Investigation for Safety of Final Quarry Bench During Mine Closure Stage – a Case Study

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Case study

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Abstract

The closure of opencast coal mining operation in Balanda mine will be a source of danger for inhabitants or any other infrastructure near the surface of ultimate quarry bench from safety point of view. In view of the above, MCL (Mahanadi Coalfield Limited) and the management of the Balanda opencast mine conducted a variety of design research and academic institutions to conduct a slope stability analysis of Balanda ocp (opencast project). It is also important here to note that the Birla Institute of Technology, Mesra, Ranchi, has prepared a study report on the above. This paper deals with design of ultimate quarry bench and discusses various geo-technical parameters for carrying out stability analysis.

1. Introduction

Balanda opencast mine is located in the south-eastern part of Talcher coalfield in Angul district of Orissa, India and falls under the administrative control of Mahanadi Coalfields Limited (MCL). The mine was sanctioned for an annual rated capacity of 1.0 Million ton in 1959 and the project is in operation since then. The mine has come on the verge of closure. There is only one coal seam dipping at 2° - 4° with thickness as 13-14 metre and overburden rock above coal seam is 65-70 metre. The present working is in western part near dip side lease hold boundary of the mine close to fault F_2 - F_2 (Fig 1 & 2). To delineate the location of fault F_2 - F_2 and geo-technical properties of rock strata, four boreholes were drilled near the present working face (Srivastava, Jha, and Shandilya 2015).

2. Objective Of Mine Closure Planning

- To allow a productive & sustainable after use of the site which is acceptable to the mine management and regulatory authority.
- To bring back to its original shape of the land as far as practicable for use of land for agriculture, fishery, etc.
- To protect public health and safety.
- To eliminate environmental damages and thereby encourage environmental sustainability.
- To minimise adverse socio-economic impacts.

3. Stability Analysis Design Parameters

The parameters regarding geo-engineering, which are analysed are as follows (Sharma, Sengupta, and Roy 2015): -

- Geo-technical parameters
- Hydro-geological parameters
- Seismic and blasting effect

3.1 Geo-technical parameters—The main geo-technical parameters which are used in the calculation of slope angles are (Murthy 2002):

1. Cohesion and angle of internal friction of rocks mass in natural conditions.
2. Bulk density of dump materials.

The shear strength parameters i.e. cohesion and angle of internal friction of rock strata have been determined in the laboratory of BIT, Mesra (Birla Institute of Technology, Mesra) by testing drilled cores from all the four boreholes (table - 1). Core logging was done to ascertain the litho-logical composition of the rock strata. From the uni-axial compressive strength determined in the BIT, Mesra laboratory, cohesion and angle of internal friction are estimated by ISRM method (International Society of Rock Mechanics) in the following manner (eqn. 1) (ISRM 1977) (Agustawijaya 2007).

$$\sigma_1 = C \times A [\sigma_3 / C + T/C]^n \dots\dots\dots (1)$$

Where,

σ_1 = Major Principal Stress,

σ_3 = Minor principal stress i.e. confining pressure,

T = Tensile strength,

C = Compressive strength,

A' and n' are coefficients and indicates for different types of rocks. The cohesion and angle of internal friction for the above rock properties are determined from major principal and confining stress by drawing Mohr's envelop (Fig. 3).

Table 1: Geo-technical properties of rock strata

Rock Strata	Depth in metre	Bulk Density (kN/m ³)	Compressive Strength (MPa)	Angle of internal friction (deg)	Cohesion (MPa)
Sand stone	0-8.00	22.5	4.83	39.4	3.1
Sand stone	8.00-10.5	19.9	9.89	33.0	2.4
Sand stone	10.5-14.77	22.3	4.2	39.1	3.0
Sand stone	14.80-21.45	19.8	5.74	33.2	2.4
Sand stone	21.45-25.60	21.9	5.5	36.8	2.9
Sand stone	25.60-28.30	20.6	4.84	32.1	2.8
Sand stone	28.30-32.16	21.8	8.33	36.4	2.9
Sand stone	32.16-36.48	15.8	1.96	29.7	1.9
Sand stone	36.48-40.78	20.1	2.24	32.9	2.8
Sand stone	40.78-47.45	14.0	2.38	28.2	1.6
Sand stone	47.45-51.30	20.5	1.12	34.3	2.9
Sand stone	51.30-60.00	19.5	1.5	30.5	2.4
Sand stone	60.00-70.00	20.0	2.0	32.7	2.8
Coal	70.00-83.00	18.0	1.4	30.2	1.7

3.2. Hydro Geological Parameters – As per the hydro-geological study carried out, annual runoff estimation based in the rainfall runoff relationship established is 558 mm. The approximate area of the colliery, which is considered for estimation of surface runoff, is 4.8 sq. kms (48,00,000 sq. m), thus the estimated total surface runoff generated annually, is 26,78,400 M.cum. As per the hydro-geological study, 23% of total rainfall goes to the ground water table, 32.5% goes back to the atmosphere as evaporation and rest 44% of the rainfall goes as surface runoff to nearby water course. Hence, very negligible amount of rainwater is stored in the surface of the mine. Also due to very low permeability of rocks constituting

Balanda mine, there is no existence of seepage line within the whole rock mass except in the bedding plane, which is insignificant in the stability analysis. Due to above reasons, the hydrostatic pressure as well as seepage force will have negligible effect on the rock strata constituting the quarry batter. The chances of slope failure due to these reasons are envisaged as negligible and has not been considered in the slope stability analysis (Murthy 2002) (Moosavi, Shirinabadi, and Gholinejad 2016) (Sengupta and Roy 2015) (Besimbaeva et al. 2018)

3.3. Seismic & blasting effect-

Ground vibration on account of earthquake causes immense damage to quarry batter. The seismic effect has been considered as per latest "Indian standard criteria for earthquake resistant structural design (fifth edition) IS: 1893-2002" (IS 1893 (part 1) 2002). The project falls under seismic zone-III and the basic horizontal seismic coefficient is 0.04 for zone-III as per Indian standard code. An equivalent static approach employing use of a seismic co-efficient is adopted here. In seismic co-efficient method, the design value of horizontal seismic co-efficient, α is computed as given value (eqn. 2) (Mosinets and Shemyakin 1974):

$$\alpha = \beta \times I \times \alpha_1 \dots\dots\dots (2)$$

β = Co-efficient depending upon the foundation strength. In this case $\beta = 1.0$.

I = Factor depending upon the importance of the structure.

In this case, $I = 1$,

α_1 = Basic horizontal seismic co-efficient.

In this case, $\alpha_1 = 0.04$ as this project falls under zone - III.

Hence, design value of horizontal seismic coefficient = 0.04

The effect of blasting in the quarry benches is measured and a blasting co-efficient of 0.04 has been taken into consideration in the stability calculations (Singh et al. 2012). Summation of seismic and blasting co-efficient (0.04 + 0.04) is multiplied with dead load of potential failure block of the quarry for taking into account the seismic and blasting effect on the quarry slope.

4. Stability Analysis

Slope stability analysis has been done for a factor of safety of 1.2 by both Fellinius method and Bishop's simplified method (Roy 2008). Later acknowledging all the approved factor of safety recommended by various organisation/bureaus such as " National coal board, U.K.", "United states D'Appolonia consulting engineers", "Mines branch Canada" ,"Stability of pit slopes and dumps by G.L Fiesenko, Russia for

opencast mine slope design", a factor of safety of 1.2 is considered here (Besimbaeva et al. 2018) (Chaulya and Prasad 2016) (Ranjan et al. 2017).

With the above geo-engineering parameters, stability analysis was done with the help of Fellinius and Bishop's simplified method. The recommended safe slope angle is obtained in the range of 47° to 57° (table - 2) corresponding to overall rock strata height of 80 to 60 metre respectively for a factor of safety of 1.2 (Sengupta, Sharma, and Roy 2014).

Table 2: Safe slope angle versus existing quarry batter with factor of safety of 1.2

Height of overall rock strata including coal strata (metre)	Safe Slope Angle (deg)
80	47
70	53
60	57

Conclusion

This paper presents a geo-technical approach to deal with quarry bench design during mine closure stage based on the study carried out by Birla Institute of Technology, Mesra, Ranchi and Central Mine Planning and Design Institute, Ranchi. The mine has been worked out by both dragline and shovel-dumper combination (Fig. 1 & 2). The shovel-dumper benches have already been reached to a final position. All the shovels and dumpers deployed in over-burden removal have been diverted to some other mines of Mahanadi Coalfield limited. Further movement of these top benches is not feasible at present in absence of any shovel-dumper. Hence, the existing position of the top benches is at their final position (Fig. 2). Presently, the 30-40 metre height of bench is being worked out with the help of 2 draglines (one of 20/90 & other of 10/60). The average height of dragline bench is about 35 metre. Out of this, the top 10 metre strip of overburden rock is being de-capped with the help of 10/60 dragline and the bottom 25metre overburden bench is being excavated by 20/90 dragline, which is following the other dragline along the strike length of the mine. Thus the above two draglines are working in horizontal tandem manner. After mining of these benches, the final quarry batter as per recommendation of the study report [2] will vary between 32° to 43° which will be flatter than the maximum allowable slope angle of 47° to 57° with a factor of safety of 1.2. Hence the closed mine will not pose any safety problem regarding stability of final benches.

The views expressed in this paper are those of authors and not of the organization they belong.

Declarations

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Declaration:

The authors declare that they have no conflict of interest.

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Figures

Figure 1

Surface plan of Balanda op. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Typical view of section AB

Figure 3

Mohr's diagram from compressive strengths of drilled core

Figure 4

4a & 4b: Abandoned mine, filled up with water in the decoaled area (sump) and reclamation done on the overburden dump