

PIT SLOPE ANGLE OPTIMISATION OF BHANEGAON OPENCAST COAL MINE, NAGPUR AREA, WESTERN COALFIELDS LIMITED - USING NUMERICAL METHODS.

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Abstract-Coal is a major source of energy in India and other parts of the world. Since last decade, demand of coal gone up many fold. Coal is major raw material for thermal power station, 85% of India's coal production is consumed by thermal power station. Major portion of the countries' coal demand is met through open cast coal mines and very little from underground coal mines. Since the coal deposit closer to the surface are depleting fast therefore in future coal deposit have to be mined at greater depth. As the depth of mining the coal increases the stripping ratio also increases. Therefore the mining organization tries to mine the coal with the steepest possible overall slope angle vis-à-vis sufficient stability. This leads to the substantial reduction in quantity of overburden to be removed. This is realized through financial benefits. Since working at steeper slope angle with sufficient stability also reduces the surface land required for stacking the overburden. This exercise was conducted for the dip side working of Bhanegaon open cast coal mine WCL Nagpur area to optimize the benefits of reduction in overburden that is to be mine for exposing the coal and also reduction in the surface land requirement for storage of the overburden. It was found that the dip side pit is stable at steeper angle which is suggested based on numerical methods analysis. A 2D approach using Finite Element Method with the help of Rocscience RS2.0 has been used to analyze the above situation.

Keywords - Slope Stability, FEM, Bhanegaon. SRF, FOS

I INTRODUCTION

The present case study of Bhanegaon OCP is surrounded by river Kanahan and Pench (Fig-1) which are the major rivers of the region. Confluence of river Kanahan and Pench exist at the north-east corner of the project. The Bhanegaon Opencast Project lies in Latitude 21°16'37" to 21°15'36" and Longitudes 79°10'12" to 79°08'41".

Bhanegaon open cast mine comes under the ambit of Western Coalfields Limited is located at a distance of 33 Km from Nagpur. This mine has been commissioned for revenue life of 26 years and is currently running on its 5th year of revenue life. The coal is supplied to Khaparkheda Thermal Power Plant which is around 5 Km from the mine. The proposed depth of the dip side is expected to be 220 meters. In this mine the optimized pit slope of the mine is to be determined at which its stability is justified to the standard limits.

The objective of the present work is to investigate in the context of slope stability of an open pit coal mine. More specifically, the widely used geotechnical software Phase2 of Rocscience Inc. is used by applying shear strength reduction technique. The scope of the work is to obtain the maximum pit slope angle at which mine can be extracted profitably.



Fig .1 – Satellite image of Bhanegaon opencast Mine

The paper starts with the problem statement and the definitions and assumptions of the baseline model. It continues with the presentation of the results, in terms of slip surfaces, kinetics of collapse mechanisms, and failure extents. These issues are addressed by means of discussion on shear strain localization, displacement vectors distributions and plastic regions, respectively. The paper ends with the conclusions that were drawn from the work. The entire block of Bhanegaon is covered by thick layer of Alluvium including Black cotton soil and river sand. The geology of the area is described below:

Soil/Alluvium-Alluvium in this block consists of black cotton soil followed by loose sand with pebbles. The entire block is covered by a thick layer of this formation.

Talchir Formation-This formation, consisting of green shale and fine grained sandstone.

Barakar Formation- The total column of Barakar can be broadly divided into three units. The upper 35-80 m of strata consist of medium to coarse grained sandstone and shale, but devoid of coal seams. The middle 110-123 m of strata contain the five coal horizons and the lower horizon of about 100 m of fine grained sandstone, shale and thin bands of coal.

Motur Formation- It has medium grained sandstone with intermittent beds of clay/shale.

Kamthi Formation- It is represented by yellowish brown medium to coarse grained sandstones, shale and clay.

II. STABILITY ANALYSIS METHODS:

Limit equilibrium methods have been used for many decades by geotechnical engineers, particularly for slope stability problems. These methods calculate a safety factor (SF), which is defined with respect to the shear strength of the soil as the ratio of the available shear strength to the shear stress at failure (Duncan and Wright, 2005). They are in use because of their simplicity.

Generally the stability problems are complex which cannot be solved easily by limit equilibrium methods. Numerical methods such as finite element method (FEM), provides engineer to conduct more comprehensive slope stability analyses. The main advantage of numerical methods is that there is no need to assume of slip surface. Failure occurs naturally through zones in which soil's shear strength is less than the applied shear stresses (Duncan, 1996; Griffiths and Lane, 1999). Addition to that, numerical models are able to generate stress-strain distributions (deformational response), which is of crucial importance for the interpretation of slope behavior, and also to address and analyze precisely complicated geometries, simulate pit excavation stages and their effect on the stress state. It is important for engineers to understand the limitations of the numerical methods, before using them. In present case Finite Element Method is used to analyze the slope stability. The aim of any open pit mine design is to provide an optimal excavation configuration in the context of safety, ore recovery and financial return (Read and Stacey, 2009)

2.1 Finite Element Method

RS2 is a program for 2D finite element analysis of geotechnical structures for civil and mining applications. Applicable for both rock and soil, RS2 is a general purpose finite element analysis program for tunnel and support design, underground excavations, surface excavation, slope stability, embankments, dynamic analysis, foundations, consolidation and groundwater seepage.

With the FEM the whole problem domain is, divided into non-overlapping regions connected to each other through points called nodes. The behavior of each element satisfying equilibrium conditions, compatibility, material constitutive behavior and boundary conditions is described and the elements are assembled together. A large set of simultaneous equations (several thousands) have to be stored and solved to obtain the solutions

III. Data collection

The slope stability analysis was performed for the dip side of Bhanegaon opencast mine. The following data mentioned in Table-1 is obtained from various sources which are used for the model analysis.

IV. Model Preparation

In the present work, a typical cross section of open pit coal mine in Bhanegaon, has been used for case study. Boundaries, geometric conditions and lithological features (geologic materials with their respective geotechnical properties) of the problem are all shown in Table-1 and have been used for numerical analyses. The cross section (Fig-2) is considered representative of the slope under-examination. Generally, geometric features, material properties, boundary conditions and other characteristics related to the models were all considered in the software analyses. The model is prepared for the present site conditions with pit slope angle of 34° .

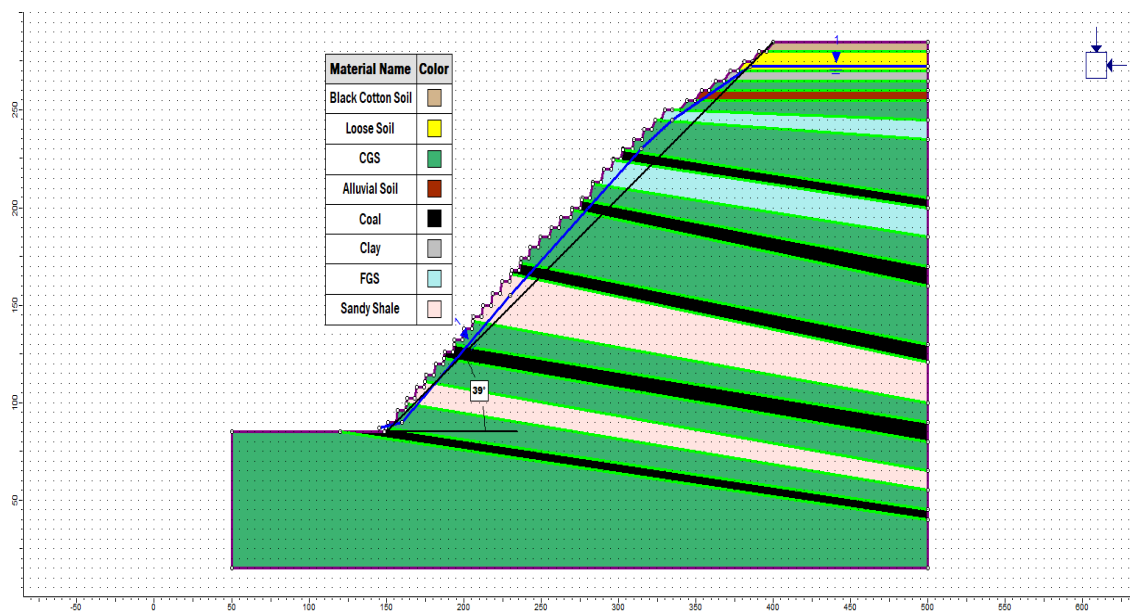


Fig .2 – Model of open cast mine at Bhanegaon.

V. Model Analysis

After running the model it is observed that the critical SRF value is 1.71. Minimum FOS for this slope is 1.30. It means that slope is over safe. Models are prepared for different pit slope angles and the following values are obtained which are arranged in tabular form in Table-2.

From Table-2, it is clear that as the pit slope angle increases critical SRF value decreases. At 39° pit slope critical SRF value is 1.33 which is acceptable as per standard guidelines. Graph is plotted between FOS and pit Slope angle in Figure-3.

Table 1- Properties of material

Parameter	Black Cotton Soil	Loose Soil	Coarse Grained Sandstone	Alluvial Soil	Coal	Medium Grained Sandstone	Clay Soil	Sandy Shale
Unit Weight (KN/m ³)	17.5	18	27	18.3	12	27	17.7	24
Friction Angle (in degrees)	33	28	27	25	30	35	20	14
Cohesion (kPa)	10	20	2700	6	1000	2700	7	3000
Young's Modulus (MPa)	25	16.5	1910	4.2	2000	1910	2.68	1110
Poisson's Ratio	0.28	0.3	0.28	0.34	0.3	0.28	0.38	0.29
Tensile Strength (kPa)	0	0	500	0	400	1000	0	800

Table 2- Result of Analysis

Stages	Parameter				
	Critical SRF	Maximum Displacement (m)	Maximum Shear Strain	Major Stress (KPa)	Minor Stress (KPa)
I	1.71	4.42	0.220	6405.84	5668.34
II	1.57	4.02	0.203	6405.84	5668.34
III	1.49	1.11	0.056	6417.57	5666.28
IV	1.41	1.92	0.097	6453.75	5666.55
V	1.36	2.55	0.131	6488.50	5667.13
VI	1.33	6.60	0.332	6481.94	5652.25

The analysis of model at different pit slope angles shows the variation of shear strain, displacement and shear stress. The most acceptable pit slope angle is 39° with respect to all the parameter viz. FOS, strain, stress and displacement. The pit slope stability in terms of shear strain, plasticity, total displacement is shown in Figure-4 to Figure-6 respectively.

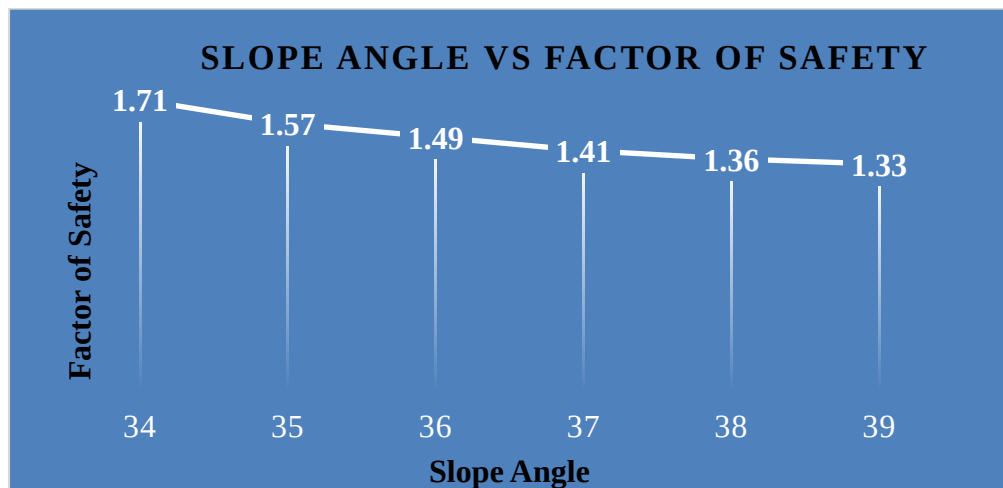


Fig .3 -FOS vs slope angle
Maximum Shear Strain Value-Shear strain localization

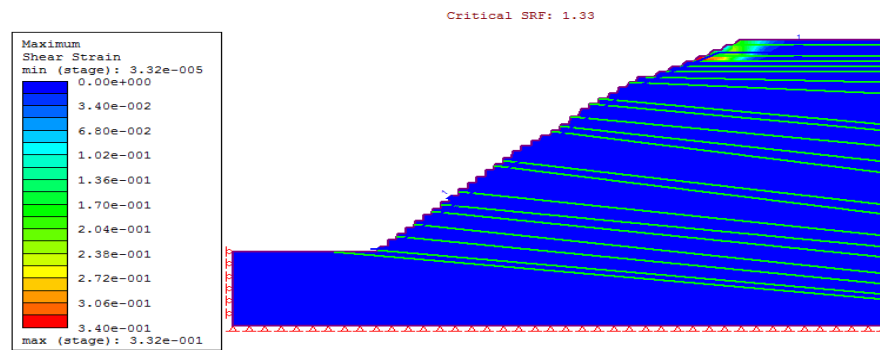


Fig. 4- Maximum shear strain contour

The potential slip surface of the examined model is discussed in terms of shear strain localization. In other words, it is considered that the concentration of maximum shear strain in the model at the time of failure corresponds to the developing failure surface of the slope. The slope failure surface generated by Phase2 is shown in above Figure-4 by means of maximum shear strain contours. The maximum accumulation of shear deformations seems to be developed in the top benches.

Yielded Element-(Plastic Regions Propagation)

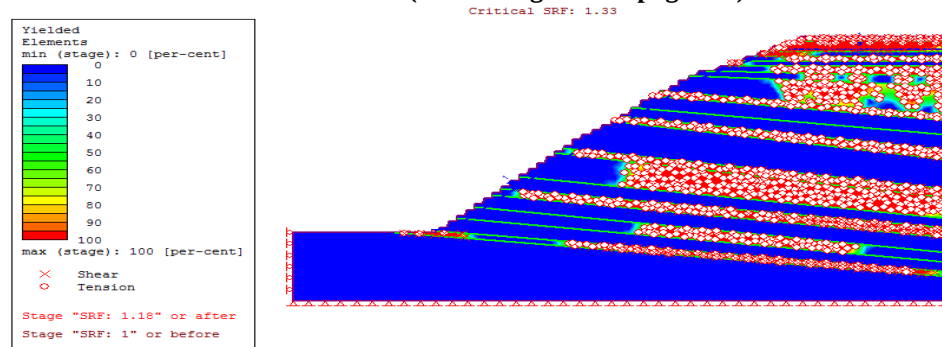


Fig. 5- Plastic region propagation

Figure-5 show plasticity i.e. whether the element is in tension, shear, or in neutral state. This helps in finding out the failure which different part of the slope undergoes.

Total Displacement

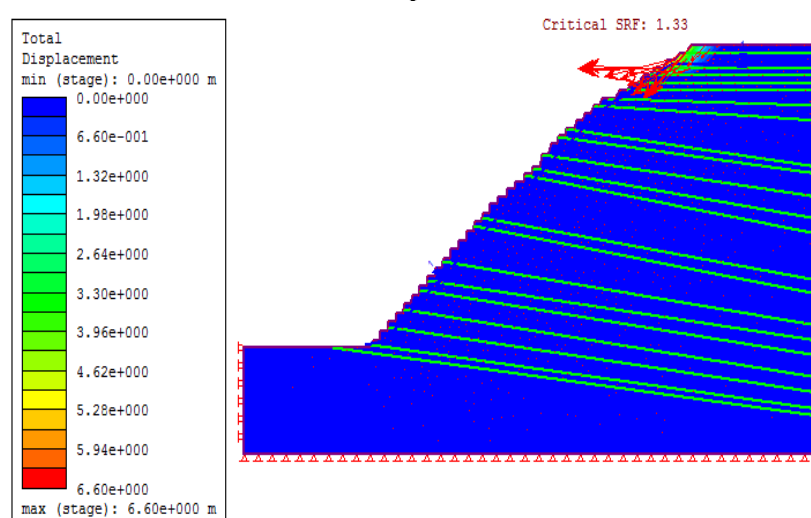


Fig. 6- Total displacement

Total displacement provides good qualitative information about forthcoming the failure. Also it helps in predicting the failure in terms of displacement. Also it is possible to find out how fast the failure is approaching.

SRF vs. Maximum total Displacement

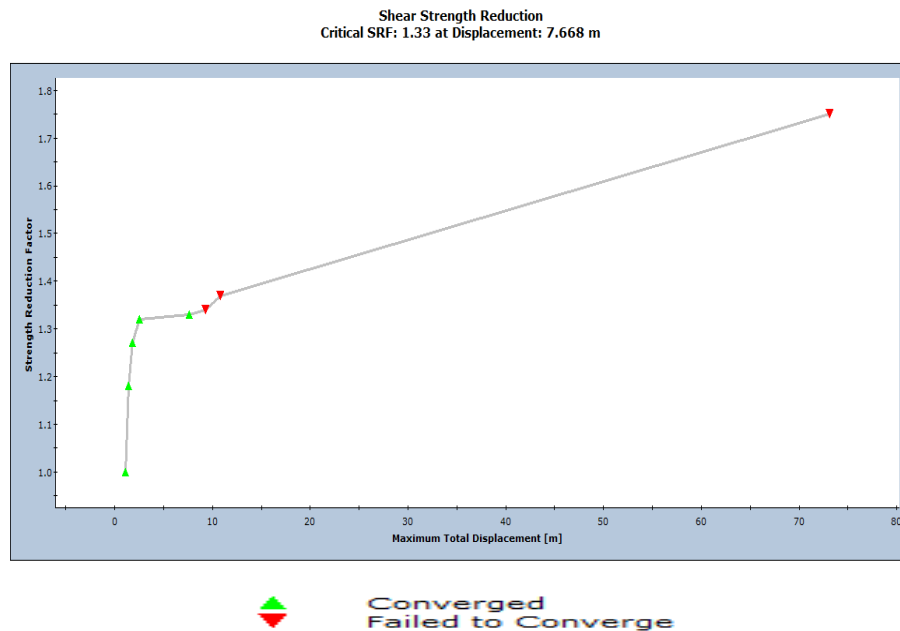


Fig.7- SRF vs Maximum total displacement

As SRF increased the strength properties are decreased. As strength decreases the maximum displacement increases. At some point the slope will fail and deformation will increase rapidly and the finite element analysis will not converge. It is this point of non-convergence that defines the critical SRF.

Result & Discussion

- (i) Slope design of open pit mine is a relation between stability and economics (Steffen et al., 2008). If the slope is steeper then it will be less expensive to construct, as steeper slopes result in the reduction of the stripping ratio, i.e. the ratio of waste to ore. On the other hand, if the slope is flatter it will be more stable.
- (ii)

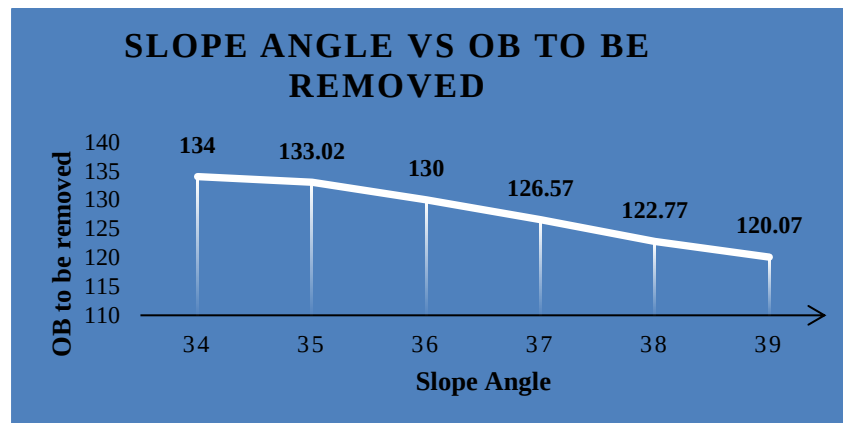


Fig.8-Slope angle vs over burden to be removed

At the current pit slope angle of 34° there is removal of approximately 135 Mm³ of overburden quantity but at 39° this quantity reduce to 120 Mm³. It has been shown in Figure-8.

- (iii) Pit slope with overall slope angle of 34° and 39° have been compared to explore the stability status. To access the stability following parameter has been compared viz. FOS, strain, displacement, stress distribution and plasticity. After comparing both the slope with 34° and 39° it is found that there is marginal change in various parameter though the FOS is reduced to 1.33. It can also be concluded that FOS does not reveal the stability status since it is a ratio of stabilizing and destabilizing forces.

Conclusion

- (i) On stability analysis of existing slope it was found that there is sufficient scope to steepen the slope and in turn reduce the quantity of overburden to be mined per tonne of coal.
- (ii) Steepening existing slope from 34° to 39° it could save the overburden to be mined by 15Mm³ maintaining the defined stability as per statutory requirement.
- (iii) Above exercise will reduce existing stripping ratio from 1:4.75 (slope angle 34°) to 1:1.35 (slope angle 39°).

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