# ASSESSMENT OF SLOPE STABILITY IN OPENCAST COAL MINES USING SOFTWARE

**Tavitinaidu. P[1], Dr. Anupam Bhatnagar[2]**

*[1]Tavitinaidu. P, Student of Dept of Mining Engineering, College of Technology and Engineering, Udaipur, Rajasthan, India*
*[2]Professor Dr. Anupam Bhatnagar, Dept of Mining Engineering, College of Technology and Engineering, Udaipur Rajasthan, India*

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**Abstract -** *Slope stability analysis is important in any opencast coal mines. A failure of slope in a working area of mine can give rise a significant economic losses and safety impact. The fundamental failure modes are varied and complex. Such mechanisms are governed by engineering geology condition of rock mass which are almost always unique to a particular site. Using the FLAC/Slope software stability of slope is analysis. The work was aimed at study of stability of slopes using numerical modeling, at the same time study the different failure mechanism. The purpose of this project is to learn and assess this FLAC/Slope software. As the study of the software is easy, it can be concluded that it is user-friendly. Based on parametric studies it can be concluded that slope angle plays a major role on slope stability*.

***Key Words***: ***Slope stability, FLAC/Slope, Numerical Modelling, Slope angle, Failure modes***

## 1. INTRODUCTION

The various methods of mining a coal seam can be classified under two headings namely opencast mining and underground mining. The opencast mining is now the most mainstream technique for the significant bit of the world's coal creation. In India, the demand of coal in the year 2016-17 was estimated 884.87 MT whereas the domestic availability of coal was estimated 724.71 MT. Here, the gap of 160.16 MT was projected to meet through the imports (Satyanarayana *et al.* 2018). In this regards, open cast mining technology can play a vital role to full fill the demand of estimated coal production. As the open cast mining methods is a very financially cost effective mining methods which allows the high grade of mechanization and more, enormous creation volumes. In India, the opencast mining methods accounts for about 95 per cent of coal production (DGMS Report, 2016). Consequently, the utilization of opencast mining innovation going further step by step with the most extreme arranged stripping ratio being arranged presently turning upward to 1:15, at the profundity about 500 m enormous creation volumes (Stacey *et al.* 2003). The exhibition of the opencast mine to a great extent relies upon the utilization of steepest incline conceivable which ought not to come up short during the life of the mine. Thus, it is necessary to study the behaviour of the slope for efficient performance of the opencast mine.

### 1.1 Necesicity for the Present Study

The Indian Coal Mining Industry has experienced the pit slope failures at Dorli OC-I of M/s SCCL, SRP OC-I of M/s SCCL, Medapalli OCP of M/s SCCL, KTK OC sector-I of M/s SCCL and Kawadi OCP of M/s WCL. The Indian Coal Mining Industry is moving towards deeper opencast mines upto a depth of around 500m like Manuguru OC-II Extension and RG OC-II extension. In India, Lot of accidents have been occurred due to highwall slope failure (table 1.1). These slope failure accidents in Indian mines have taken place due lack of sound design of slopes and lack of monitoring. So, the coal industry has identified slope design, monitoring and stabilization as one of the thrust areas.

**Table 1** Accidents due to highwall failure in Indian opencast coal mines (DGMS report, 2016)

| Year | State | Name of Mine | Name of company | Date of accident | No of persons killed | No of persons seriously injured |
|---|---|---|---|---|---|---|
| 2007 | Jharkhand | Chasnalla | IISCO | 21-aug 07 | 1 | 0 |
| 2008 | Madhya Pradesh | Jayant colliery | NCL | 17-dec08 | 5 | 0 |
| 2009 | Maharashtra | Sasti OCP | WCL | 04-jun-09 | 2 | 0 |
| 2010 | Maharashtra | Umrer OCP | WCL | 28-sep 10 | 1 | 1 |
| 2011 | Jharkhand | Chasnalla | IISCO | 9-mar-11 | 1 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2011 | West Bengal | Dalurband OCP | ECL | 14-jun-11 | 1 | 0 |
| 2012 | Odisha | Bharatpur OCP | MCL | 21-apr-13 | 1 | 1 |
| 2013 | Odisha | Kulda OCP | MCL | 10-aug 13 | 13 | 0 |
| 2014 | Madhya predesh | | SECL | 01-jul-14 | 2 | 0 |
| 2015 | Nill | | | | | |
| 2016 | Jharkhand | Rajmahal OCP | ECL | 29-Dec-16 | 23 | 0 |

**1.2 Location of the mine area**

Study area Open cast mine is situated in southern extremity of Kothagudem area of Khammam district and is well connected by road (Vijayawada and Bhadrachalam road) 160 km from Vijayawada and 280 km from Hyderabad, and railway (branch line from Dornakal Jn of Delhi-Chennai-Grand trunk railway line). It covers the mine area of 410 Ha and 902 Ha. For all the services including over burden dumps etc. The project area falls between North latitudes 17º27'18" and 17º28'04" and East longitudes 80º37'30" and 80º39'45" in Survey of India Topo sheet No.65-C/11.The property is of basinal in structure and sloping from three sides. The maximum gradient is 1 in 5 and the average gradient is 1 in 10.The seam thickness as well as the parting between seams varies within a wide range as shown in table given below.

**2. Analysis of Highwall Slope Failure –Case Study**

**2. 1 Project Background**

The study area of open cast mine is there exist three main coal seams in the area, viz, Top seam, Middle seam and Bottom seam. All the seams in the above mines were extensively developed/depillared by caving/stowing. Even after working these four underground mines by conventional methods for about 25 years, only 5.50 M.T. out of 81 M.T. of coal could be extracted which works out to 7 per cent of total reserves and still about 71 M.T. of reserves were left in the form of developed pillars and goaf, which can be extracted by Opencast mining. The Project was sanctioned by Government of India at an estimated capital cost of Rs. 415.93 Crores on 16.06.1995 for rated capacity of 2.00 M.T. per year. Environmental clearance from Ministry of Environment and Forests was obtained in the year 1993.

**Table -2**Geological succession in Study area Block

| Age | Group | Formation | General Lithology | Maximum Thickness(m) |
|---|---|---|---|---|
| Alluvium | | | Soil cover | 4.57 |
| Permian | Lower gondwana | Baraka | Predominantly sandstone with 3 to 4 workable coal seams and subordinate shale's/clays | 187.76 |
| | | Talchir | Mg. Greenish sandstone/ siltstones | 25.95 |
| Fault/unconformity | | | | |
| Achaeans | | | Hornblende gneisses and garnetiferous micaceous | 4.86+ |

The coal bearing Barakar formation predominantly consists of grey and grey white sandstones with subordinate shales and coal seams. The Study areaarea represents a flat terrain with minor low lying ground located in the centre of the block. Bolligutta hill representing the Gondwana -Proterozoic contact stands up as a ridge all along the northern boundary.

The study area block broadly owes its preservation in the form of graben due to two major faults which are sub-parallel to each other and aligned approximately in northwest direction. The coal seams trend in East-west to East-Northwest, West Southwest and gentle dips towards the centre of the basin in the western and central of the block. There are number of normal gravity type faults with throw varying from less than 10 to 200 m.

### 2.2 Geo-Hydrology

There is no major drainage course cutting across the area. The mean annual rainfall is about 1100 mm. Well fractured rock mass, existing open cast working have made the geo-mining condition of the quarry to drained condition for all practical purposes after implementing an effective drainage system. If the slope mass is not provided with effective drainage system then the slope mass condition would be in untrained geomining condition.

### 2.3 Geo-Mechanical Properties

It is prudent to know the lithological units in which the slope is to be cut. Engineering properties of these litho units will influence the analysis for slope stability. The different geo-mechanical properties of mine slope were conducted at the Rock and Soil Mechanics Laboratories.

The samples were tested to determine density and shear strength parameters. The shear strength is one of the important engineering properties. Direct shear tests were conducted on direct shear test machine. The rock mass rating method was also used to estimate the rock mass properties. The final result of highballs rock mass is summarized in Table. 4.1. The rock mass strength of lithology was appropriately reduced due its unfavourable orientation. All the lithology are dipping towards excavated pit.

The derived values are likely to be valid for the entire quarry. The slope stability analysis was done on the basis of these data. It may however be prudent, from time to time, to re-examine the local changes in the different geotechnical parameters.

**Table- 3** Study area Block Particulars of the Seams

| Seam | Thickness of seam (in mtrs) | | Thickness of partition (in mtrs) | |
|---|---|---|---|---|
| | From | To | From | To |
| Top seam | 3.20 | 11.80 | | |
| | | | 10.00 | 23.00 |
| Middle seam | 1.80 | 11.40 | | |
| | | | 4.30 | 44.50 |
| Bottom seam | 2.40 | 29.0 | | |

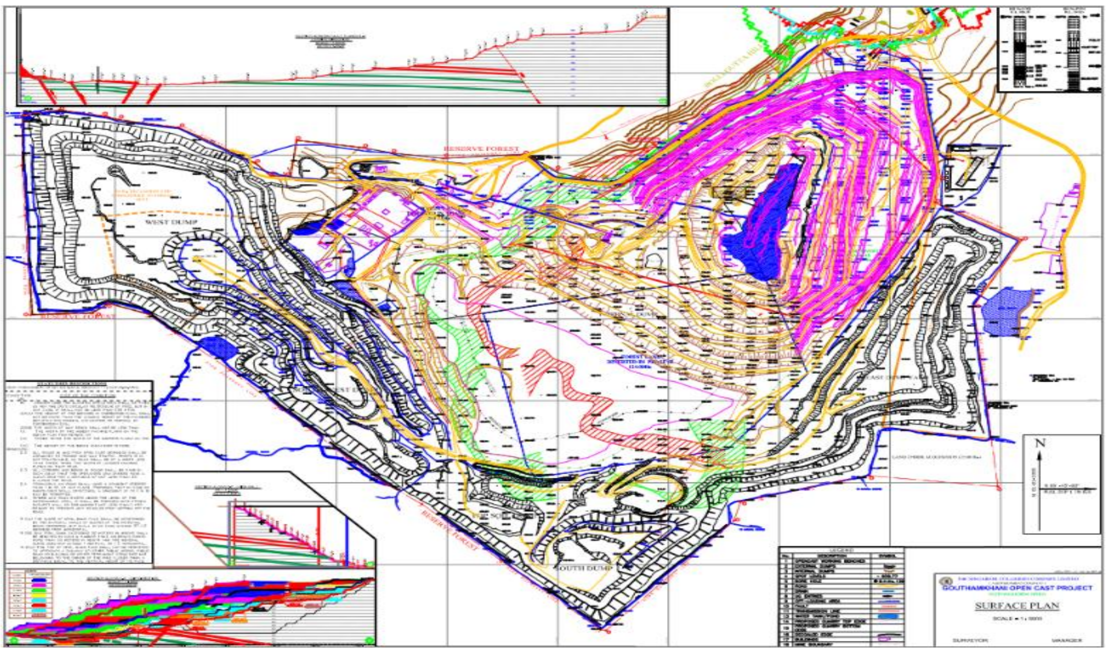


**Fig. 1** Study area surface Plan

**Table-4** Fine highwall bench configuration of the study area

| Geo mining condition of high wall | Bench parameters | | | Overall Pit slope (degrees) |
|---|---|---|---|---|
| | Height(m) | Exposed width(m) | Individual Bench Angle (degrees) | |
| Top soil, Weathered sandstone (Top 20 m) | 5 | 5 | 70 | 45 |
| Sand stone (Remaining 240m | 10 | 9.5 | 80 | |

**Fig -2**: Study area

**2.4 Overview of FLAC**

FLAC/Slope is a mini-version of FLAC that is designed specifically to perform factor-of-safety calculations for slope stability analysis. This version is operated entirely from FLAC's graphical interface (the GIIC) which provides for rapid creation of models for soil and/or rock slopes and solution of their stability condition.

FLAC/Slope provides an alternative to traditional "limit equilibrium" programs to determine factor of safety. Limit equilibrium codes use an approximate scheme - typically based on the method of slices - in which a number of assumptions are made (e.g., the location and angle of interslice forces). 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, it provides a full solution of the coupled stress/displacement, equilibrium and constitutive equations. Given a set of properties, the system is determined to be stable or unstable. By automatically performing a series of simulations while changing the strength properties, the factor of safety can be found to correspond to the point of stability, and the critical failure (slip) surface can be located.

**Table- 5** Physico mechanical properties of rock sample

| **Section** | **Density** | **Tensile strength** | **Cohesion** | **Internal friction angel** |
|---|---|---|---|---|
| Top soil | 2530 kg/m$^3$ | 3780 kPa | 8 × 10$^3$Pa | 39$^0$ |
| Fine grained sand stone | 4208 kg/m$^3$ | 4960 kPa | 4 × 10 $^3$Pa | 36$^0$ |
| Coarse grained sad stone | 3900 kg/m$^3$ | 5621 kPa | 8.5 × 10$^3$Pa | 40$^0$ |

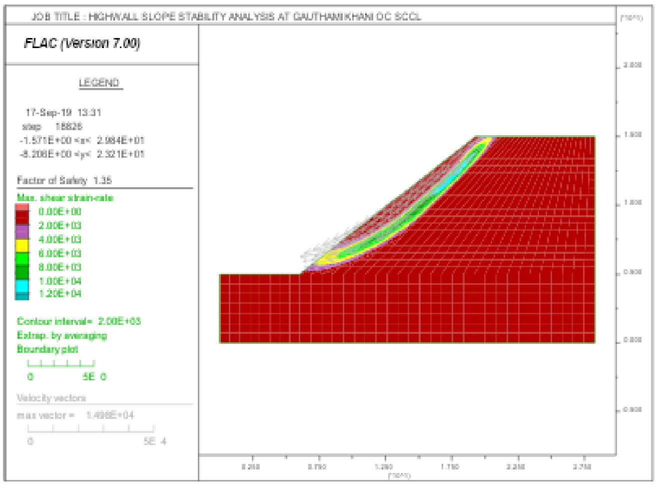


**Fig. 3** Representative model with Slope Angle = $30^0$, Depth = 30m, Factor of Safety = 1.35 (Top soil)

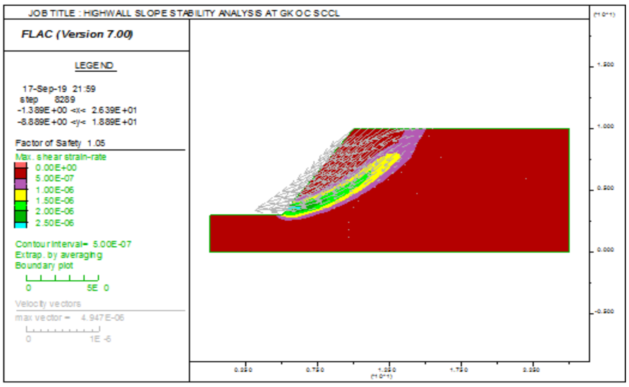


**Fig. 4.**Representative model with Slope Angle = $40^o$, Depth = 30m, Factor of Safety = 1.05(Top soil)

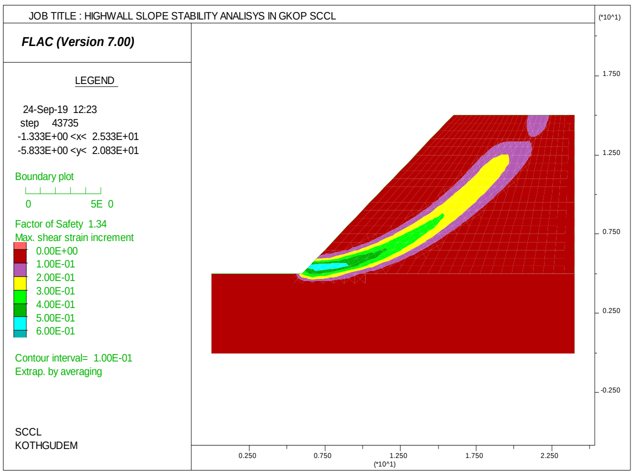


**Fig. 5** Representative model with Slope Angle = $30^0$, Depth = 30m, Factor of Safety = 1.34 (Fine grained sand stone)

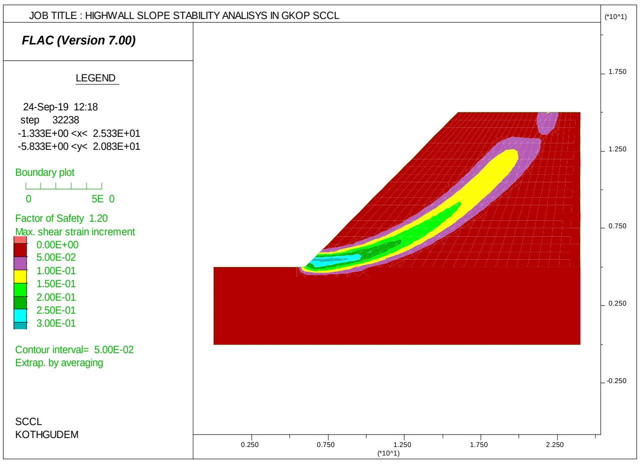


**Fig. 6** Representative model with Slope Angle = 40$^0$, Depth = 30m,

## 3. CONCLUSIONS

An assessment of the engineering and structural geology, strength properties and related geotechnical controls indicated following optimum design parameters for final high wall slopes.

These recommendations are valid with well-developed drainage system and controlled blasting to avoid any damage on the standing final bench slope mass. The final standing slope should be kept in undamaged in-situ rock mass condition. If any deviation is observed or the remedial measures are not effective then this slope angle has to be corrected accordingly. The slope monitoring of active ultimate mine slope is also strongly recommended to detect any instability well in advance. The periodic loose dressing of high wall faces is also advisable.

The final slopes should be formed at pit cessation stage. In other words, cut the final slopes, backfill the area or vacate the area around final slope. The operating bench width should never be less than double of the bench height. The unavoidable small-scale bench failures associated with weak brown sandstone and intermittent clays could be arrested on these wide benches and large-scale slope failure can be avoided. The extra wide bench will arrest the local bench failures and there would not be any operational problem.

The exposure should be made within such an area, where the bottom could be touched within a maximum one year. This patch should be backfilled immediately. Long term exposure reduces the strength quickly in weak rock mass and results in slope failure. .

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**AUTHORS**

Tavitinaidu .P
M.Tech Student Final year
Mining Engineering , C.T.A.E,
Udaipur, Rajasthan, India

Dr.Anupam Bhatnagar
Faculty of Mining Engineering Department, C.T.A.E,
Udaipur, Rajasthan, India