolt
- Rock Dowels
- Steel reinforcement

2.6.4 Ground inclusion

It is a metal bar that is driven or drilled into competent bedrock (rock which is not highly fractured or broken up) to a provide stable foundation for structures such as retaining walls and piles, or to hold together highly fractured or jointed rock.

2.6.5 Piles:

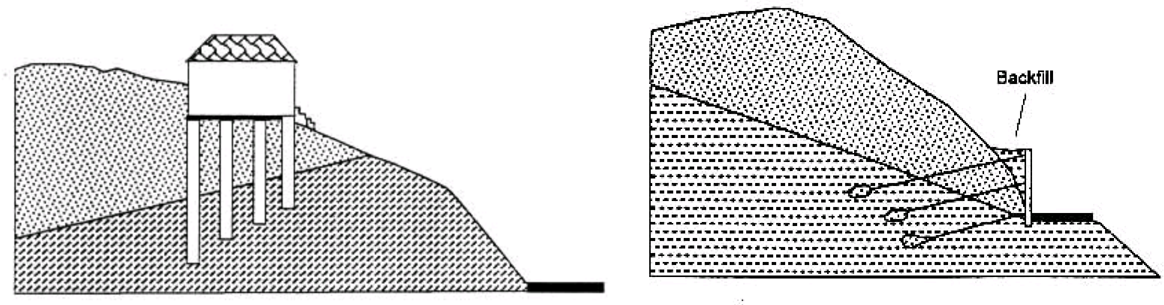


Figure 18: Stabilization through Piles

- Piles are long, relatively slender columns positioned vertically in the ground or at an angle (battered) used to transfer load to a more stable substratum.
- Piles are often used to support or stabilize structures built in geologically unstable areas.
- Piles used as foundation for structures constructed on compressible soil or weak soil.
- Grouped piles used as a retaining wall: Anchors are generally used to increase the effectiveness of pile walls

2.6.6 Geo- synthetics reinforcement

Geo-synthetics are porous, flexible, man-made fabrics which act to reinforce and increase the stability of structures such as earth fills, and thereby allow steeper cut slopes and less grading in hillside terrain. Geo-synthetics of various tensile strengths are used for a variety of stability problems, with a common use being reinforcement of unpaved roads constructed on weak soils.

2.6.7 Retaining Walls:

Engineered structures constructed to resist lateral forces imposed by soil movement and water pressure.

Retaining walls are commonly used in combination with fill slopes to reduce the extent of a slope to allow a road to be widened and to create additional space around buildings

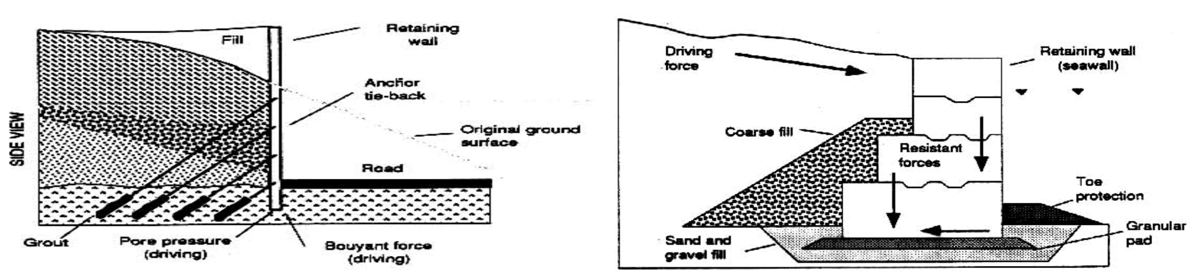


Figure 19: Retaining Walls

2.6.8 Other Techniques

Rock Mass Improvement and Stabilization Methods

- Grouting
- Chemical Stabilization
- Biological Stabilization

Controlled placement of spoil

Improving drainage at the base of the dumps,

Blasting/ ripping of the floor, Garland drain/ bund near toe of dump,

- all along the periphery of dump edges,
- 5 m away from the toe of the dump – toe cutting.

Proper spoil leveling

- To check rainwater ponding at top,
- Dumping in depressed zone,
- Liquefaction of dump toe

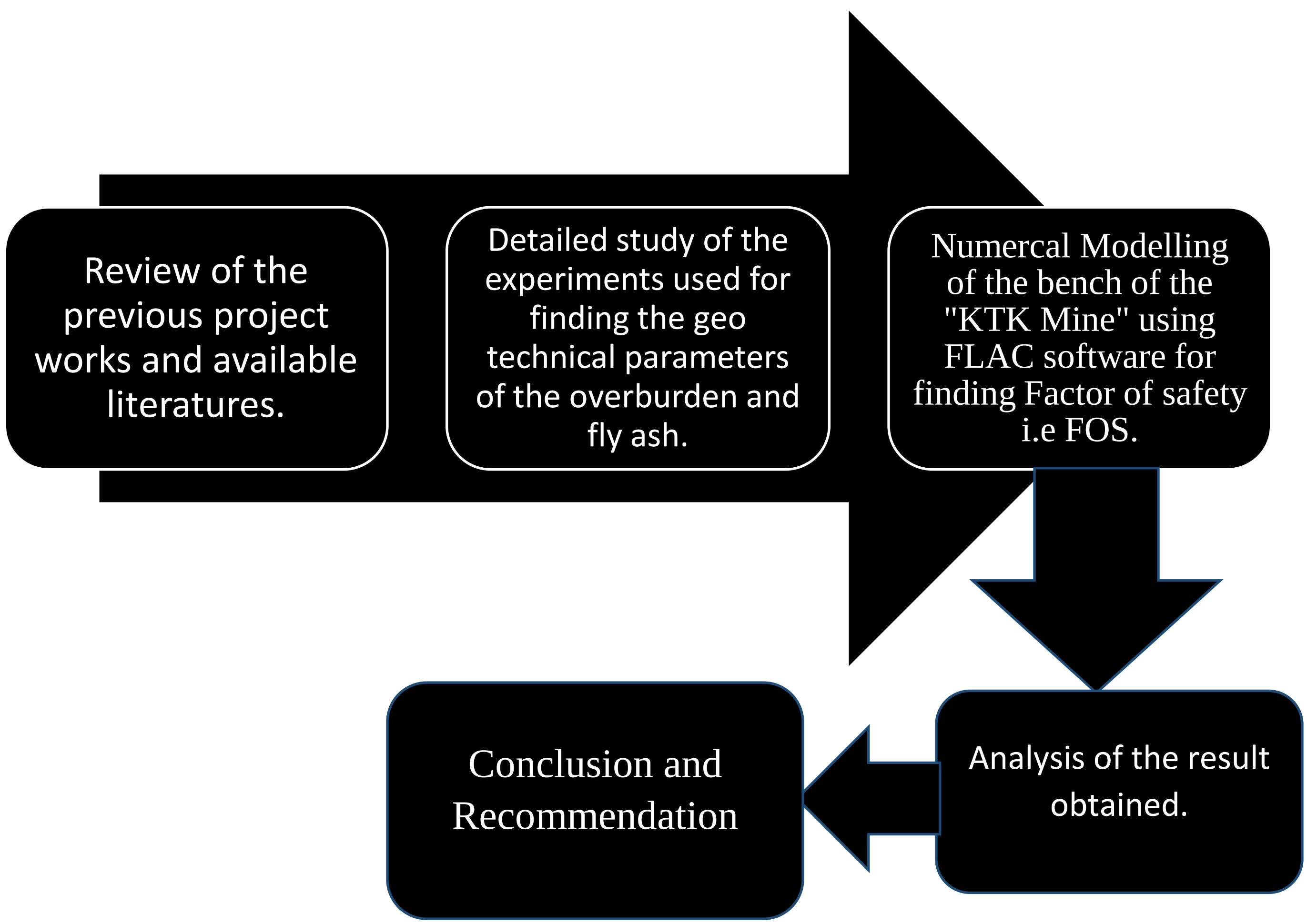
Planting of self-sustaining grass and plants

- To check the soil erosion,
- To avoid the formation of deep gullies, form terraces, 1 m wide at the height of each about 6m.

CHAPTER 3

PROJECT METHODOLOGY

3.1 PHASE OF OUR PROJECT



3.1.1 Description of the Study Area:

KTK OC mine, SCCL is located at a distance of 3 km from Bhupalapalli. It has a leasehold area of 336 ha. The maximum depth of workings in the mine is up to 85 m. A total of 5 seams are being worked in the mine. Production started in 2009 with an annual target of 1.2 million tons of coal 13 million m^3 of OB removal. The stripping ratio of the mine ranges from 1:10 to 1:12. KTK OC mine is presently producing 50000 tons of coal per month. The total production is interlinked and is being transported to Kakatiya Thermal Power Station (KTPP) Chelpur located on the Bhupalapalli – Warangal PWD road at a distance of 15 km from the mine. KTPP Chelpur, a 500 MW power station, is presently producing 2200 TPD of fly ash and 600 TPD of Bottom ashes. This is likely to be doubled with the installation of an additional 600 MW power plant now under construction.

3.1.2 Method of Dumping Fly-ash and OB

The current method of transporting OB being practiced in the mine, i.e. hauling and dumping through dumpers followed by dozing, would be continued. The fly ash would be dumped in between the OB heaps at the rate of 30% of the OB material (approximately 3 trucks of OB and 1 truck of fly-ash. The same procedure will be followed for dumping 15% fly ash. While dozing the OB and fly ash heaps, a nearly homogenous mixture would be formed along the slope and it would progresses up to the boundary of the dump area.

3.1.3 Experimental Investigation:

Before going for modeling using the FLAC software we are required to find few geo-technical parameters mentioned below:

Firstly, to know the nature of the dump i.e. whether the overburden mixed with 30% fly ash is sandy or clay in nature, we are required to know the grain size distribution of the same mixture.

Thereafter we are required following geotechnical parameters of both the overburden and overburden dump mixed with 30% fly ash

1. Dry density (kg/m3)
2. Cohesion (Pa)
3. Angle of internal friction (degree)

For these things following experiments are required to perform in the lab:

<u>Procter hammer test</u> – to determine dry density

<u>Direct Shear test</u> – to determine cohesion and angle of internal friction

3.1.3.1 Grain Size analysis

Soil is a porous mass consisting of aggregates of particles of different shapes and sizes that are held together by inter-particulate electrochemical forces. Thus the variations in size of particles of the grains in a soil mass can form one of the basis of classification of soils. Though grain size particle distribution in soil is not adequate to predict engineering properties of soils, it provides enough information to classify the soil as coarse grained or fine grained. Soil fraction with size greater than 0.075 mm is known as coarse and lesser than that as fines.

Table 2: Variation of the nature of the soil with the particle size

Particle Size	Fraction
> 4.75 mm	Gravel
0.075 mm – 4.75 mm	Sand
0.002 mm – 0.075 mm	Silts
< 0.002 mm	Clay

PROCEDURE

The sieves are arranged on top of one another such that the coarsest one was at the top and the finest one at the bottom. 1 kg of oven dried soil sample is taken and placed on the coarsest sieve. The entire assembly of sieves is placed on the sieve shaker and shaken for about 10 min. The material retained on each sieve is recorded in a tabular format and the cumulative percentage retained is calculated. The cumulative percentage of fines is also calculated and the graph between percentage of fines and grain size is required to plot.

From the observations it was found that samples are sandy in nature.

3.1.3.2 Procter hammer test

MOISTURE-DENSITY RELATION (COMPACTION) TEST

Purpose:

This laboratory test is performed in the laboratory to determine the relationship between the moisture content and the dry density of a soil for a specified compaction effort. The compaction effort is the amount of mechanical energy delivered to the soil mass.

This test is known as the Proctor test because this method employs the type of equipment and methodology developed by R. R. Proctor in 1933.

Significance:

Mechanical compaction is one of the most common and cost effective means of stabilizing soils. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the "maximum" density measured in a standard laboratory test), and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density.

The optimum water content is the water content that results in the greatest density for a specified compact effort. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less pervious, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density.

The soil compacted lower than (dry of) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density.

Test Procedure:

I. First of all we took the measurement of the empty mold and then it fixed to the base plate. Then we attached the collar.
II. After that we took 2.5 kg of sample and added 100 ml of water. It was then thoroughly mixed. T
III. The wet sample thus formed was then divided into three parts. Then we roughly divided this into three parts.
IV. Then we filled this mold with one part of the soil and compacted it with 25 evenly distributed blows with the standard rammer.
V. Thereafter, we added to the mold and the blows were given as per aforesaid. In this way all the parts were added to the mold and were compacted by giving uniformly distributed blows.
VI. Then we removed the collar and trimmed the top of the soil to ensure fit within the mold.
VII. Then we detached the mold from the base plate and recorded its weight.
VIII. Thereafter for the determination of the moisture content, we took some amount of soil from the mold in a tin container.
IX. The 50 ml water was then added to the soil and repeated the above steps.

Following is the figure explaining the steps involved in the test:

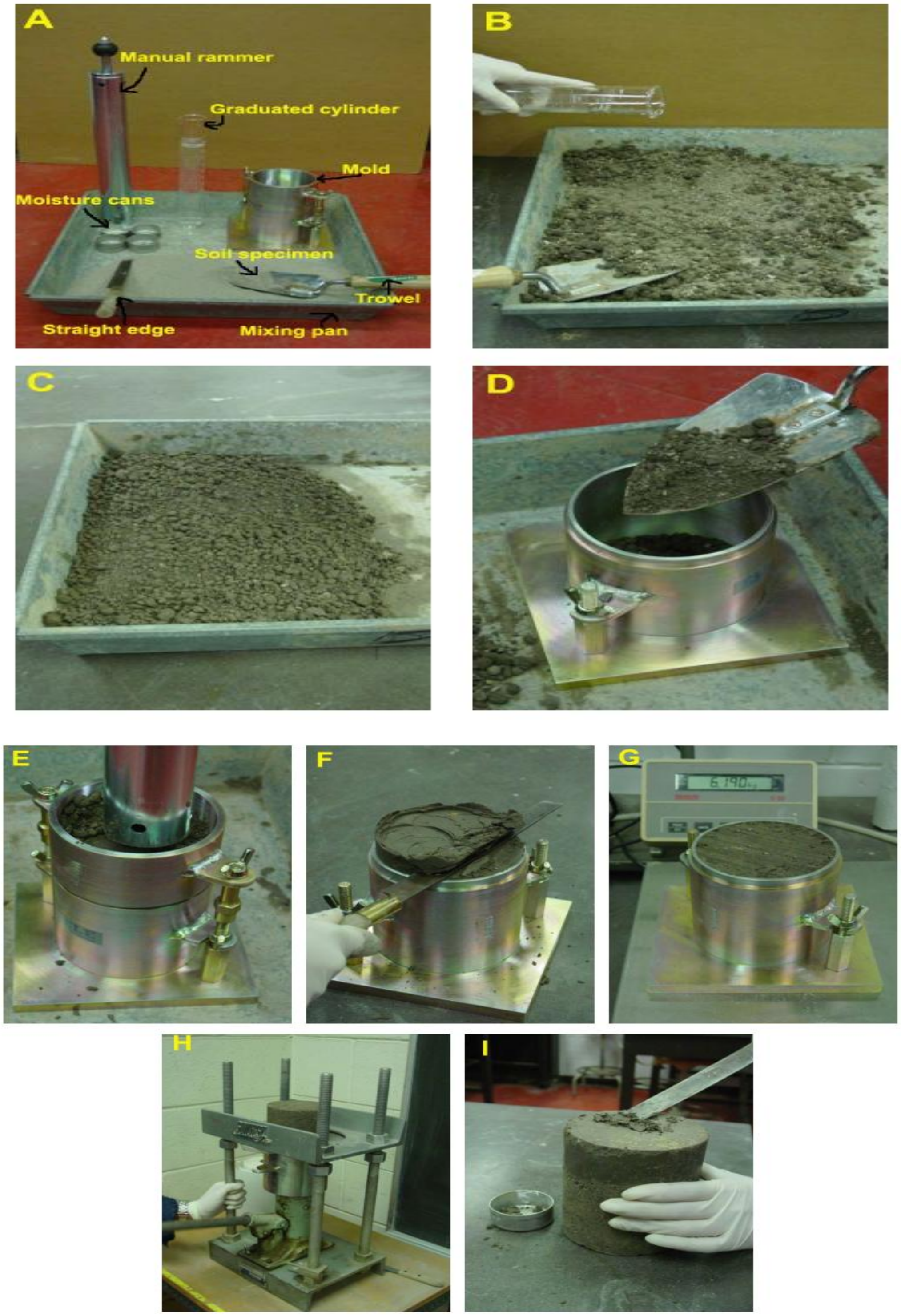


Figure 20: Steps involve in Procter Hammer Test

OBSERVATON:

Table 3: Dry density of both sample i.e. overburden and overburden + 30% fly ash used in modeling

Overburden	Overburden + 30% fly ash
1.812	1.50232
1.919	1.55232
1.984	1.576255
2.029	1.607597
1.971	1.649873

3.1.3.3 Direct Shear Test

Shear strength is generally employed to describe the strength of rock materials, to resist deformation due to shear stress. Rock resists shear stress by two internal mechanisms, *cohesion and internal friction.* Cohesion is a measure of internal bonding of the rock material whereas the angle of internal friction is caused by contact between particles, and is denoted by the internal *friction angle, φ*. Different rocks have of course different cohesions and different friction angles. Shear strength of rock material can be determined by both the *direct shear test* and by *tri-axial compression tests.*

Shear strength in a soil arises from the fact that there occurs a surface frictional resistance along the sliding plane, interlocking between individual rock grains and cohesion in sliding surface of soil model. The shear strength of soil is given by Mohr-Coulomb expression:

$$\tau = c + \sigma_n \tan\phi$$

where c = cohesion and φ = angle of internal friction.
Therefore, by combining the above three equations,

PROCEDURE:

i. In a test of soil, there are two basic stages. First nominal load is applied to specimen and then failure is induced by applying a shear stress.
ii. If no water is allowed to escape from or enter into specimen either during consolidation is un-drained test.

iii. If the specimen is allowed to consolidate under normal load but no drainage of water is allowed during shear, it is called consolidated un-drained or consolidated quick test.
iv. Then we took the dimensions of the shear box and also the amount of the sample.
v. Then we took required weight of sample in a tray and added some amount of water to it, at its optimum moisture content.
vi. Thereafter thorough mixing of this mixture was done.
vii. Thereafter we assembled the shear box with the shearing pins screwed in.
viii. Then in three layers, sample was then transferred to the shear box.
ix. Then by fixing the top plates on the shear box, we transferred it to the loading frame.
x. Then we attached weights to the loading frame and the set the dial gauges to zero.
xi. After that the machine was started and the readings of the proving ring were taken up to failure of the sample.
xii. It was repeated by taking different weights i.e. normal stress and recorded the observations.

OBSERVATION:

The variation of shear stress with normal stress has been shown below:

Normal Stress vs. Shear Stress for

Table 4: Overburden Sample

Normal Stress, N **kg/cm2**	Shear Stress, **τ , kg/cm2**
0.5	0.269
1.0	0.676
1.5	0.839
2.0	1.183
2.5	1.596

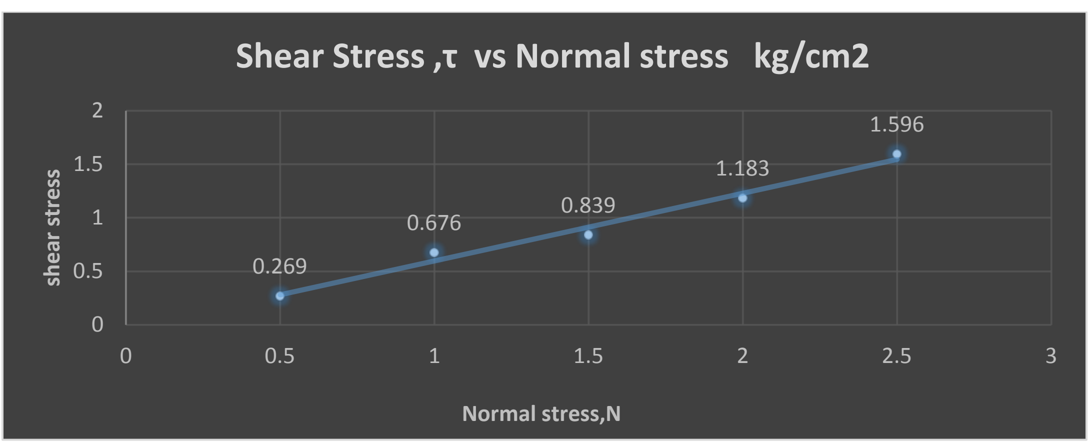


Figure 21: Variation of Shear Stress versus Normal Stress for Overburden

Following parameters were obtained from the graph,

Cohesion = intercept on the y axis = 0.0285 kg/cm2 = 2705.85 Pa

Angle of Internal Friction = slope of the straight line= arc-tan (0.597) = 30.84°

Table 5: Overburden + 30% fly ash

Normal Stress, N **kg/cm2**	Shear Stress, **τ , kg/cm2**
0.5	0.364
1.0	0.538
1.5	0.867
2.0	1.159
2.5	1.246

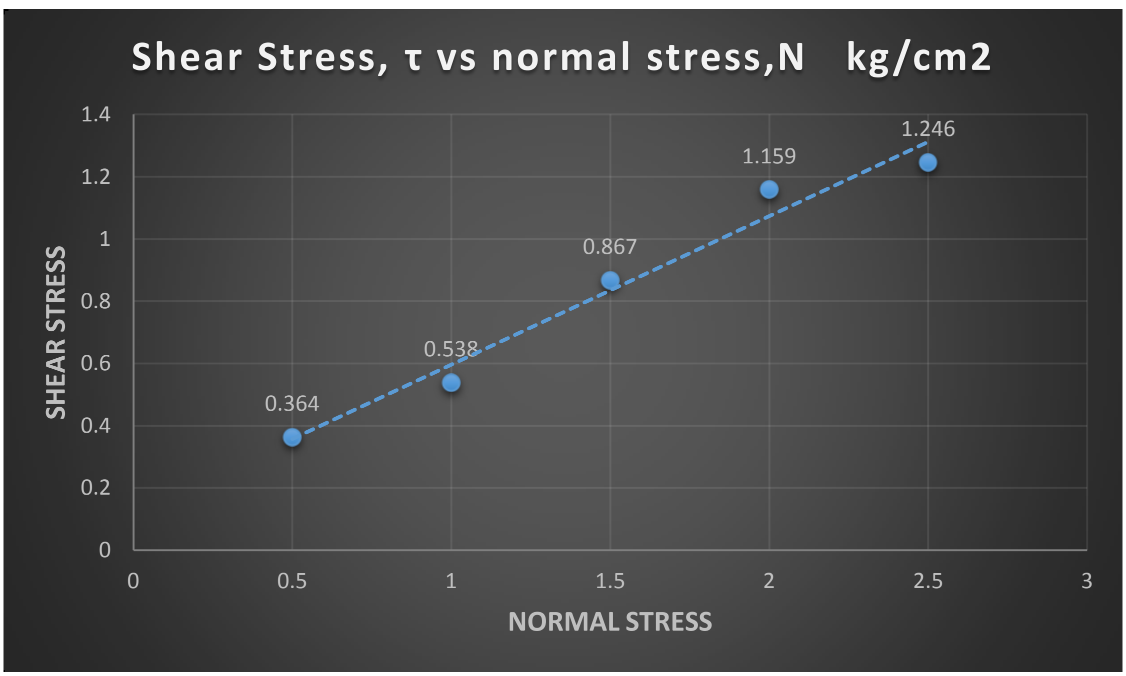


Figure 22: Variation of Shear Stress versus Normal Stress for Overburden + 30% Fly Ash

Following parameters were obtained from the graph,

Cohesion = intercept on the y axis = 0.0647 kg/cm2 = 6347.07 Pa

Angle of Internal Friction = slope of the line = arc tan (0.506) = 26.87°

3.1.4 FLAC MODELLING OF THE MINE BENCH:

In modeling of the mine benches of the dump using FLAC slope, we have categorized it into two parts:

I. Modeling using simple bench of dump height 30m
II. Modeling using 3 layers of the bench each having dump height 30m

3.1.4.1 DESCRIPTION OF FLAC SLOPE 5.0:

FLAC/Slope is a mini-version of FLAC which stands for the "Fast Lagrangian Analysis of the Continum" that is designed specifically to perform calculations of factor-of-safety for slope-stability analysis. This version is operated entirely from FLAC's graphical interface (the GIIC) which helps in the rapid creation of models for soil and/or rock slopes and then solves the model to analyze the stability condition.

FLAC/Slope provides an alternative approach to traditional "limit equilibrium" programs to determine factor of safety. Several assumed failure surfaces are tested, and the one giving the lowest factor of safety is chosen. Equilibrium is only satisfied on an idealized set of surfaces.

In contrast, FLAC/Slope provides a full solution of the coupled stress/displacement, equilibrium and constitutive equations. With the assigned set of properties, the system determines that whether the slope is stable or unstable. It automatically performing a series of simulations while changing the strength properties ("shear strength reduction technique), the factor of safety can be found corresponding to the point of stability, and the critical failure (slip) surface can be located.

However, FLAC/Slope does take longer to determine a factor of safety than a limit equilibrium program. But, with the advancement of computer processing speeds (e.g., 1 GHz and faster chips), solutions can now be obtained in a reasonable time. This is what makes FLAC/Slope a practical alternative to a limit equilibrium program, and thus provides greater advantages over a limit equilibrium solution:

1. There is no need to specify a range of trial surfaces in advance for any failure mode which develops naturally

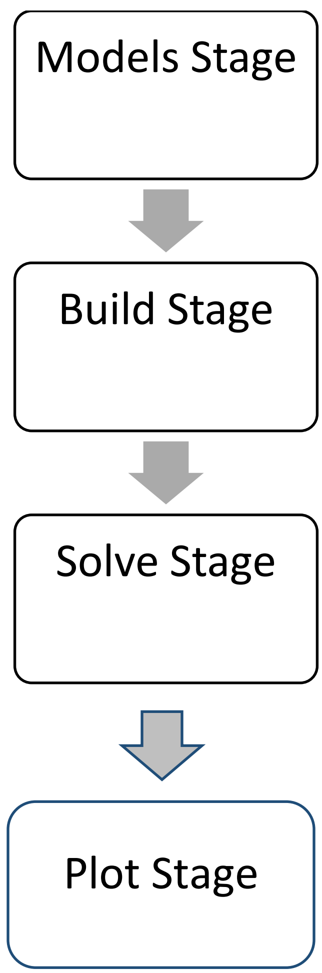
2. There is no need of assigning artificial parameters (e.g., functions for inter-slice force angles)

3. Multiple failure surfaces (or complex internal yielding) evolve naturally, if the conditions give rise to them.

4. Structural interaction e.g., rock bolt, soil nail or geo-grid, can be modeled realistically as fully coupled deforming elements, not simply as equivalent forces.

5. The solution consists of mechanisms that are feasible kinematically. While the limit equilibrium method only considers forces, it does not include kinematics.

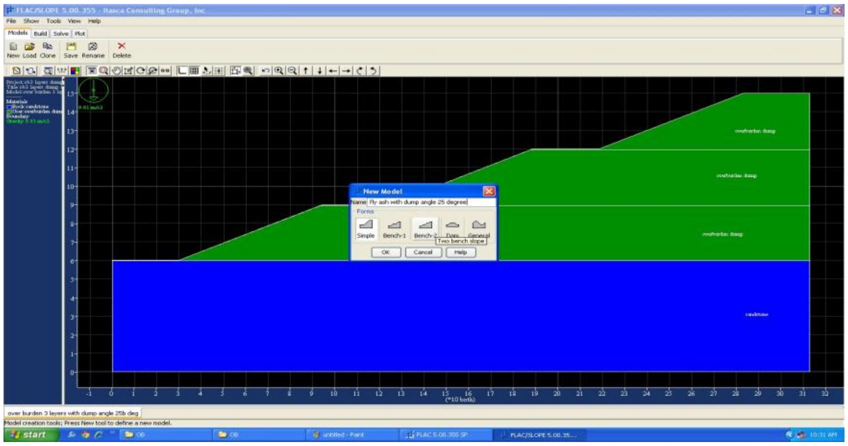
3.1.4.2 Stages involved in FLAC modeling



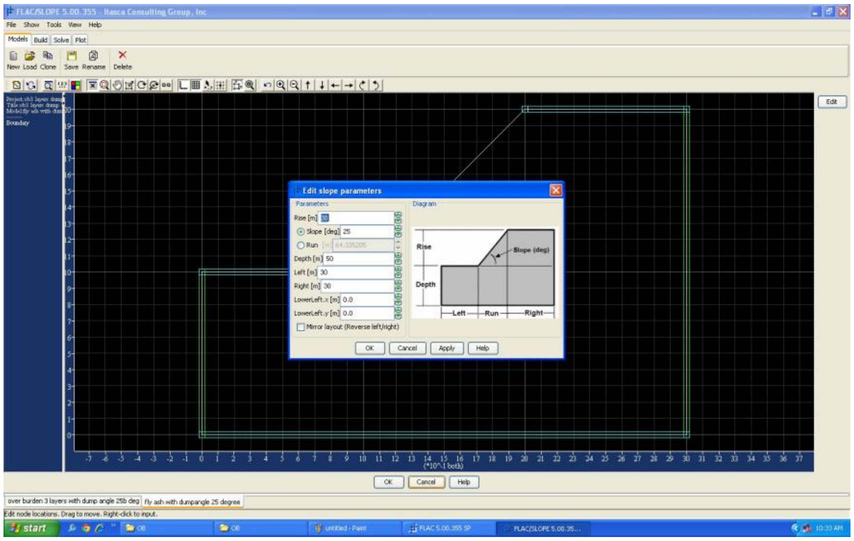
Details of the stages in FLAC modeling:

1. **Model stage:**

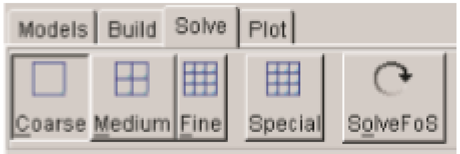
This is the first stage in which the name is assigned to the new model. This allows easy access to any model and results in a project. New models can be added to the tabbed bar or deleted from it at any time in the project study. Models can also be restored (loaded) from previous projects and added to the current project.



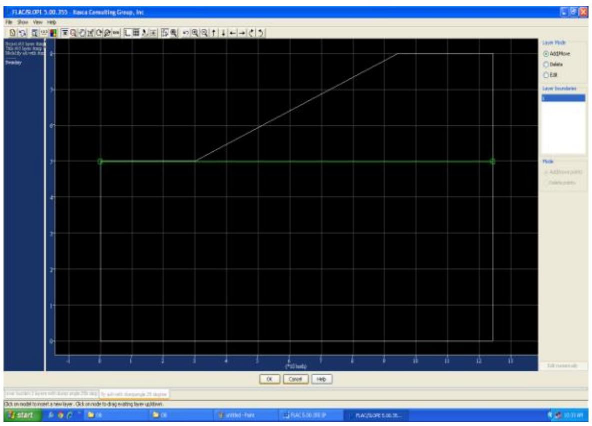
After assigning the name to model we are required to set the design parameters of that bench we want to analyze.

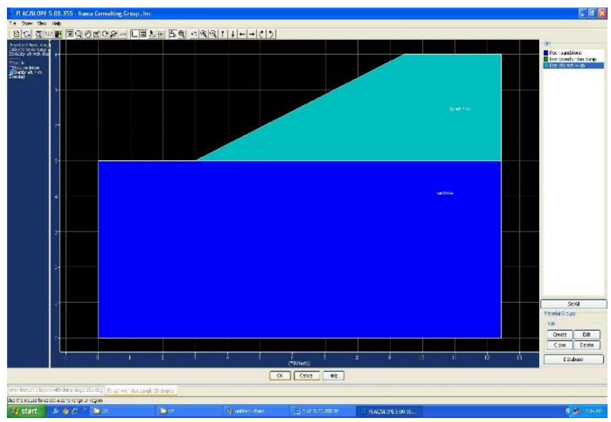


2. **Build stage:**

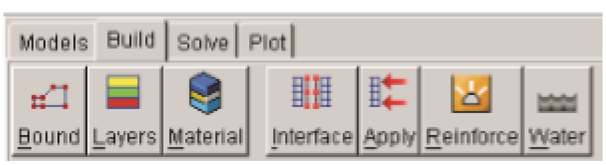


In this stage, all different attributes like the number of layers, material properties etc are assigned to represent the real natural bench slope.

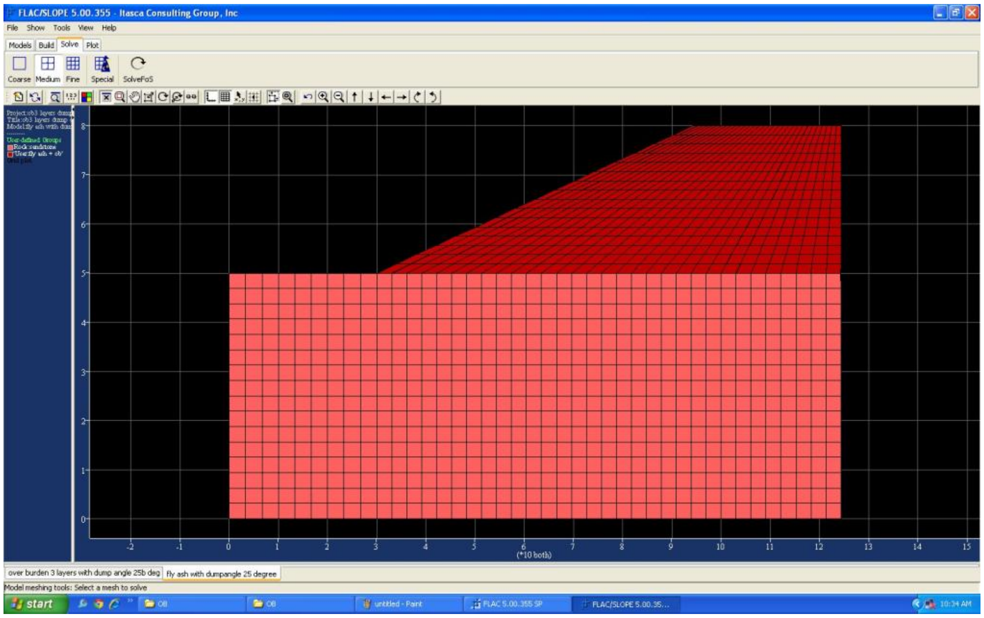


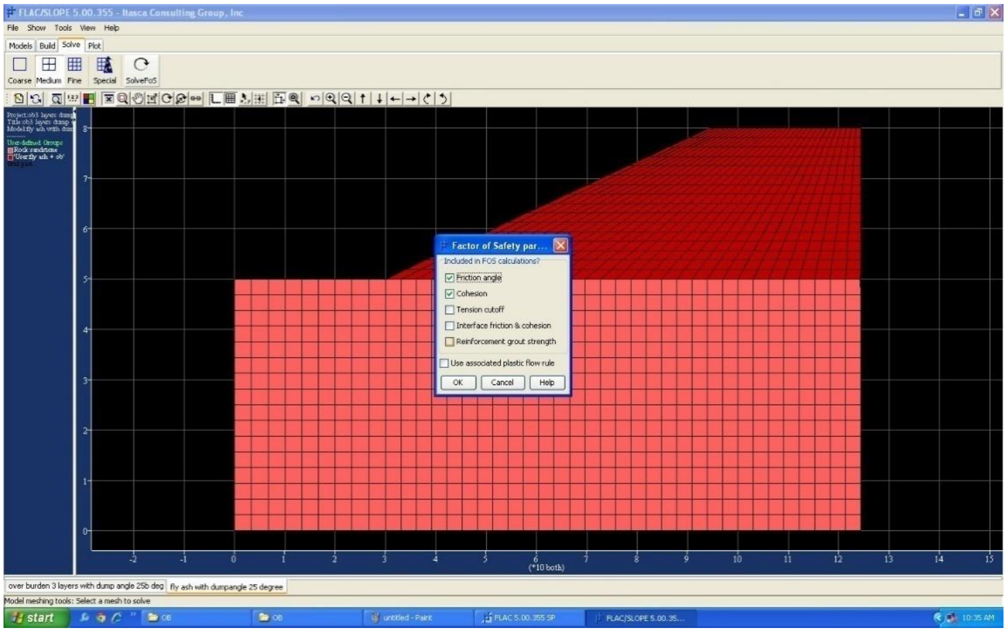


3. **Solve stage:**



After defining the model i.e. assigning all parameters we are required to solve the model that we have designed. For this, first of all we have to choose the grid pattern as shown in figure and then hit “solve FOS”. After this a dialogue box will appear asking about the factors which we want to include like cohesion, angle of internal friction, tension etc.





4. Plot stage:

This is the final stage of the modeling in which we print the result obtained.

3.1.5 FLAC modeling of the KTK OC mine dumps

Category 1: Simple mine bench

Height= 30m

Following observation were obtained from the FLAC after solving the models, about the variation of the FOS with slope angle:

Table 6: FOR OVERBURDEN

Slope inclination in degree	FOS
25	1.43
26	1.35
27	1.30
28	1.26
29	**1.21**
30	1.17

The red shaded data tells about the stable FOS for the dump.

Table 7: For Overburden+ 30% fly ash

Slope inclination in degree	FOS
25	1.34
26	1.30
27	1.24
28	**1.20**
29	1.16
30	1.12

Category 2: Benches with 3 layers having 30m height of each deck.

Table 8: For overburden

Slope inclination in degree	FOS
25	1.38
26	**1.28**
27	1.13
28	0.69

Table 9: For Overburden+ 30% fly ash

Slope inclination in degree	FOS
25	1.43
26	1.28
27	**1.21**
28	1.18

Print plot of different slope geometry:

Overburden:

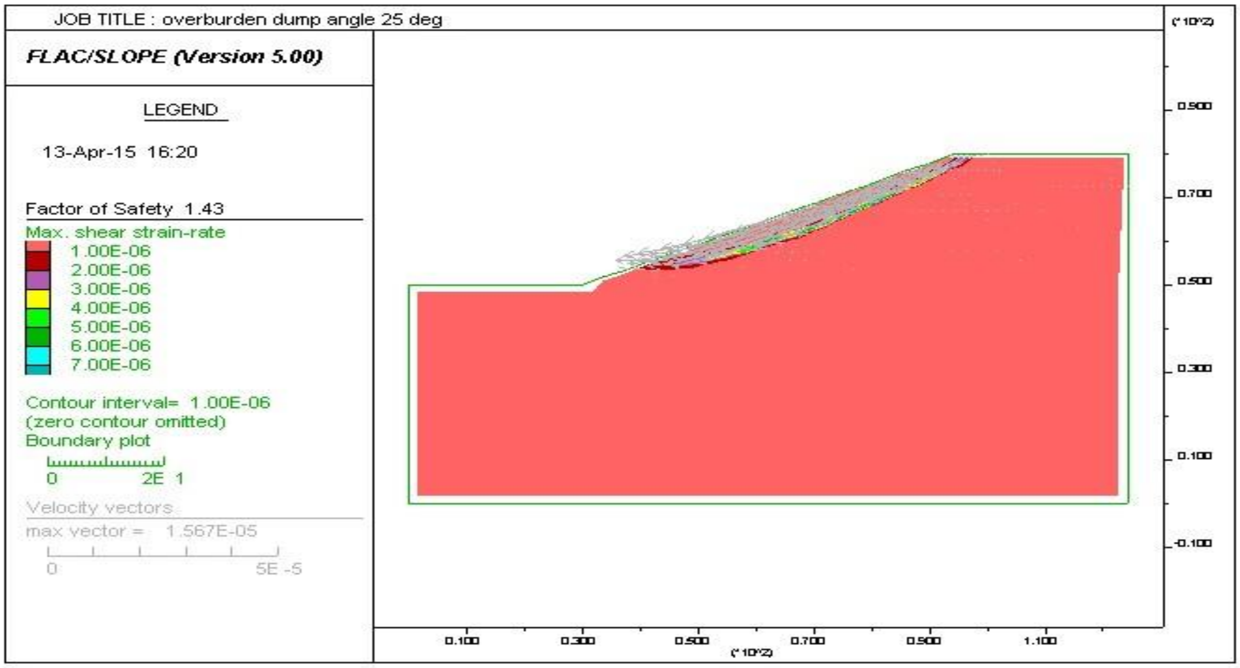


Figure 23: overburden dump angle 25 degree

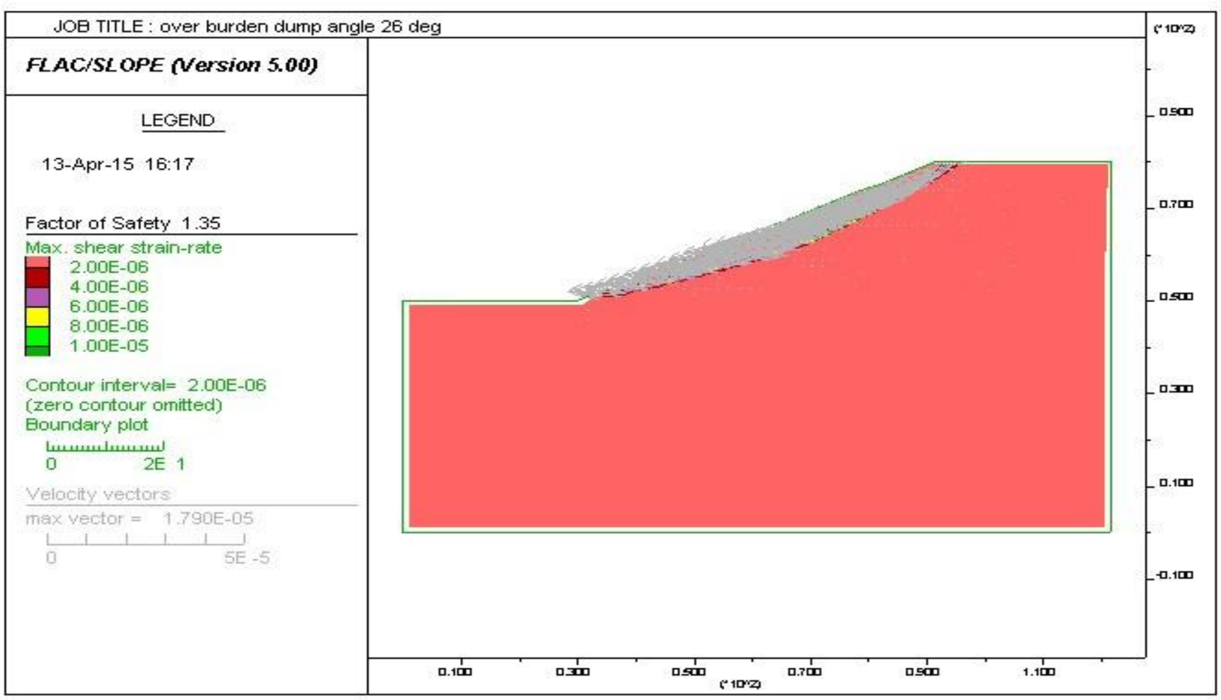


Figure 24: overburden dump angle 26 degree

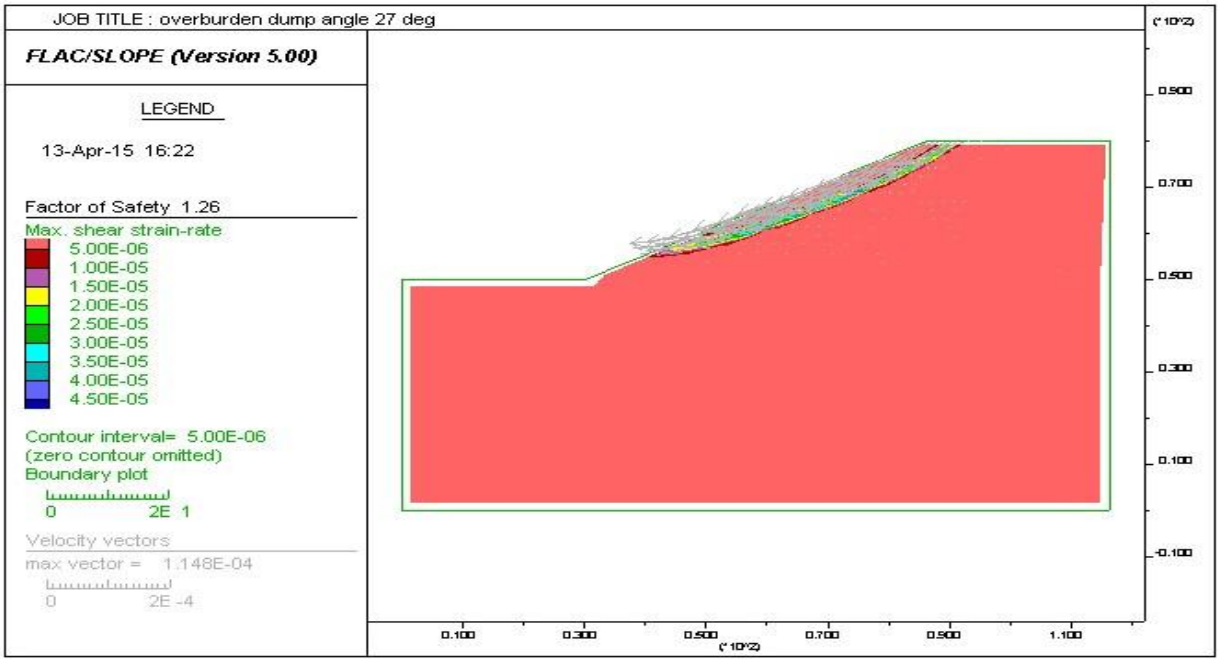


Figure 25: overburden dump angle 27 degree

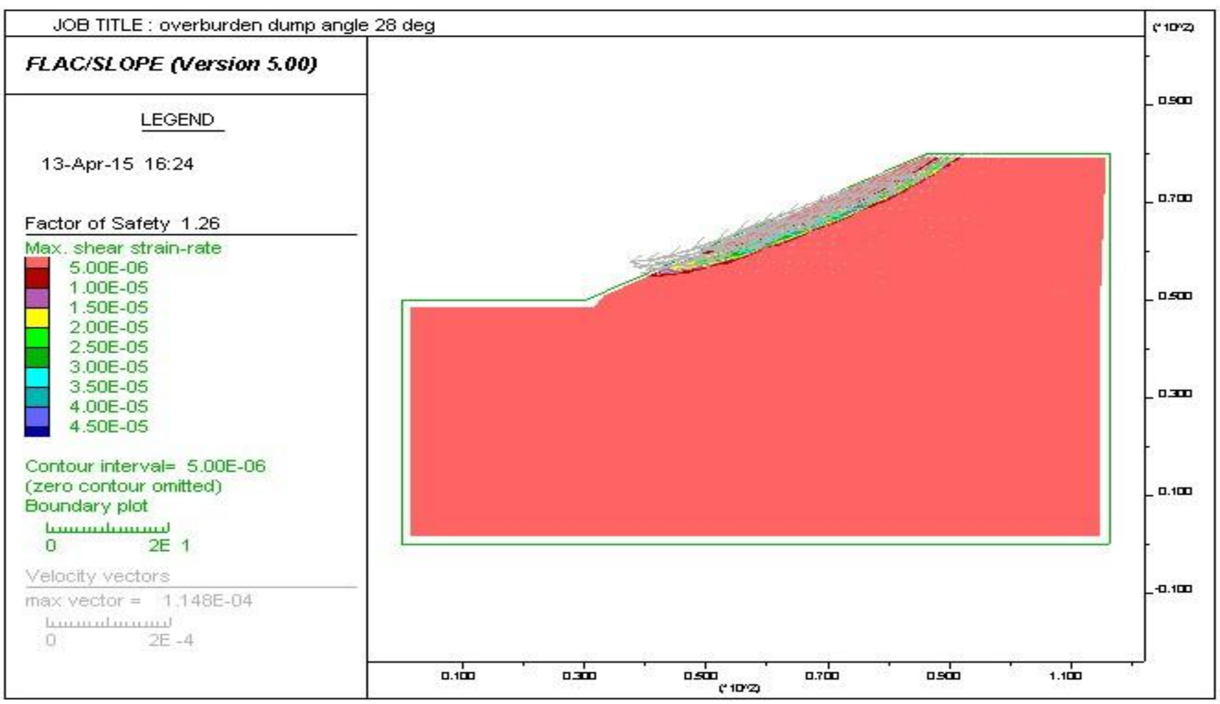


Figure 26: overburden dump angle 28 degree

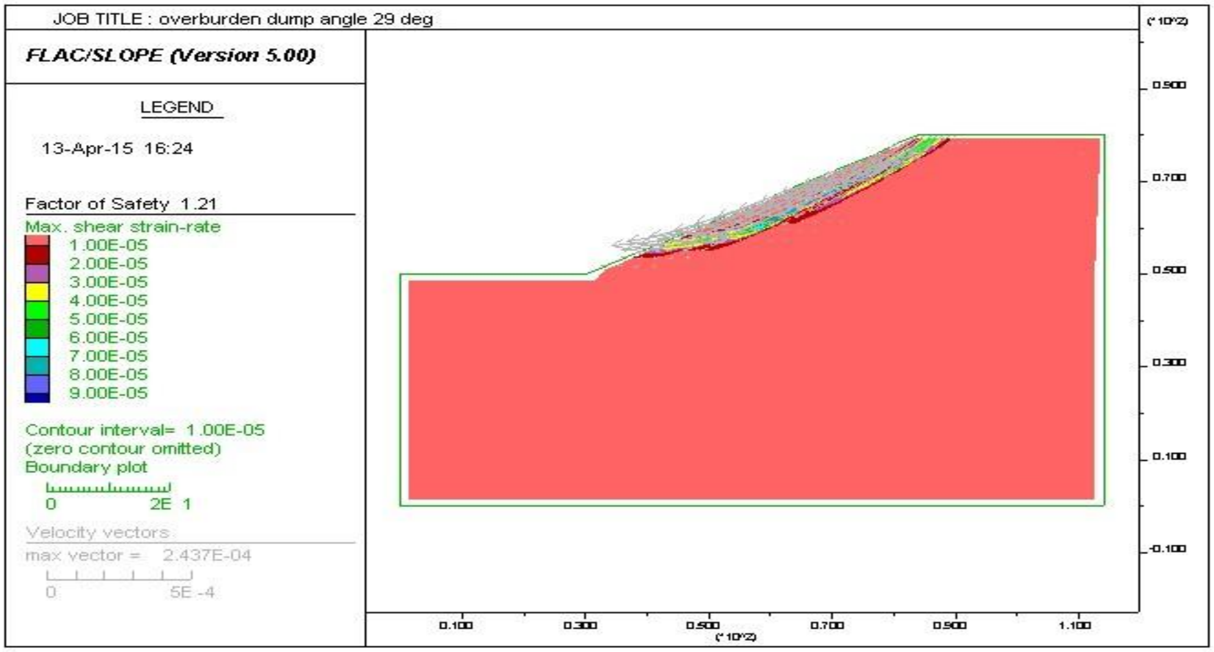


Figure 27: overburden dump angle 29 degree

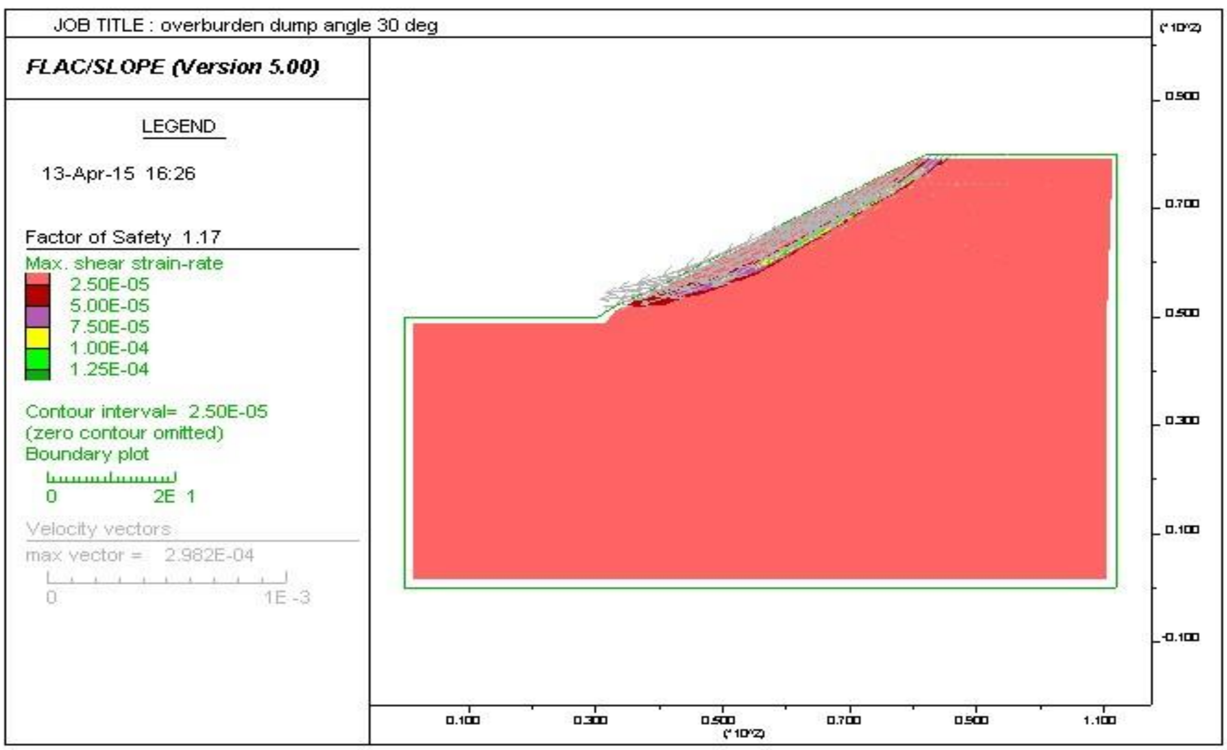


Figure 28: overburden dump angle 30 degree

OB+ 30% FLY ASH

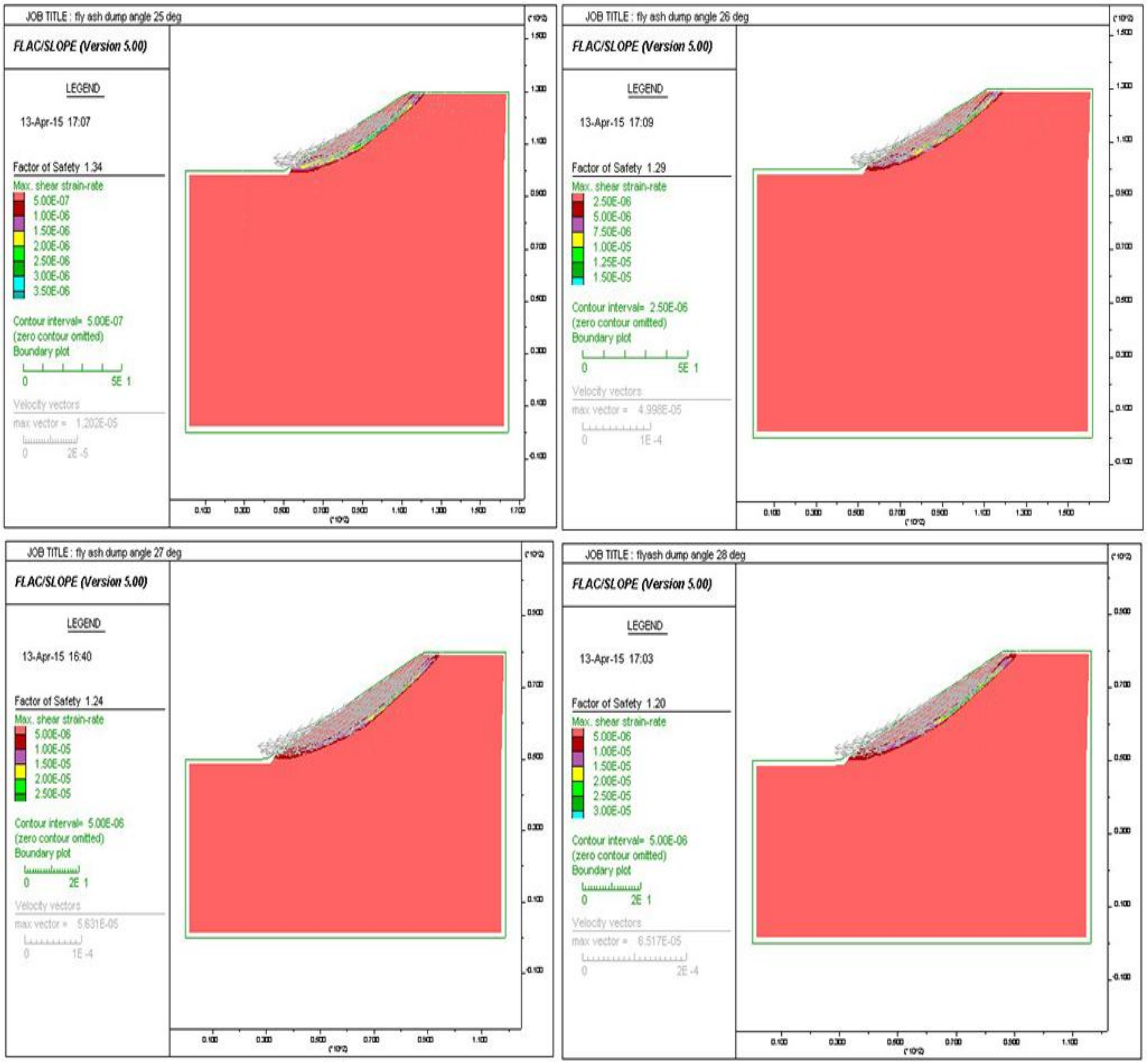


Figure 29: variation of FOS with slope of overburden dump + 30% fly ash

Overburden sample with 3 layers:

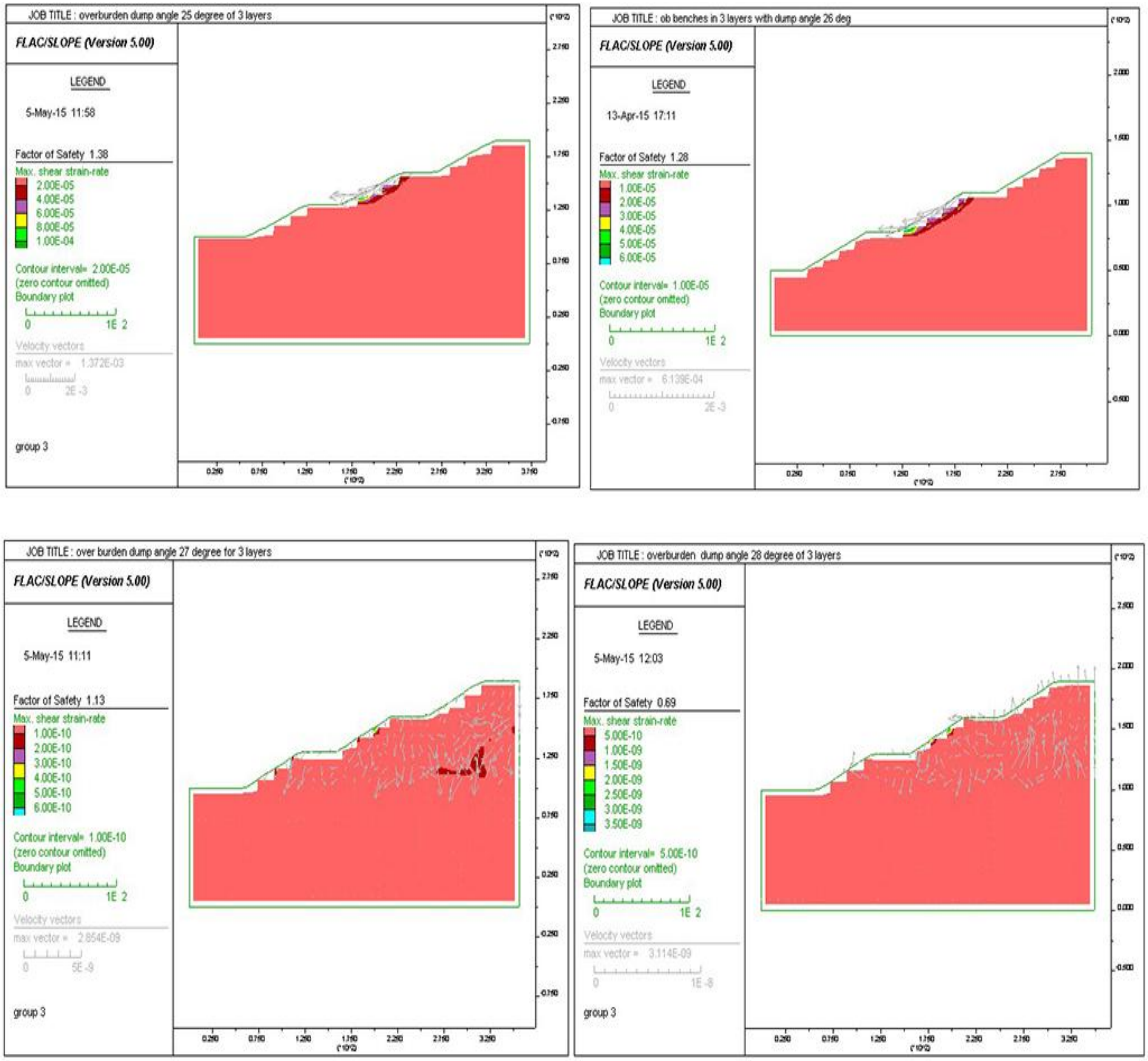


Figure 30: variation of FOS with slope of overburden dump containing 3 layers.

Fly ash + overburden with 3 layers:

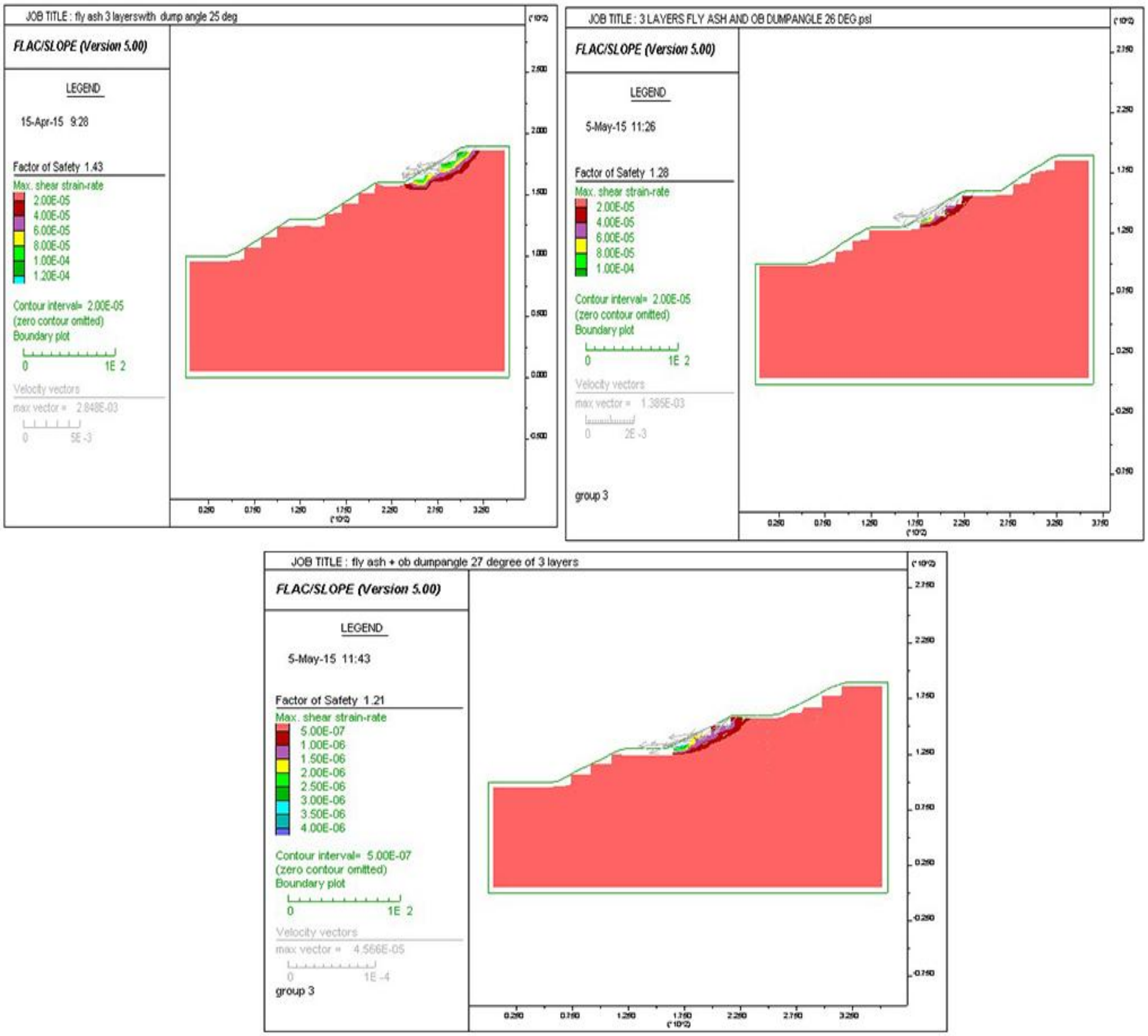


Figure 31: variation of FOS with slope of overburden dump + 30% fly ash containing 3 layers.

CHAPTER 4

CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Following conclusions were drawn after the completion of all experimental works:

1. After doing experimental investigation the geo technical parameters of the both sample i.e overburden and overburden + 30% fly ash was found which is shown below:

Table 10: Geotechnical parameters of the sample

SAMPLE	COHESION	ANGLE OF INTERNAL FRICTION
Overburden	2705.85 Pa	30.84 °
overburden + 30% fly ash	6347.07 Pa	26.87°

Here the reason behind the increase in the cohesion of the sample after mixing fly ash is that fly ash has binding property due to which it holds the particles together. And because the fly ash is softer and finer it offers less resistance against the relative motion of the particles that is why its angle of internal friction reduces after mixing fly ash.

2. **Factor of Safety FOS > 1.2** i.e. stable dumps for both samples are shown below:

Table 11: FOR SIMPLE BENCH

SAMPLE	SLOPE ANGLE	FOS
Overburden	29	1.21
overburden + 30% fly ash	28	1.20

Table 12: FOR 3 LAYERS

SAMPLE	SLOPE ANGLE	FOS
Overburden	26	1.28
overburden + 30% fly ash	27	1.21

3. With the addition of fly ash i.e. at 30%, packing of the voids would become more compact as they reduce the void ratio. Hence it increases the FOS. This would allow the dump to becoming little bit more steeper with reasonable "Factor of Safety" which will further reduce the cost of dumping with greater height of the dump.

4.2 Recommendation:

- Top soil should be protected against rainfall by taking measures like plantation, geo-synthetics, or jute/coir reinforcement.
- The compaction control should be periodically checked for proper compaction of overburden and fly ash mixture.
- Gully drains may be provided along the slope at regular intervals during monsoon/cyclone.

4.3 Scope for Future Work:

- The effect of groundwater and rainfall on the slopes stability can also be examined with the help of FLAC software.
- FLAC modeling can be extended to the three dimensional model which may give more realistic view of the slope.
- Fly ash and the overburden can be mixed in other proportion like 25%, 35% or 40% and stability of slope can be analyzed.
- Instead of using some other numerical modeling software like PLAXIS can be used for the slope stability analysis.

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