Modelling and Design of Open Pit Slopes-A Case Study

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Abstract - *In Opencast mines benches are developed with certain inclination known as slopes. These slopes must be stable during entire life of the mine, thus facilitating further development of benches. Such maintenance of developed slopes without failures is known as Slope stability. The analysis for the study of such slopes is known as Slope stability analysis. These slopes can also be seen in dump areas. Failure of slopes causes deprivation of production, additional stripping cost for recovery and excessive handling of failed material, sometimes even burial of heavy machinery under the failed slopes. Thus proper design of slopes is needed to avoid its failure, using field experience, rules of thumb followed by sound engineering judgement. In the recent decades, more importance is given in designing stable slopes in Opencast mining operations. So, basic objective of the project involves: (a) Understanding the different types and modes of slope failures. (b) Modelling and design of open pit slopes by software approach. For modelling and design of open pit slopes GEO-SLOPE software is used, parametric studies are made by widely varying basic input values like cohesion, internal angle of friction, unit weight of the rock given to the software based upon design made in it. Thus finding factor of safety for the slopes and investigating failure mechanisms in them. Based on the significant studies, it can be concluded that as the slope angle increases factor of safety decreases. It is also concluded that as the Cohesion and angle of internal friction increases, the factor of safety increases. Recommendations for future work are given on the basis of designs.*

Key Words*: *Slope stability, Open pit mining, GEO-SLOPE, Cohesion, Angle of Internal Friction, Factor of Safety.

1. INTRODUCTION

In Opencast mines benches are developed with certain inclination known as slopes. These slopes must be stable during entire life of the mine, thus facilitating further development of benches. Such maintenance of stable slopes without failures is known as Slope stability. The analysis for the study of such slopes is known as Slope stability analysis. These slopes can also be seen in dump areas. Failure of slopes causes deprivation of production, additional stripping cost for recovery and excessive handling of failed material, sometimes even burial of heavy machinery under the failed slopes. In the recent decades, the concept of slope stability analysis emerged within the domain of rock engineering to address the problems of design and stability of excavated slopes.

In India, the number of operating opencast mines is steadily increasing as compared to underground mines. It is due to advantages of higher productivity, quick return of investment, low gestation period from opencast mines. On the contrary, opencast mining involves environmental issues such as contamination of acquifers, land degradation and socio-economical problems.

Due to development of opencast mines to larger depths, maintenance of stable slopes has become much more importance. As a result analysis of stability of operating slopes and ultimate pit slope design are becoming a major concern. Hence maintenance of pit slope angles that are as steep as possible is of vital importance to the reduction of extra stripping cost, loss of machinery & lives of men etc, will have direct consequences on the economy of the mining operation. The prime objectives of the project are addressed towards: a) Understanding the different types and modes of slope failures. b) Modelling and design of open pit slopes by software approach (GEO-SLOPE).

Studies are made on Various factors affecting stability of slopes[1],Types of slope failures[1], Factors to be considered in assessment of stability[2] and on Methods of analysis[2].

2. GEO-SLOPE

GEOSLOPE-SLOPE/W computes the factor of safety of earth and rock slopes. SLOPE/W can effectively analyze both simple and complex problems for a variety of slip surfaces shapes, pore-water pressure conditions, soil properties, analysis methods and loading conditions. Using limit equilibrium, SLOPE/W can model heterogeneous soil types, complex stratic graphic and slip surface geometry, and variable pore-water pressure conditions using a large selection of soil models. Analysis can be performed using determininstic or probabilistic input parameters. Stresses computed by a finite element stress analysis may be used in addition to the limit equilibrium computations for the most complete slope stability analysis available. With this comprehensive range of features, SLOPE/W can be used to analyze almost any slope stability problem encountering in geotechnical, civil, and in our mining engineering projects

3. Features of GEO-SLOPE

GEO-SLOPE facilitates different features [3] for easy analysis of developed models such as:

1. A choice of many analysis methods like Morgenstern-Price, Spencer, Bishop methods etc .,

2. Pore-water pressure conditions can be defined using piezometric lines or spatial functions.

3. Reinforcement to the slopes can be made using Anchors, Nails.

4. Various soil, rock material models can be developed.

5. Easy investigation of slope geometry.

6. Fast, Parallel solving of slip surfaces and analyses.

7. Transient stability analysis.

4. Creating the Model and its Analysis

This chapter involves creating the model and it's analysis in the GEO-SLOPE software. Following shows different steps in creating the model:

- Definition view.
- Solve manager.
- Results view.
- Page layout mode.

These are the four basic steps involving creating model in GEO-SLOPE software. Definition view consists of few steps which are stated below:

- Registering the model.
- Basic analysis of properties.
- Creating definite Geometry.
- Assigning the material parameters.
- Slip surface modulations.
- Pore-water pressure conditions.

We can also assign multiple material properties, vary water pressure assignments etc., to our design based on the data available.

Following explains detailed steps in creating model

- Definition View
  The basic definition view consists in defining our project with proper input parameters. Various sub-components like naming the project, selecting the mode of project like 2D, 3D, asymmetric etc., with slope analysis condition are present in this view. After registering and assigning basic desired properties definite geometry is created by developing required X & Y – coordinates. Later material parameters are assigned, and slip surface modulations, pore-water pressure conditions are allotted to the designed model.

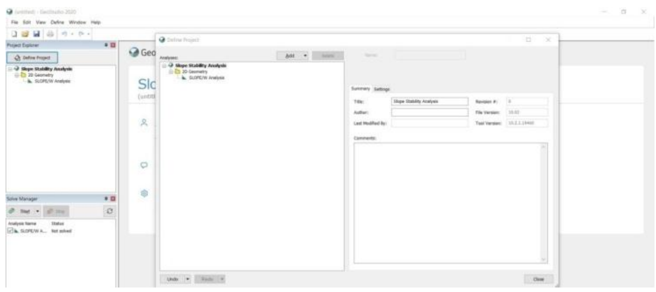


Fig-1. Definition view

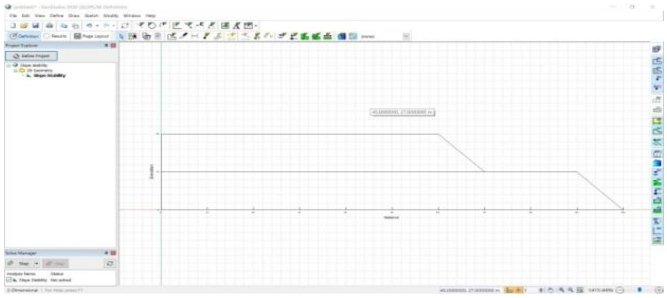


Fig-2. Basic design of the model

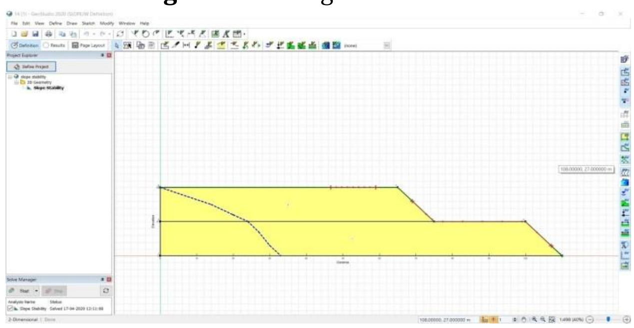


Fig-3. Model with material assignment, slip surface conditions etc.,

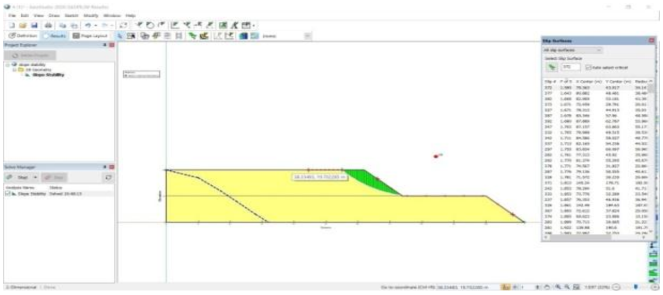


Fig-4. Result view of critical failure surface with factor of safety.

- Solve manager:
  Solve manager view, leads the developed model to get ultimately solved with desired parameters. Before particular model is solved, it is developed in proper way by assigning material parameters, slip surface conditions, pore-water pressure conditions etc.,
- Results view:
  This is the final step done, for the model to get solved. This view shows the design with failure surface along with several slip surface failures, contour conditions like pore-water pressure condition, water head condition, pressure head condition,

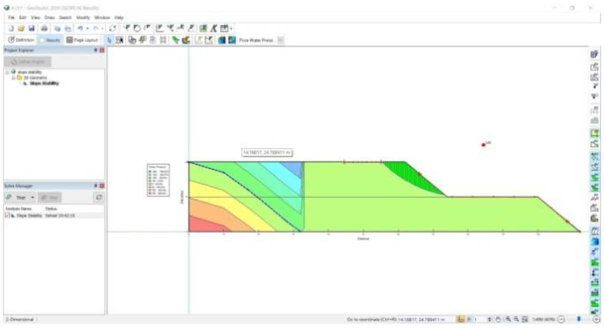


Fig-5. Pore-water pressure condition in the slope with failure surface.

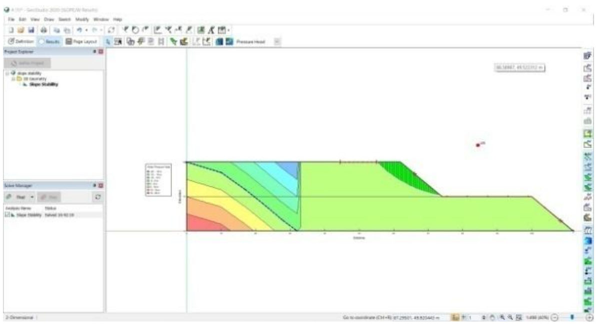


Fig-6. Pressure head condition in the slope with failure surface.

5. Design of Optimum slope

The objective of the investigation was to study and design of stable slopes. The typical analysis components are cohesion, angle of internal friction and unit weight of the rock. For this field data is obtained from the mines near Narasaraopet, Guntur dist. Andhra Pradesh and analysis is made.

Initially two benches were developed in software assigning definite X & Y co-ordinates, slope angle of single bench varying from 35-60 degrees and with varying cohesion, internal friction angle values which was described below, two unit weights of the samples i.e., 22.5 KN/m3 and 25KN/m3 were taken and analysis made in software.

Following table showing FOS of the design with Slope angle-35 degrees with unit weight of 22.5KN/m3

Slope angle	Unit weight	Internal friction angle	Cohesion	Factor of safety
35	22.5	30	10	1.588
35	22.5	30	15	1.794
35	22.5	30	20	1.981
35	22.5	32	10	1.684
35	22.5	32	15	1.891
35	22.5	32	20	2.089
35	22.5	35	10	1.838
35	22.5	35	15	2.044
35	22.5	35	20	2.250

Following table showing FOS of the design with Slope angle-35 degrees with unit weight of 25KN/m3

Slope angle	Unit weight	Internal friction angle	Cohesion	Factor of safety
35	25	30	10	1.546
35	25	30	15	1.732
35	25	30	20	1.914
35	25	32	10	1.643
35	25	32	15	1.829
35	25	32	20	2.015
35	25	35	10	1.796
35	25	35	15	1.982
35	25	35	20	2.168

Following table showing FOS of the design with Slope angle-40 degrees with unit weight of 22.5KN/m3:

Slope angle	Unit weight	Internal friction angle	Cohesion	Factor of safety
40	22.5	30	10	1.497
40	22.5	30	15	1.677
40	22.5	30	20	1.857
40	22.5	32	10	1.590
40	22.5	32	15	1.710
40	22.5	32	20	1.951
40	22.5	35	10	1.739
40	22.5	35	15	1.919
40	22.5	35	20	2.099

Following table showing FOS of the design with Slope angle-40 degrees, unit weight-25KN/m3

Slope angle	Unit weight	Internal angle of friction	Cohesion	Factor of safety
40	25	30	10	1.461
40	25	30	15	1.623
40	25	30	20	1.785
40	25	32	10	1.554
40	25	32	15	1.717
40	25	32	20	1.878
40	25	35	10	1.702
40	25	35	15	1.865
40	25	35	20	2.027

Following table showing FOS of the design with Slope angle-45 degrees, unit weight-22.5KN/m3

Slope angle	Unit weight	Internal angle of friction	Cohesion	Factor of safety
45	22.5	30	10	1.339
45	22.5	30	15	1.412
45	22.5	30	20	1.700
45	22.5	32	10	1.419
45	22.5	32	15	1.601
45	22.5	32	20	1.784
45	22.5	35	10	1.546
45	22.5	35	15	1.728
45	22.5	35	20	1.911

Following table showing FOS of the design with Slope angle-45 degrees, unit weight-25KN/m3

Slope angle	Unit Weight	Internal angle of friction	Cohesion	Factor of safety
45	25	30	10	1.302
45	25	30	15	1.466
45	25	30	20	1.631
45	25	32	10	1.382
45	25	32	15	1.546
45	25	32	20	1.711
45	25	35	10	1.509
45	25	35	15	1.673
45	25	35	20	1.838

Following table showing FOS of the design with Slope angl-50 degrees, unit weight-22.5KN/m3

Slope angle	Unit weight	Internal angle of friction	Cohesion	Factor of safety
50	22.5	30	10	1.237
50	22.5	30	15	1.406
50	22.5	30	20	1.535
50	22.5	32	10	1.310
50	22.5	32	15	1.485
50	22.5	32	20	1.619
50	22.5	35	10	1.426
50	22.5	35	15	1.601
50	22.5	35	20	1.752

Following table showing FOS of the design with Slope angle-50 degrees, unit weight-25KN/m3

Slope angle	Unit Weight	Internal angle of friction	Cohesion	Factor of safety
50	25	30	10	1.202
50	25	30	15	1.360
50	25	30	20	1.484
50	25	32	10	1.275
50	25	32	15	1.438
50	25	32	20	1.567
50	25	35	10	1.391
50	25	35	15	1.548
50	25	35	20	1.700

Following table showing FOS of the design with Slope angle-55 degrees, unit weight-22.5KN/m3

Slope angle	Unit weight	Internal angle of friction	Cohesion	Factor of safety
55	22.5	30	10	1.157
55	22.5	30	15	1.322
55	22.5	30	20	1.465
55	22.5	32	10	1.225
55	22.5	32	15	1.390
55	22.5	32	20	1.547
55	22.5	35	10	1.334
55	22.5	35	15	1.498
55	22.5	35	20	1.662

Following table showing FOS of the design with Slope angle-55 degrees, unit weight-25KN/m3

Slope angle	Unit weight	Internal angle of friction	Cohesion	Factor of safety
55	25	30	10	1.124
55	25	30	15	1.272
55	25	30	20	1.415
55	25	32	10	1.193
55	25	32	15	1.340
55	25	32	20	1.488
55	25	35	10	1.301
55	25	35	15	1.449
55	25	35	20	1.596

Following table showing FOS of the design with Slope angle-60 degrees, unit weight-22.5KN/m3

Slope angle	Unit weight	Internal angle of friction	Cohesion	Factor of safety
60	22.5	30	10	1.103
60	22.5	30	15	1.236
60	22.5	30	20	1.360
60	22.5	32	10	1.171
60	22.5	32	15	1.307
60	22.5	32	20	1.431
60	22.5	35	10	1.280
60	22.5	35	15	1.418
60	22.5	35	20	1.544

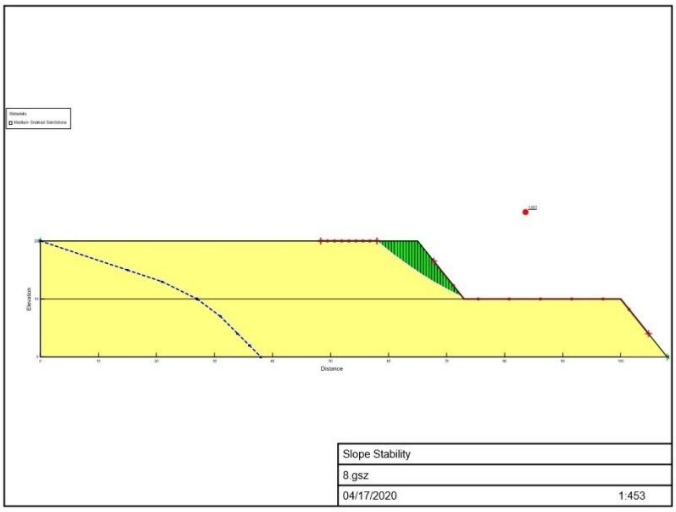
Following table showing FOS of the design with Slope angle-60 degrees, unit weight-25KN/m3

Slope angle	Unit weight	Internal angle of friction	Cohesion	Factor of safety
60	25	30	10	1.076
60	25	30	15	1.199
60	25	30	20	1.311
60	25	32	10	1.144
60	25	32	15	1.268
60	25	32	20	1.382
60	25	35	10	1.251
60	25	35	15	1.376
60	25	35	20	1.494

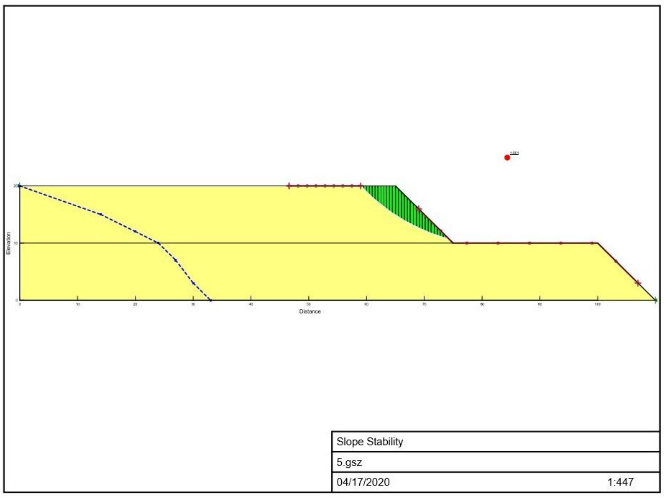
As the data obtained from the above analysis FOS of the design varies between 1.076 to 2.250.A high FOS causes low risk of failure of the slope i.e., it must be more than 1 and must be within 1.5-1.7 to minimize the risk of slope failures. The FOS is taken more than 1 due to the reasons mentioned below:-

- The possible presence of geological disturbances within the bench slope.
- The variability of water pressure and properties of rock within the bench.
- The errors on testing the geotechnical properties of rock and also errors in calculation of optimum slope angle.

The average value of factor of safety 1.6 is considered as stable slope and respective designs are shown below



Design with slope angle-50, unit weight-22.5,Internal angle of friction-35,Cohesion-15.(FOS-1.601)



Design with slope angle-45, unit weight-22.5,Internal angle of friction-32,Cohesion-15.(FOS-1.601)

6 RESULTS AND DISCUSSION

1) Based on the analysis done, it is concluded that as the pit slope angle increases i.e., alternately from 35-60 degrees it is observed that factor of safety been decreasing thus effecting stability of slope. The slope angle of 35 degrees is having a factor of safety of 1.588 which is quite safe, while slope angle of 60 degrees is having 1.103 which can be observed in above mentioned tables.
2) It is also concluded that as the Cohesion and angle of internal friction increases, the factor of safety increases. For slope angle of 35 degrees at internal angle of friction-30 degrees & cohesion-10, factor of safety is 1.588, while for same slope angle but with angle of internal friction-32 degrees & cohesion-15, factor of safety is 1.891.

7. CONCLUSION

Open cast mining is a very cost-effective mining method allowing a high grade of mechanization and large production volumes. Mining depths in open pits have increased steadily during the last decade which has the increased risk of large scale stability problems. It is necessary to assess the different types of slope failure and take cost effective suitable measures to prevent, eliminate and minimize risk. The different types of slope stability analysis techniques and software are available for slope design. Numerical modelling is a very versatile tool and enables us to simulate failure behaviour and deforming materials.

GEO-SLOPE is user friendly software, provides for rapid creation of models for soil/rock slopes and solution of their stability condition. Moreover it has advantage over a limit equilibrium solution like any failure mode develops naturally, there is no need to specify a range of trail surfaces in advance and multiple failure surfaces (or complex internal yielding) evolve naturally, if the conditions give rise to them.

In this project, the parametric study carried by widely varying the cohesion, angle of internal friction and ultimate slope angle showed that with increase in ultimate slope angle, the factor of safety decreases. Moreover cohesion and angle of internal friction are quite important factors affecting slope stability. With increase in both the parameters the stability increases.

Conduct of slope stability assessment in Indian mines is mostly based on empirical and observational approach; hence effort is made by statutory bodies to have more application of analytical numerical modelling in this field to make slope assessment and design scientific. This will ensure that suitable corrective actions can be taken in a timely manner to minimize the slope failures and the associated risks.

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