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STUDY OF HIGHWALL MINING TECHNOLOGY

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ABSTRACT
Coal is an extremely important element in the industrial life of developing India. In power, iron and steel, coal is used as an input and in cement; coal is used both as fuel and as an input. Currently out of the total coal production in India 80% of which comes from opencast mines. The problem accordingly is that an India despite having the fourth largest coal reserves and being the third largest a coal producing country in the world, India needs to import to meet its growing requirements. Many of the opencast mines are reaching their pit limit. A Significant amount of coal is blocked in the non-working thin seams, in the high walls. As an approach to this significant problem a proven technology in USA and Australia came into existence namely HIGHWALL MINING to extract the blocked coal reserves in thin non-workable seams and coal blocked in the high wall of open cast mines. In India, the high wall mining is in the nascent stage. So far in India two high wall mining projects have been worked out; one by Singareni Collieries company Ltd at RG l area and other by South Eastern Coalfields Ltd at Sharda opencast mine.

Keyword- Highwall mining technology, Opencast coal mining, Coal reserves extraction, Thin seam mining, Blocked coal recovery

1.0 INTRODUCTION
In India specifically about 80% of coal is produced from opencast mines only. Unfortunately, many of the Indian opencast mines are reaching their pit limits. As to satisfy the growing needs of coal usage in various sectors a new method of mining was introduced to extract the remains of coal in the thin seams of the high walls. High wall mining is a semi-underground and semi-surface mining method. This mining method is used to extract the remaining coal reserves after the economic threshold imposed by stripping ratio for surface mining operations is reached. Long rectangular entries are punched into the coal seam from the high wall left by the previous surface mining operations to recover part of the remaining coal reserves. Small pillars are left to separate the holes or entries to prevent the overburden strata from collapsing. It is a remotely operated coal mining technology closely related to the mining machinery. The method comprises extraction of coal from a series of parallel entries driven in the coal seam from the face of the high wall. These entries are unmanned, unsupported and unventilated.

High wall mining operations started in Singareni Collieries Company Ltd in December- 2010 at RG OC. II and presently working at Medapalli opencast project since January-2012. Medapalli Opencast project is situated on the Southern Bank of river Godavari. High wall mining is proposed to extract the left-out coal from V. IV, III, IIIA, II and I seam in ascending order beneath the final pit slope of Block-A and Block-B.

2. OBJECTIVES OF THE PROJECT
To recover the blocked coal of high wall which is not feasible for extraction by any conventional method currently available, without sacrificing human safety.

3. Methods of Highwall Mining
The following methods are generally practiced with highwall miner: (Prasanta, 2007; Dixit, 2012)

3.1 Contour Mining
When the coal seam appears at outcrop in hilly area, conventional method of mining i.e. opencast or underground may not be best economic choice. Highwall mining can be used economically and safely, since it follows the contour of the coal seam along the sides of the hill.

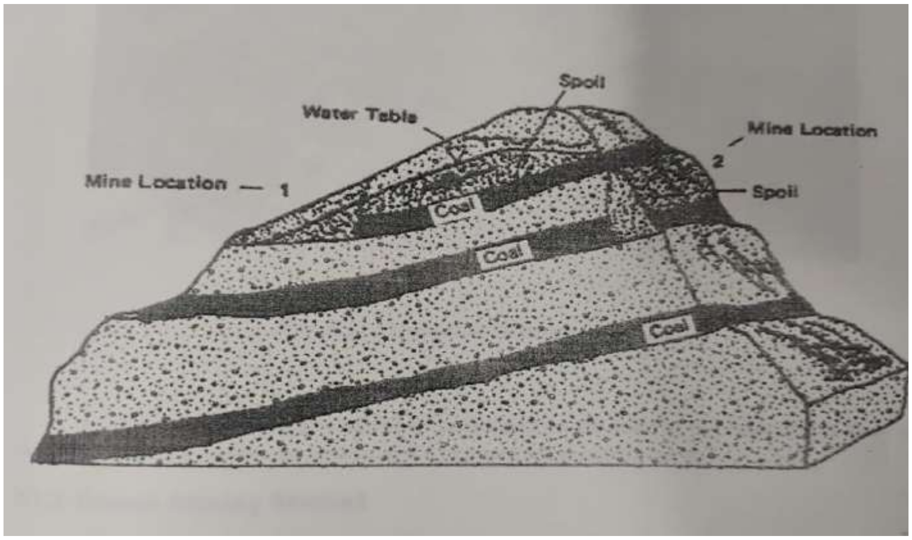

Fig. Contour Mining

3.2 Trench Mining

Trench mining offers an economic option for mining thin reasonably flat coal seams which may not be suitable to opencast mining. In this method, an artificial highwall is created by making a trench at convenient place up to the coal seam. The miner is positioned on the floor of the seam within the trench and entries are driven on both sides of the purposely prepared trench.

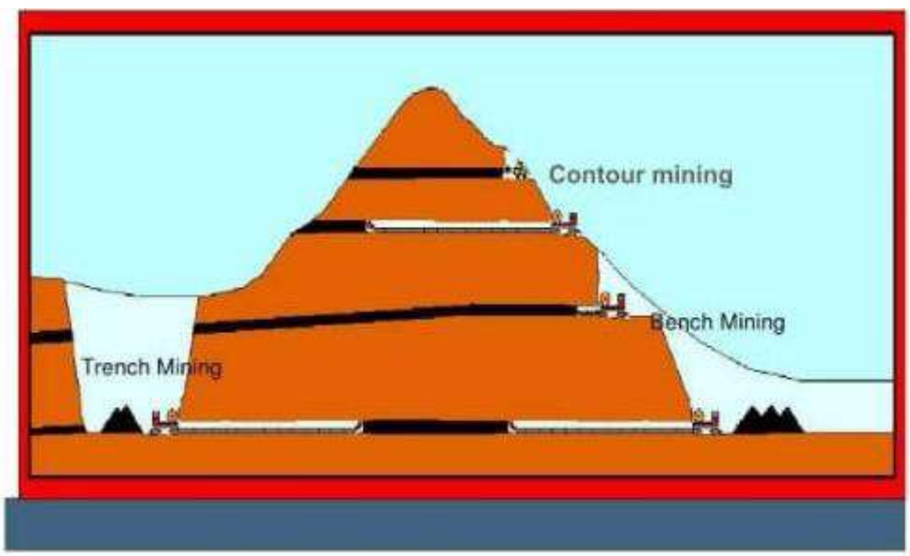

Fig. Trench Mining

3.3 Opencast Mining

High wall mining from opencast pit practiced when the opencast mine reaches its economic stripping ratio or mining is not possible because of some surface constraint like protected forest, villages and any permanent structure. The miner is positioned on the floor of the seam in front of the high wall, and galleries are driven into the high wall.

Fig. Opencast Mining

4. Design Methodology

A protective bund shall be provided at the working level to arrest the small boulders falling from the lower portion of the standing high-wall slope

A bund or garland drain or a combination of the two shall be provided, at the high- wall crest to avoid inrush of surface rain water into the pit. The water diverted along garland drain/bund shall always be diverted away from the quarry.

The existing tension cracks if any shall be filled and sealed properly before the onset of the monsoon. The drain should be properly graded to promote quick water movement and minimize the chances of pounding.

High wall slopes shall be checked for loose rock and adequate precautions shall be taken for a distance of 15 metres on either side of the equipment under operation.

Adequate steps, including provision of suitable garland drains, shall be taken to prevent accumulation or flow of water on surface above the panel.

The width of the bench formed against high wall shall not be less than the maximum dimension of the launch vehicle plus 10 meters for movement of machinery like front end loaders, dozers, graders, tractors with or without attachments.

Blasting Operations shall not be carried out with in 500 m from the high wall equipment. No person shall be admitted in to the galleries made in high wall.

Standard Operating Procedures [SOP] for installation and maintenance of face machinery & equipment viz. Continuous Miner, Loader, Launch vehicle and associated power equipment's shall be framed based on the hazard apprehended.

Since high wall mining is a relatively new method, the methods for systematically designing a high wall mine to meet the challenges mentioned previously are still needed. This section will introduce the methods for high wall mine structural designs that are critical for safety of the miners and mining operation.

4.1 STABILITY OF THE HIGH WALL TOP SURFACE

The middle part of Figure I shows an apparent landslide of the top soil zone over the underlying bedrock. Due to the high elevation difference between the top and bottom of the high wall, any sliding of the top soil and debris from the top surface of high wall will be hazardous to the workers and mining equipment on the working bench below, However, since a high wall mining operation normally starts from the bench created by a previous contour mine or from the bottom of an open-pit mine, the stability of the high wall top surface should have been dealt with before the high wall mining operation. Even in such a case the high wall mining operators should examine the top surface of the high wall very carefully and take precautionary actions to avoid any potential land sliding at the high wall top.

4.2 STABILITY OF MINE ROOF

Roof falls are likely to occur in mines with weak and thinly bedded immediate roof strata in Large roof falls in a mine entry could create significant difficulties to a high wall mining the following two forms: (1) tensile failure at the middle part of mine entry due to excessive roof sag and bed separations, and (2) cutter roofs at the comer of the entry. It should be noted that a mine entry created by a continuous miner in a high wall mining operation is normally between 9.5 and 11.5 ft wide, which is much narrower than the normal width of the mine entries and crosscuts (typically 20 ft) in underground coal mines. However, since the mine roof is not bolted, the bed separation and sagging of thin and weak rock layer in the immediate roof is of the most concern. Once a rock layer detaches from its overlying strata, it can be treated as a beam with fixed ends.

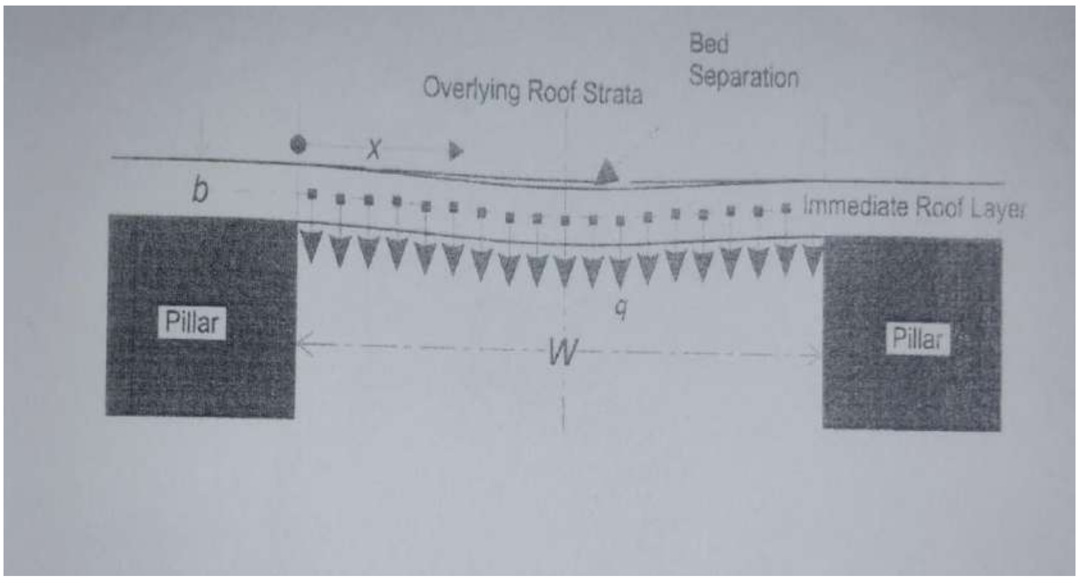

Fig. Stability of mine roof

Using the beam theory, the deflection of the detached roof layer at a given point of interest can be determined using the following equation:

Where S(x)-beam deflection at the point of interest, inches

X - Distance from the pillar edge, inches

W - Load per unit length of a 1-inch thick beam, lbs/in

b -Layer thickness, inches

B-Density of the rock. Ibis/ft3

E - Modulus of elasticity, psi High wall Mining Safety

I - Moment of inertia

L - Width of the entry.

4.3 Web pillar design

- Gallery stability also influenced with RMR, RQD values of immediate roof.
- Here the web pillars are designed with a factor of safety 2 keeping in view of long term stability of the pillars.
- Safety factor = pillar strength/stress on the pillar.
- Pillar strength (Mpa)=0.25*C*h(-0.36)+(H/250+1)*(w/h-1)
- Stress on the pillar (MPa)=0.027*H

Where: C-uniaxial compressive strength of 25 mm coal cube sample (MPa)

H - Height of extraction in m

D - Depth in m

W - Effective width of pillar in m

The CIMFR pillar strength equation has been developed over a couple of decades after analysis of a large number of pillar stability observations from a gamut of Indian mining scenarios.

On the basis of past experiences from Indian coalfields it has been observed that a pillar safety factor of more than 2.0 is long-term stable, i.e. for many decades.

A safety factor between 1.5 and 2.0 may be taken as medium-term stable. i.e. stable for a few years. If the safety factor of the pillar is 1.0, it may be treated as short-term stable, with a stand up time of a few months. Due to the presence of important surface features like Flood Protection Bund, the web pillars are designed for safety factor of 2.0.

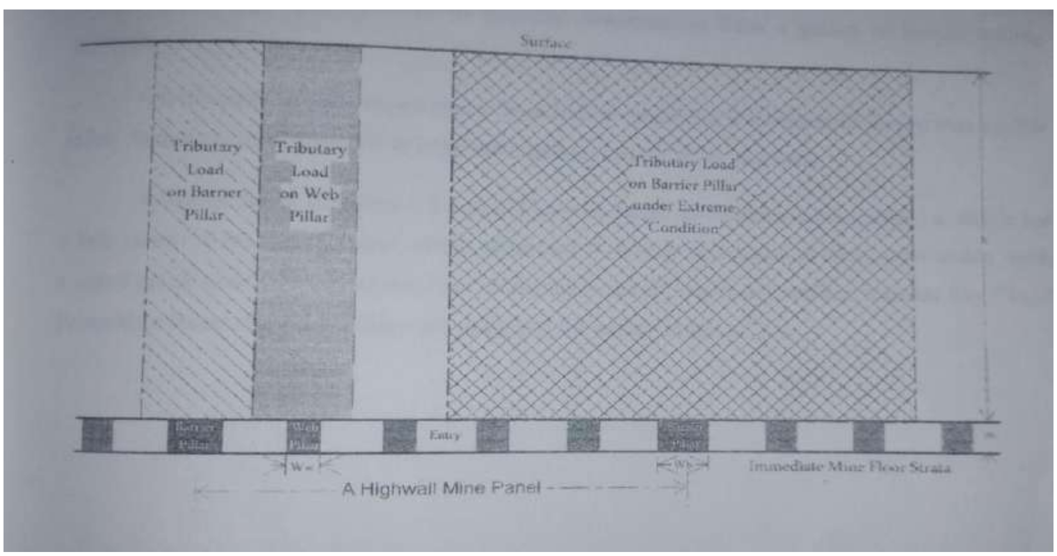

Fig. Web pillar design

4.4 Design and Stability

Geography, regulations and geological conditions are external factors that determine where and how high wall miner can be used to extract coal. Roof conditions have a great influence on machine performance in certain seams. Mine water is another major problem. The structural aspects of overburden and poor material play a significant role in the predictive behaviour of rock masses in response to mining operations, especially of high wall stability and the formation of spoil dumps (Mishra, 1998). Bedding planes are the most important

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discontinuities, followed by joints, relevant to rock slope stability. Transcurrent (strike-dip) faults, unless major, usually do not lead to slope instability.

4.5 Pillar Design for High wall Mining

High wall stability through proper ground control engineering is of paramount importance to safe operations. Geologic structures and stability of web and barrier pillars affect high wall stability (Shen and Duncan, 2001; Duncan et al., 1999; Zipf, 1999; Vandergrift et al., 2004.

Table 1: Equations used for designing web and barrier pillars

Eq. no	Equation	References
1	$SF_{WP} = \frac{S_i[0.64+0.54W_{WP}/H]}{[S_V(W_{WP}+W_E)/W_{EP}]}$	Zipf, 1999 and Zipf, 2005
2	$OB_{Design} = 0.75 * O_{BMAX} + 0.25 * O_{BMIN}$	
3	$W_{PN}=N(W_{WP}+W_E)+W_E$	
4	$SF_{BP} = \frac{S_i[0.64+0.54W_{BP}/H]}{[S_V(W_{PN}+W_{BP})/W_{BP}]}$	
5	$S_P = \frac{1.04(H)(w+B)(1+B)}{(w)(l)}$	Mark *et al.*, 1995
6	$S_P=S_C\left[\left(0.64+\left(0.54\frac{W}{h}\right)\right)-\left(\frac{0.18W^2}{hl}\right)\right]$	
7	$S_P=S_C\left[0.64+\left(0.54\frac{W}{h}\right)\right]$	
8	$L_P=S_V(W+W_E)/W$	
9	$S_{WP} = S_V (W_{WP}+W_E)/W_{WP}$	
10	$S_{BP} = S_V (W_{PN}+W_{BP})/W_{BP}$	

S_i = in situ coal strength (lb/in2)	L_P = average vertical load on the pillar
S_V = in situ vertical stress	W= pillar width
W_{WP} = web pillar width	SF_{WP}= stability factor of web pillar
W_E = highwall miner cut width or entry width	SF_{BP} = stability factor of barrier pillar
S_P = pillar stress (lb/in2) or pillar strength	OB_{MAX} = maximum overburden depth
H = overburden depth or mining height (ft)	OB_{MIN} = minimum overburden depth
W = pillar width (ft)	W_{PN} = panel width
B = entry or crosscut width (ft),	W_{BP} = barrier pillar width
l = pillar length (ft).	h = pillar height
	S_C = in situ coal strength

Equation 1 is sensitive to in-situ coal strength. Overburden depth may be taken as the maximum overburden depth on a web pillar, or alternatively as a high average value as given in equation 2. For design purposes, the stability factor for web pillars typically ranges from 1.30 to 2.00. If the number of web pillars in a panel is selected as "N", then the panel width is given by equation 3. A barrier pillar is commonly used to separate adjacent panels and prevent ground control problems from cascading along the entire length of high wall. Neglecting the stress carried by web pillars, the stability factor for a barrier pillar is determined by equation 4. Web pillar stress is calculated using equation 5. One of the reasons for the wide acceptance of formula 6 is that in addition to pillar width and height, the effect of pillar length is also accounted for. In case of high wall mining where the pillar length (miner penetration) is much greater than either the pillar height or width, the formula can be simplified as given in equation 7. It is found that high wall mining encounters horizontal and vertical stresses similar to those found in board and pillar method. The height of overburden determines the width of the barriers between the entries. The high wall miner's depth of advance into the coal seam is also determined by how much force must be applied to the string of push beams. This force must overcome changes in elevation due to undulations as well as any roof material that may fall on top of push beams. Once pillar strength and pillar loading equation 8 is estimated, the stability factor is calculated as:

SF = SP /LP

The stability factor for barrier pillars can be as low as 1.00.

5. DESCRIPTION OF HIGH WALL MINER

Underground and surface mining operations by extracting coal from exposed horizontal scams in open pit mines. This is done via a mobile system that contains a continuous miner controlled from the operator cabin, a retractable cable conveyance system, and a vertical conveyor that handles and stacks the coal for transport.

The point at which the cost to remove the over burden exceeds the economic value of the covered resources in a surface mining operations is referred to as the final high wall. The exposed strata left by surface mining operations offers exposed coal bed seams that can be efficiently extracted by high wall mining techniques.

5.1 OPERATIONS

High wall miner extracts coal from exposed seams by driving a cutter module into a coal seam under a high wall. The high wall mining machine is positioned on pit floor or on a bench beside the high wall in front of the coal seam. A cutter head attached to a string of push beams is thrust into seam .The coal seam is mined by the shearing action of the cutter head that raised and lowered to dig out the entire height of the coal seam. The mined coal is transported out of the seam along conveyors inside the push beams. Additional push beams can be added to the string to extend the depth into the high wall to which the operation can mine. Each push beam segment is coupled to the next by a connection that supplies control and power to the cutter head. A control system automated by a device such as a programmable logic controller typically controls the cutter head operation remotely from the cab, overseen by an operator.

5.2. FEATURES OF HIGH WALL MINER

Some high wall miner systems offer advanced detection systems to guide the cutting operation with greater accuracy. A gamma-ray detection system allows the system to detect gamma radiation emitted from surrounding rock to impose a limit to cutter head motion as it approaches the boundary between coal and rock. This allows the operator to direct the cutter module precisely in applications where it is desired to leave fixed amounts of coal in the roof and floor, such as in weak strata conditions. A solid state, fiber-optic, gyro based navigation and steering system can offers higher precision control over the cutter head position by reporting real-time cutter location data.

The push beam mechanisms may be totally enclosed to prevent contamination of the mined coal. The couplings between each push beam segment can offer flexibility to aloe the string to navigate unevenness in the land.

The anchoring system consisting of drills that penetrate into the surface below the high wall miner can offer improved stabilization to ensure accurate positioning of the cutting operation.

Fig. High Wall Miner

5.3. SPECIFICATIONS OF HIGH WALL MINER

Length base-16.6m

Width base-8.3m

Weight miner-225T

Length of push beam-6m

Weight of push beam-5150kg

No of push beams-50

Max push force In-136T

Max push force Out-276T

5.4 PARTS

The main parts of the high wall miner are

1. Cutter unit
2. Push beam
3. Reels and chain
4. Anchoring
5. Generator
6. Control panel

5.4.1 Cutter unit

Cutter unit is basically the cutter head of continuous miner. Operation is fully remote controlled from the surface operator's cabin. Cutter modules are chosen as per thickness of coal seam. Power of cutter varies from 240KW to 350KW. The entire cutter modules are interchangeable with the machine.

Fig. Cutter unit

5.4.2 Push Beam

Push beams are 6m long, rectangular, reinforced steel box structures joined together to form a string, which connects the high wall mining system to the cutter assembly.

The push beam string is the back bone of the machine: pushing and pulling the cutter module in and out of the high wall with retract forces up to 363T at 345bars.

The push beams also transport mined coal and support the hose chain that supplies control and power to the cutter.

Fig. Push Beam

Moving coal inside the push beam (via a pair of screw conveyors) protects the coal from contamination and the moving mechanical parts from rock debris, resulting in higher availability.

5.4.3 Reel and chain

Power chain for cutter module consists of

Electrical cables

Hydraulic cables

Cooling water lines

Methane sensor cables

Control cables

Hoses and cabling are protected by steel plating, and the length is greater than 300m.

Fig. Reel and chain

5.4.4 Control unit

The high wall miner is operated from the control cabin of the machine it is fully graphical touch screen interface and is automated mining mode and also gamma ray sensor. All machine diagnostics accurate heading and pre alignment and consists of fibre optic gyro guided steering.

5.4.5 Generator

The generator consists of 1500 KW and 80 KW auxiliary set built in a sound attenuated 20 ft container mounted on tracks.

Fig. Generator

This is used to supply power to the high wall machinery at the time of the extraction process.

6. Components of A High wall System

There are two variants of high wall mining systems, namely auger mining and continuous high wall mining. In auger mining, a circular cutter head much like a drill bit cuts the coal and the coal is taken to the surface by a series of spiral flights. Continuous high wall miner (CHM) systems were introduced in 1980. In CHM system, a modified continuous miner is used for cutting of coal and a belt or screw conveyor system is used to transport the cut coal to surface.

Following are the major components of a high wall system (approximate figures based on CAT HW300 Miner):

6.1 Launch Vehicle

The launch vehicle houses most of the controls and other drive mechanisms, cables reels, communication reels, power center, etc. It stays at the face and is often anchored to the ground to prevent movement. Typical dimensions L x B x H: 16 m x 10 m x 8.4 m.

6.2 Cutter head Unit

Two types of cutter heads are usually available: • Low-seam cutter, for seams 0.8 – 1.6 m thick • High-seam cutter, that mine seams 1.3 – 3.5 m thick

The cutter modules are interchangeable and quickly attached to the power head assembly. The cutting cycle is fully automated yet allows the operator to manually adjust the machine function as the coal seam varies. This allows the cutter module to accurately follow the coal seam

6.3 Push beam Transfer Mechanism

Push beams are 6 m long rectangular reinforced steel box structures joined to form a string. The push beam conveyors transports cut coal to the launch vehicle. It also supports the hose chain that supplies control and power to the cutter.

6.4 Operators Cabin

The Cat HW 300 is equipped with a comfortable, air-conditioned cab that offers a full view of the mining operation and the high wall. Major features include: • Gyro Navigation System to ensure parallelism of the galleries and maintain adequate pillar thickness throughout the gallery • Gamma sensors positioned on the miner to sense the depth of coal in the roof or floor of a drive. These crystal sensors detect radiation given out by the strata. • Continuous Methane Monitoring System to monitor methane at the face. At 0.75%, it relays a warning to the operator and at 1.25%, it shuts off power supply. • Temperature control to monitor the temperature of the face.

Fig. Operator Cabin

6.5 Other Components

Power and control cables for cutter head, methane sensor cables, hydraulic pressure hose for cutter, water circulation for cooling cutter's motors and dust suppression, etc. Hoses are often protected by steel plates and links.

7. Suitable condition

High wall mining methods are useful to mine the:

Coal blocked in the high walls of a opencast mines due to un-economic stripping ratio

Coal blocked in the boundaries of opencast mines

Coal blocked in thin seams for which no conventional mining method is available or economically viable.

Coal seams in hills and in forest area.

Coal block below roads, permanent surface structures and villages.

Coal seam where conventional extraction is a constrained for a various reason.

8. CHALLENGES

The most significant challenge for a high wall mining operation is the stability of mine structures, including mine roof and pillars. Failure of high wall is a major safety hazard in high wall mining operations. Since a high wall mining system involves an expensive capital investment, any failure of mine pillars or roof resulting in damage of machinery can cause a significant economic loss to the company. In addition, recovery of the entrapped mining equipment underground could be a dangerous operation. Therefore, design and operational efforts should emphasize on maintaining the stability of the roof and pillars so they will not fail prematurely during the active mining time.

Apart from mine design aspects, the high wall system must satisfactorily stand up to the following design complexities:

* A secure method of attachment between push beams that can be engaged and disengaged quickly

* Horizontal hinge design that allows the string and cutter to navigate through seam undulations

* A simple design with minimal electrical and hydraulic connections

* Structural rigidity that ensures mining in parallel drives

* Push beams that can be stacked high for storage in limited space, under bad conditions

* Excellent mobility and manoeuvrability in congested areas.

9. ADVANTAGES

The following are the advantages of the high wall mining

1. Cost

2. Flexibility

3. Safety

4. Production

5. Productivity

6. Applicability

9.1.1 Cost

High wall mining is clearly cheaper, due to the lower establishment and development costs. No in-seam support or transport systems are required, the cost of ventilation measures is negligible and the capital cost is a fraction of that of a longwall.

9.1.2 Flexibility

High wall mining can economically access smaller blocks of coal and is more readily able to avoid geological structures or others impediments to production. The mobility of the high wall mining equipment makes it easy to move around a pit, from pit to pit or from mine to mine.

9.1.3 Safety

Remotely controlled operations, so all personnel remain outside the entries and therefore not exposed to underground hazards such as roof fails, gas, dust, irrespirable atmospheres, flooding vehicle, movements in confined spaces, etc, with the use of ventilation or inert gas, high wall mining can continue in gassy seam conditions that would stop or Impede underground mining.

9.1.4 Production

Modern high wall mining equipment operate in seam height of 0.76 meters to 3.05 meters in one pass and seam dips of up to 12 degree. Coal production for machine ranges from 0.5 million tons per year for low seams, in a continuous operation.

9.1.5 Productivity

High wall mining requires fewer personnel 1.5 million tonne pa, compared to around 90 people (3 shifts) to get the same output from underground mine.

10. DISADVANTAGES

1. The roof and floor should be strong.
2. Length of push beam which is generally 300m.
3. Seam free from geological disturbances.
4. Flat seam 8 to 12 degrees
5. Moderate make of water.

11. OUR INNOVATION

11.1 Roof Bolting Technique

Considering the average height of holes in high wall mining which normally varies from 0.9 to 3.05 m and the instability of immediate roof at that hole heights with the length of extraction,

The mechanized roof bolter technique can be applied to keep the immediate roof intact that prevents separation which is the main cause for failure.

The roof bolts shall be inserted into the roof by proper drilling arrangements provided slong the length of the push beams.

The bolts would be of minimum length when inserted vertically upward. The lengths of bolts can even be increased by inserting them slantly upto the limits permissible.

11.2 Back Filling Measure

Keeping in mind the use of push beams to transport or carry the coal from the face to the mouth.

By reversing direction of the auger motion the supply of filling material from the mouth to the face might be done to provide for the back filling of the material.

Various improvisation techniques for the backfilling can be obtained by practical application of this method at the site and can further be developed on the basis of results so obtained so that the filling material be dumped efficiently with some compactness.

11.3 Two Trench Technique

So far we have seen the high wall technique in the light of single trench technique in which, in a panel, multiple parallel holes are made with desired web pillars in between them.

In case of hills, where trenches on the both sides of the seam are possible, in panel, a noel can be drawn from trench and now after leaving the desired web pillar width, next hole can be made from the opposite side up to the acceptable depth.

This might decrease the loads on the web pillars and subsequently on the barrier pillars. This extra safety might be utilized in enhancing the further coal extraction by robbing the barrier pillars at last or even working parts of barrier pillar.

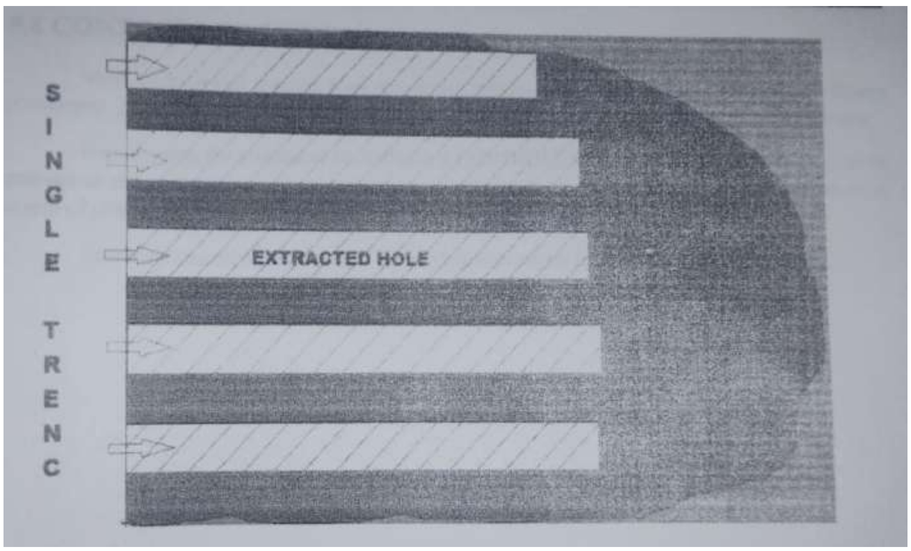

Fig. Single Trench Technique

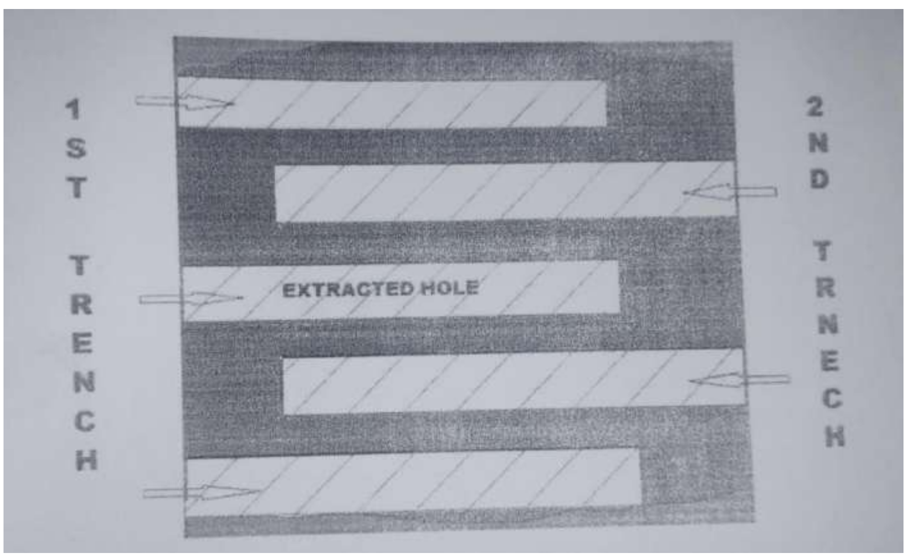

Fig. Double Trench Technique

14. CASE STUDY

High wall Mining in the form of Auger Mining started in 1983 in USA ADDCAR System in High wall Mining started in 1990. The proposal of High wall Mining was studied by project planning department of SCCL and identified the mines having potential for extraction of Coal by High wall Mining Technology. Board has approved the FR of extracting coal by high wall mining technology on 2005.

SCCL is pioneer in India to adopt this technology to extract hidden coal from high wall of Opencast Mine and other inaccessible places which cannot be extracted by any other methods of mining. In view of the conservation of coal it was proposed to gainful extract the coal logged in the high walls and barrier of opencast mines by “High wall Mining Technology”. SCCL entered in to agreement with M/S Advanced mining technologies to extract about Six Million Tonnes of coal from four opencast Mines in a span of Six Years. Availability of High wall face in main requirement for continuous working of this technology and there is potential in SCCL to meet this requirement. As per CIMFR study report, permission was obtained from DGMS authorities for working of high wall mining operations in Block-A at North West side of workings of Medahalli Opencast project.

13. CONCLUSIONS

High wall mining systems can serve as a means of transition, with low capital cost. from surface mining to underground mining. The stability of the high wall can be achieved by obtaining comprehensive geological information, proper web and barrier pillar design. Factor of safety should be adequate to ensure long-term stability. Regular high wall monitoring should be conducted during mining operation to assess its stability and surface subsidence. There are many techniques of high wall movement monitoring. The rate of monitoring relies on rate of ground movement. Proper catch bench design, blasting patterns and dewatering of potentially unstable zone are important to minimize high wall failures hazards. Even with diligent geologic mapping, careful geotechnical designs, and adequate monitoring programs, the chances for instability still exist.

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