A Method for Depillaring of Thick Seams Standing on Pillars with Cable Bolt Support

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The studies were undertaken to maximise the safe recovery from the thick seam of Chirimiri area at NCPH mine, standing on pillars and improve production and productivity by way of modified method of mining. Under the geo-mining conditions of the mine, several options were reviewed in depth for their suitability and the final choice was put to depillaring with cable bolt as high roof support. The roof coal band of 3.5 to 5.0 m thickness was reinforced such that the bolt remained anchored at least 1.5 m within the sandstone roof. The top section coal was thereafter recovered by systematic slicing in one or two passes, with recovery around 75 per cent. The hanging type support helped in keeping the floor free of obstruction for the movement and manuevering of SDL. The efficacy of the roof support was studied in the mine, wherein 19-22 mm diam old haulage ropes of 5.0 to 6.5 m length were used as cable bolts. The experiment was repeated in 4 panels of 22-52 pillars and under 33-256 m depth cover. The method first of its kind, facilitated depillaring of seams of 6 to 8 m thickness, improved the strata condition, safety, and achievement in respect of conservation, production, and productivity. The method improved the level of recovery from 40 to 75 per cent, productivity from 1.4 to 2.8, and production from 3000 to 13000 t/month while the cost of production decreased from Rs. 443 to 417 with marginal investment towards mechanisation for coal loading, drilling, and grouting of the cable bolts. The cable bolts installed with over 8 t anchorage to the immediate roof served as support to the exposed roof and ensured the safety of the workers and the workings.

Introduction

The NCPH mine of Chirimiri area under SEC Ltd, developed 6-8 m thick No. 3 seam extensively on pillars. The depillaring was limited to only 4.8 m along the floor; leaving rest of coal within the goaf with the level of recovery invariably below 40 per cent due to non-availability of effective long supports. Moreover, the conventional supports in form of a jungle of props and chocks obstructed the SDL operation. Due to weak parting along the roof, coal band caved up to full height even in early stage of depillaring when efforts were made to withdraw the easy coal under unsupported roof. Fallen coal in the goaf frequently caused potential danger of spontaneous heating.

In view of the problems, the Central Mining Research Institute (CMRI) undertook the exercise developing suitable method of extraction with better recovery, conservation, and safety. The method deploying a piece of old haulage rope as cable bolt was developed to keep the roof supported during mining irrespective of the working height. The critical inputs to the experimental trial of the method were: (a) Drilling of long holes in coal/sandstone roof, (b) Full grouting of the cables ensuring sufficient anchorage strength, and (c) Stability of the cable bolts even after blasting of the roof coal. The system named Chirimiri Method of Mining was conceived and tried to mitigate support problems during thick seam mining at NCPH mine. The studies cover the reliability of the cable bolts as support, its impact over caving and settlement of the goaf with due regard to safety, conservation, production, productivity, problem of spontaneous heating and overall economics.

The basin has five coal seams developed in Barakar stage including 6-8 m thick No. 3 seam having 9.30 mt of coal logged in pillars at NCPH mine. The seam No. 3 is overlain by a thin band of shale and 10 cm thick layer of graphite. This is followed by 3-4 m thick coarse sandstone poorly laminated and massive in character. The formation on the whole appeared to be competent and stable. The immediate roof could be 3.0 m thick likely to cave after 30-35 m advance of the face irrespective of the cable bolting. The seam was developed on pillars of size varying from 25 to 30 m centre to centre along the floor up to 3 m height leaving coal/shale/sand stone band in the roof. The developed pillars were divided into artificial panels by the fire proof stoppings and the number of pillars within the panels varied from 22 to 50 pillars.

Conventional Mining Method

Three panels within the old lease mine were depillared by conventional method of splitting and slicing. During the final extraction, the pillars were split by level drivages fol-
followed by slicing up to 4.8 m height. The slicing method was associated with the problem of heightening of roof due to progressive failure and/or separation of the coal band along the graphite roof. As a result, initially, high recovery of up to 65 per cent was reported within a first few pillars followed by weighting and roof fall in the subsequent pillars when the recovery dropped up to 30 to 40 per cent. The support of even 4.8 m high roof was a real problem in view of non-availability of large size timber props. The ribs left on either side of the slices, were subjected to high stress due to slow winning. Resultant side spalling added new dimensions to the method of extraction of the developed pillars and invariably the workings had to be abandoned midway with very poor recovery, low production and productivity.

The depillaring operation was adopted by conventional cycle of drilling and blasting and manual loading of coal on tubs. The loading of the coal was done under poorly supported roof due to ineffectiveness of large size props and non-availability of such props in sufficient number. Scrapper was subsequently introduced at a stage to improve the safety of the workers when only few of them were exposed to such hazards during anchoring of the scrapper and drilling of roof coal. The method under ideal condition yielded 40 to 45 per cent recovery with production level below 200 t/d and the productivity around 1.4.

**Mining Concept with Cable Bolts**

The miners were familiar with slicing method of pillar extraction mechanised with SDL for loading and pit props as the support.

Main problem in the exploitation of a thick seam was the support of high roof so essential for the safety of the workers engaged for lifting of the blasted coal. The use of wire ropes under tension while reinforcing the roof was more efficient as a support and cost-effective with no scope of flexure or buckling. The suspended support hanging in the roof kept the floor free for the movement of the workers or the loading machines. It was decided to use full column grouted steel ropes as cable bolts for advance support of the immediate coal band in the roof and also the immediate sandstone roof. Its application, however, was fraught with the following operational problems:

(i) Drilling of a large number of long vertical holes through coal and sandstone interface.

(ii) Installation of 6-8 m long rope in the roof.

(iii) Reliability in the installation and grouting of long cables for adequate anchorage.

(iv) Impact of the blasting of the coal roof over the anchorage of cable portion left over in the immediate roof.

(v) Chances of delayed caving of the reinforcement roof.

**Drilling of Holes for Cable Bolting**

In the trial stage of the cable bolting, long holes in the roof were drilled manually using normal coal drills where a crew of 4 persons could drill 2-3 holes in a shift. The experiments of the cable grouting and blasting of the immediate coal roof revealed 50 per cent drop out as their grouting was confined within the coal roof. The anchorage of some of the cables was over 10 t after the installation and anchorage remained over 10 t even after blasting of the roof coal. The preliminary trial revealed the possibility in respect of the following: a) Possibility of getting adequate anchorage in holes of desired length and b) Anchorage remained unaffected by blasting of roof coal.

The problem was solved by the co-operation of the local engineers when a hydraulic drill was assembled; using the SDL power pack at Korea workshop, SECL. The system is shown in Figure 1(a), comprising hydraulic system and hoses connected to the drilling machines for lifting with the help of a chain drive and a drill mounted on pinion. The system was able to drill 12 vertical hole of 6-8 m length including 1.5-2 m within sandstone roof in a shift. Later, tyre mounted assembly of drilling was fabricated for the purpose of mobility of the machine, as shown in Figure 1(b).

**Grouting of Cable Bolts**

The arrangement for full column grouting of the cables is shown in Figure 2. The holes of 43 mm diam were drilled across the coal band and 1.5 m within the immediate sandstone roof. The mouth of the hole was rimmed to 80 mm diam over 20 cm length by improvised coal drilling bit. The holes in general, were kept vertical. The system improved and modified in stages served fairly well except the mobility of the system which has to be shifted from place to place manually.

The rope of the desired length was inserted in the hole along with: (a) vent tube of 5 mm diam and (b) grouting tube of 12 mm diam. The assembly was held-up in position by a tapered circular wooden block of 5 to 10 cm
and length nearly 15 cm. The block had three holes to accommodate the rope (22-25 mm diam), vent hole (5 mm diam) and a grouting hole of 10 mm diam. The wedge-shaped block was tightly fitted at the mouth of the hole. The breathing and the cement injection tubes were loosely tied to the rope keeping the inner end of the breathing tube up to the end of the hole.

The cable assembly was inserted in the hole with one end of the vent tube dipped in water bottle. The gout mix comprising of cement, water and hardcrete in the proportion of 50 kg, 30 l and 2 l, respectively, was prepared in the grouting tank attached to a compressor for injecting the slurry (Figure 3). The grouting assembly was mounted on another trolley for site injection through hose.

The injection tube was set nearly 15 cm below the end of the cable and as soon as the vent tube set at the extreme end gave indication of slurry flow; the grouting tube was withdrawn. In order to avoid ungrouted socket; injection was continued even during the withdrawal of the grouting tube. The vent tube was pulled out and the total operation was completed within 2 min.

As a modification; the grouting tube was inserted close to the hole mouth inbye wooden block and the slurry was pushed upward up to the end of the hole. With the indication of full column filling; it was taken out and the open end was plugged by jute/cotton waste. It was possible to grout 12-18 holes in a shift in case the setting of the grouting assembly was not to be changed. A crew of 4 persons could pull the trolley; arrange the grouting set-

Fig. 1 — Hydraulic drilling machine developed at Korea Workshop
up and grout 12 holes in a shift. The grout started setting within 30 min and gained full strength within 4 h.

Anchorage Testing of the Cable Bolts

A new haulage rope 6/6/1 FMC (Fiber Main Core) steel wire rope of 20 mm diam is known to sustain 20 t ultimate load under tension. With the use, rusting and pitting and loss in lubrication, its ultimate strength dropped up to 15 t. It was decided to use the rejected rope as cables for the bolting of the high roof for depillaring of the thick seams. The rope pieces of the length equal to the thickness of the roof coal band +1.5 m +0.10 m, preferably, cut by gas were used for the purpose of roof grouting. The cable bolts installed in a development gallery were tested for their anchorage strength after 8 h. The roof coal up to the full height was blasted down in stages when only 1.5 m of the cable was anchored to the immediate sandstone roof. The anchorage of the grouted portion was over 6 t even at this stage. As the cable bolts were the only support of the high roof; efforts were made to ensure hundred per cent reliability. The efficacy of the bolts as a support to high roof was undoubtedly established before the depillaring operation was suggested on experimental basis.

Roof Coal Winning

The coal band of 3-5 m thickness left on the roof was blasted down in stages during depillaring. The thickness of the roof coal band under the condition of the NCPH mine varied within 3 to 5 m which required nearly 1 kg explosive per hole, and total effective length of the cartridges nearly 1 m only. For the purpose, the blasting practice with Uniring Cord and Soligex explosive was recommended. The holes as such has to be deck charged as shown in Figure 4. The detonating fuse has to pass over the spacers and ensure detonation of all the cartridges. Nearly 6 kg explosive is required in case cyclic
Detonating fuse inside the spacer

Detail A

Permitted explosive in jumbo cartridge

Fig. 4 — Charging and stemming arrangement for a long hole blasting

 believers inspected after the blasting and dressing were found in a good condition with exposed wire ropes hanging for a height of 1.5 m and a clean cut at 1.5 m horizon in the roof.

In some of the holes, 0.6 m thick layer of coal was intentionally left after blasting. It remained attached with the roof in the area supported by cable bolts. It was interesting to note that in the adjoining area not supported with cable bolts even 2 m thick layer of coal came down in the second round of blasting.

System of Roof Support - Proposal

The crux of depillaring exercise in thick seams has been efficient support system effective even in high workings. The supports set in-between roof and floor worked under compression, the strength of which dropped with height due to buckling in the case of steel and tapering in the case of timber supports. It was therefore planned to use the cable bolts as support using steel ropes of reliable and uniform strength under tension. The slicing option with fender against the goaf was preferred for depillaring and support for different locale was suggested as follows:

(i) Support of Development Galleries

All the development galleries are reinforced by cable bolt support by three rows at 1.6 m interval between the rows and the bolts intersecting the coal band and additional 1.5 m within the immediate sandstone roof.

(ii) Support of Splits

The splits being driven to low height along the floor will be supported by pit props immediately after blasting of the face. The roof will be reinforced immediately thereafter by 3 rows of cable bolts installed 1.6 m apart and bolts in the same row 1.2 m apart. The splits were supported by pit props 1.2 m apart keeping 3 m clear space in-between the pit props to facilitate movement of the SDL.

(iii) Support of Slices

Slices were supported by pit props on both the sides of 1.2 m interval followed by cable bolts at 1.6 m interval. Indicator props made of two pieces of steel pipes joined by wooden pieces were installed in the rib side of a slice to indicate the status of rib loading. Ledges of roof coal were supported by bolts and W straps.

Fig. 5 — Junction support with cable bolts / rope switching

The spacing of the holes drilled for blasting varied between 0.7 to 1.0 m and hole was charged by three cartridges of Indocol explosive weighing 140 g only. The remaining empty length of the hole was stemmed tightly and 10 such holes were blasted in one round. The cable bolts inspected after the blasting and dressing were found in a good condition with exposed wire ropes hanging for a height of 1.5 m and a clean cut at 1.5 m horizon in the roof.

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(iv) Support of Goaf Edges

The goaf edges were supported by skin-to-skin steel chocks with wooden lagging in the upper portion and a row of pit props outbye at 1.0 m interval, in addition to cable bolts. The height in this zone was retained to normal development height and no roof could be blasted in this zone.

(v) Support of Juncions

The junctions were supported by long cable bolts, a pair of rope stitched across through eye bolts of 1.7 m length installed at 1.6 m interval along the rope. For the stability of the roof under the condition, a coal stump was left on the goaf side (Figure 5) in the corner with rope end anchorage.

Method of Depillaring

The depillaring system was conventional splitting and stooking, maintaining their height equal to that of the normal development height. The pillars were divided in two stooks and the stooks so formed were extracted by slicing, keeping the height of the slices equal to that of the splits and the development headings. The steps involved in the extraction of the pillars are summarized as follows:

(i) Cable bolting of all the development galleries of the panel before the start of the depillaring operation.

(ii) Systematic support of the development galleries 2 pillars within the goaf line using tabular steel props and timber/steel chocks.

(iii) Drivage of 5 m wide split gallery for dividing the pillar in two halves and its systematic support with tubular steel props and chocks in addition to the cable bolting.

(iv) Drivage of 4.8 m wide slice from the goaf edge leaving 2.5 m thick fender and support of the low
Table 1 – Geo-mining parameters for the experimental domain of NCPH mine

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Panel 15</th>
<th>Panel 16</th>
<th>Panel 17</th>
<th>Panel 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel size, m x m</td>
<td>115 x 135</td>
<td>200 x 220</td>
<td>180 x 190</td>
<td>190 x 200</td>
</tr>
<tr>
<td>No. of pillars</td>
<td>22</td>
<td>43</td>
<td>52</td>
<td>38</td>
</tr>
<tr>
<td>Pillar size, m x m</td>
<td>22.5 x 22.5</td>
<td>25 x 25</td>
<td>22.5 x 22.5</td>
<td>30 x 30</td>
</tr>
<tr>
<td>Seam thickness, m</td>
<td>6.5</td>
<td>7.5 - 8.0</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Depth cover, m</td>
<td>33 - 58</td>
<td>37 - 70</td>
<td>46 - 103</td>
<td>119 - 256</td>
</tr>
<tr>
<td>Coal reserve within the panel, t</td>
<td>70,000</td>
<td>2,49,000</td>
<td>1,98,885</td>
<td>2,93,000</td>
</tr>
<tr>
<td>No. Of cable bolts</td>
<td>5.0</td>
<td>6.5</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Cable bolt size, m</td>
<td>1.2 x 1.2</td>
<td>1.2 x 1.2</td>
<td>1.2 x 1.2</td>
<td>1.2 x 1.2</td>
</tr>
<tr>
<td>Bolt anchorage, t</td>
<td>18</td>
<td>&gt;10</td>
<td>&gt;10</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

General ground condition:
Disturbance/Joints/Fissure/Pillar spalling | Not perceptible | Not perceptible | Not perceptible | Perceptible

<table>
<thead>
<tr>
<th>Panel no</th>
<th>Panel 15</th>
<th>Panel 16</th>
<th>Panel 17</th>
<th>Panel 18</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total production from the panel, t</td>
<td>53,000</td>
<td>1,89,240</td>
<td>1,47,759</td>
</tr>
<tr>
<td></td>
<td>Level of recovery, per cent</td>
<td>75</td>
<td>76</td>
<td>74.3</td>
</tr>
<tr>
<td></td>
<td>District O.M.S.</td>
<td>2.01</td>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Cost of production/t</td>
<td>Rs 417</td>
<td>Rs 395</td>
<td>Rs 405</td>
</tr>
</tbody>
</table>

height roof by steel pit props in addition to cable bolts.
(iii) Chance of delayed caving of the roof due to its reinforcement by cable bolting resulting in air blast.

(v) Support of the slice edge by steel chock and cross bars and the goaf edge by steel chocks.

The sequence of depillaring suggested with the cable bolt as support for the high roof and conventional pit props and chocks for low height roof is shown in Figure 6. Extraction of roof coal was resumed on retreat under only cable bolt support from the inbye end of the slice.

The experimental panel was located in the farthest corner of the property with natural barrier all around as a precaution against any unforeseen problem. The coal seams of the area had several active fires and records of palaeo fires and the estimated incubation period of 9 months. It was, therefore, desired to have small size panel which could be extracted within the incubation period at the lowest expected production level. A panel No. 15, located along the common boundary of Kurasia and, NCPH mine appeared to be the ideal site for the experimental trial as it had natural barrier on two sides while stoppings could be made on the rest of the sides. The experiment was continued for another three panels of different geominning conditions of NCPH mine as summarized in the Table 1.

Experimental Details
The method of depillaring with cable bolt support for high roof was adopted as a test case for No. 3 seam of NCPH mine. The experimental trial even with all preparations had many doubts in the mind of mine operators and safety officials. Some of these doubts and apprehensions were as follows:

(i) Chances of overridding of the goaf with the weakening of stooks due to increase in height.
(ii) Chances of spontaneous heating of loose coal left in the goaf.

(iii) Efficacy of the cable bolts as a support to the immediate roof after blasting of the roof coal to full thickness.

(v) Support of the slice edge by steel chock and cross bars and the goaf edge by steel chocks.
Table 3 – Summarised strata control parameters of the experimental domain

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Panel 15</th>
<th>Panel 16</th>
<th>Panel 17</th>
<th>Panel 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum convergence, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Within the working area</td>
<td>8</td>
<td>18</td>
<td>28</td>
<td>37</td>
</tr>
<tr>
<td>- Along the goaf line</td>
<td>26</td>
<td>20</td>
<td>36</td>
<td>97</td>
</tr>
<tr>
<td>- Inbye goaf</td>
<td>23</td>
<td>55</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>- Convergence rate before fall, mm/day</td>
<td>2-4</td>
<td>2-3</td>
<td>2-3.5</td>
<td>3-4.5</td>
</tr>
<tr>
<td>Load on support, t</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Maximum up to goaf edge</td>
<td>11</td>
<td>12.5</td>
<td>7.6</td>
<td>18</td>
</tr>
<tr>
<td>Maximum stress variation, kg/cm²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Up to goaf edge</td>
<td>11</td>
<td>21</td>
<td>18.2</td>
<td>24</td>
</tr>
<tr>
<td>- Within the goaf</td>
<td>21</td>
<td>52</td>
<td>32</td>
<td>31.9</td>
</tr>
<tr>
<td>Maximum exposure of goaf, m²</td>
<td>3,300</td>
<td>2,425</td>
<td>1,100</td>
<td>1,350</td>
</tr>
<tr>
<td>- Local fall</td>
<td>4,100</td>
<td>5,900</td>
<td>4,900</td>
<td>5,400</td>
</tr>
<tr>
<td>- First major fall</td>
<td>5,100</td>
<td>7,950</td>
<td>6,775</td>
<td>6,180</td>
</tr>
<tr>
<td>- Second major fall</td>
<td>5,500</td>
<td>9,200</td>
<td>8,825</td>
<td>10,080</td>
</tr>
<tr>
<td>- Third major fall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsidence record</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Maximum subsidence, m</td>
<td>2.64</td>
<td>2.40</td>
<td>Not measured</td>
<td>Not measured</td>
</tr>
</tbody>
</table>

The experimental trial conducted in small panel of 22 pillars under 40 m depth to normal panel of 51 pillars under 100-150 m depth and medium size panel of 30 pillars under 250 m depth cover (Table 2) showed progressive improvement in production, productivity, and safety of the workers and the workings.

The economic impact with the implementation of this technology as compared to the conventional method of depillaring was found to be very encouraging. The information, given below, in respect of economic impact from NCPH mine support it.

Estimated production from 1.04.97 to 31.03.98: 1,54,793 t
Sale price of annual production (sale price Rs 859.82/t): Rs 13,30,94,117
Estimated cumulative production up to March, 1998: 8,25,000 t
Sale value of cumulative production: Rs 70,93,53,500
Reduction of production cost per tonne: Rs 76
Additional profit with introduction of the technology during trial period: Rs 6,27,00,000

Ground Control Parameters
The caving of the roof started with the first local fall with 3300 m² exposure in panel 15 and main fall after 4100 m² exposure. The recurring major falls occurred after 5100 and 5500 m² exposure with practically no adverse impact over the goaf edge and the working area. Bolting of the nether roof did not delay the settlement of the goaf as it remained within the immediate sandstone roof bed. The ground movement was monitored regularly for load on supports, roof convergence, bed separation, surface subsidence, caving sequence, and settlement of goaf. Some of the salient findings pertaining to the method of mining is summarised as in Table 3.

Conclusions and Recommendations
The Chirimiri method of mining was conceived, planned, and executed with an aim to transfer the technology in letter and spirit and monitor its techno-economic feasibility. The experiment started in a small panel with 22 pillars in view of past record of heating in the area and conservative estimate for the production from the experimental panel. The advance preparation of the panel by way of cable bolting of all the development galleries mechanization of drilling and grouting and evacuation of coal by SDL proved to be very advantageous when the targeted production was achieved within three months and the panel which was expected to lost 10 months was extracted within 7 months.

The speed of depillaring process has been found to be essential to keep the stress field to minimum, restrict spalling in stooks, ribs and pillars and to control the chances of spontaneous heating. No slice extraction
should be deferred for the third shift and no stook should be left for the next week to keep the damaging parameters within control.

The main apprehension of anchorage loss to the cable bolts due to blasting of the roof coal band proved wrong and the cable bolts retained adequate anchorage to serve as the advance support to the freshly exposed roof. The roof on the other hand caved regularly without any sign of weighting.

The performance of the cable bolts remained satisfactory under all the conditions and the production and productivity improved with the experience of the miners. Coincidentally, the formation in one of the panels (Panel No. 18) was geologically disturbed and the roof had two to three sets of open joints. The cable bolt support even in such a condition remained very effective, though the immediate roof coal band was additionally supported by bolts and W-straps. The system proved to be safe and productive because of the advance preparation and efficient support planning.

Acknowledgement
The financial support from the Ministry of Coal, Govt of India and the monitoring cell of the CMPDI is acknowledged.