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Numerical Analysis of High Wall and Dumps Slope Stability

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Abstract

Slope stability is one of the major concerns in the field of mining and civil engineering. There were numerous cases of slope failures being reported in a year all over the world, and the process of understanding the rocks or soil forming these slopes was still being a puzzle due to their dynamic anisotropic behaviour. This study mainly focuses on understanding the influence of different parameters of Slope Stability and designing the models of slope stability along with the different sections and Monitoring of Highwall and Dumps (Internal and External) using Galena Software

Keywords: *Slope, High Wall, Dumps, Slope Stability, GALENA*

1. Introduction

"Slope failures have always been rejected as an unavoidable force. This is especially true when it involves loss of life or property. Advanced Numerical Techniques for Rock Slope Stability Analysis-Applications and Limitations."

Any slope either naturally formed or man-made, formed of rocks, soil or of waste dump, having multiple layers with discontinuities or of simple geometry can pose threat to the living kind or to the property at one or the other point of time. Hence a proper understanding of the behaviour and the condition of a slope before working by it and a proper understanding of the properties of the material forming slope before designing it is very important in order to minimize the damage severity or casualties due to the slope failure. It's a known fact that understanding the nature of geo-material is still being a puzzle due to its dynamic anisotropic behaviour. But with the advancement in technologies and computational strength the stability state of slopes is being analysed with utmost possible accuracy. The stability state of a slope is generally quantified by the safety factor. The typical stability problems in soil mechanics may be divided into the widely known techniques for solutions of soil mechanics may be divided into two principal groups- The slip Line method and the Limit equilibrium method (Chen, 1975).

There have been several techniques to decide the protection thing of a slope of which restriction equilibrium technique (LEM) and the electricity discount technique (SRM) or the shear electricity discount technique (SSRM) are presently the maximum familiar techniques for calculating the protection thing of a slope. Despite of every technique having its personal limitations, electricity discount method has proved to reveal large efficacy in calculating protection thing via way of means of now no

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longer regarding any assumptions in finding the sliding floor of a slope as observed in restriction equilibrium methods. In maximum of the analyses via way of means of SRM both the use of Finite Element code (FEM) or Finite Difference code (FDM) the rock mass cloth version used is a linear elastic – flawlessly plastic version wherein the shear electricity is constrained via way of means of the Mohr-Coulomb criterion.

The electricity anisotropy is being delivered via a ubiquitous joint version, which limits the shear electricity in keeping with the Mohr`s Coulomb criterion in a detailed path being the discontinuity orientation. Speaking of the shear electricity, shear electricity properties – cohesion (C) and friction angle (ϕ) in conjunction with the parameters of slope geometry display a large impact at the calculated fee of thing of protection. In the Shear Strength Reduction (SSR) method, the factor of safety (FOS) is defined as the ratio of the actual shear strength of the material to the minimum shear strength required to prevent breakage. The fracture surface is automatically detected by the zone in the material where the applied shear stress intersects the shear strength of the material(Dawson, et al. 1999).

2. Field data

The Opencast Project is located in South India. This mine consists of eight seams such as Seam1, Seam2, Seam3, Top Seam, Bottom Seam, Thick Seam Top, Thick Seam Bottom and Index –I seam. The general gradient of the seams of this mine varies between 1 in 3 and 1 in 5.5. The details of the seams are listed in Table 1. The minimum depth of the mine is 13 m and that of maximum is 200 m.

Table 1. Details of the seams of OCP

Seams	Thickness(m)
Seam1	0.57
Parting	19.68
Seam2	1.87
Parting	9.07
Seam3	2.86
Parting	6.03
Top Seam	0.86
Parting	5.22
Bottom seam	0.56
Parting	2.78
Thick seam top	2.80
Parting	5.29
Thick seam bottom	2.58
Parting	8.47
Index – I	3.72

Out of all these coal seams, thick seam top, thick seam bottom and Index – I seams are proved for workable. This thick seam was already developed with bord and pillar method. Two panels were extracted in the dip side properties of this seam. The developed galleries of thick seam and virgin Index – I seam are being extracted with the opencast mining technology. The mineable reserves of this mine is 13.69 mt proved based on the exploration data (borehole density is 20 per square km). The life of this mine may extend to 12 years. The general geology of the mine site and mine plan are shown in Figures 1 and 2 respectively.

The general excavation technique is the shovel and dumper combination for winning the coal seams. The shovel of 5 m^3 is assigned with the 60 T dumpers. The coal seams of thick seam top, thick seam bottom and Index - I are being extracted with the departmental equipments. The overburden is excavated with the offloading equipments. After the loading of the blasted overburden into the dumpers, the dumpers are travelling to external dump yard (rise of the deposit) for dumping the overburden material.

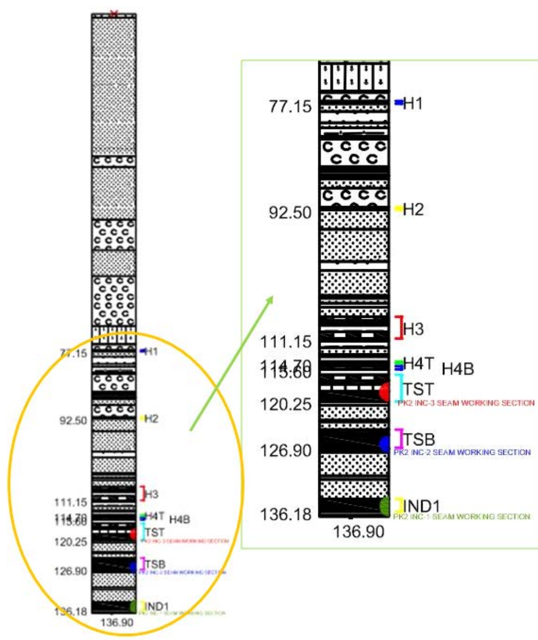

Figure 1. Lithology of the mine site (BH No. 552).

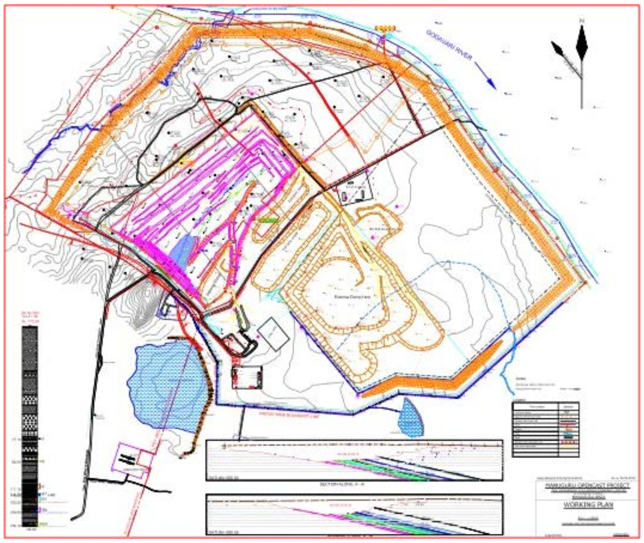

Figure 2. Opencast mine plan.

Figure 3. Shovel and dumper working in the mine.

The height of the bench is maintained with 10 m with a bench angle of 70 degrees. However, this bench is formed by blasting of two blasts of 5 m height each time. The gradient of the haul road way is 1 in 16. Figure 3 shows the shovel and dumper combination adopted in the mine.

3. Laboratory Testing

The overburden material of South India OCP mine from five locations are collected and tested using direct shear test to know the overburden dump properties such as cohesion and angle of internal friction. Also, the particle size distribution analysis is performed for determination of uniformity coefficient and coefficient of gradation.

3.1 Direct Shear Test

Direct shear test (also called 'shear box test') is a laboratory test used to measure the shear strength properties like shear strength, cohesion and angle of internal friction of soil or soil type material. For single material type, to determine cohesion (C) and the angle of internal friction (φ), at least three direct shear tests at three confining stresses are required. The cohesion and angle of internal friction are determined by plotting the shear strength on the x-axis and the normal stress on the y- axis. The y-intercept of the best fit line gives cohesion, and slope of the curve is the friction angle. Here, it is assumed that the material follows Mohr-Coulomb failure criteria as given in the equation.

The shear strength (r) of a soil sample is expressed by the equation.

$$r = C + \sigma_n \tan \varphi$$

where, C is cohesion, σ_n is effective normal stress, and φ is angle of friction.

The angle of internal friction (φ) is a function of relative density of compaction of the soil, grains size, shape and distribution in a given soil sample. For a given sample, an increase in the void ratio (i.e., a decrease in the relative density of compaction) will result in a decrease of the magnitude of angle of internal friction (φ).

During this test, the specimen is placed in a shear box of size 30 cm × 30 cm × 30 cm having lower and upper box. During tests, upper box is fixed while lower box is loaded horizontally applying a normal stress on the top of the upper box. The shear loads and corresponding shear displacements are recorded until the sample fails. The sample is normally saturated before the test is run, but can be run at the in-situ moisture content.

Figure 4 shows the test procedure adopted in the rock mechanics laboratory to determine the cohesion (c) and the angle of internal friction (φ) of overburden dump samples. Three tests have been carried out for three overburden samples with three variations of normal stress. These tests are useful to find the cohesion and angle of internal friction of overburden dump material.

The ponding of the sample has been carried by 2.4 kg weight for ten times. The rate of strain is 1.010 mm/min, capacity of proving ring used is 20 kN with 996 divisions with calibration factor of 0.0198 kN/div. For a particular set of sample three normal load are varied to find the cohesion and angle of internal friction. Table 2 shows the direct shear test results of overburden dump material at three confining stresses (i.e. 50 kPa; 100 kPa and 150 kPa) at zero moisture content.

Figure 5 is plotted between the shear displacement and shear stress for three different overburden dump samples. It is observed (from the Figure 5) that the shear displacement of 6.0 mm, 6.5 mm and 7.0 mm occurred for the normal stress of 50 kPa, 100 kPa and 150 kPa respectively. Figure 6 is plotted between maximum shear stress and maximum normal stress for determination of cohesion and angle of internal friction of overburden dump material.

The best fit line is obtained (Figure 6) as $y = 0.73x + 18.33$ and is compared with the equation 1. Then the slope ($\tan \phi$) and intercept (cohesion) of the line are obtained as $\tan \phi = 0.730$ and intercept $C = 18.33$ kPa. Now, the angle of internal friction is obtained as $\phi = \tan^{-1}(0.730) = 36.12^0$. The overburden properties are listed in Table 3.

Figure 4. Direct shear apparatus.

Table 2. Direct shear test data of overburden dump material at 0% moisture

Test No.	Normal Stress (kPa)	Shear Stress (kPa)
1.	50	57
2.	100	87
3.	150	130

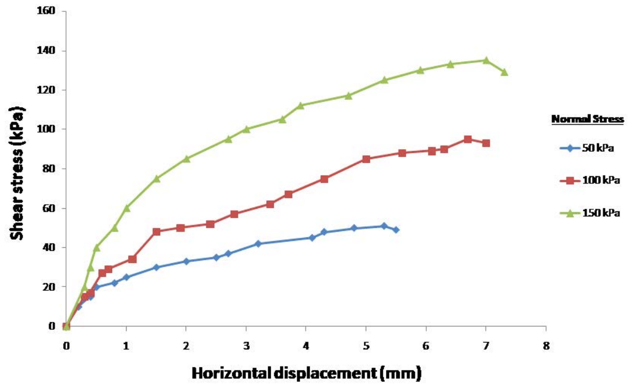

Figure 5. Shear stress versus shear displacement of overburden dump material.

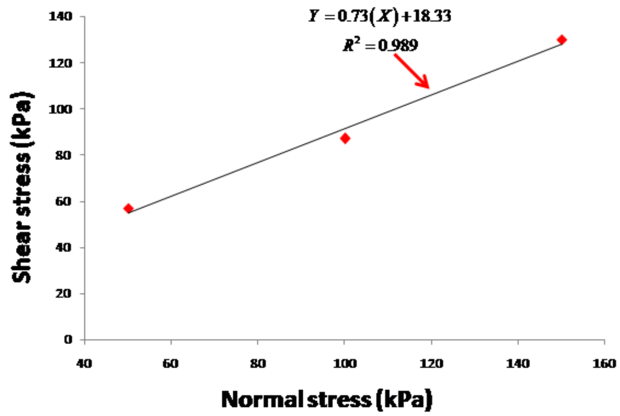

Figure 6. Shear stress versus normal stress of overburden material.

Table 3. Overburden properties

Material type	Unit weight, ρ (kN/m^3)	Cohesion, C (kPa)	Angle of Internal Friction, $\phi(^0)$
Overburden material	19	18.33	36.12

4. Numerical Analysis of Slope

The Modified (or Simplified) Bishop's Method is an extension of the Method of Slices and is generally used for calculating safety factors of slopes. As shown in Figure 7, weight of i^th^ slice (W_i) acts vertically downward. The resistive force (T_i) and normal force (N_i) act at the base of the slice. By simplifying the assumptions that forces on the sides of each slice are horizontal and no shear force exists at the vertical sides of the slice, the problem becomes statically determinate and suitable for hand calculations.

The method has been shown to produce factor of safety values within a few percentage of the “correct” values. The equation 5 represents the safety factor of the slope based on the Bishop’s Method.

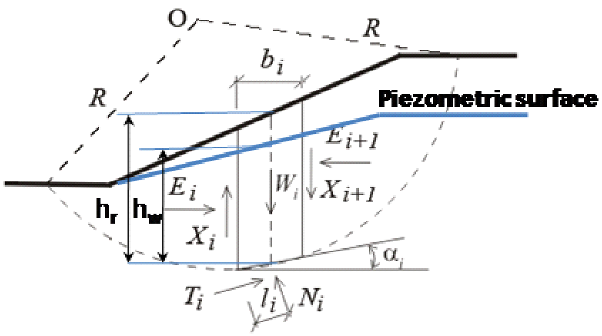

Figure 7. Bishop’s simplified method of slices.

$$SF = \sum(([c` + ((wi/bi) - rui)\tan\Phi)/Ai)/(\Sigma(wi/bi)\sin\alpha i)$$

where, SF is the safety factor

$$A_i = \cos\alpha i + \frac{\sin\alpha i \tan\Phi}{SF}$$

c' is the effective cohesion, φ' is the effective angle of internal friction, b_i is the width of each slice, assuming that all slices have the same width, W_i is the weight of each slice, r_{ui} is the pore water pressure of each slice and is expressed as $r_u = (h_w/h_r)(\gamma_w/\gamma_r)$, γ_w and γ_r are bulk density of water and geo-material respectively. The parameters, h_w and h_r are height of piezometric surface and that of slice respectively as shown in Figure 7. SF is obtained by iterative method. An initial value of SF is assumed and then Newton-Raphson or other iterative techniques are applied to estimate the final SF until difference between SFs for two consecutive iteration is minimal.

4.1 Slope Stability Analysis

In this analysis, a total of thirty (30) slope models are developed considering AA’ or North - South, BB’ or West - East, CC’ or North - South, DD’ or West - East, EE’ or North - South and FF’ or West - East sections for detailed stability analysis. Out of these models.

- Eight slope models are developed for ultimate pit or final pit (four models for ultimate highwall and four other models for ultimate internal dump) along the section AA’ (N-S) and BB’ (W-E) considering both wet and dry conditions.
- Eight slope models are developed for working mine (four models for highwall side and four other models for production front) along the section CC’ (N-S) and DD’ (W-E) considering both wet and dry conditions.
- Eight slope models are developed for ultimate external overburden dump (four models for left hand side and four other models for right hand side) along the section EE’ (N-S) and FF’ (W-E) considering both wet and dry conditions, and The rest six slope models (six models for highwall and two models for dump) are developed for proposed highwall and overburden dump considering both wet and dry conditions

All the slope models of the pit and dumps are developed based on the general lithology of mine site (Figure 8a) and dump (Figure 8b) and the various sections are taken on the final stage plan, working plan and ultimate overburden dump. The rock mass properties listed in Table 4 are applied to all the models of highwalls, production fronts and ultimate highwalls. However, the internal and external overburden dumps are assigned the properties as listed in Table 5. Based on the rain fall data at the mine site, the peizometric surface is applied in all the slope models (wet condition) till 10 m below the surface from toe of the bottom most benches.

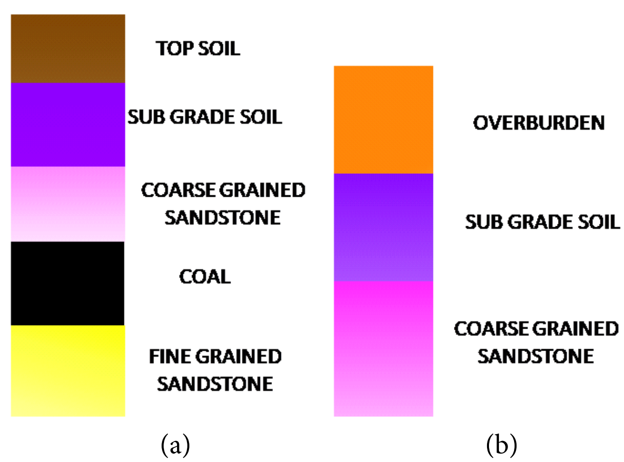

Figure 8. General Lithology of the mine site and dump used for stability analysis. (a) Lithology of mine site. (b) Dump material.

5. Modelling

5.1 Ultimate Pit

5.1.1 Ultimate Pit Along AA' (North – South) Section

Figure 16 shows the ultimate mine plan of South Indian OCP mine. The section AA' of the mine along the dip-rise (N-S) direction is taken for the detailed slope stability analysis of the ultimate highwall and the ultimate internal dump (Figure 9). The left (north) portion of section AA' (or dip side) consists of highwall and the right (south) side (or rise side) of section AA' consists of internal dump only (Figure 9). Dip side ultimate highwall consists of 20 benches having surface and bottom RL of 760 mRL and 558 mRL respectively. The height of each individual bench is 10 m with hidden width of 3.64 m and exposed width of 6.36 m. The overall slope angle of the dip side highwall is 45 degrees.

Based on Figure 10, the slope stability models of section AA' and BB' are modelled for dry and wet conditions. After analyzing, the safety factor values of the ultimate highwall along the section AA' (Dip-rise) found to be 0.75 for wet condition and 1.40 for dry condition as shown in Figures 11 and 12.

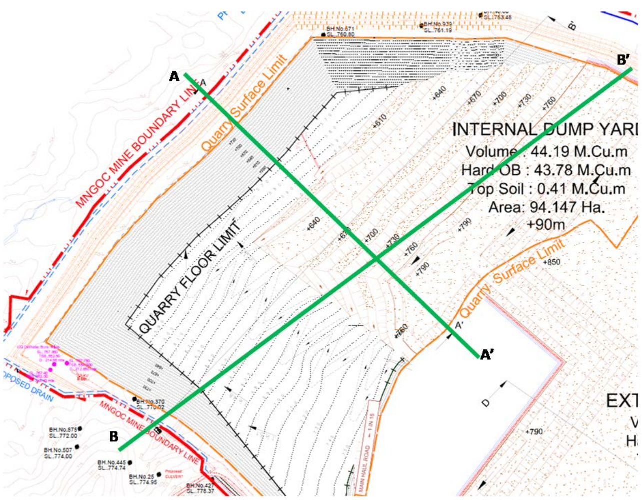

Figure 9. Final stage mine plan of South India OCP.

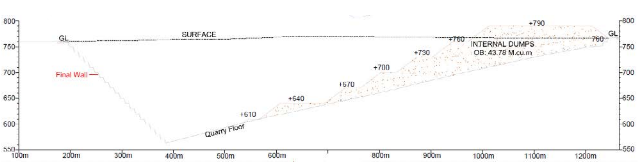

Figure 10. Section AA' (N-S) of the final pit.

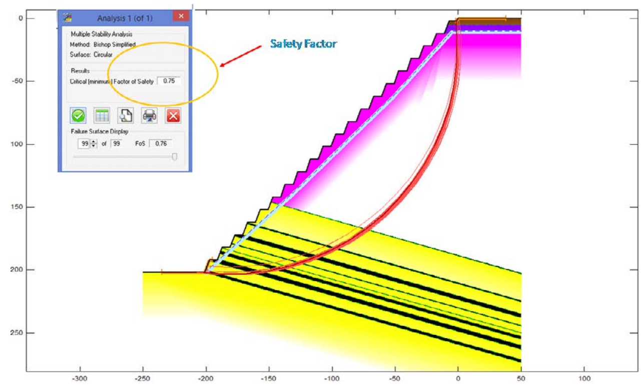

Figure 11. Ultimate highwall (dip or north) with wet condition along section AA'.

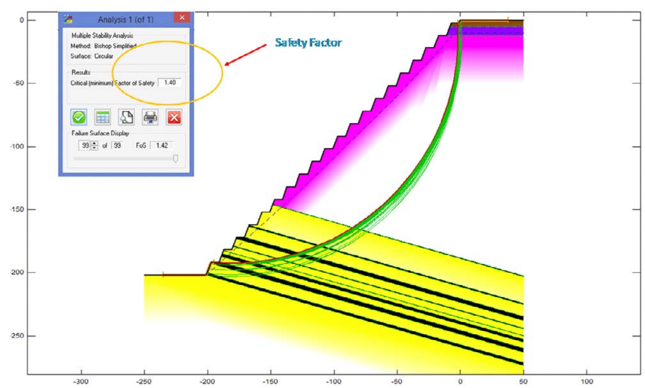

Figure 12. Ultimate highwall (dip or north) with dry condition along section AA'.

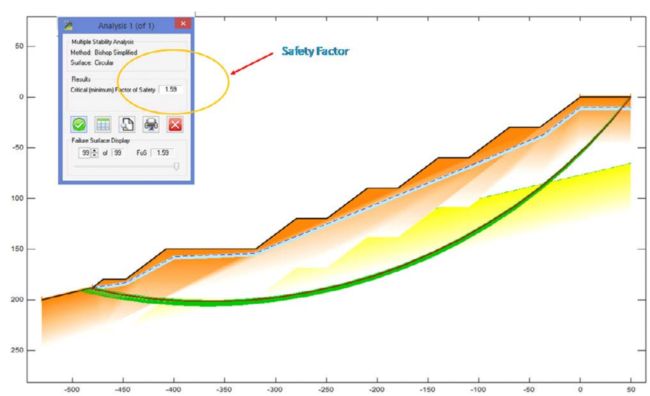

Figure 13. Ultimate internal dump (rise or south) with wet condition along section AA'.

The right (south) or rise side of the section AA' (Figure 9), represents the ultimate internal dump as shown in Figure 10. The mine management propose to dump the overburden material to a height of 160 m in six decks in the rise (north) side after exploitation of coal. The ultimate internal dump consists of six benches with a deck

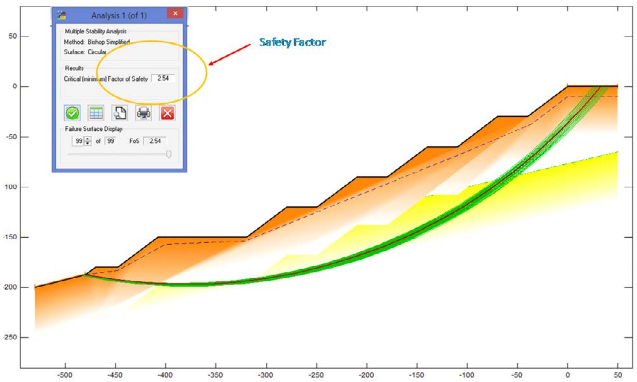

Figure 14. Ultimate internal dump (rise side or south) with dry condition along section AA'.

height of 30 m. The exposed and the hidden widths of the bench are 30 m and 40 m respectively. The deck angle and overall slope angle of the internal dump are 36.86^0 and 21.6^0 respectively. The RLs of bottom most benches is 600 mRL and that of top most bench is 790 mRL.

Figures 13 and 14 show the slope stability models of the ultimate internal dump along AA' or N-S section for wet and dry conditions. These internal dump models have the safety factor of 1.59 and 2.54 for wet and dry conditions respectively.

5.2 External Overburden Dump

5.2.1 External Overburden Dump Along EE' (North – South) Section

The excavated overburden material from the mine is proposed to dump outside of pit and inside of pit. The outside of pit is the external dump. In this external dump, the blasted overburden is proposed to dump the material adjacent to the mine for a maximum height of 90 m in three decks or benches. Height of an each deck is 30 m, hidden and exposed widths of the deck are 40 m and 30 m respectively. The angle of the deck is 36.87^0. The RL of the floor and surface of the dump are 760 mRL and 850 mRL respectively.

The section EE' and FF' of the external dump are considered for the detailed stability analysis of the dump (Figure 15). The material properties listed in Table 5 are applied to all the models of the dump.

As shown in Figures 15–17, the left (north) and right (south) sides of the external dump along EE' section is presented. The overall slope angle of 23.2^0 and 26.56^0 for left and right sections respectively, after performing the slope stability analysis of the left (north) side section of

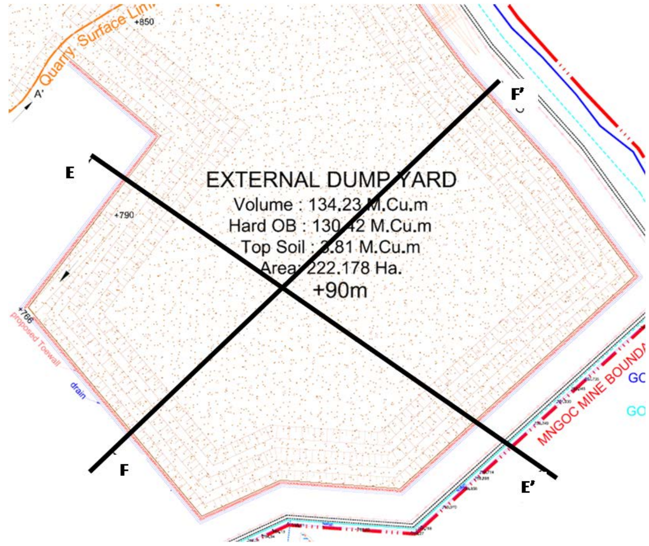

Figure 15. Plan of ultimate external dumps.

Figure 16. Section EE' of external dump.

Figure 17. External dump along section EE' (N-S).

external dump, the safety factor values are observed as 0.97 and 1.82 for wet and dry conditions as shown in Figures 18 and 19 respectively.

As shown in Figures 20 and 21, the right (south) side section of the external dump has the safety factor of 0.85 and 1.56 for wet and dry conditions respectively.

5.3 Recommended Highwall and Overburden Dumps

5.3.1 Recommended Highwall for the Mine

The highwall of the ultimate pit along sections AA' (or dip side) and BB' (or west side) have the safety factor value of 0.75 and 0.76 for an overall slope angle of 45^0 in wet conditions. These safety factor values of both the sections suggest that the highwall may get deteriorated due to wet condition. Hence, the highwall geometry must properly be designed to improve the stability of the ultimate pit. The proposed highwall for dip side consists of 21 benches with a bench angle of 70^0. Out of this, top six benches are of 5 m height and bottom 17 benches of 10 m height. A berm of 10 m is kept after six smaller benches (at 728 mRL) from the surface (at 760 mRL) and also 30 m berm is kept at 658 mRL. As shown in Figure 48, the hidden and exposed widths are 3.64 m and 6.36 m for 10 m benches and that of 1.82 m and 3.18 m for 5 m height benches. The overall slope angle of the highwall is 41.52^0. Figure 22 shows the schematic diagram of the highwall in the dip side or along section AA' is proposed to improve the safety factor of the ultimate highwall.

After performing the slope stability analysis of the proposed highwall, the safety factor found to be varying from 1.30 to 1.99 for wet and dry conditions respectively. Figures 25 and 26 show the slope models of proposed highwall for wet and dry conditions.

In order to know the stability of benches of proposed highwall above the berm and below the berm, the detailed slope stability analysis is performed. The safety factor value for the top thirteen benches (from 658 mRL to 760

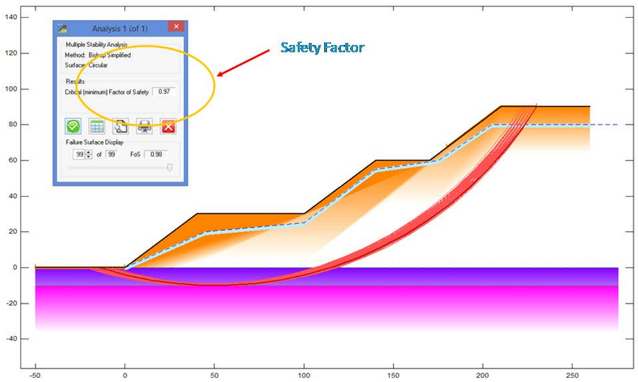

Figure 18. External dump left (north) side for wet condition along section EE'.

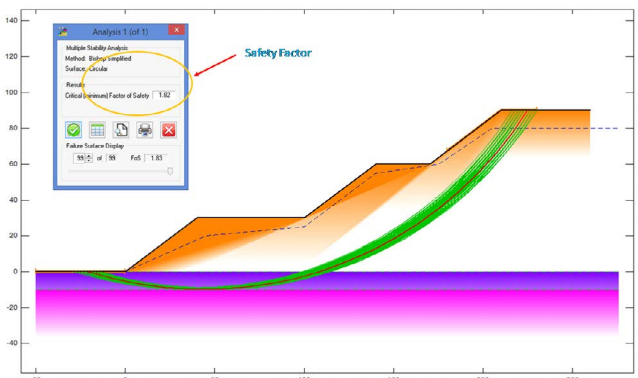

Figure 19. External dump left (north) side for dry condition along section EE'.

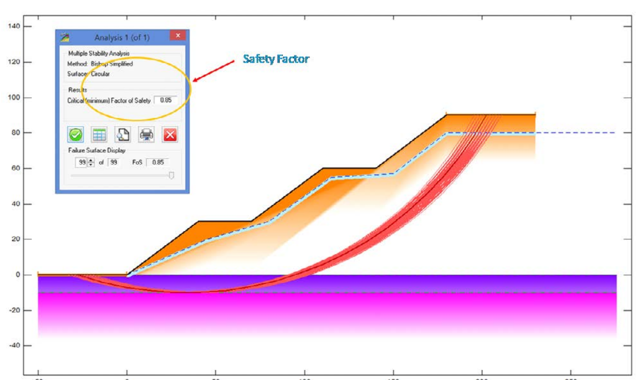

Figure 20. External dump right (south) side for wet condition along section EE'.

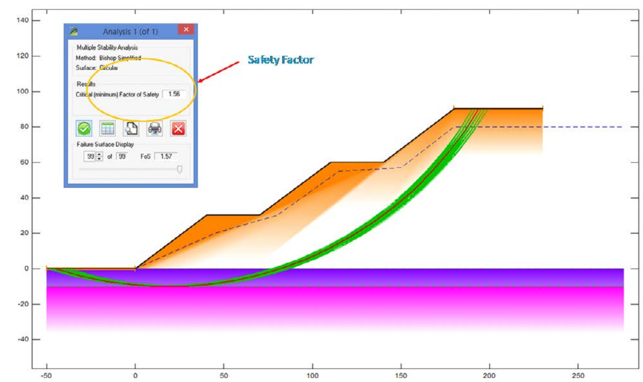

Figure 21. External dump right (south) side for dry condition along section EE'.

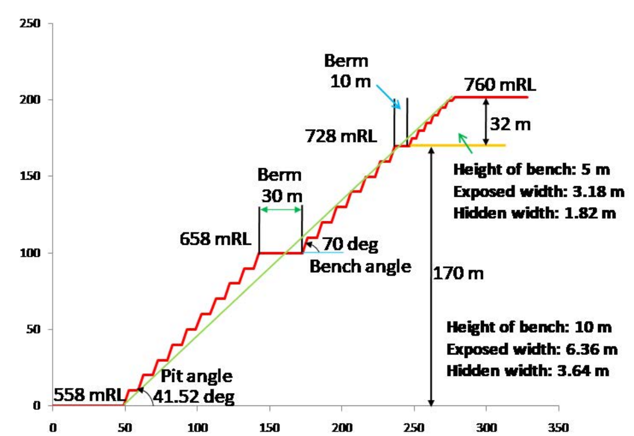

Figure 22. Proposed highwall for OCP located in South India

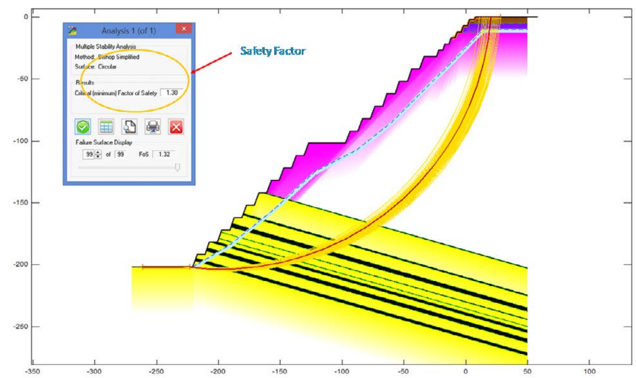

Figure 23. Proposed highwall model for wet condition.

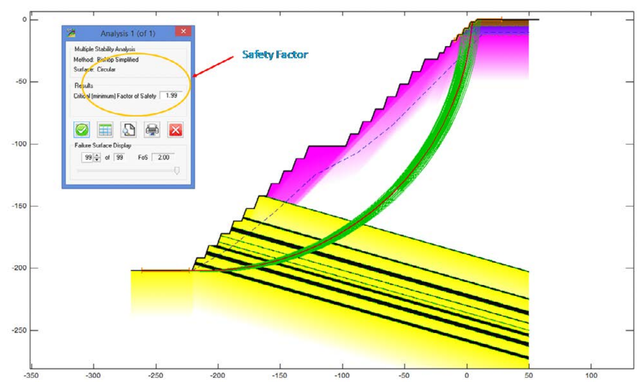

Figure 24. Proposed highwall model for dry condition.

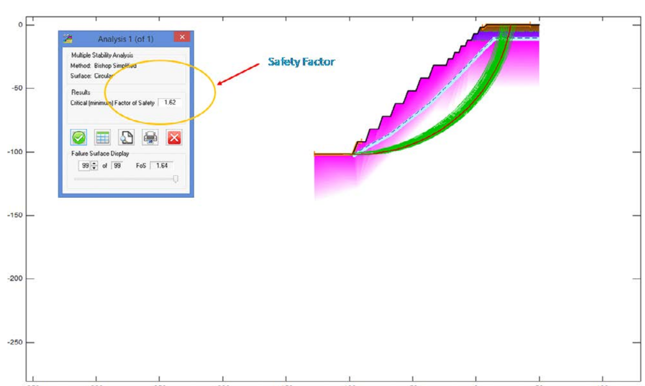

Figure 25. Detailed analysis for top thirteen benches above berm of the proposed highwall.

mRL) varies from 1.62 to 2.07 as shown in Figure 25 and similarly for the bottom ten benches (from 558 mRL to 658 mRL) varies from 1.45 to 1.99 as shown in Figure 26.

6. Conclusions

The slope stability models are developed and analyzed based on the Lithology of the mine site, tested overburden

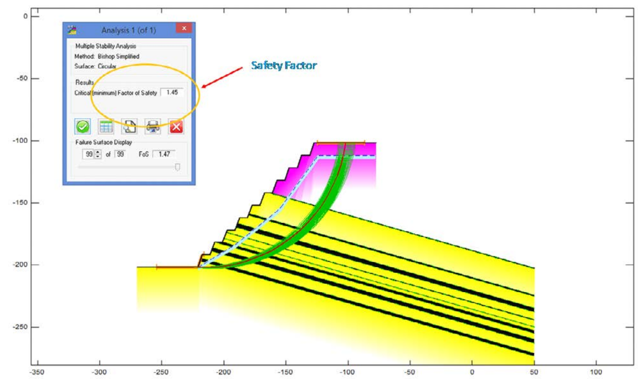

Figure 26. Detailed analysis for bottom eight benches below berm of the proposed highwall.

dump material properties and derived rock mass properties using Hoek-Brown failure criterion and other necessary data of the mine. The following conclusions are drawn based on the slope stability analysis of OCP mine located in South India.

- The overburden samples from the mine site are collected and tested for the determination of overburden dump material properties. It is found that cohesion and angle of internal friction are 18.33 kPa and 36.12 degrees respectively.
- The intact rock properties of coal bearing strata including coal are collected from the mine site and these properties are used for estimation of rock mass properties using roclab software or Hoek-Brown failure criterion.
- All the slope stability models are developed and analyzed for wet and dry conditions. For all wet slope stability models; the phreatic surface just below 10 m from surface is considered.
- The safety factor values of the ultimate highwall along the section AA' (N-S or Dip to rise) varies from 0.75 to 1.40 and that of section BB' (W-E) has the safety factor of 0.76 and 1.33 for wet and dry conditions respectively.
- The safety factor values of ultimate internal dump along AA' (N-S or Dip to rise) section varies from 1.59 to 2.54 and that of section BB' (W-E) varies from 1.54 to 2.05 for wet and dry conditions.
- For the working benches along CC' (N-S or Dip to rise) section, it is found that the safety factor lies from 4.51 to 6.54 for highwall (South) and 3.25 to 5.13 for production front (North) for wet and dry conditions respectively.

Table 4. The brief conclusions of the slope stability models of OCP mine located in South India

Sl.No	Slope models	Width of the model (m)	Height of the model (m)	Overall slope angle (Deg)	Safety factor	
					Wet	Dry
1	Ultimate highwall along AA' section (North)	202	202	45	0.75	1.40
2	Ultimate internal dump along AA' section (South)	480	190	21.6	1.59	2.54
3	Ultimate highwall along BB' section (West)	162	162	45	0.76	1.33
4	Ultimate internal dump along BB' section (East)	250	120	25.64	1.54	2.05
5	Highwall along CC' section (South)	295	50	9.62	4.51	6.54
6	Production front along CC' section (North)	270	50	10.5	3.25	5.13
7	Highwall along DD' section (West)	87	60	34.6	1.69	2.32
8	Production front along DD' section (East)	120	35	16.26	10.88	15.17
9	External dump along EE' section (North)	210	90	23.19	0.97	1.82
10	External dump along EE' section (South)	180	90	26.56	0.85	1.56
11	External dump along FF' section (West)	180	90	26.56	0.85	1.56
12	External dump along FF' section (East)	180	90	26.56	0.85	1.56
13	Proposed highwall	230	202	41.29	1.30	1.99
14	Proposed external dump	200	90	24.22	1.32	2.15

- For the working benches along DD' (W-E) section, the safety factor of highwall (West) lies between 1.69 and 2.32 for wet and dry conditions respectively. The safety factor of production front (East) varies from 10.88 to 15.17 for wet and dry conditions respectively.
- For the external dump, the minimum and maximum safety factor values of dump along EE' (N-S) and FF' (W-E) sections are 0.85 to 1.82 and 0.85 to 1.56 for wet and dry conditions respectively.

7. References

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