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Improved underground mine design for reducing subsidence at Barapukuria Coal Mine, NW Bangladesh

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Abstract

Barapukuria Coal Mine (BCM) is located at Dinajpur district, NW Bangladesh. Total area of the BCM is about 5.25 km^2 and coal encountered at a depth range between 118 and 509 m. Six major coal seams (seam-I to seam-VI) were identified at BCM of which greater thickness of seam-VI (~36 m). The estimated coal reserve is about 390 million tons and nearly 64 million tons are extractable. The annual production of coal is about 1 million tons. The coal is high volatile, bituminous nature and low sulphur content with calorific value is 11040 Btu/lb. Based on geological, hydrological and other technical parameters, fully mechanized underground long-wall mining method is applied for extraction of coal in BCM. Long-wall retreating mining method is also applied for extraction of coal from single face with the operational area protected by moveable hydraulic pressure roof support system. These supports are moved forward result the roof behind them collapses to form an extensive abandoned area named goaf. Using volume of the goaf area, amount of caved space is measured and how much filling materials should be required to reduce subsidence is determined. Estimated filling cost of 10 faces is about US$ 3.1 million. Coal in the BCM is extracted from seam-VI, using a multislice long-wall top coal caving mining method. The production of coal from 11 long-wall faces of 1st slice and the first face-1204 of the 2nd slice have already been completed. Recently, coal production is going on from the second face-1203 of 2nd slice. Long-wall top coal caving mining method will be applied for coal production and face-1210 will be developed in BCM. It is estimated that nearly 0.75 m ground subsidence may occur for mining of 1st slice and for 5th slice resulting ground subsidence occurs (~2.25 m). Improving underground mine design at BCM by filling process, subsidence will be reduced and production may be increased significantly.

Keywords: *Barapukuria Coal Mine, Mine development, Mining method, Subsidence, Coal production.*

1. Introduction

The Barapukuria coal deposit was discovered in 1985 by the Geological Survey of Bangladesh (GSB) over an area of 5.25km^2 at a depth ranging from 118 to 509 m under Parbatipur Upazilla in Dinajpur District, Bangladesh. Geographically, Barapukuria coal basin is lies between the longitude 88°57'E to 88°59'E and the latitude 25°31' N to 25°35'N, respectively [Fig. 1, 1]. GSB further operate more detailed surveys to confirm the presence of approximately 390 million tons and nearly 64 million tons are extractable. The composition of coal is ash 16.2%, volatile matter 27.6%, fixed carbon 46.2% and sulfur 0.57%. The calorfic value is 10450 Btu/lb and rank of coal is high volatile bituminous [1]. There are six major coal seams encountered at BCM, and greater thickness of seam-VI about 36 m. BCM is operated to extract about 1 million tons of coal per year. At present coal is producing from seam-VI applying the fully mechanized underground long-wall mining method and long-wall top coal caving (LTCC) method [2]. The production of coal has completed from 11 long-wall faces of 1st slice and the first face-1204 of the 2nd slice has already completed [2]. The development work of second face 1203 of 2nd slice has already been completed. After completion of 1203 long-wall face coal production, face-1210 will be developed and LTCC mining method will also be applied for coal production [2]. As the mined out area in BCM is caved in, subsidence at the surface level has become a great problem. Mining of 1101 coal face initiates caving from the lowest strata in the immediate roof and propagates upward into the Gondwana Formation and up to the base of lower Dupi Tila and finally reaches up to the surface [6]. BCM subsidence zone is divided into three types: (a) Gondwana Formation zone or fractured zone (b) Lower Dupi Tila Formation or aquiclude zone and (c) Upper Dupi Tila Formation or surface zone [6]. The present study aims to calculate the rate of subsidence, improve underground mine design for reducing subsidence, and find out the filling materials to fill the goaf area by filling method.

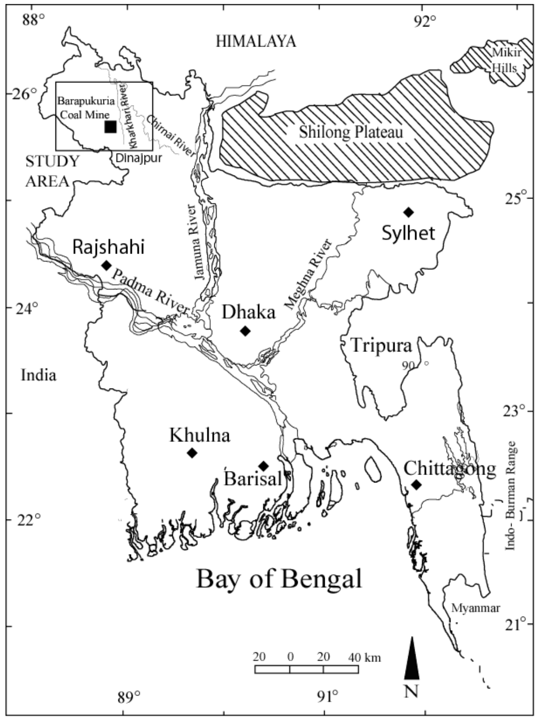

Figure 1: Generalized map showing location of the study area.

2. Stratigraphy of the Barapukuria coal basin

The stratigraphic succession of the Barapukuria coal basin is shown in Table 1. It is subdivided into Basement Complex, Gondwana Group, Dupi Tila Group, Barind Clay Formation and recent alluvium in an ascending order. The Precambrian Basement Complex consists predominantly of diorite, granodiorite, quartzdiorite, granite, schist and gneiss. The Permian Gondwana Group is mainly consists of sandstone with subordinate shale, conglomerate and thick to thin coal seam. The overlying Dupi Tila Group is sub-divided into lower Dupi Tila and upper Dupi Tila formations of Pliocene age. The lower Dupi Tila Formation is consists chiefly of mudstone with subordinate siltstone and sandstone. The upper Dupi Tila Formation consists mainly of sandstone with minor siltstone and mudstone. The Barind Clay Formation is characterized by clay and sandy or silty clay. The top of the succession is recent alluvium, consists of sand, silt and clay.

Table 1. Stratigraphy of the Barapukuria Coal Basin [7].

Age	Group/Formation	Lithology
Holocene	Alluvium	Sand, silt, clay
Pleistocene	Barind Clay Residuum	Clay and sandy clay
Pliocene	Upper Dupi Tila	Sandstone, pebbly sandstone and clay/mudstone.
	Lower Dupi Tila	Sandstone, claystone and mudstone with silica and white clay.
Permian	Gondwana	Feldspathic sandstone, carbonaceous sandstone, shale, coal beds.
Precambrian	Basement complex	Diorite, granodiorite, quartzdiorite, granite and gneiss

3. Mine design

3.1. Long-wall mining method

Long-wall mining method is an exploitation method used in flat line relatively thin tabular deposit in which a long face is established to extract the deposits Movable hydraulic roof support, a shearing machine and an armored conveyer are used for extracting coal. This method is used when ore strength is weak to moderate, tabular deposit with low dip (<12°), large in areal extend, thin bedded (1 to 5 m) with uniform thickness and moderate ore grade [7]. Considering all these parameters being fulfilled at Barapukuria coal deposit, long-wall mining method is applied at BCM. The mining method involves removal of coal from single face, generally 80 to 200 m long with the working area protected by moveable roof support. As the coal is extracted these supports are moved forward so that the roof behind them collapses to form an extensive abandoned area called "goaf". Since coal seam VI (thickest), the only seam to be extracted at BCM, a multislice long-wall mining would be adopted. The design of long-wall mining method which is used in BCM and surface subsidence occur as result of goaf area collapsed (Fig. 2).

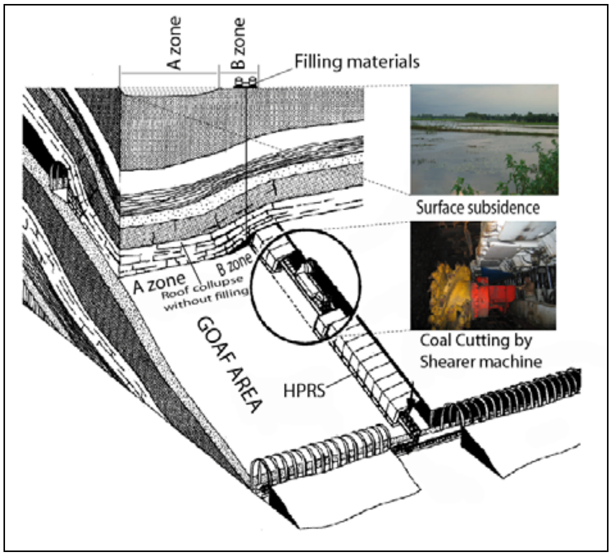

Figure 2. Long-wall mining method with surface subsidence (A zone) at BCM.

3.2. Mine development

During ore production it is needed to develop the mine with proper mine design. To access easily to or near to the coal seam a series of shafts and roadways should be excavated from surface to underground. The arrangement and the excavation engineering of main shafts and roadways, which serve for mining level stated as mine development. The main shafts and roadways excavated for mine development is called development roadways such as shafts, pit bottom, main haulage roadways, main return airway, main cross-cut etc. The arrangement methods of minefield development roadways mainly depends upon certain conditions of minefield geology and accessible mine technique.

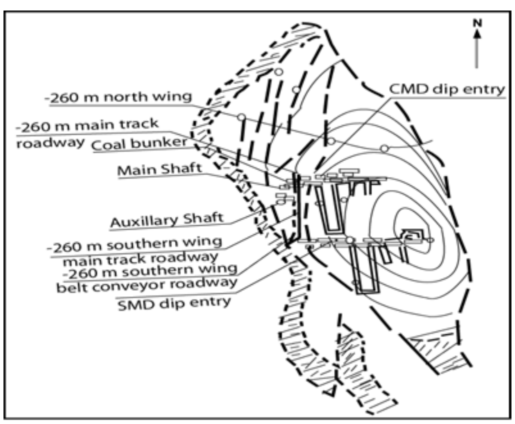

Figure 3. The development plans of Barapukuria coal mine, NW Bangladesh (CMC, 1993).

The Barapukuria coal field is divided into 3 mining areas: a northern mining area, a central mining area and a southern mining area [1]. Coal faces in BCM were primarily designed near to the vertical shafts in the central area of the coal field. But the mine was redesigned to include southern area of the coal field due to a major water flood accident during the construction underground mining area, the whole minefield is now divided into two mining districts, as southern mining district and northern district. In 1994, a construction contract was sign between the Bangladesh government and China National Machinery Import and Export Corporation (CMC) for the development of BCM [1]. The current development works run through the No. 1 (southern) mining district by long-wall mining method and later the northern area will be mined by adopting room and pillar mining method. The proposed succession and developing plan of the Barapukuria coal mining project at a glance shown in fig. 3.

To extract the coal in BCM, access from the surface is made through two vertical shafts, diameter of each shaft is 6 m. Here one is main shaft, 326 m deep, is used for transport of coal. Another one is auxiliary shaft, 320 m deep, is used for transport of human and machineries [1]. Two shafts are also used for maintaining the proper ventilation system through the underground roadways and tunnels. Including the vertical shafts the mine has total 11 km of underground roadways and tunnels [1]. In the southern mining district, the road way arrangement pattern for the development of the Barapukuria coal mine project is shown in Fig. 4 (a).

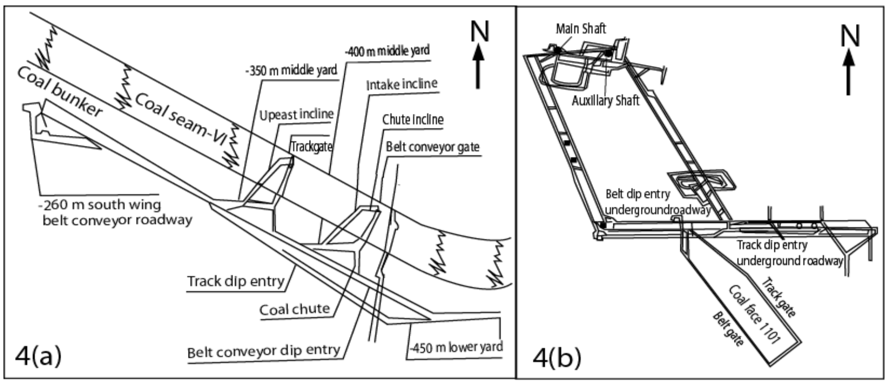

Figure 4. (a) Road way arrangement of the Barapukuria coal mine, NW Bangladesh (CMC, 1999); (b) The development plan of the road way and 1101 coal face tunnel of the BCM (CMC, 2003).

The sub-level haulage entry (belt conveyor gate) and air return entry (track gate) are laid out in parallel to the coal face. The single entry layout is adopted between two sub-levels while the double entry layout and the roadway driving along the goaf are used for the successive sub-level mining. Coal from seam-VI is extracted in multi slice method in descending order at the upper part of the seam. Each slice is separated vertically from the next one by sections of unworked coal of approximately 3 m [1]. The slice geometry and the whole mine plane at a glance is shown in Fig. 4b.

3.3. Mine subsidence

Mine subsidence is the depressions, sags and cracks in the surface above an underground mine. Subsidence happen after the coal is removed and the ceiling or roof of the mine collapses. By using a range of modern engineering techniques to design the layout and dimensions of underground mine workings, surface subsidence can be controlled. To prevent subsidence, efforts have been by drilling deep holes in the soil, rock and filling mine voids with different types of materials i.e. sands, fly ash and mine refuse material to stabilize the surface (Fig. 6). By applying National Coal Board (NBC, England, 1975) method, it is estimated that nearly 0.75 m ground subsidence may occur for mining of 1^{st} slice and for 5^{th} slice resulting ground subsidence occurs (~2.25 m) at BCM [6]. Mining of 1101 coal face causes caving from the lowest strata and moves upward into the Gondwana Formation and up to the Lower Dupi Tila Formation and finally to the surfaces [6]. Filling process can not eliminate subsidence but reduce it and to allow an increase in coal recovery over the caving mining methods. So underground mine design of BCM must be improved or redesigned to get rid of this phenomenon. By improving the design and applying filling process, subsidence can be reduced in minimum level. In the improved mining design there will include some other development work such as surface water reducing plant, pipeline through skip shaft and roadways and finally to the coal face (Fig. 2).

4. Filling processes

4.1. Filling methods

The hydraulic filling method can decrease the effects of subsidence at about 12 times from its total caving in a non-filling condition by hydraulic filling of voids with sand with respect to caving [8]. In the hydraulic filling method, filling materials are used for sand, gravel, concentrator tailings or slag etc. In BCM, sand from Kharkhari river bed (Fig. 1) can use as filling source materials. Pipeline hydraulic transportation is used to borrow the stope. So in improved underground mine design, the whole arrangement of filling process must be included. The advantages of filling method are good adaptability, high ore recovery rate, safe operation of filling, making use of industrial waste and protect the surface from adverse subsidence.
Hydraulic Sand Stowing (HSS) is widely in use for extraction of coal pillars from underground coal seams. For a long time, HSS has been practiced in several coal producing countries for obtaining a large recovery of coal in spite of having adverse mining conditions [5]. HSS is the mode of voids filling in which sand water mixture is prepared at surface and is allowed to gravitate to the underground voids to be filled. So improved underground mine design of BCM includes the constructions of surface plant to prepare sand water mixture and pipeline to gravitate the mixture to the underground. Without causing harmful surface subsidence, almost 100% recovery of coal from an underground mine is obtainable by the application of stowing methods in which the goaf area created by the extraction of coal is solidly filled with mine residues or cheaply obtainable solid [5]. So HSS can be implemented in the BCM, reduce the severe effect of land subsidence and at the same time increase the coal production.

4.2. Filling materials

HSS is yet an effective filling process in coal mine where sand is used as a filling material. In the case of BCM, it is recommended that the filling materials for this operation will be taken from the nearby Kharkhari river, distance of which from the mine area is about 1.8 km and the depth is about 4 to 9 m. During the dredging of the river sand is carried out by pipeline. The necessities of the river dredging are the increasing depth of the river, for sufficient irrigation water, river ecosystem will be accomplished with navigable routes and reducing potential flooding in the region. Before filling process, surface treatments have to be accomplished as the filling materials will come from the river by pipe line with >40% water as a solution form. According to the Bashundhara Dredging Company Limited (BDCL) upto 60% of the water present in sand is reduced before filling works. So a water reducing plant is needed at the surface to reduce the water from sand. Otherwise water expulsion from the wet sand will occur underground flooding. After reducing about 60% of the 40% water come with sand, the water content of sand becomes 16%. By establishing pipe line through the skip shaft, the sand water mixture will be gravitated into the underground. Then it is transported to the golf area for filling.

4.3. Filling cost calculation

Cost is the main fact in any operation associated with mining. If the whole filling process becomes very costly and economic loss happens then the process must be avoided. So it should be kept in mind that the filling process will be implemented when the overall condition, supply of filling materials, dredging and reclaimed cost are favorable. It is not possible to fill 100% voids or goaf area. Approximately 60% of total volume is possible to fill up. From the study, it is estimated that a total cost of the 60% filling of following faces is about US$ 3.082864 million. The calculations are shown in Table 2.

Table 2. Filling cost estimation for 10 coal faces (1st slice) of BCM.

Serial no:	**Name of Longwall Coal Face**	**Coal Face Dimension (L** x W x H**) m^3**	**Coal Face Volume - V_1(m^3)**	**Fillable volume- V_2=V_1× 60% (m^3)**	**Estimated cost = (V_2 × 2.486) US$**
1.	1101	460 × 105 × 2.7	130410	78246	194519.56
2.	1106	562 × 121 × 2.7	183605.4	110163.24	273865.81
3.	1109	558 × 106 × 2.7	159699.6	95819.76	238207.92
4.	1103	609 × 141 × 2.9	249020.1	149412.06	371438.38
5.	1104	670 × 141 × 2.9	273963	164377.8	408643.21
6.	1114	546 × 126 × 2.9	199508.4	119705.04	297589.72
7.	1105	560 × 164 × 2.9	266336	159801.6	397266.77
8.	1108	560 × 164 × 2.9	266336	159801.6	397266.77
9.	1112	537 × 116 × 2.9	180646.8	108388.08	269452.76
10.	1111	535 × 98 × 3	157290	94374	234613.76
					Total = 3082864.66 (US$ 3.082864 million)

According to the Association of River Dredging Companies Bangladesh (ARDCB) the total cost of every cubic feet is US$ 0.0704 (5.5 TK) at a distance 1.5 km to 2.00 km with filled up by hydraulic sand stowing method.

As $1ft^3 = 0.02832\ m^3$

So, the cost of per cubic meter of filling is = US$ 0.0704 ÷ 0.02832 = US$ 2.486

In the case of coal face-1101, the cost of 60% filling is = US$ (78246 × 2.486) = US$ 194519.56

Thus calculating the cost for each coal face, it is estimated that a total cost of the 60% filling of 10 faces is about US$ 3.082864 million.

In the present mine design, 0.75 m ground subsidence may occur for mining of 1st slice in non-filling condition. With the filling of 60% of each coal face, there remain 40% voids. So,

For 100% voids subsidence occur = 0.75 m

For 40% voids subsidence occur = (0.75 × 40) ÷ 100 = 0.30 m

So the reduced subsidence is about = (0.75-0.30) m = 0.45 m

Thus for improved mine design with 60% fill up of goaf area subsidence may reduce 0.45 m for mining of 1st slice and 1.35 m for 5th slice.

5. Conclusions

Long-wall retreating mining method is applied in BCM for extraction of coal from single face (80 to 200 m long) with the operational area protected by moveable HPRS system. These supports are moved forward result the roof behind them collapses to form an extensive abandoned area named goaf. Using volume of goaf area, the amount of caved space is measured and how much filling materials should be required to reduce subsidence is determined. It is estimated that ground subsidence may occur for mining of 1st slice and 5th slice are ~0.75 m and ~2.25 m, respectively. Recently, underground mine design has been faced risky subsidence. Applying the HSS filling method, the subsidence of BCM can be reduced significantly by improving underground mine design. The filling cost of each face is about US$ 3.1 million. If the HSS method is applied immediately, the subsidence will be reduced and overall surface area will be protected from such disaster. The reduction of subsidence is necessary not only saving the living people of the mine area but also increase of coal production significantly.

6. Acknowledgment

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