Oblique Longwalling of a Developed Coal Seam

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Abstract: Field observations of mining induced stresses indicated a strong influence of overlying strata property over stability of a coal pillar facing goaf line under massive roof strata. Squat pillars, designed as per the norms of ICMR (Indian coal mines regulation) 99, are found to be stable against a caving goaf. But splitting of pillars in advance of the extraction line during conventional method of depillaring creates a threat of overriding under massive roof strata. Value and nature of mining induced stresses on pillars, obtained by a long term field study, suggest that splitting of pillars in advance of a depillaring face should be avoided. Addressing problems related with liquidation of a developed coal seam under massive roof strata, a mining method, may be called oblique longwalling, is introduced which may be suitable for mechanised depillaring of a developed coal seam under above mentioned geominning conditions.

Keywords: coal pillars, abutment loading, depillaring and roof strata.

Introduction

More than 70% of the total coal reserve of India is workable by underground mining while, at moment, around 70% of the total coal production of the country is coming through opencast mining. The present techno-economic scenario of the coal industry supports this reverse trend of coal production but, at the same time, the scope of underground mining methods is being enhanced as the coal production target of the country is being increased every year to meet the growing demand of energy. Unfortunately, the amount of coal reserve in virgin seams is very little in the country. Indian coal industry adopted one of the simplest way (development of pillars) of coal production and so, as a result, most of the coal seams are extensively developed and standing on pillars. Suitability of the available technical support and know how to maintain required level of production and safety and low capital investment favoured the coal production strategy by way of formation of pillars. Now, development of most of the coal seams is complete and the industry is looking for the huge amount of coal locked in pillars. Depillaring of the developed coal seams is facing serious problems due to the presence of massive overlying strata, shallow depth cover and poor engineering support. Violent roof failure during liquidation of coal seams under massive roof strata (Gupta and Ghose, 1992; Singh and Singh, 1990) has always been a serious challenge for underground winning of coal from Indian coal fields. Depillaring of a developed coal seam under massive roof strata is rather more difficult due to continuous threat of

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Around 900 million tonnes of coal are locked in pillars at Bharat Coking Coal Limited (BCCCL) only while Coal India Limited (CIL) owns six other such subsidiaries and most of them have similar reserve of developed coal seams.
overriding of pillars. Under such geominning conditions the design of the natural support: coal-pillars and a complete layout of the associated depillaring coal face is an important issue to optimise production, productivity and safety.

![Diagram of pillar and load](image)

**Figure 1**: Failure of tributary area load method after cantilever formation.

Assessment of safety factor of a coal pillar, basically, requires two parameters: (1) strength of the pillar and (2) load on the pillar. In fact, calculation of actual load on a pillar is more complex than the determination of the pillar strength. An empirical relationship has been developed by CMRI (Sheorey, 1992) to assess pillar strength considering large number of failed and stable cases of different coal mines of the country. Tributary area load method is widely used by the practising mining engineers to assess the amount of mining induced stresses. Tributary area method provides good estimation of the mining induced stress for symmetrical excavation under stable overlying strata condition. Winning of pillars increases span of excavated area resulting fall/breakage of overlying strata where the application of tributary area method is very difficult (Figure 1). Indian coal mines regulation (ICMR) 99 (ICMR, 1957) gives clear idea about the size of pillars (Table 1) under different geominning conditions but the regulation related with extraction of pillars, unfortunately, does not provide such information. The guidelines of depillaring is described in ICMR 100(2) which, in fact, provides more emphasis on safety. ICMR 100(2) states:

"The extraction or reduction of pillars shall be conducted in such a way as to prevent, as far as possible, the extension of a collapse or subsidence of the goaf over pillars which have not been extracted."
Conventional method to win a pillar is splitting, stooking and, finally, slicing of the stooks (Figure 2). During slicing of the stooks, it is very difficult to judge the dimension and frequency of the ultimate rib to be left inside the goaf. This problem further complicates with the advance of extraction line due to dynamic loading initiated by caving of the massive roof strata. Undoubtedly, the nature and value of support resistance offered by a rib is difficult to be achieved by any other system of support. The chances of high amount of roof convergence during installation period of the conventional support system can effectively be controlled by a natural support: stook/rib. For a subcritical span of the extraction, the good support resistance efficiency of a rib plays positive role for mining operation at face. But, as soon as the width of extraction becomes critical, these ribs face a situation of crushing leading to a chance of dynamic loading on face. This behaviour of stooks increases the intensity of dynamic loading which is not desirable for the depillaring operation under massive roof strata. In the beginning of a depillaring panel clean sweep extraction of few pillars\(^2\) may be followed by formation of ribs. The design of a suitable rib against roof strata of different strength may be done according to the knife edge method. However, enmasse caving of roof rock mass of Indian coal fields has limited the success (CMRI Report, 1987) of this method.

\[\text{Figure 2: Layout of a conventional depillaring panel of Indian coal mines.}\]

\[^2\text{Depending upon the caving characteristic of the overlying rock mass.}\]
Table 1: Pillar size variation as per ICMR 99, 1957.

<table>
<thead>
<tr>
<th>Depth covered (m)</th>
<th>Pillar size (centre to centre) for different roadway widths (B), m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B=3.0</td>
</tr>
<tr>
<td>Below 60</td>
<td>12</td>
</tr>
<tr>
<td>60 to 90</td>
<td>13.5</td>
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<tr>
<td>90 to 150</td>
<td>16.5</td>
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<tr>
<td>150 to 240</td>
<td>22.5</td>
</tr>
<tr>
<td>240 to 360</td>
<td>28.5</td>
</tr>
<tr>
<td>Above 360</td>
<td>39.5</td>
</tr>
</tbody>
</table>

In this paper, a simple idea of depillaring; may be called oblique longwalling of a developed coal seam, is introduced. On the basis of field observations and simulation results, the splitting of pillars in advance of a depillaring face is found unsuitable and unfavourable under massive roof strata. Discussing the problems of a depillaring face under massive roof strata this paper presents two case studies to show the influence of overlying roof strata on nature and amount of the mining induced stresses in and around a depillaring face. Field studies indicated that special care must be taken to arrest the overriding problems during depillaring under massive roof strata. Observed value of mining induced stress (vertical) is used as a basis to replace conventional depillaring consisting splitting, stooking and slicing of pillars by oblique longwalling.

Field observations

A number of depillaring coal faces were monitored to visualise the influence of overlying roof strata on nature and amount of mining induced stresses and the results are discussed in the paper of Singh et al., 1996. Results of the two field studies of induced stresses (vertical) are presented below to show the influence of overlying roof strata on the pillar stability. Roof strata of Sonachora seam (Lachhipur colliery) was massive sandstone while the roof of Rana seam (Girmi Colliery) was weak and laminated (Figure 3).

![Figure 3: Upper stratigraphic column of the two coal seams.](image-url)
Girmit colliery

The study panel of Girmit colliery (Rana seam, 3m thick) consisted of 39 pillars each of 18.3m x 18.3m (corner to corner) in three rows. Average depth cover of the panel was 54m and overlying roof strata was very weak and easily cavable consisting thin layers of shale and sandstone. The extraction of the pillars was done by splitting and slicing. A pillar was split into two stooks by a 4.2 m wide level drive followed by two slices (each of 5.5m width) of each stook and leaving a 1.5m wide rib against the caved goaf.

Due to presence of the multilayered easily cavable roof, depillaring in the panel didn't experience any strata control problem. The maximum observed value of mining induced stress (vertical) was 1.6 MPa (Figure 4) over the stook when adjacent stooks were extracted. The caved goaf of Girmit colliery exerted an influence up to 20m ahead of the face. It is evident from the plot of Figure 5 that the core of the stooks facing goaf line did not experience excessive abutment loading. Weak overlying roof strata was the main reason behind the problem free depillaring of the panel which adopted conventional pillar liquidation method: splitting, stooking and slicing of the stooks.

![Figure 4: Variation of induced stress with face position (Girmit colliery).](image)

![Figure 5: Stress concentration over stooks (Girmit colliery).](image)

Lachhipur colliery

There were 43 pillars (19.5m x 19.5m, corner to corner) in the study panel of Sonachora seam (3.4m thick) of Lachhipur colliery. Liquidation of these pillars were planned with hydraulic sand stowing due to massive overlying roof strata and the presence of another developed coal seam (Lower Kajora) at 34 m height from this Sonachora seam. Depillaring started with splitting of a pillar into four stooks (each 7.5m x 7.5m, corner to corner and bord width 4.5m) by level and dip rise drivages, maintaining diagonal face line and advancing from dip to rise. First two and half pillars (1500 sq. m.) were worked with
stowing but, due to lack of sand, another five and half pillars (3200 sq. m.) were, first, split to stooks and, thereafter, stooks were extracted leaving 2m thick fender against goaf without stowing. At this juncture extraction of stooks was stopped but nine and half pillars (6800 sq. m.) above the extraction line were split and the stooks were left intact (Figure 6) without stowing. After this much working in the panel the overlying strata destabilised and local roof fall took place inside the goaf. Although working (stooking of pillars) was stopped in the panel, the roof movement caused crushing of first row of stooks followed by major roof fall up to the goaf line. The crushing of stooks, in rhythmic sequence, continued until it reached the last row of stooks formed against the squat pillars. The remaining 26 pillars of the panel (14500 sq. m.) were extracted with stowing and without any overriding problem as shown in Figure 6.

![Diagram](image)

**Figure 6:** Summary of mining propositions of the panel.

The development of mining induced stresses (vertical) against caved and stowed goavcs are shown in Figure 7. The caved goaf exerted an influence up to 50m advance of the face while the range of influence reduced to 40m against the stowed goaf. Dynamic loading after crushing of the front row of stooks caused extensive damage and overriding which could only be arrested by the last row of stooks falling under the cover of solid pillars of the panel. A stook of 7.5m x 7.5m (corner to corner) was considered quite competent for 100m depth cover but the presence of massive roof strata caused heavy abutment loading. The core of the pillar got crushed (Figure 8) after experiencing 13.3 MPa induced stress. The *in situ* strength of a 30 cm cube of Sonachora coal seam was only 8 MPa but the core of a stook of 7.5m x 7.5m (corner to corner) probably acted under a confined triaxial state.
Figure 7: Variation of induced stress with face position (Lachhipur colliery).

Figure 8: Stress concentration over stooks (Lachhipur colliery).

Discussion

It is clear from the above mentioned field studies that the nature of overlying strata is responsible for overriding of pillars/stooks during depillaring. Splitting/stooking of pillars in advance of a depillaring face under massive roof strata may further increase the intensity of the problem. Dynamic loading during break of the beam formed by massive roof strata of Sonachora seam caused overriding of pillars/stooks. The presence of large number of stooks due to splitting of pillars ahead of the face could not provide the required support resistance resulting crushing of all splittled pillars except the last row of stooks which were, in fact, under cover of the solid pillars from behind (Figure 6).

To assess safety of mining structures under the observed maximum value of induced stress, strength of the pillars were calculated using CMRI formula written as:

\[ S = 0.27 \sigma_{\varepsilon} h^{-0.34} - \frac{H}{150} (0.6 + \frac{150}{H}) (\frac{W}{h} - 1) \] MPa \hspace{1cm} (1)

where, \( S \) is strength of pillar, \( \sigma_{\varepsilon} \) is strength of one inch cubes of coal (MPa), \( h \) is extraction height (m), \( H \) is depth of roof cover (m) and \( W \) is pillar width (m).

For the maximum observed value of induced stress (13.3 MPa) in the panel, the safety factor of the stooks was 0.69 only. While for the same value of induced stress the safety factor of the squat pillar (designed as per the norms of ICMR 99\(^3\)) was 1.23. A general nature of most of the pillar strength formulae shows sharp decrease of pillar

\(^3\) Generally, ICMR has given stable pillars for Indoan geo-mining conditions.
Figure 9: Influence of width height ratio over strength of a pillar (after Gale, 1992)

strength (Figure 9, after Gale, 1992)) with the decrease of its size. Whereas the conventional depillaring adopts splitting and stooking of pillars ahead of the extraction line resulting poor support density in and around a depillaring face. The effect of w/h ratio on pillar strength is considered to reflect confinement distribution developed within the pillar. In fact, compressive strength of brittle materials, such as coal, is enhanced for higher value of w/h ratio as the simultaneous yielding of pillars edge produces spontaneous confinement to the pillars core. Basic mechanistic explanation of this confined core concept may be found in Wilson (1983) while the enhanced version of this concept is presented by Salamon (1992). Remedy of the overriding of stooks under massive roof strata is thought in terms of practical application of this confined core concept and so the depillaring method suggested here avoids splitting of the pillar.

Estimation of pillar load

Both, the theory of elasticity and the principles of soil mechanics do not completely explain the behaviour of coal measure formation and hence, a reliable simulation of the geo-mining condition of a field in mathematical or physical models becomes an extremely difficult task. Empirical formulation, based on in situ measurements, is an accepted way to estimate rock mass behaviour and, therefore, a detailed field study was conducted (Singh et al., 1996) to visualise the development of abutment loading on the coal pillars of shallow depth cover. On the basis this field study, the best fit equation for ultimate induced stress ($S_u$) over a coal pillar is given as:

$$S_u = 0.0033I + 0.059H - 9.85 \text{ (MPa)}$$ \hspace{1cm} (2)

where, $H$ is the depth cover (m) and $I$ is cavability index (Sarkar, 1987) which represents the influence overlying roof strata on the development of the induced stress.

Range of influence ($R$) ahead of a depillaring face may be estimated by the expression:

$$R = 0.106I + 0.1H - 12.45 \text{ (m)}$$ \hspace{1cm} (3)

Problems like above discussed case of Lachhipur colliery.
These expressions were derived on the basis of limited field observations of Indian coal fields so the availability of more field data may further improve the reliability of these relationship with possible modifications.

*Oblique longwalling*

It has been shown that splitting of pillars ahead of a depillaring face under massive roof strata may not be a suitable choice. If we replace the conventional depillaring method by oblique longwalling of pillars (Figure 10), keeping the extraction line diagonal to the galleries, then the chance of overriding can be arrested up to large extent. Due to presence of galleries along dip-rise and strike directions, face line has to be diagonal. Pillar liquidation starts from dip to rise so the two deepest corners of a panel are available to start with a diagonal line of extraction. Out of these two corners, one corner may be selected according to the presence of geological discontinuities in the roof strata.

![Figure 10: Layout of an oblique longwall face to win a developed coal seam.](image)

One of the main problems of this method may be the design of support in and around the depillaring face. Investigations on different simulated models suggested a particular configuration of line of extraction and support system. A patent application with the details of this mining method is under consideration. This method has scope to adopt most of the mining machinery for improved productivity and safety. As the requirement of support density and pattern will be similar to that of a longwall face, the cavability index based design (Sarkar, 1985) should work without problem. Broken nature of mining due to conventional depillaring will be replaced by a clean and longwall type face. This type extraction will improve production, productivity and safety under moderate roof strata. Support density estimation norms for a longwall caving face under a roof cavable with extreme difficulty (Sarkar, 1985) are not well proved. Application of oblique longwalling for extremely massive roof strata may face, relatively, more difficulties due to the galleries in advance of the face. Under such geo-mining conditions, a different method of pillar liquidation (Sheorey et al., 1995) may be adopted at the cost of recovery and productivity.

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5 Which creates complex and dangerous structural configuration during conventional depillaring.
Conclusions

Increasing coal production strategy of Indian coal mining industry is dependent upon the success level of exploitation of coal seams standing on pillars. Continuous threat of overriding of pillars/stooks and low productivity are two major problems being frequently encountered by the coal industry of the country during conventional method of depillaring under massive roof strata. Mechanisation of a depillaring face is an urgent need for effective winning of huge amount of coal locked in pillars. Oblique longwalling of a developed coal seam under moderate roof strata may be an effective solution to arrest overriding of stooks, standing in advance of the extraction line, and to increase recovery and productivity through mechanisation.

References


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