High wall slope stability assessment of open pit coal mine- A case study

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Abstract

An opencast coal mine is being operated by Singareni Collieries Company Limited (SCCL) is located at Peddapalli District of Telangana State. The mine is situated on the southern bank of river Godavari. There are six coal seams under exploitation in the mine viz. – I, II, IIIA III, IV and V seams. The mine is working with an annual targeted coal production of 4.09 million tones. The present working depth of the mine is 193m with a stripping ratio of 5.57 m^3/tonne. With the removal of overburden of about 300 million m^3in the mine, resulted in the formation of high wall slopes towards south side.The high wall slopes are developed in Barakarand Talcher formations. In this area, a major fault, numerous minor faults\slips, joints and shear zones are noticed and they are more or less parallel to fault. Presently, tensile cracks and vertical subsidence observed at top surface of the high wall slopes due to mining activity in this area.

An assessment of the south side high wall slopes need to be carried out in order to evaluate slope stability conditions with a view to maximise the production and concern towards conservation of the mineral with safe working conditions. Geotechnical studies covering geologic mapping, LIDAR survey, laboratory study of the material and numerical analysis using GALENA software is carried out for stability assessment of the disturbed zone in the high wall slopes. Based on above studies, recommendations for bench parameters and final pit slope stability related to disturbed area of the south side high wall slopes of the mine is discussed in this paper.

Keywords: *Slope stability, Open pit mining, Geotechnical studies and Numerical analysis*

1. Introduction:

An opencast coal mine is being operated by Singareni Collieries Company Limited (SCCL) is located at Peddapalli District of Telangana State. The mine block covers an area of about 4 Sq.km and situated on the southern bank of river Godavari. The coal deposit in the mine has the incrop almost parallel to the river bank and on the dip side. There are six coal seams under exploitation viz. – I, II, IIIA III, IV and V seams with minimum and maximum depths of 15m and 220m respectively. The strike of the coal measures is NW –SE with a gentle North-Easterly dips. The gradient of the seams varies from 1 in 5 to 1 in 10. The mine is working with an annual targeted coal production of 4.09 million tonnes with shovel and dumper combination technology (Figure 1). The present working depth of the mine is 193m with a stripping ratio of 5.57 m^3/tonne. The removal of overburden of about 300 million m^3 resulted in the formation of south side high wall benches. Presently, tensile cracks and vertical subsidence were observed at top surface in the high wall slopes due to mining activity in this area.

An assessment of the south side high wall slopes was carried out in order to evaluate bench slope stability conditions with a view to maximise the production and concern towards conservation of the mineral with safe working conditions.Geotechnical studies covering geologic mapping, lidar survey, laboratory study of the material and

numerical analysis using GALENA software is carried out for stability assessment of the disturbed zone in the high wall slopes. Based on above studies, recommendations for bench parameters and final pit slope stability related to disturbed area of the south side high wall slopes of the mine is made.

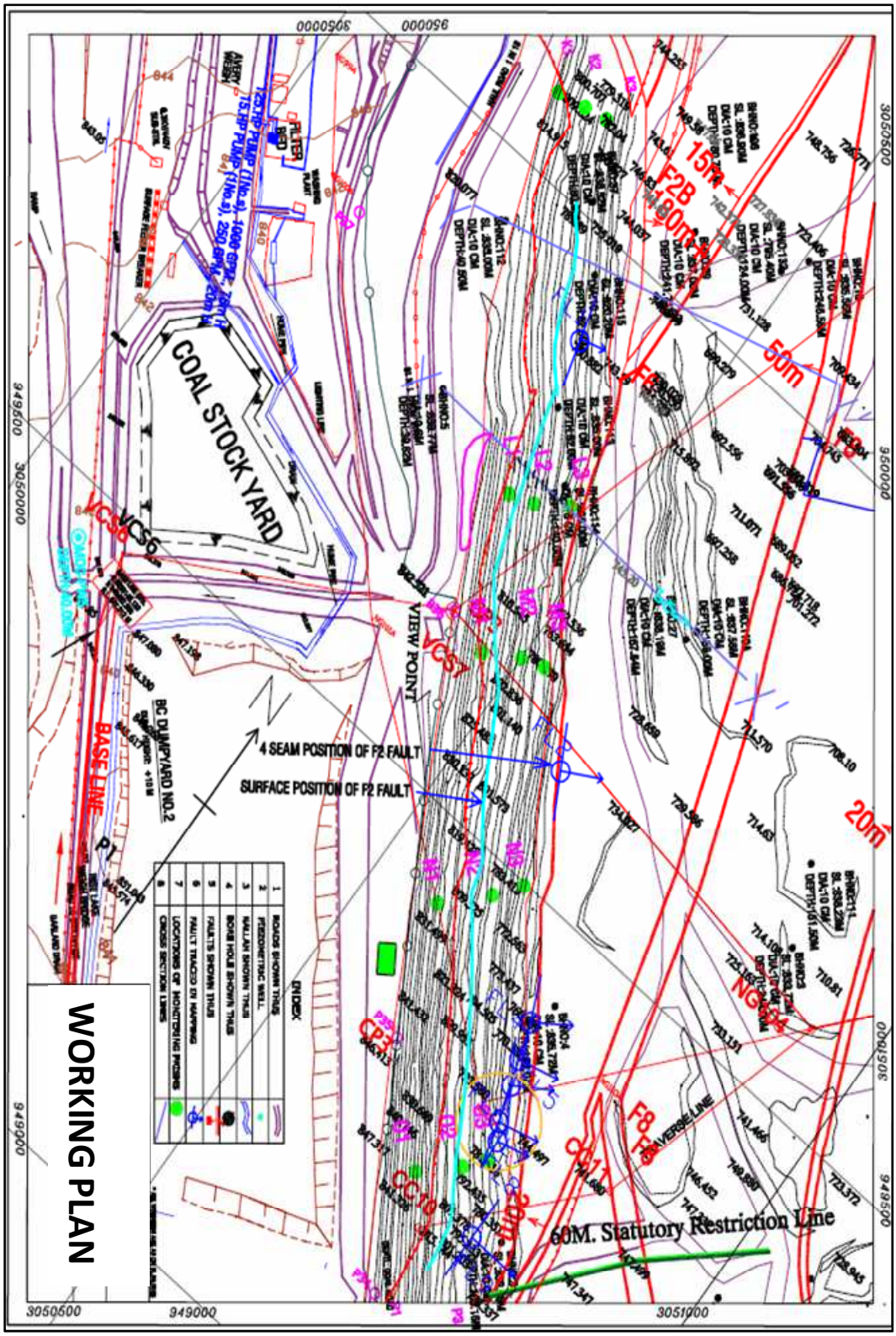

Figure 1A view of the mine workings

2. Field Investigations:

2.1 Geological Mapping along High wall Slope:

Geological mapping is carried out in the quarry where disturbed area is present (Figure 2). It is observed that top benches were developed on Talcher formation and the bottom benches were carved on Barakar formation (Table-1).

Figure 2 South side high wall benches in the mine

Table1
Geological succession at mine area

	Group	Formation	Descriptionon of material	Maximum thickness (m)
Recent	LOWER GONDWANA		Soil cover and alluvium	28.96
PERMIAN		Barren measures	Coarse to pebbly feldspathic sandstones with clays	25.91
		Barakar	Upper Member Dominantly sandstones with eight correlatable coal seams	166.33
			Lower Member Predominantly coarse grained white sandstone	79.40
		Talchir	Fine to medium grained pale greenish sandstones and khaki green shale	

While mapping the high wall benches, the exposed fault plane was traced. From the geological mapping, the measured dip angle of the fault is taken as 65°. Along the fault plane, clay occurred as predominant infilling material and infilling material got eroded where water seepage is noticed (Figures 3 & 4).

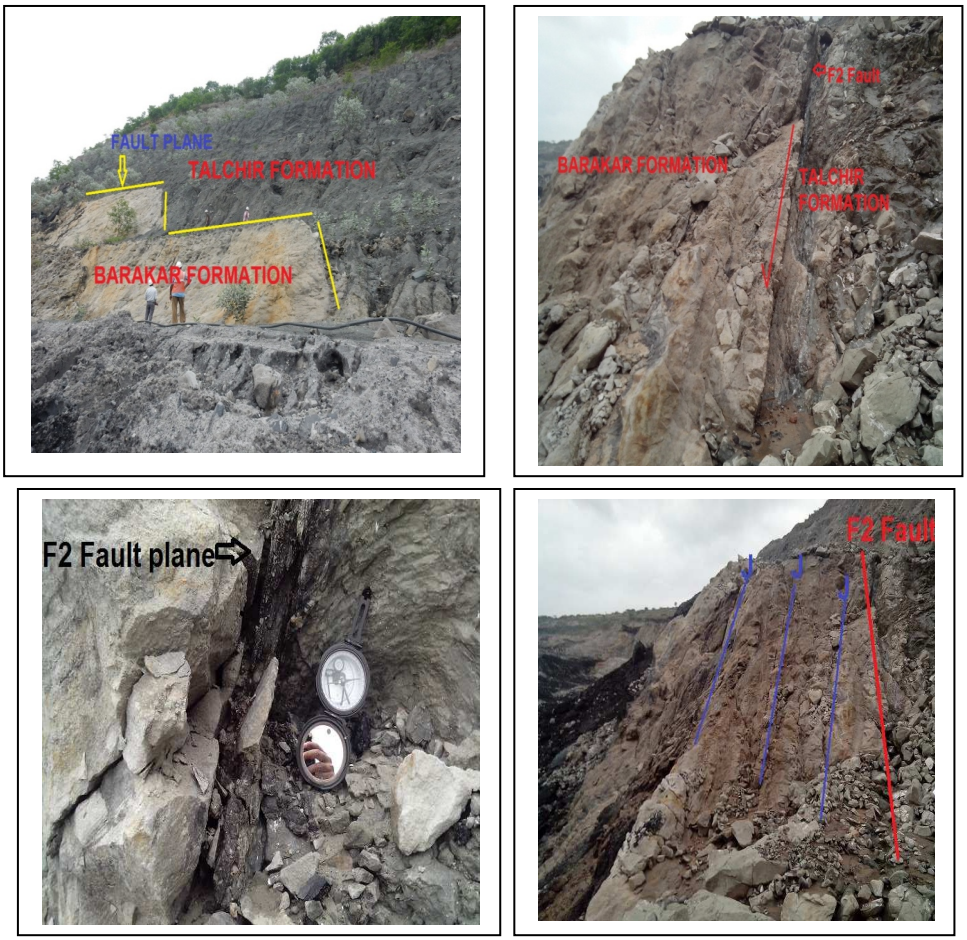

Figure 3 Shows fault plane condition in the disturbed area

In the vicinity of fault, numerous minor faults\slips and joints were noticed and they are more or less parallel to fault. Two shear zones were also mapped with 2m width and striking in N40°E direction traversing across the benches.

Almost, the entire mine block is covered with thick alluvial cover of black cotton soil, being the flood bank of the River Godavari. The thickness of the soil cover varies from 5.79m to 28.96m in the south central part close to the south western boundary of the block. In general the formations from top to bottom are soil, siltstone, sandstone and coal seams.

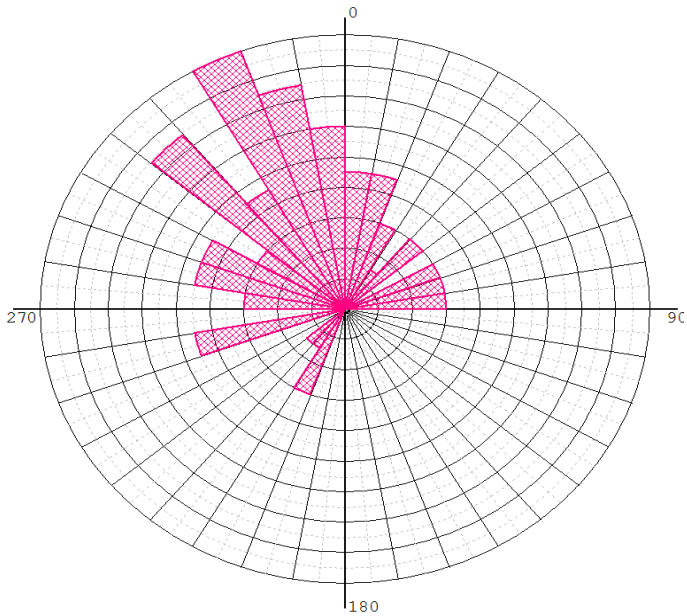

Figure 4 Rose Diagram showing trend of the joints measured on the high wall slopes

The cracks and vertical displacement observed in this area having alluvium cover of 25m which is part of Talcher formations (Figure 5). Immediately below the disturbed surface, only 3 seam, 4 seam, Index seam and 5 seams are left for extraction and all the top seams were mined out.

Figure 5 Tensile cracks and vertical subsidence at surface level of high wall slope

3. High wall Slope Stability Assessment:

The slope stability analyses of the disturbed section of south side high wall of the quarry is carried out by limit equilibrium method with using GALENA software. Limit equilibrium analysis considers the slope performance only at the equilibrium condition between the resisting and disturbing forces for sliding (GALENA version 7.0, 2016). To represent the slope performance other than the equilibrium condition, it is necessary to have an index and the widely used index used to be factor of safety. Factor of safety is calculated as the ratio of shear strength to the available shear stress required for equilibrium, integrated through the whole slide. It is assumed to be constant throughout the potentially sliding mass. For slope stability analysis of high wall with back filling, the cut-off factor of safety 1.2 is considered (Hoek, E. and Bray, J.W., 1991).

For slope stability analysis of considered high wall section is as shown in Figure 6, and profile is surveyed with lidar equipment (Figure 7).The relevant strength properties used for slope stability analyses are given in Table-2.

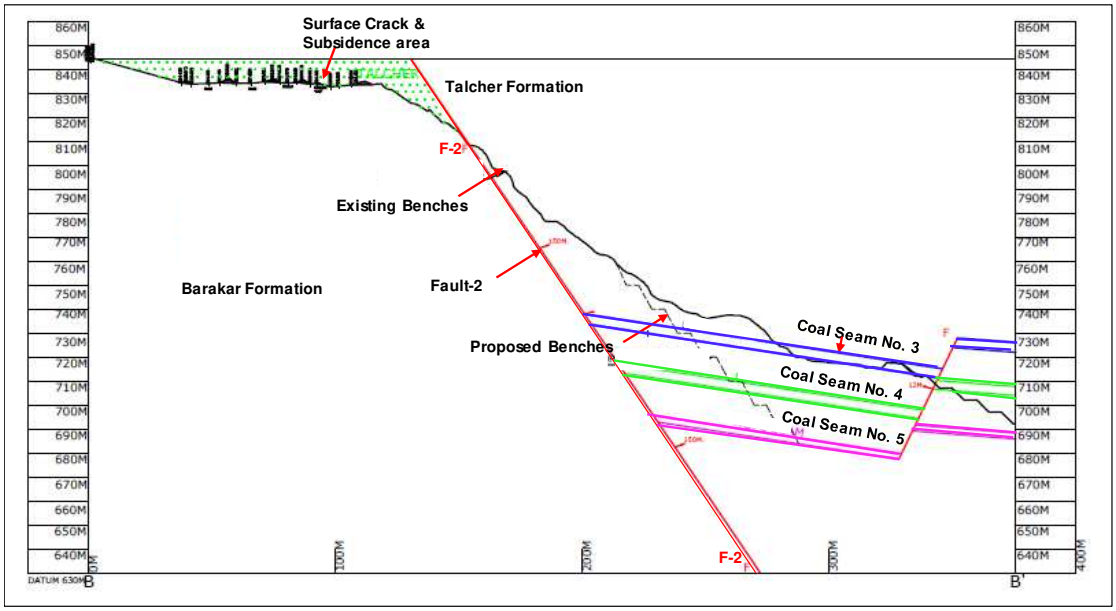

Figure 6 Disturbed area sections towards south side high wall benches

Table2
Geo-mechanical properties of different lithology of slope material

Lithology	Cohesion (kPa)	Friction angle (degree)	Density (kN/m^3)
Black cotton soil	28	18	17.5
Silty clay	25	25	17.0
Sand	05	33	16.8
Sandstone	230	28	22.0
Coal seam	190	24	14.4

Figure 7 Lidar laser scanning survey towards south side high wall benches

3.1 Results & Discussions:

The stability analysis of south side high wall benches from 835m RL to 680mRL with a platform of 25m at 735m RL found a factor of safety of 1.20 (Figure 8).The platform need to be provide a berm with broken materials along the crest. The berm serves the function of forming a 'ditch' between the berm and the toe of the slope to catch falling rocks. The platform berm for disturbed area of south side high wall should be 2.5m height by 6m width.

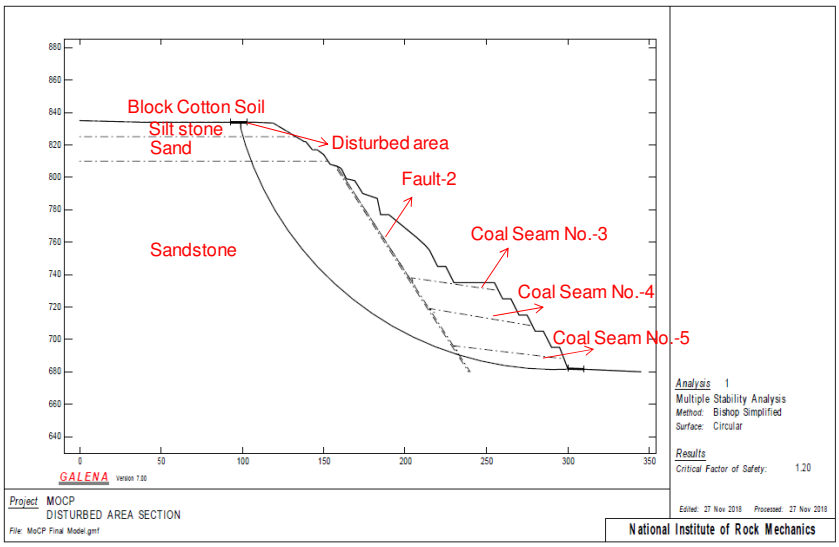

Figure 8 Disturbed area high wall slope stability analysis (NIRM Report, 2018)

The high wall benches should be maintained 10m height by 5m width with a slope angle of 65^0. The recommended top and bottom inter ramp angle is 42^0 and $48^0$with a platform of 25m at 735mRL, and final overall slope angle is 40^0 for high wall slope.

The recommended final slope for disturbed area of south side high wall benches is as shown in Figure 9. The part of the pit with final slope geometry should be backfilled immediately or there should not be any active mining near the final slopes. The final slopes should be formed at pit cessation stage.

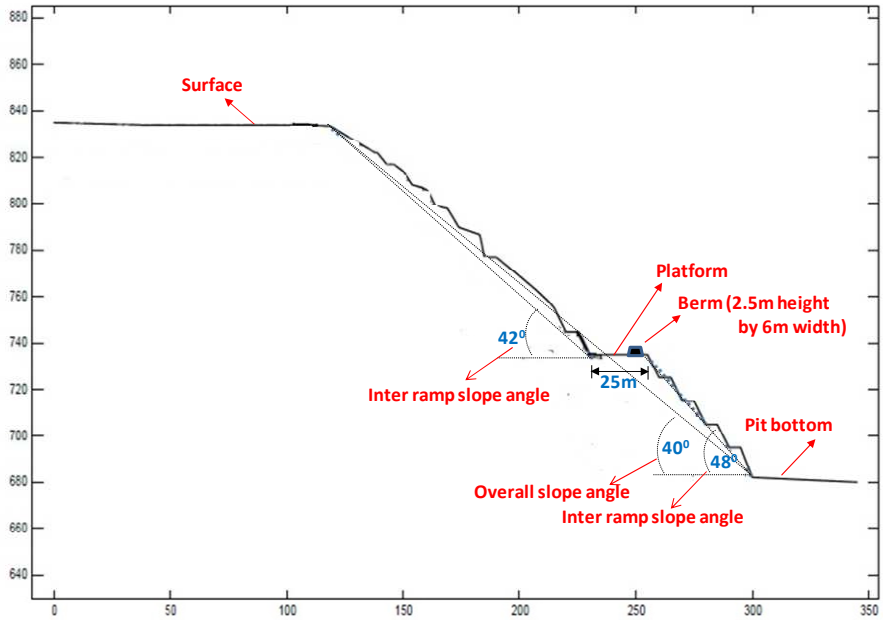

Figure 9 Final configuration of high wall benches (NIRM Report, 2018)

These recommendations are valid with well-developed drainage system and controlled blasting. If any observance is made for the occurrence of adverse hydrological condition or the remedial measures are not effective then this slope angle has to be corrected accordingly. The slope monitoring should be done for active/ ultimate mine slope to detect any instability well in advance.

The possible reason of the cracks and vertical subsidence is a fault was present in the disturbed zone. The steeper slope between 835m RL and 735m RL, weak and weathered lithology, improper drainage, and regular production blast in close proximity of fault would most likely have initiated cracks and vertical subsidence along fault. The chances of undercutting/ day lighting of the fault plane along steep dip of bench slope would be high. The day lighting fault plane under undrained condition cause slope failure in weak lithology.

The mapping of weak zones, faults and bedding planes should be a regular process in the mining area. The generated data will be used as an input parameter to reanalyze the stability to get the realistic picture of the mine slopes in different geo-mining conditions. It will help to detect any unfavourable conditions at different stages of mining at the earliest possible.

4. Conclusions:

On the basis of the geotechnical studies, the possible reasons of the cracks and vertical subsidence in high wall slope is because of steeper slope, weak and weathered lithology, improper drainage, and regular production blast in close proximity of the

fault. The chances of undercutting/ day lighting of the fault plane along steep dip of bench slope would be high. The day lighting fault plane under undrained condition cause slope failure in weak lithology.

The recommended top and bottom inter ramp angle is 42^0 and $48^0$with a platform of 25m at 735mRL, and final overall slope angle is 40^0 for high wall slope. The high wall benches should be maintained 10m height by 5m width with a slope angle of 65^0. The high wall slope design optimized with a view to maximise the production and concern towards conservation of the mineral with safe working conditions.

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