Continued Production from an Open Pit Coal Mine Under Unstable Slope Conditions - A Case Study

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Abstract

Soft and weathered overburden mass interbedded with a 1.0-1.5m thick white clay band, a 0.5-3.5m thick fire clay band immediately above the coal seam and ingress of rain water in the overburden mass were collectively responsible for the slope failure of a surface coal mine which did not have a history of such a failure. Bieniawski’s Rock Mass Rating (RMR) was observed to vary from a high of 45-53 at the old quarry area to a low of 14-19 near the failure zone on rise side. Post failure displacement monitoring revealed that rainfall of 28.45 cms had accelerated the movement rate upto 14 cm/day vertically and 4 cm/day horizontally in an area isolated by a major tension crack. This paper presents reasons of slope failure, results of ground deformation monitoring, geotechnical investigations and measures for continued but safe mining operations.

Key Words: Coal handling plant, Slope failure, Stability, Mine workings Displacement monitoring

1.0 Introduction

The mine lies in central India and is worked by a shovel-dumper combination for an annual coal production of 0.5 million tonnes (Fig.1). A small slide confined to the overburden mass above a white clay band occurred on June 19, 1995 on the rise side of the pit. A second slide involving around 1,10,000 cu.m. of overburden material occurred on August 11, 1995 threatened the stability of a Coal Handling Plant (CHP) and the mine workings. The slide material covered some 30,000 cu.m. of coal in the rib form (Fig.2).

Systematic field investigations including the displacement monitoring on and around the slope near the coal handling plant (CHP) started on August 16, 1995 were tailored to assess the causes of these failures and the stability status of the CHP and the mine workings. An emergency action plan formulated on August 18, 1995 for remedial measures consisted of (i) stabilisation of the slipped material and its removal from top of the coal seam by constructing a 1-1.5m wide and 1-1.5m high retaining wall of sand bags resting against cement grouted steel columns anchored into 0.5-1m deep holes in coal; (ii) displacement measurements with level, EDM and steel tape of stations constructed on the potentially unstable ground between the CHP and the pit-edge; (iii) construction of a drain to divert the rain water away from the CHP and the slide area; (iv) measures to control progressive development of tension cracks towards the CHP; and (v) to maintain a safe and uninterrupted coal production (Jhanwar et. al., 1995).

The first priority of the whole exercise was to maintain the safety of men and machinery
with continued production and the second priority was to ensure the stability of the CHP.

The investigations were also aimed at resolving the following key questions:
(i) Why any failure in this mine did not occur in the past?
(ii) Why did the failures occur on the rise side and near the CHP only?
(iii) Is the CHP safe? If not, should it be shifted?
(iv) Is it possible to continue coal production? If yes, with what precautions?
(iv) What should be the optimum slope design?

Fig.1 - Location of the mine, the failure zone and the workings

2.0 Geological Description

The mine lies on central part of the eastern limb of a regional anticlinal structure of Wardha valley coalfield. The 14.85 - 17.86m thick coal seam within the Barakar formation incrops
below 20-50m thick Kanthi formation. The inclination of the seam is about 1 in 4 due North - East. The dip of the seam flattens over south-eastern side. A number of thin carbonaceous shale bands are present within the upper part of the seam.

The overburden consists mainly of murrum, medium grained soft and weathered sandstone, carbonaceous shale and a fire clay band (Fig.2). The thickness of the fire clay band is 0.5-3.5m and lies immediately above the coal seam. Moderately jointed and highly decomposed sandstone lying above the fire clay band forms a major part of the overburden. A 1.0 - 1.5m thick white clay band lies above the sandstone. The soil mass above the clay band is composed of 1.0 - 1.5m thick clayey sand also known as murrum. Some discontinuous joints trending N 80º and dipping at 65º into the slope face on the rise side of the mine over-looking the working area were also present. Both the clay band and the fire clay band were dipping into the slope on the rise side and away from the slope on the dip side.

![Fig.2 - Cross section of the slide zone](image)

3.0 Geotechnical Investigations

Details of different joint sets and clay bands are given in Table I. Three joint sets are identified at site (Bieniawski, 1979).

Table I - Discontinuities detail

<table>
<thead>
<tr>
<th>Joint-1 = N16º/20º</th>
<th>Bedding joint, moderately to closely spaced, high persistency (10-20m), moderately open to open, with slightly rough face and slightly weathered at a few locations, oxidised hard filling, clay filling is noticed at places.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint-2 = N50º/77º</td>
<td>Critical joint, widely spaced, medium persistency (3-10m), moderately open (0.5-2.5mm) to open (2.5-10mm), planner with</td>
</tr>
</tbody>
</table>
slightly rough to smooth surface, wet joint near slide boundary.

Joint-3—N221°77′

Moderately spaced at (200-600mm), low persistency (1-3m), separation varying from tight to very tight (<0.1mm to 0.5mm), planar with slightly rough surface, hard coated mineral filling, dry.

Clay band:

White clay band of thickness ranging from 1.0 to 1.5m in the overburden mass; Fire clay band of thickness 3-3.5m.

Rock mass ratings RMR were estimated for both coal and the overburden in the existing pit area on both the rise and the dip side (Table II). RMR values were also assessed on the rise side rock mass extending from the old quarry area to the present mining area and the variation has been shown in Fig. 3.

Table II - Assessment of RMR and other parameters

<table>
<thead>
<tr>
<th>RMR Parameters</th>
<th>Coal</th>
<th>Sandstone on Rise Side of Present Pit</th>
<th>Sandstone on Dip Side of Present Pit</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQD</td>
<td>8</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Comp. strength</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Spacing</td>
<td>8-10</td>
<td>10-15</td>
<td>8-10</td>
</tr>
<tr>
<td>Condition</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Ground water</td>
<td>4-10</td>
<td>4</td>
<td>10-15</td>
</tr>
<tr>
<td>Basic RMR</td>
<td>45-60</td>
<td>39-44</td>
<td>50-57</td>
</tr>
<tr>
<td>Adjustment</td>
<td>-5</td>
<td>-25</td>
<td>-5</td>
</tr>
<tr>
<td>Final RMR</td>
<td>40-55</td>
<td>14-19</td>
<td>45-52</td>
</tr>
<tr>
<td>Rock Mass class</td>
<td>Fair rock</td>
<td>Very poor</td>
<td>Fair rock</td>
</tr>
<tr>
<td>Cohesion*</td>
<td>0.2-0.3 MPa</td>
<td>&lt; 0.1 MPa</td>
<td>0.2-0.3 MPa</td>
</tr>
<tr>
<td>Fric. angle*</td>
<td>25°-35°</td>
<td>13°-16°</td>
<td>25°-35°</td>
</tr>
<tr>
<td>Cohesion**</td>
<td>0.2-0.3 MPa</td>
<td>15°-18°</td>
<td>—</td>
</tr>
<tr>
<td>Fric. angle**</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* from RMR; ** from back analysis

4.0 General Description of Failure

Causes of the two failures and the sequence of events with their explanations have been given in the following paragraphs.

4.1 Causes of failure

Examination of geological features, overburden characteristics, ground water conditions and other site characteristics helped in identifying the following causative factors as responsible for these slides.

(i) A general depression of the ground surface overlooking the present mining area facilitated the ingress of rain water into the overburden mass.
(ii) Occurrence of whitish clay band,
(iii) Presence of upto 3.5m thick fire clay band immediately above the coal seam,
(iv) Occurrence of about 10m thick top soil in the slide area which is absent in the old mined out area,
(v) Occurrence of highly weathered sandstone in the overburden mass near the CHP,
(vi) Presence of some discontinuous joints daylighting into the rise side slope face,
(vii) Rainfall augmenting the ingress of water into the overburden and reducing the shear strengths of the clay band and the fire clay band.
(viii) Ground vibration due to blasting, CHP and heavy traffic nearby may have some contribution.

4.2 Sequence of failures and explanations

The failure sequence and the explanations are given in the following paragraphs.

(i) Depressed ground profile on the rise side slope of the pit area helped ingress of rain water into the top soil.
(ii) The clay band prevented the percolation of water into the sandstone. The clay band lost its shear strength and initiated a planar failure which transformed into a circular failure surface in the top soil.
(iii) Once the top soil and the clay band failed and slipped into the pit, the rain water started entering into the sandstone below the clay band.
(iv) The fire clay band prevented the downward percolation of the rain water into the coal seam. The fire clay thus got lubricated and triggered a second slide. Again the slide surface was a combination of a planar surface along the fire clay band and a slip circle above it in the sandstone.
(v) The old mine area remained free of slides as the overburden in the old mined out area was fair as indicated by RMR of 45-52. It gradually reduced to very poor as indicated by RMR of 14-15 on the rise side in the existing pit area (Fig.3).

Fig. 3 - Deterioration of rock mass towards slide zone
5.0 Displacement Monitoring

5.1 Monitoring network

Forty seven stations were installed for measuring both vertical and horizontal movement of the ground surface near the CHP (Fig. 4). Due to very limited time available, 0.6m long pieces iron rods of 25mm diameter were used for monitoring stations. A length of 0.3 to 0.45m of the iron rod was hammered into the ground surface and the rest was kept protruding outside.

Levelling on top of these iron rod stations and change in distance between them was measured. Levelling was done to determine the change in reduced levels of different stations. For this purpose, an existing permanent station with known reduced level was chosen as a bench mark so that absolute vertical displacements can also be estimated. The positions of all the monitoring stations, the CHP and the tension crack are shown in Fig. 4. An Electronic Distance Measuring instrument (EDM) was stationed on a reference station (J1.1) on the dip side across the mine to measure the horizontal distance and its change in respect of the monitoring stations.

In addition to these measurements, day-to-day information on ground strain variation in the critical zone near the CHP was computed as shown between stations named as \( A_i \) through \( A_{10} \), \( B_i \) through \( B_{10} \), \( C_i \) through \( C_{10} \), \( D_i \) through \( D_{10} \), \( E_i \) through \( E_{10} \), \( F_i \) through \( F_{10} \), \( G_i \) through \( G_{10} \), \( H_i \) through \( H_{10} \), \( I_i \) through \( I_{10} \), \( J_i \) and \( K_i \).

Development of new tension cracks along the rise side of the pit near the CHP and elongation of the cracks were also observed to evaluate and identify the progressive risk factor in this zone (Fig. 4).

![Fig. 4 - Plan showing the locations of monitoring stations, CHP & tension cracks](image)
5.2 Results of monitoring

Analysis of the displacement measurements over 47 monitoring stations and opening of tension cracks has shown that the area was stable up to August 28, 1995 when the horizontal displacement rate was 0.5 cm/day. A heavy downpour from August 29 to September 1, 1995 increased the horizontal displacement rate up to 4 cm/day. Similarly, the vertical displacement rate remained at 1 cm/day up to August 28, 1995.

The measurements also established that the heavy rainfall of 28.45 cms from August 29 to September 1, 1995 was the main reason for accelerated movement of approximately 14 cm/day vertically and 4 cm/day horizontally which caused the detachment of an area measuring 40 m along the pit edge and 10 m across it and isolated by the first major tension crack. The maximum vertical displacement/ subsidence over this period was 69.45 cm recorded at A4, C5 and D5 stations respectively. The variation with time is shown in Fig. 5.

Continued visual observations revealed the existence of 3 more tension cracks running almost parallel to the pit edge and isolating the detachable blocks at a distance of 5-10 m.

The maximum horizontal elongation between different stations as measured by steel tape was 13.7, 18.0 and 16.7 cm between station pairs E4-E5, A4-B4 and B4-B5 respectively (Fig. 6). Regression analysis has shown that the following semi-logarithmic relation best fits the observed displacement behaviour with correlation coefficient more than 90 percent.

\[ \log(u) = A \times t + C \]

where, \( u \) = displacement, cm 
\( A = 0.07-0.12 \)
\( C = 0.08-0.43 \)

![Graph showing vertical displacement vs time](image)

**Fig. 5 - Vertical displacement vs time**
6.0 Suggested Remedial Measures

The immediate and the long-term remedial measures for the safety of the CHP and the workings and continued mining are given in the following paragraphs.

6.1 Immediate measures

It was suggested not to mine the coal rib ABCD providing toe resistance to the slid debris but continue mining coal along the face AF (Fig. 7) with a restricted face width of 35m till the 1995 monsoon was over.

For the purpose of controlling further downward movement of slid debris under gravity and to allow continued mining activity near this zone, a retaining wall of sand bags of 1.5-2.0m height resting against steel angle posts anchored into coal was constructed.

It was also suggested to exercise controlled blasting upto 100m from the CHP line. Shifting of the CHP was suggested in the event of extraction from coal rib near the failure zone as the displacement measurements indicated that the slide influence was extending towards the CHP.

6.2 Long-term measures

Following long-term suggestions were made to the mine management:

(i) To prevent recurrence of such failures in future, it was suggested to maintain three benches, each with approximately 8m height on the rise side pit limit keeping the overall slope angle not exceeding 40 degrees.

(ii) Surface drainage should be arranged to minimise water ingress into the overburden mass during rainy season.
iii) Monitoring of displacements with level and EDM in and around the rise side slope and facilities like the CHP etc. should be continued. Similarly, a continuous watch should be kept on the development of tension cracks in the area.

Fig. 7 - Suggested mining strategy
7.0 Conclusions

The following conclusions are drawn:

(i) Presence of a clay band within the soft and weathered overburden mass and a fire clay band immediately above the coal seam, joints and bedding planes dipping into the slope and ingress of rain water into the overburden played a key role in triggering failures on the rise - side of the pit.

(ii) Dip-side slope continues to remain stable mainly due to the presence of joints dipping away from the slope face and the material being compact and unweathered unlike the rise-side slope.

(iii) The old mine area did not have a history of slope failure due to a relatively better overburden material and absence of soil top.

(iv) Post-failure displacement monitoring established that the rainfall accelerated the movement rate upto 14 cm/day vertically and 4 cm/day horizontally before the monitoring points were destroyed.

(v) The instability zone was moving towards the CHP as evident from the development of tension cracks. Extraction of the coal rib was likely to add to the instability of the CHP. Since the CHP was a permanent structure and further rainfall was not ruled out so it was suggested to shift the CHP away from the existing location.

(vi) The case history has established that appropriate geotechnical studies, quick stability assessment and continuous displacement monitoring can not only help continued mineral extraction in a safe way even under unstable slope conditions but also assist in identifying long-term and cost-effective safety measures even if detailed laboratory and field geotechnical studies are not possible due to shortage of time.

8.0 Acknowledgement

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9.0 References
