International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 04 | Apr 2021 www.irjet.net p-ISSN: 2395-0072

A Critical Review of Indian Underground Thick Coal Seam Mining Technologies and Future Prospects

NASINA BALASUBRAHMANYAM[1], DR G.BUDI[2]

[1]Deputy Director, Directorate General of Mines Safety, Government of India
[2]Assistant Professor, Indian Institute of Technology (Indian School of Mines), Dhanbad, India

---

Abstract - *Thick seams are nearly 40% of proven Indian coal reserves and their extraction by underground mining methods are ever posing technical challenge for Indian mining engineers. The Blasting Gallery method, Multi-slicing Longwall Method, Hydraulic Mining and sub-level caving method were applied in some Indian geo-mining conditions with limited success. Successful experiences of recent high capacity longwall mining at Jhanjra Project Colliery, M/s ECL in collaboration of global pioneers gave confidence to go ahead with appropriate longwall-based technology for thick seam coal mining in India. High reach Single Pass Longwall (up to 7m thick) and Longwall Top Coal Caving(LTCC) methods are gaining prominence among other methods especially in China, Australia, Vietnam and Turkey. The (LTCC) method is used extensively deployed for extracting thick and extra thick coal seams in China with more than 100 faces producing over 200 MT in conditions ranging from soft (<10 MPa UCS) to hard (>50 MPa UCS) coals.*

A thorough review of mining technologies may help in evolving suitable methods for maximizing recovery. In this paper, the journey of thick seam mining in India is suitably divided into three stages namely, the pre-nationalisation era, the post nationalisation era and the 21st Century. The status of present underground thick seam mining in India is analysed with the experiences of China, Australia and other countries. A brief study of feasibility of the LTCC in Indian geo-mining conditions for conservation and safety in the thick seam extraction is made.

***Key Words*: Indian Geo-Mining Conditions, Thick seam mining technologies, Pre-nationalisation, nationalization, 21st century, HRSPL, LTCC.**

1.0 INTRODUCTION

1.1 Though coal is going to play quite vital role with its contribution of the developing Indian national economy irrespective of ambitious goals for renewable energy (RE) development, the coal industry in India is facing significant challenges. Environmental pollution and greenhouse gas emissions with global consequences and depletion of deposits viable for opencast mining is demanding appropriate sustainable underground mass production mining methods for winning deeper coal deposits. As per Indian classification, coal seams having a thickness of 4.8m or more are termed as thick. The thick seam was not uniquely defined globally, different countries have defined on their own way as per the country specific conditions, as shown in the table 1.0 [Singh 2004)). The proportion of such thick seams that can be mined by underground methods constitutes about 60%. [1]

Table 1. Standards of seams that are known as thick seams in various countries (Singh, 2004)

Serial Number	Country	Thickness above which are known as thick seams, (m)	the quantity of deposits with thick seams (Mt)
1	Australia	4	18,128
2	China	3.5	98,883
3	Canada	4	8708
4	France	4	427
5	Hungary	3.5	225
6	India	4.8	345
7	Japan	2.3	1000
8	Turkey	3.5	6056
9	USA	3	113230
10	Poland	3.3	20800
11	Yugoslavia	3.5	8465

1.2 About 60% of the coal seams in India are thicker as shown in the Table 2.0 (Rakesh et al). Though the authors could not collect present status on the precise statistical information of thick coal reserves in India, estimates of M.M. Sen and A.K Sural (1986) could help in understanding the proportions as shown in Table 3.0. Here, extraction of thick seams (4.8 or more) has ever remained a challenge to the Indian mining engineers which constitutes more than 50% of deeper deposits.

Table 2. A portion of deposits with their seam thickness in Indian deposits (Rakesh et al.)

Coal Seam Thickness (m)	0.5-1.5	1.5-3.0	3.5-5.0	5.0-10.0	10.0-20.0	above the 20.0
Percentage of Share (%)	15	15	12	20	19	19

Table 3. Thickness-wise coal reserves (Depth Range: 0-600m) in million tons of seam thickness 5m and above. The figures related to gross reserves (sum of proved, indicated and inferred reserves) (M.M. Sen and A.K Sural,1986).

Type	Seam thickness				
	5-10m	10-20m	20-30m	30m	Total
Quarriable	4751	7262	3989	8567	24659
Non-quarriable	15873	12216	4505	874	33468
Grand Total	20624	19478	8494	9441	58127

1.3 Normally, seams having a thickness up to 4.0m can be mined with a good recovery rate by deploying conventional underground mining methods. However, the issue is only with thick seams, which was ever remained a challenging task to achieve good conservation of deposit economically and safely. A thick seam of shallow depth can be extracted with opencast mining. Due to difficulty in ground control and mechanization, the underground mining of coal has not gained importance than opencast mining today. However, the extraction of coal from underground mining is a clean coal technology, the production from opencast mining is dominating underground mining for 5 decades, and is being continued (R Singh, 2001). Thick seams of shallow cover depth can be extracted with open cast mining, whereas, deeper coal seams are more expensive to extract and not viable (Rakesh et al., 2015). With the advancement of technology, the economic stripping ratios got enhanced and the production programs for opencast coal mining are now being planned up to 250m depth from the surface. Accordingly, the underground coal production is required to be planned for a depth of cover 250 m or more (SK Singh et al) [1].

1.4 Singh 1998 and Rakesh et al ., 2015 suitably classified underground mining methods as per the seam thickness as shown in the Table 4.0.

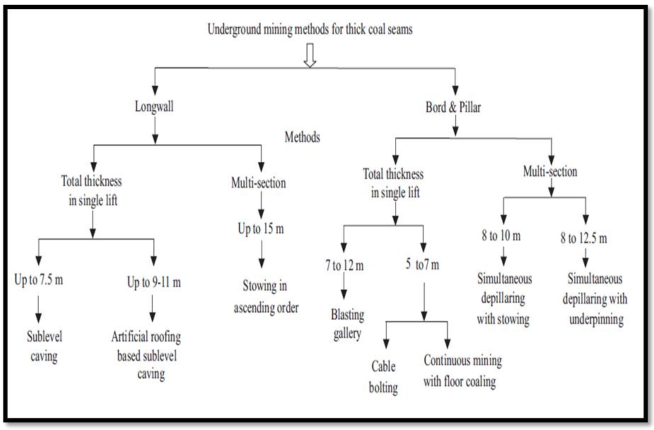

Table 4.0. classification of thick seam mining methods with respect to the seam thickness (Singh, 1998, Rakesh et al., 2015)

1.5 India has a rich experience of thick seam mining by several systems of thick seam mining which had been applied way back pre-nationalization of coal mines in India. However, those methods could not sustain with the due course of time due to either technical, operational, economical or combined impediments. The scouting for suitable thick seam mining methods was continued. Semi-mechanized bord and pillar methods by deploying LHDs, Blasting Gallery method; Wide-stall method; Multi slice longwall methods, descending shield method, Sub-level caving and integral caving; hydraulic mining methods were deployed for thick seam mining. Each of these methods have its own limitations. Some of the methods which were proven technically success could not sustain due to poor production and productivity. In addition to these, the major developments which caused almost a state of stagnation of underground coal mining mechanisation is the failure of some of the capital-intensive power supported longwall panels and at the same time the gigantic growth of opencast coal mining technology.

1.6 The Blasting Gallery (BG) method, which emerged as a prominent method of thick seam extraction from 1990s was also abandoned in the year 2020 due to spontaneous heating and strata control problems. The rate of production was also around 1000Tonnes per day and it cannot be included in bulk production technology.

1.7 Extraction of thick coal seams (up to 6.0m) by deploying Continuous Miners in virgin seams as well as seams with already developed and standing on coal pillars under favourable geo-mining conditions has gained popularity at present. However, this method requires a competent roof facilitating a comfortable cut-out distance (the maximum allowable cutting distance in a single position forming unsupported roof), which plays a major role in production and safety.

1.8 Longwall mining has proven successful even in the most difficult geo-mining condition in China and other countries like Australia. In India, at present, the High Rach Single Pass longwall mining (HRSPL) is successfully working at the Jhanjra Project mine of Eastern Coal fields Limited. At this mine, HRSPL is successfully working several panels without any significant issues. These developments boosted the morale for planning for thick seams extraction by longwall-based caving methods. Thus, the gap of safe and economic thick seam extraction from underground mining between India and other countries like China has remained unbridged.

1.9 It is pertinent to note that the longwall top coal caving (LTCC) is the method which is extensively deployed for extracting thick and extra-thick coal seams in China. It is reported that with more than a 100 LTCC faces, it is producing over 200 MT in difficult geo-mining conditions. The range of coal strengths varies from soft (<10 MPa UCS) to hard (>50 MPa UCS). Countries like Australia, Vietnam and Turkey entered the same track for thick seam mining.

1.10 In this Paper, a brief journey of thick seam underground mining is reviewed with an emphasis on the lessons learnt. Further evaluation of geo-mining parameters required for the introduction of LTCC in Indian geo-mining conditions are discussed.

2.0 UNDERGROUND THICK SEAM MINING IN INDIA

Before 1973, the most of the private mine operators adopted unscientific coal extraction mining practices. Further, the working conditions of the work persons in the mines were very poor. Due to these reasons, the Government of India nationalized the private coal mines. The nationalisation was carried out in two stages. In the first stage: the coking coal mines were nationalized during 1971–72. In the second stage: the non-coking coal mines were nationalized in the year1973. The Indian thick seam coal mining by underground methods evolved with tremendous growth in terms of production and technology and the 21st century witnessed mile stones. This journey can be conveniently classified into three phases namely:

1. Pre-nationalisation phase (up to about 1973)
   - i. Bord and Pillar Base and
   - ii. Multi-slice Longwall System Base
2. Post nationalisation phase (from about 1973 to 1999)
   - i. Bord and Pillar Base
   - ii. Longwall System Base
   - iii. Sub-level caving systems
   - iv. Hydraulic mining
3. The 21st Century era (year 2000 and beyond)
   - i. Bord and system base
   - ii. Longwall system base

2.1 The Pre-nationalisation era of the Indian coal mining history can be conveniently classified further into two bases namely: Bord And Pillar Base and Longwall System Base. The National Coal Development Corporation (NCDC) was formed in the year 1956 which initiated a number of trails with global cooperation.

2.1.1 Bord and Pillar Based systems: Multi stage/slicing was a variant of conventional bord and pillar method in conjunction with hydraulic sand stowing was the dominant method used for mining thick seams. In this method 2-3 slices of about 3.0m thickness each could be taken successfully by successive stowing of slices. Occasionally, in a system called contiguous mining, solid coal partings of not less than 3.0m in between the slices were left to give greater stability to the working area. Manual Basket loading into coal tubs and evacuation through rope haulage systems was the practice, in which production and productivity were very low, recovery of coal was very poor and economics very adverse with related problems of strata control, spontaneous heating and premature collapse. Further safety of work persons was at stake. The system was used more or less under compulsion in most of the cases.

2.1.2 Multi-slice Longwall based systems: Generally, inclined slicing was practiced in the mildly dipping coal seams although there are instances when this is applied in the semi-steep coal seams too. For steep seams, however, horizontal slicing is preferred over the inclined slicing. Usually, the longwall retreating method is adopted for inclined slicing in descending order with caving. In this method, gate roads are driven in the strong and firm ground and planned to serve more than one slice. These should preferably be located in rock so that in case of a fire, the panel could be easily sealed off. Level haulage roadways and airways are made to serve all the slices and are usually driven in coal. Independent development openings are driven in each slice commensurate with the method of working. After the slice is extracted and caved/stowed, some time is allowed for the strata to settle down. Independent development roadways are then driven for the next slice except level entries. Normally, all the slices are worked simultaneously so that both gate roads are sunk simultaneously with the advance of the respective slices. This ensures the continuous advance of both the gate roads corresponding to the advance of the respective slices. Normal practice is to form the false roof with the wire netting laid on the steel strips. Wire netting lasts up to 3 slices and offer more flexibility in operation. Sometimes in the formation of the roof of the lower slices, advantage of stone bands is taken if they exist in suitable thickness. However, timbering below the band must be so regulated that the band does not disintegrate. The following four methods need to be discussed:

2.1.2.1 Multi slice descending longwall caving using artificial wire mesh roof:

The method was worked in the 12m thick, the Sirka seam of Gidi-A Colliery in south Kanapura coalfield during 1967-77 with the assistance from France. The. Depth of the seam was about 70m, dipping at a gradient of 1 in 5 to 1 in 8. Compressive strength of coal was 243 kg cm^2. The length of face was 90m. Roof consisted of alternate layers of shale and sandstone. The roof was supported by 40T friction props and wire mesh. The 12m thick seam was divided into 5 slices of each 2.4m. The 4th and 5th together were taken by mining the 5th slice. Coal winning was by stepped faces as shown in Figure 1. In the I slice roof had to be blasted down initially to induce caving. After a 40m advance of face from barrier, the first fall took place and thereafter roof caved regularly. Sub levels had to blast to break. In the last slice as coal was hard, blasting of sub-level coal was done frequently and even then, this resulted in poor recovery of sub-level coal. During 1967-1977, 3 panels were worked and later frittered. This experiment proved to be Technically Success.

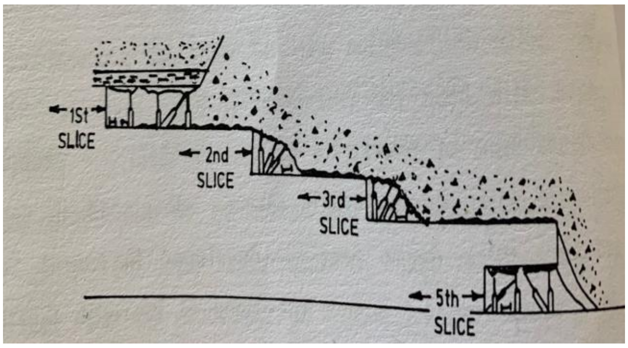

Figure 1: Multi-slicing at GIDI A longwall face

2.1.2.2 ASCENDING ORDER SLICING WITH STOWING:

i)
ii)
iii)

Pilot longwall panels of mining in ascending slicing with stowing was introduced in Kargali Top seam of Sawang Colliery in East Bokaro Coalfield. The Seam was 15 m Thick dipping at 1 in 3.5 gradient and was of Degree III in gassiness. Depth of Cover was about 180 m. Face was 90 m and75m along dip rise . Face was supported by 42 tonne friction props and hinged type roof bars.

The seam was divided in 4 ascending inclined slices, each of 3.0m each from bottom , leaving a coal parting of 6.0m between 1stand 2nd & 3rd and 4th slices and 1.2m between 2nd and 3rd slices in conjunction with hydraulic sand stowing. Also 0.6m coal was left on the roof of the 4th slice. The maximum span of unstowed void was not allowed to exceed 6.0m from the stowed goaf at any place.

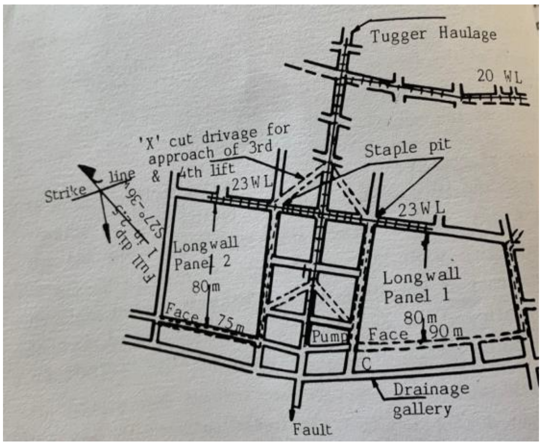

Figure 2: Configuration of the two longwall panels

An AFC was laid along the longwall face and the coal blasted of solid. About 30% of coal was loaded automatically and balance was shovelled manually over AFC. When the span between coal face and stowed goaf was reached 6m, the AFC was dismantled and shifted, and barricade for stowing was erected at a distance of 1.2m from the face and the void stowed. During stowing time, coal production similarly was obtained from the second longwall face. Only one longwall face was operated at a time and the other was under stowing at a time. The roof coal was supported by wooden props at grid pattern of 1.2m x 1.2m (between props and rows) during extraction of the first slice. The junction of gate roads and longwall face was supported by cross bars erected over cogs at an interval of 2.0m. During the extraction of 2nd, 3rd & 4th slices, 50% wooden props were replaced by steel friction props which are withdrawn while stowing.

- No major difficulty in roof control was faced during the extraction of this pilot longwall panel. But the matter was not perused further due to the following reasons:
- Interruption of sand stowing
- System of all-men all-job had not worked properly

The production of longwall face was very low (2500TPM) giving unfavourable economics and could not compete with OC system.

2.1.2.3. Jankowise method: XI/XII seam 7.5m thick dipping at 30deg at sudamdih with assistance from Poland worked this modified system of longwall stowing ascending slices with stowing.In two inclined slices in descending order with hydraulic sand stowing. Worked during 1969s. Proved satisfactory from the ground control point of view but production was very low.

2.1.2.4 Kazimer Method : The IX/X combined seam at sudamdih , 22m thick and dipping at about 27deg was worked with Polish assistance by horizontal slicing in ascending order in conjunction with hydraulic sand stowing. The method met with numerous ground control problems and was finally abandoned. Although the method was proved successfully by and large, problems were encountered due to frequent roof falls in upper slices.

2.1.2.4 Bhaska method in Assam from old Staffordshire mines in UK was worked. Hardly 20-25% recovery of the reserves yielded by this method.

Thus, at the time of nationalisation except multi lift/slice Bord and Pillar and multi slice manual longwall mining methods, there was no other significant method of thick seam mining. Multi-slicing Longwall methods like inclined, horizontal , diagonal, and transversely inclined slicing in ascending/ descending/both were worked in Indian coal mines. However, the main constraint with these methods was negotiating the high variation of thickness of the coal seams. A Set of main gates and the tailgates are required for every slice for its operation whereas preparing and maintaining the gate roads was a challenge and also costly. These methods suffered strata control problems, spontaneous heating/fire problems, restriction due to methane emissions and shortage of sand for stowing causing most unsafe conditions.

2.2 THICK COAL SEAM MINING - POST NATIONALISATION

Mainly, the age old mining system of conventional bord and pillar method with manual basket loading in to tubs which are hauled up to the surface by rope haulage systems accounted for about 20% of coal production. This was major limiting factor in 1980s. in late 1960's , the scraper loaders mounted on track-line were deployed for loading the tubs were introduced. However, this scraper system failed to cope up with the requirements due to its own limitations. Wooden supports were replaced by point anchor bolts and wedge type roof bolts which increased safety and productivity. Belt conveyors taken the place of rope haulage systems. This development avoided a series of rope haulage systems and chaotic track-line circuits. The basket loading was almost abolished during the past decade by the introduction of Load Haul Dumpers (LHDs) for mild gradients and Side Discharge Loader (SDLs) for steeply dipping coal seam. Longwall retreat with caving introduced three decades ago, has recorded few successes due to the limitations in the method and its application in Indian geo-mining conditions. After formation of CMPDIL, a centralised planning body, as a subsidiary of CIL, a technology strategy was formulated and seeing the need of rationale mining of coal reserves, it became imperative to include "Thick seam mining as the technological thrust area" for R&D. The clear objective was to develop an array of mining techniques which would meet the specific needs of both developed and virgin thick seams in a wide variety of geo-mining conditions in our coal fields. The first International Symposium on method of working thick coal seams was held in November, 1964 at the Indian School of Mines, Dhanbad under the auspices of Mining, Geological and Metallurgical Institute of India. The second International symposium was organised by Indian School of Mines, Dhanbad at Dhanbad in 1977. Third International Symposium on "Thick seam mining problems and issues" was held in November 1992 by Central Mining Research Station (Council of Scientific &International Research), Dhanbad.

Subsequently, the following developments taken place, namely:

- Mechanised bord and pillar methods and
- Blasting Gallery method introduction

2.2.1 BLASTING GALLERY (BG) METHOD:

The BG method was introduced in East Katras colliery in Jharia Coal fields (BCCL) in 1987 in collaboration with Charbonnages de France, a French mining company. This method was attracted Indian coal mining planners due to the following advantages:

Thick coal seams of up to 11m can be extracted in s single lift with about 75% of recovery. Capital investment is moderate (compared to longwall). This applies to virgin and developed coal seams. Highly flexible as there will be a set of four independent LHDs (remote controlled by cord).

The development for extraction by the BG method includes a method similar to that of Bord and Pillar method along the bottom section with conventional height and widths of 3.0m and 4.8m respectively. Loading of coal from goaf as well as face is carried out by Load Haul Dumpers(LHDs) operated by remote control. Evacuation of coal by Armored Chain Conveyor fitted with crusher as well as manually operated pneumatic pick to bring down the coal lump sizes for further transport by belt conveyors.

The basic principle of the BG method consists of long holes drilling and blasting the roof and sides of a gallery in a ring pattern at the regular intervals of 1.5m as shown in the Figure 3 and figure 4.

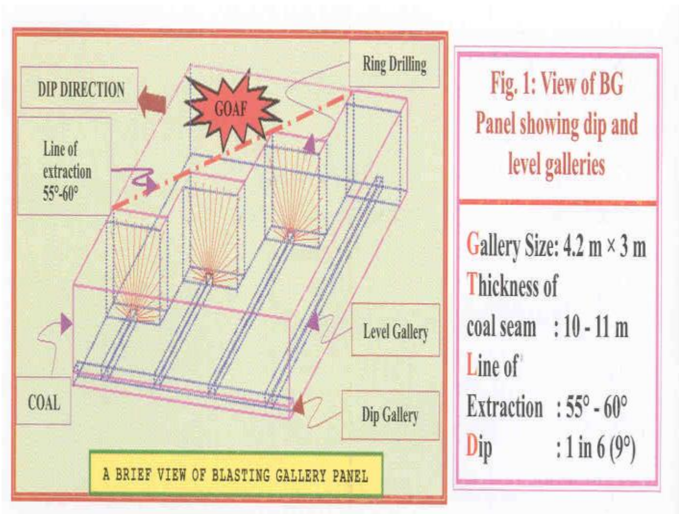

Figure 3. Isometric View of Blasting gallery method

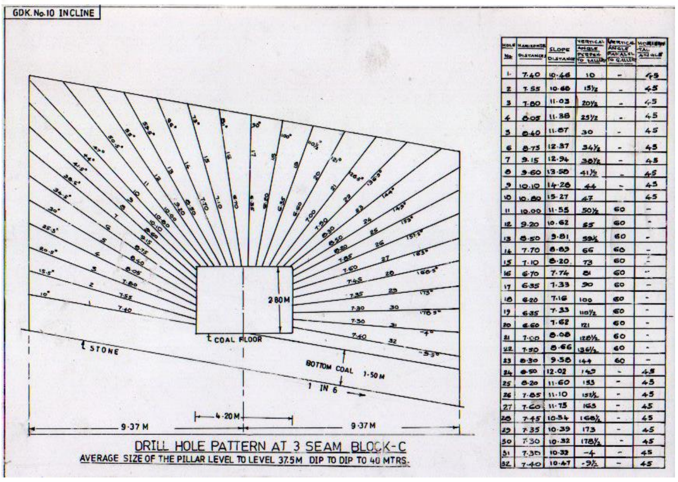

Figure 4. Long-hole drilling patten for blasting in ring hole pattern

It is to note that, at the East Katras colliery the panel faced severe strata control issues and failed due to overriding of pillars within no time. Then, in Chora – 10 Pit Colliery in Raniganji (ECL) where it was introduced, problems of fire led to abandon the method sooner and the method was abandoned in the Coal India Limited. The method was also introduced in the mines of M/s SCCL with the same collaboration of Carbonnage de France. It was first introduced at Godavarikhani No. 10 Incline mine in the year 1989 in No.III seam (about 11m thick). Subsequently, the method was applied at GDK-8 Incline, VK-7 Incline, GDK – 11 A Incline and in 2006 in No. 21 Incline (in the year 2006) and finally at Vakilpalli mine. The last BG panel was worked in Godavarikhani No.11 Incline mine which was sealed off abruptly due to fire. At present the Blasting Gallery method is nowhere applied in India. Thus, the Blasting Gallery method can be said to be another abandoned method of thick seam extraction.

In almost all the mines of SCCL, the method was fraught with either fire or strata control or both the problems. Practically dealing with recovery of LHD from goaf had been a frequent risky task. Roof support by 150mm x 150mm steel girders upon 40T yield capacity hydraulic props at a spacing of 1.5m all along the galleries as well as supporting the junctions in a special way were been tough tasks. The main attributes for abandonment of BG method goes to its limitations namely: It is applicable only to non-gassy seams, highly prone to spontaneous heating, Overriding of pillars , danger of air blast and risky of supporting the roof.

2.2.2 Sub-level caving and integral caving : Sub Level caving method:

During 1975, the longwall mining was the global trend. The Government of India formulated 'Project Black Diamond'. The Project Black Diamond foreseen introduction of 130 powered supports Longwall (PSLW) faces by the year 2000. Initially, the first fully mechanized self- advancing PSLW face was introduced in Moonidih mine in Jharia Coalfield in 1978. After that, many sites in BCCL, ECL, WCL, & SECL deployed with Longwall technology, but did not gave the desired results due to improper site selection, support selection and indigenous technology support. Approximately 30 powered support Longwalls are bought from various countries like France, China, Germany, Russia and Poland. Most Longwalls were not fruitful in terms of production and efficiency. There were many failures in succession at Churcha (SECL) and Khottadih (ECL) mines. The reasons were dynamic loading onto powered supports, lack of spares, improper estimation of powered support capacity and improper exploration results (Mondal P.K. et al, 2002, Goyal S.D. et al., 2002 and Deb and Verma, 2004). The contribution of Longwall mining accounts for a meagre production of about 2-4% of the total underground production in India[8]. Except sublevel caving mining method was applied at the East Katras colliery, no other longwall panel worked for thick seam mining.

However, In India , the sublevel caving mining method was applied at the East Katras colliery (Singh et al., 1993) to liquidate a 7.5 m thick coal seam (avg.comp. strength 280 Kg/cm2) at 147 m depth by mechanized longwal mining (in collaboration with Cdf, France). A Longwall panel having 210 m panel length and 100m face length was worked by a retreating Longwall method.

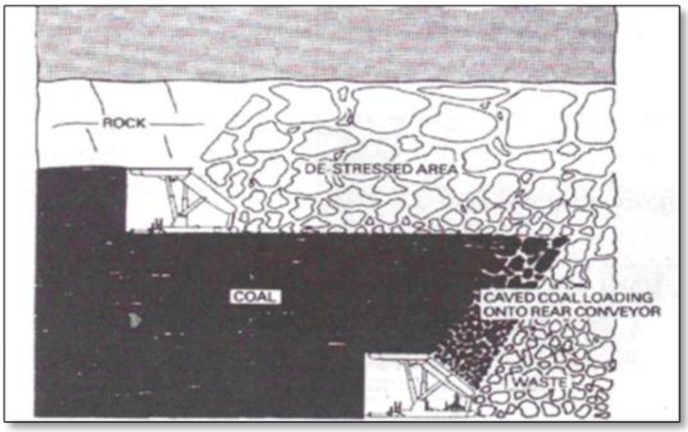

Figure 5: The sub-level caving method (after Bewick, 1983)

The total mining operation within the panel was divided into three phases.

i. Longwall mining of the 2.5 m thick top section along the roof for the first 90 m of the panel under the intact multilayered immediate roof strata.
ii. Extraction of the 2.5 m bottom section along the floor for the first 90 m of the panel with sublevel caving of the remaining 2.5 m thick middle section parting (lying directly below the broken overlying strata caused by top section Longwall mining).
iii. Extraction of a 2.5 m thick bottom section for the remaining 120 m length with an integral caving of the 5.0 m thick top coal bed under intact strata.

During top section working, the face was just a normal Longwall with undisturbed 30-33 m thick roof followed by settled goaf of old overlying seam workings. At the time of sublevel caving, the sublevel section, after 12 m advance operated under broken debris of 2.4m thick coal band as the only roof. Caving of sub-level coal was very good, but had frequent mixing of stone and a heavy load on supports. During an integral caving, the coal flow was normal from the very beginning because of extended regular caving of the immediate roof.

Chock shields of 0.556 MPa setting load density (at 32 MPa leg pressure) and 0.567 MPa yield load density (at 38 MPa leg pressure) were used. However, the chock shields did not perform well. Field monitoring showed a rapid increase in setting load, density of the support in relation to the yield load density. This was followed by a large amount of leg closure during mining cycles of the sublevel caving face under the broken rock strata. Thus the trail failed at East Katras Colliery during the 1990s.

Bottom of Form

2.2.3 DESCENDING SHIELD METHOD:

The Samla seam 5.4m thick , lying at a depth of about 280m at Kottadih mine was planned to extract in two slices using artificial wire net roof. The top slice 2.4m thick was extracted by longwall caving method. Coal winning was by blasting and roof support was by 40T hydraulic props. Artificial roofing was laid on the floor of the top slice. Vertically below the top slice bottom slice though planned was not extracted resulting in the premature stoppage of the trail.

2.2.4 HYDRAULIC MINING:

Hydraulic mining was selected as an alternative to facilitate liquidation of pillars developed in seam No.X , which is flat (less than 7°) and of 7.5m thickness at Gopalichak colliery BCCL . The compressive strength of X seam coal was over 270 kg/cm2. The experimental extraction was carried out in three phases.

In the first phase of trial, the pillar was split in two stooks to be recovered on retreat with monitor on either side of the stooks. The monitor failed to cut coal even up to 3 m distance and flushing of blasted coal was not possible beyond 5-6 m. The roof convergence was up to 5mm, load on support 10 tons and recovery up to 40%.

In the second phase, the pillars were split in three stooks of less than 5 m thickness. The proposal was to blast the coal and flush out loosened coal by the monitor. The stooks at this stage were, however, crushed and started yielding. Maximum convergence up to 102 mm and load on hydraulic props set in different split galleries reached up to 80 tons during this trial. The level of recovery remained below 20% due to stress concentration over the stooks.

In the third phase, the panel was developed in virgin patch by forming four rectangular pillars. In this experiment, the maximum convergence was within 12 mm and load on supports was within 14 tons whereas level of recovery improved to 65%. The trails were not encouraging and hence discontinued there only[6].

2.3 THICK SEAM MINING IN 21st CENTURY

Though global underground coal mining technology has made very rapid strides, it has been relatively stagnant in India.

At present the methods of thick seam mining in India can best be classified into the Bord and pillar base and longwall mining based:

1. Bord and Pillar Based
   a. Semi-mechanised Bord and Pillar system with Side Discharge Loaders (SDLs)/Load Haul Dumpers (LHDs)/Universal Drilling Machines (UDMs) extracting thick seams in sections in conjunction with hydraulic sand/bottom ash/processed overburden.
   b. Semi-mechanised Bord and Pillar system by deploying remote controlled LHDs and roof support by Cable bolting method,
   c. Mechanised bulk production from Bord & Pillar/Room & Pilar system by deploying Continuous Miners (CMs)

2. Longwall mining based Mechanised Power Support Longwall (PSLW) methods.

The Longwall and continuous miner technologies are considered to be mechanized technologies. The methods adopted to extract the thick seams to the maximum possible in the deposit are as follows:

2.3.1 BORD AND PILLAR BASE

3.6.1 Continuous miners: Continuous miner technology was introduced in India in various subsidiaries of Coal India Limited (CIL) and Singareni Collieries Company Limited (SCCL). In CIL, South Eastern Coalfields Ltd (SECL) had introduced for the first time in the country, the "continuous miner'' technology at zero seam underground mine of Chirimiri area in the year 2002, Western Coalfield Limited (WCL) introduced CM technology at Tandsi project in the year 2002 and Eastern Coalfields Limited (ECL) introduced CM technology in Jhanjra project in the year 2007, and all these projects are running successfully. Similarly, SCCL introduced this technology at Venkatesh Khani No.7 Incline, Kothagudem area in 2005, and till date four continuous miner panels (CMP) namely CMP-2, CMP-3, CMP-3A and CMP-3B were extracted successfully, using non-caving yield pillar technique. Table shows the present mines in which thick seams are being extracted by deploying continuous miners.

Table 5: Continuous Miners workings in Indian coal mines (year 2020)

Sl. No	Mine, Area	Coal seam, thickness (m)	Cutting height (m)	Continuous Miner Model
1	Shyamsunder- pur, ECL	R VII, 4.78m	4.5	Joy Global 12CM15
2	Jhanjra Project, ECL	R V, 5m	4.6	Caterpillar CM150

3	Jhanjra Project, ECL	R VI, 4.8m	4.5	Joy Global 12CM15
4	Khottadih ug Project, ECL	R VI,4.8m	4	SHANXI TIANDI EM-340-33/55
5	PVK 5 Incline, SCCL	King Seam, 6.5m	4.6	Eichoff
6	GDK 11 Incline, SCCL	No.1 seam, 3-6.0m	6.0	CAT N 345
7	Santhikhani , SCCL	Salarjung, , 4.0-5.0m	4.6	Joy Global
8.	Vindhya Mine, SECL	L1B, 3.0-4.5m	4.5	JMS
9.	Vijaya West, SECL	Seam 3, 3.5-4.5m	4.5	JMS
10.	Haldhibadi, SECL	4A Seam, 3.0-4.5m	4.5	JMS
11.	Khaira, SECL	6 Bottom seam & 7 Top seam, 2.2-5m	4.5	JMS
12.	Bangwar, SECL	7 Top Seam, 4.5m	4.5	JMS

2.3.2 LONGWALL SYSTEMS:

Longwall Mining in India: Presently only three longwall panels are working in India (Table 2). The Extended height Single Pass Longwall system was introduced at Jhanjra Project Colliery of M/s ECL in R-VI Seam with a maximum extraction height of 5.2m by deploying Support shield supports of height range 2.6m ~ 5.6m and 11000kN Support yield load @ 43.8Mpa. The face length of the panel is 145 m and panel length is 1666 m. Maximum height of extraction is 5.5m with a rated support resistance of 121 T/m² capacity. Extraction was commenced on 18.08.2016 and it produced 2,89,740 tonnes of coal with a face retreat of 426.50m as on 30.11.2016. No significant strata control issues were faced in the panel and subsequent panels being extracted.

Table 6: The details of the mines with working Longwall panels in India (year 2020)

Sl. No	Name of the Mine	Name of the seam & its Thickness	Cutting height	Longwall equipment
1	Moonidih colliery, BCCL	16Top & 2.9m	2.9m	Zhengzhou Coal Mining Machinery Group Co.Ltd., China
2	Adriyala Longwall Project, SCCL	No.1 seam & 7.0m	7.0m	Adriyala Model Supports, CAT, Germany
3	Jhanjra Project, ECL	R VI & 4.5-5.2m	4.5-5.2m	CODCO, China

Thus, with the development of technology, the height of the shearer and the supports of the High reach Single Pass Longwall (HSPL) method have already gradually increased to 5m and above. The upper bound of coal seam thickness in Coal Seam is 6m by the single pass Longwall (Kose & Tatar, 1997). This method offers the following advantages:

- Cutting, powered supporting, discharge of coal and ventilation system is same as the Longwall system. The recovery rate of coal from the deposit is good.
- The ration Gate roads developed to tonne of Coal obtained is low.

The Limitations of HRSPL method include:

- During face transfers the heavy powered roof supports transportation is difficult requires a cross sectional area of 6-10 sq.m.
- Gate roads in Longwall panels in many underground coal mines are generally driven at a height of 2 - 3.5m. With a cutting height on the Longwall face of up to 5 or 6m, there will be a sudden step between the gate roads and the Longwall face. The free face of the step that exceeds the height of the gate roadways could cause spall on the Longwall face, resulting in unsafe conditions for equipment and personnel working at the face or the roadways.
- Spalling, especially of high Longwall faces, may cause many difficulties in mining operations, such as overloading the armoured face conveyor (AFC) or causing danger to the personnel working along the Longwall face.

3.0 FUTURE OF THICK SEAM MINING AT HIGHER DEPTHS BY UNDERGROUND MINING METHODS IN INDIA

3.1 After this brief review on the status of underground bulk coal production technologies of India, it can be concluded that at present there is no bulk production technology for extraction of thick seam from higher depths. At higher depths the following problems are expected:

a. High horizontal stress causing drivage and maintenance of roadways becomes difficult. Extraction by Bord and Pillars/ Room and Pillar method of working becomes difficult due to the high stress regime.

b. High temperature and ventilation Problems requiring air cooling mechanisms

For higher depths, longwall mining only the available option globally.

Since HRSPL has limitation of extracting maximum up to 6m thickness, several prominent researchers visioned LTCC as suitable option to bridge the technological gap. But in India, LTCC potential is not yet entrenched due to several economic and technical reasons existed previously. Earlier, coal mining was mostly the state activity and hence the requisite high investments caused an hindrance. Second, longwall mining was not so successful till recent years.

3.2 In a recent development, a study for feasibility of LTCC was carried out in India by the Singareni Collieries Company Limited (SCCL) in collaboration with CISRO, Australia. In this project, it was undertaken to determine geo-physical properties of the mine site by geo-physical methods and established a detailed geotechnical data base required for the evaluation of LTCC method. The study area was in a mine with longwall mining working culture in Ramagundam coal belt of Godavari Valley Coalfields. However, the study was restricted to No.III seam whereas longwall mining was predominant in No.I seam only. The No. III Seam (8m-11m thick) was extracted either by Bord and pillar in two sections or BG method in some of the mines in the area.

3.3 LTCC MECHANISM:

The movement of roof strata in LTCC can be considered to be similar as single pass longwall method (Vakili, 2009, Galvin, 2016). A large scale LTCC model developed by Le et al. (2017b) confirmed the similarity. As such, in order to restrict to the scope of the research subject, it is presumed that geo-mining conditions of the study areas are favorable for working a conventional single pass longwall mining.

3.3.1 There are two variants of this method. One uses the front armoured face Conveyor (AFC). Another variant uses a rear AFC also. The second variant of LTCC is popular thick seam mining method in China (Shen and Guo, 2012; Shi and Huang, 2015). LTCC is a combination of the traditional longwall method with a mechanism of caving the top coal and drawing it from rear AFC. Gate roads are developed along the bottom section of the seam, the Powered Roof Supports (PRS) are equipped with AFC on its rear side, PRS has a rear canopy which protects and controls fractured top coal as shown in the Figure 6 and Figure 7.

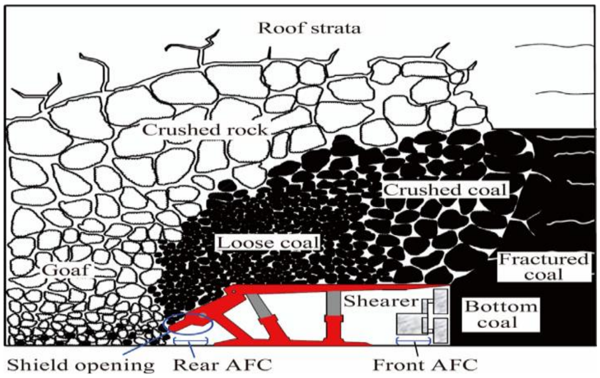

Figure 6: Conceptual model of top coal fractured and drawn in LTCC (after Jiachen Wang et al)

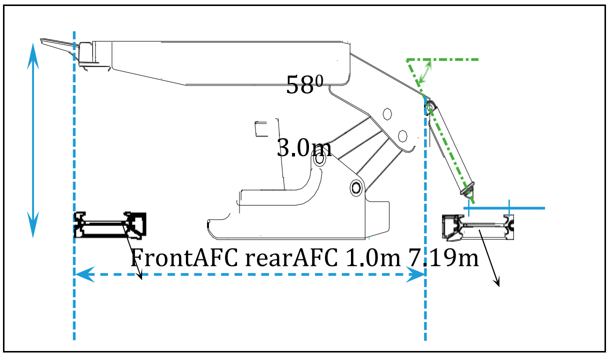

Figure 7: Typical Hydraulic support and AFCs for LTCC (After Huo, Y.; Song, X.; Zhu, D.,2020)

LTCC method has proven its own merits over the multi-slice longwall method and other thick seam underground mining methods. LTCC can be conveniently and economically deployed in thick seams with comparatively less manpower. When it is a choice among High reach Single Pass Longwall mining (HRSP) over the LTCC method, the LTCC has its natural advantages of lower face height. Lower height of face itself is smaller and requires comparatively low-cost equipment and offers better face conditions.

3.4 Geo-Mining conditions for LTCC:

3.4.1 The essential constituents of the LTCC method are
(i) top coal (the unmined section of coal seam which is in the upper portion of a coal seam that lies over the face support),
(ii) immediate roof (roof strata that fail and cave immediately, or with little delay on support advance) and
(iii) main roof (the strata above immediate roof and below fractured zone) which is demonstrated the figure 3 (Xu 2004, Peng 2008 and Vakili 2009).

Figure 8: Roof strata in Longwall Top Coal Caving face (Vakili, 2009).

3.5 Geo- Mining Parameters for LTCC

- The movement of roof strata can be considered to be similar as single pass longwall method (Vakili, 2009, Galvin, 2016). A large scale LTCC model developed by Le et al. (2017b) confirmed the similarity.
- A complete evaluation of caving behavior is pre-requisite for application of LTCC in a coal seam. Top-coal caving is the fundamental aspect which decides performance of LTCC working. While extracting top coal by this method, substantial amount of coal is left and lost in the goaf. There is another issue of dilution of top coal drawn with roof rocks. As such, the top coal caving operations shall be meticulously controlled and optimized. According to the experiences maximum front vertical abutment stresses are likely to be at a distance of 6-7 m in front of the face. About 1.5 m thick layer of top coal just above the power supports is fractured desirably whereas further 3.5 m thick layer of coal above this fractured coal are moderately fractured.
- For studying the top coal caving mechanism, there are several intrinsic and non-intrinsic parameters to be studied. The intrinsic parameters include the thickness, strength, inclination, deformation properties of coal seam, roof sandstone strength and geology. The non-intrinsic parameters include the mine life, financial health of mine, equipment's health and life (Manoj Khanal et al., 2011). Summary of parameters influencing top coal cavability are shown in Table 4.

3.6 The Indian coal seams at depths have no dissimilarity with Chinese LTCC faces which are being worked under difficult geo-mining conditions. Indian coal seams are comparatively harder. The harder the coal the lesser the top coal failure and fragmentation , which directly affects the system. Hard coals may break into large blocks and creates a stable arch. To overcome this problem, a vibration system that located on the top of shield was invented. This system can produce a vibration with low frequency and high power that causes a reduction in cohesion and friction angle, and hence the stable arch was simply fall down. Coal recovery was increased and dilution was decreased.[9] Similarly there are roof softening techniques adopted in China for improving LTCC performance, which includes hydro-fracturing and also blasting the top coal by suitable arrangement. In view of these, LTCC shall be right option for present study and future adaptation.

4.0 DISCUSSION

4.1 India, the world's third largest coal producer in the world, presently producing about 85% of coal from opencast mining. The opencast mining has its own implications due to depth and environmental constraints. Development and extraction of coal is almost in ending stage upto 300m depth. Hence it is required to get bulk output from deep seated underground mines. Bulk production is possible by opening new coal blocks suitable for sophisticated mechanisation to work beyond 300m and managing existing coal resources in underground mines to achieve sustaining improvements. Pillar extraction in multi stages is the only successful traditional underground mining method which gained more significance. Research from 30 years is carried out for a method that improves the percentage of extraction in different underground mining conditions.

4.2 The Country needs to focus on Longwall mining and should initiate a policy to introduce high capacity Powered Roof Supports (PRS) Longwalls which can extract in both CIL and SCCL in feasible either outright purchase/ Hiring. If Longwall faces planned abundantly, it creates competition in foreign equipment manufacturers and develops indigenous market too which would bring down cost of production. Different modules like mine developer cum operator (MDO), Technology provider cum operator (TPO), Hiring of equipment and Risk/gain sharing can be worked out with foreign stake holders. As the coal blocks mostly affected by geological disturbances, very few blocks are available for introduction of Longwall. The blocks which are not feasible for Longwall, are planned to be worked with Continuous miners. Population of Continuous miners are increasing year by year. Hence, the number of Continuous miner units, in the country should be multi-folded to develop and extract 3-6 m thick seams. A Continuous miner can cut a height of 4-5m. The Continuous miner is being suited to most of the Indian geo-mining conditions, but due to its less rate of recovery from thick seams is the disadvantage

4.3 The Blasting gallery is a typical mining method suited for thick seams which is working with moderate success in GVCF in terms of production. At the same time, it cannot produce bulk output from panels. The caving behaviour in underground coal mining have a peculiar nature, due to the associated strata in India. The BG method had a potential to extract 12 m thick seams, but due to shorter incubation period of the Indian coal seams the method is getting abandoned.

4.4 A single pass Longwall can extract up to a height of 6m and the top coal is being left behind when it comes to a thick seam. Sub-level caving has a scope to extract the full seam but the rate of development and time to prepare a panel takes longer duration.

4.5 In India to extract a thick coal seam with a good rate of recovery, initiatives to be taken to introduce a state-of-art technology. An acceptable and appropriate technology introduction is need of the hour, should be with large volume, safe method and low cost.

5.0 RECOMMENDATIONS:

5.1 Absence of efficient and reliable indigenous technology of mining thick seams is a major constraint. The search for efficient and economic system of mining thick seams has been the priority agenda in the action plans formulated in this country and the search continues. The problems are many and varied and no one technique can be of universal application.The objective of this paper is what have been our experiences and results of technology thus far used for thick seam coal mining and in which direction we move from here? Such an exercise must necessarily look into what others in the world have done and what could be the impact of developments made elsewhere in the world in the Indian scenario. Import of technology proved else where is definitely a quick solution subject to stydy in depth , modifications to suite site specific conditions as well as development of capability of manufacture of associated equipment indigenously and development of human resource to cope up the requirements.

5.2 The following recommendations which were deliberated by B.B.Dhar and T.N.Singh , central mining reseach station , Dhanbad india vide their lead paper on " Thick seam mining - problems and issues" during procedings of the international symposium on the subject are valid even today:

(i) Development of thick seams without ascertaining the method of final extraction must be stopped immediately.
(ii) Work on creation of an information base for thick seam deposits and mining needs to be taken up urgently.
(iii) A thick seam mining cell at an appropriate level needs to be constituted to constantly overview the status of thick seam mining in india and abroad and advise the planners in problems related to thick seam mining.

REFERENCES:

1) Singh Satyendra K. , Agrawal Harshit, Singh Awanindra P. Rib stability: A way forward for safe coal extraction in India. International Journal of Mining Science and Technology 27 (2017) 1087–1091
2) Ashish Kumar Dash, Ram Madhab Bhattacharjee. Role of convergence behaviour for superior recovery of thick coal seams in underground mines by blasting gallery. Journal of Mines, Metals and Fuels · April 2016
3) Singh Satyendra K. , Agrawal Harshit, Singh Awanindra P. Rib stability: A way forward for safe coal extraction in India. International Journal of Mining Science and Technology 27 (2017) 1087–1091
4) Singh, R. and Singh, T. N. (1993): Influence of mining dimension on overlying strata deformation.Proceedings of the 4th Asian Mining, International Conference on Geology, Mining, Mineral Processing, Calcutta, India, pp. 349-60.
5) Sinha PK, Verma RK, Jain DK. Research and development efforts in thick seam mining: present and future scenario. In:Singh TN, Dhar BB, editors. Proceedings of International Symposium on Thick Seam Mining. Dhanbad, India: CMRI, p. 471±92.
6) Das, T.K. and Singh, T.N. (1995) *Hydraulic Mining at Gopalichak Colliery of Jharia Coalfield.* Journal of Mines, Metals & Fuels, 43 (1&2). pp. 7-16. ISSN 0022-2755
i. Sandeep Kumar, A. Ravikumar, K. Ravinder Reddy, T. Anil, J. Pavan Kalyan.Case Study On Blasting Gallery Method . International Research Journal of Engineering and Technology (IRJET) June 2020
7) The 19th National Seminar on Underground Coal Mining, The Future Overground lies below ground,SCCL
8) Tien Dung Le, Rudrajit Mitra, Joung Oh ⇑, Bruce Hebblewhite . A review of cavability evaluation in longwall top coal caving. International Journal of Mining Science and Technology 27 (2017) 907–915
9) Tien Dung Le, Chengguo Zhang, Joung Oh,Rudrajit Mitra, Bruce Hebblewhite. "A new cavability assessment for Longwall Top CoalCaving from discontinuum numerical analysis", International Journal of RockMechanics and Mining Sciences, 2019
10) Kumar, Rakesh, Arun Kumar Singh, Arvind Kumar Mishra, and Rajendra Singh. "Underground mining of thick coal seams", International Journal of Mining Science and Technology, 2015
11) Bingxiang Huang, Youzhuang Wang,Shenggen Cao. "Cavability control by hydraulic fracturing for top coal caving in hard thick coal seams", International Journal of Rock Mechanics and Mining Sciences, 2015
12) Tien Dung Le, Xuan Nam Bui. "Effect of Key Parameters on Top Coal First Caving and Roof First Weighting in Longwall Top Coal Caving: A Case Study", International Journal of Geomechanics, 2020
13) Wang, Jiachen, Shengli Yang, Yang Li, Like Wei, and Haohao Liu. "Caving mechanisms of loose top-coal in longwall top-coal caving mining method", International Journal of Rock Mechanics and Mining Sciences, 2014
14) M. Khanal, D. Adhikary, R. Balusu. "Prefeasibility study—Geotechnical studies for introducing longwall top coal caving in Indian mines", Journal of Mining Science, 2015