Longwall Stress Distribution in 1101 Coal Face of the Barapukuria Coal Mine, Dinajpur, Bangladesh

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Abstract

Coal was extracted from Barapukuria Coal Mine using the method of Inclined Slicing Roof Caving Longwall Mining along the strike, and the sequence of mining the slices was from top to bottom. Mining of 1101 coal face initiates caving from the lowest strata in the immediate roof and propagates upward into the Gondwana Formation, to the base of Lower Dupi Tila and finally up to the surface as well. The redistribution of stresses was analyzed by Peng (1986) and Wilson (1981) methods. The results show that the stresses are relatively large; and the magnitude of front and side abutment pressure ranges from 1.3 to 6.92 MPa and 2.6 to 22.75 MPa, respectively. The side abutment pressure may affect the surrounding rock mass up to 147.04 m from the face line. As a consequence of stress redistribution surrounding them, the rib pillars may start to deform, which ultimately affects the gate road geometry and overall strata stability of the 1101 coal face. The process of caving was reflected in the downward sag of the roof strata in the gateroads as soon as it is under the direct effect of 1101 advanced coal face. However it is recognized that this might eventually be necessary to control strata movements and to reduce mining problems which might arise from multi slicing mining conditions in thick seams like Barapukuria condition. It is mandatory for the mine authority to carry out a detailed study for the gob forming process and expansion of the materials. As mining experience is gained so far from the 1101 coal face operation, the mine planning and method of roof control should be modified and developed in the light of the experiences, because failure of the project would be unacceptable for economic, political and social grounds of the country.

Introduction

Coal mine in Barapukuria basin in Dinajpur district, Bangladesh (Fig.1) enters into the coal mining era for the first time. As the country has no coal mining experience in the past, Barapukuria Coal Mining Company (BCMC) is expected to bring about a number of other mining related activities in the country. Barapukuria coal mine is promptly organized by the Jiangsu Coal Geology Company, CMC, China, under the direct supervision of Petrobangla, Bangladesh. Currently trail basis production is under process, which is a modern and large scale one with a production capacity of 1 million tones annually. Coal mining industry itself is a very complicated technology, with frequent problems faced in the mine. One of such problems in the BCMC is the rock mechanical problem in the 1101 working face. So far a number of investigations were focused on the type, reserve, quality and mining methods of the BCMC. Feasibility study has confirmed that substantial amount of coal reserves occur in that coal basin. It is noticeable that none of the organizations or researchers till date have undertaken any detailed works based on roof control technique of that particular coal mine working face. In a nutshell, the authors tried to establish a research work to overcome the geomechanical problems of the coal face.

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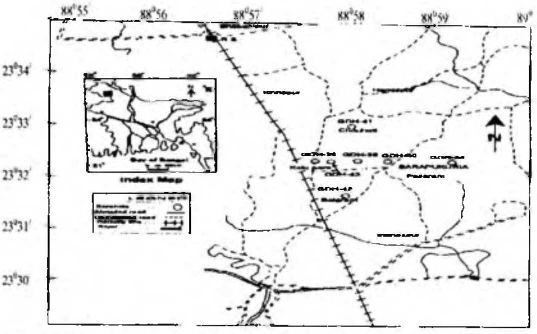

Fig.1: Location map of the Barapukuria Coal Mine area, Dinajpur District, Bangladesh.

Method of Study

The redistribution of stresses around the periphery of the 1101 coal face is calculated by using Wilson principal. For this analysis a computer program in Turbo C++ is used for accuracy. It is assumed that due to mining of 1101 coal face, stress may superimpose over the in situ stress field surrounding the coal seam and also the sides of rib pillar. Again for calculating the height of the coal seam in the upper damaged zone of the strata, Luo, 1997, and Peng, 1984, formula is used.

Results and Discussions

Strata Behavior of 1101 Coal Face

When a longwall face is developed in the coal seam, the natural equilibrium in these strata is destroyed. Thereafter a longwall face of sufficient width and length is excavated in the rock mass, the overburden roof strata are disturbed in order of severity from the immediate roof towards the surface, forming a subsidence trough. There are three distinct zones of disturbance in the overburden strata in response to longwall mining. Although each zone can be identified by the failure characteristics of the strata, the thickness is not well defined which may vary. Due to the mining of coal seam VI of 1101 coal face of the BCMC, the mining induced disturbed zone may be determined from the Luo, 1997, formula.

Immediately above the mining of 1101 coal face, a false roof of 0.3 to 0.6 m is present, which may instantly collapse after the shearer and the face supports advance. This roof mainly consists of weak or soft carbonaceous shale and well jointed or fractured sandy shale. Right after the shearer cutting, if the support is not advanced immediately, the unsupported roof between the face line and the canopy tip will fall in a short period of time. The complete caving region may range in thickness from 7.5 to 15 m. This zone consists of hard shale, sandy shale, and weak sandstone, where joints and fractures are not well defined or less pronounced. Generally the roof caves in shortly after the support has advanced, and the caved fragments are larger in size. The caving line is located near the rear edge of the canopy or sometimes extends a little bit in to the gob area. In general roof stability is pronounced in this zone, but cyclic loading and unloading of the support may also affect the roof behavior.

From the calculation, the partial caving zone has a thickness of 15 to 30 m, which mainly consists of thick or strong sandstone and sandy shale. This zone can be left unsupported for more than 5 to 8 hours and thereafter will still remain intact. The roof stability of the partial caving zone may not be affected due to cyclic loading and unloading of the support advancement, and the resulting force acts towards the rear side of the canopy. The upper strata of this zone may show significant degree of bending and fracturing of the stratigraphic horizon, which ultimately affects the hydraulic characteristics of the Barapukuria basin. Hence this zone may be stated as the main threat for the mine, as it has a probable chance of direct connection between the Upper Dupi Tila aquifer to the coal face.

Whereas the fracturing zone may ranges in thickness from 50 to 125 m, the strata of this region are broken into blocks and cracks due to bed separation. As a consequence, the main roof Gondwana sediments and some portion of Lower Dupi Tila aquifer may affect severely, as a result the basin may face

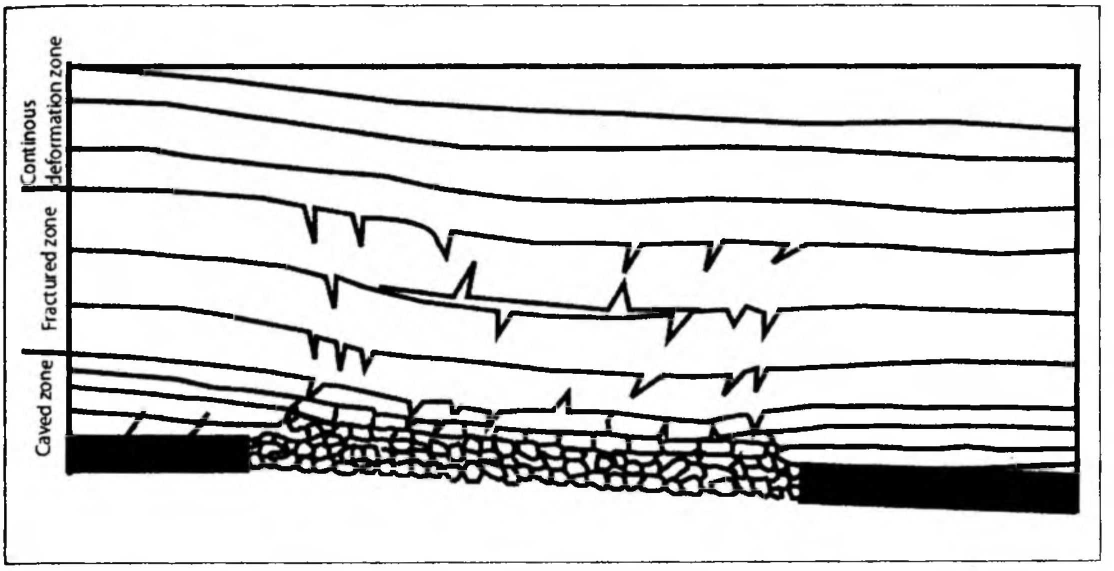

Fig. 2: Schematic representations of the individual strata condition of 1101 longwall coal face.

hydrogeological imbalance condition. Schematic illustration of the caved and fracture zone is given in Fig.2. Due to formation fracture, the sagging propagates up to the surface, where bending of strata is gradual and distributed over a large surface area. By this time a nominal amount of subsidence is found within the mine boundary area.

Immediate roof

Movements of the three zones discussed on strata behavior of 1101 coal face, having different degrees of effects on roof control at the longwall face. The effect decreases as the strata are located further upward from the roof line. The immediate roof of that portion, which is lying immediately above the roof line of the mining horizon, mainly consists of low strength carbonaceous shale, black shale and well jointed or fractured sandy shale. The weight of the immediate roof must be fully supported by the powered support, because of strata in the gob area being broken and caved, which cannot transmit horizontal force along the direction of mining. In the design of a coal mine, the immediate roof is the basic consideration of roof controlling method. The rock type and thickness of the immediate roof are the major factors for the selection of various roof control techniques.

In 1101 coal face, caving initiates from the lowest strata in the immediate roof and propagates upward into the fractured zone, i.e., top of the Gondwana Formation and base of lower Dupi Tila. In the process of caving, each of the strata sags downward as soon as it is under the direct effect of 1101 coal face advance. When the downward sagging exceeds the maximum allowable limit of the strength of rock mass, the stratum breaks and falls. Thus the gap between the top of the rock pile and sagged stratum continues to decrease as the caving process propagates upward. When the gap between the successive stratums vanishes, the caving stops. According to *Peng, 1984;* the height of the caving zone may satisfy the following condition:

$$H - d = h_{im} (K - 1) \quad \dots (1)$$

$$d < d_0 \quad \dots (2)$$

Where, H = mining height

d = sagging of the lowest uncaved strata

d_0 = maximum allowable sagging (without breaking) of the lowest uncaved strata

h_{im} = thickness of the immediate roof or caving height

K = bulking factor of the immediate roof

Hence, the caving height or the thickness of the immediate roof required to fill up the mined out gob area, can be determined from Equ.1

$$h_{im} = \frac{H - d}{K - 1} \quad ...(3)$$

Here it is noted that d and K must be determined at the same location. The ideal place is within the area beginning from the point when the sagged but uncaved stratum first makes contact with the rock piles to the point when the rock piles have been compressed to the final stage (*Peng, 1986*).

An approximate relationship between the caving height, seam thickness and the overburden depth was given by *Peng and Chiang (1984)* as:

$$h_{im} = h\ 0.439\ \ H\ 1.544 \quad ...(4)$$

Where, him is the caving height

h is the overburden depth

H is the seam thickness

From the above stated equation, it is calculated that the maximum thickness of the caving zone is 47 m within which the Gondwana Formation may be severely affected by the sagging process (bending and intense fracturing or displacement of strata) due to mining of 1101 coal face.

Main roof

The main roof generally refers to the slightly broken but uncaved strata in the lower portion of the fractured zone. Its movements will affect the stability of the immediate roof and thus the supports in the face area. Above the main roof, the strata movements are far away to have a significant impact on the face area, as shown in Fig.2. The thickness of the main roof may be determined by examining the stratigraphic column above the coal seam, of which the characteristics feature of strata separation. Depending on the immediate roof thickness ? h, overburden depth (m), and referencing the first caving distance of main roof, L; the main roof of 1101 coal face in the ii-iii class, of which practically signify the obvious to violent index of main roof *(CMC, 2003)*.

Longwall Stress Distribution

Practically a low modulus seam is sandwiched between relatively stronger and higher modulus roof and floor strata, which are loaded by the weight of the overburden or superincumbent pressure. When the longwall face proceeds, abutment pressures will form around the edges of the gob and superimpose on those created during entry developments. Fig.3 shows the abutment pressure distribution around a retreating longwall. The abutment pressure in front of the face line is called the front abutment pressure; those along both sides of the face in the gob area are the side abutment pressure. The front and side abutment pressures intersect at the corners of the face and superimpose on each other. Both pressures decrease exponentially away from the edges of the face and return to the superincumbent pressure some distance away.

Front Abutment Pressure

The front abutment pressure can be first detected at a distance of unit times the overburden depth i.e. 250 m away from the 1101 coal face line. Initially the magnitude of this pressure is very small but begins to increase rapidly when the face approaches within 30 m and reaches its maximum value when the face is 1-6 m away. After that, the pressure drops drastically and vanishes at the face line, as shown in Section CC in Fig.3. The width of the front abutment pressure depends not only on the overburden thickness but also on the position along the face advance, which is not uniform across the face width. It is wider at both ends of the face and decreases towards the center of the face. In general, the magnitude of the maximum front abutment pressure ranges from 0.2 to 6.4 0 (where 0 is the average in-situ superincumbent pressure), (*Peng, 1984*). The magnitude of front abutment pressure in the case of 1101 coal face of BCMC, falls within the range of 1.3 to 6.92 MPa, which depends upon the local variation of superincumbent stress condition. Usually, the front abutment pressure is lower when the face is near the rib pillars and larger near the side of the adjacent mined-out face. When 1103 coal face will be started to mine, a large amount of abutment pressure may impact on its gate road due to the mining of 1101 coal face front abutment pressure.

Depending on the physical properties of the immediate roof and the main roof, the peak front abutment pressure occurs either at the corners or at the center of the coal face. As the immediate roof of 1101 coal face is weak, the peak front abutment pressure occurs at the corners of the face, because a weak roof does not impose a strong weighting effect on the center. The peak pressure will remain at the corners as long as the weighting of the main roof does not take effect on it.

Side Abutment Pressure

The side abutment pressure change can be felt at the ribs side both the belt gate and track gate entry at about the same distance away from the face line as the front abutment pressure. The maximum side abutment pressure begins to increase when the longwall face advanced up to some distance, which reaches the maximum value and there after stabilizes. Depending upon the face width, geology, and seam properties, the side abutment pressure at the ribs side may reach the maximum value either before the face arrives or after the face has passed.

The side abutment pressure is largest at the ribs of both the belt gate and track gate entry and decreases exponentially away from the active face workings, as shown in Section RR in Fig.3. Theoretically the magnitudes of the side abutment pressure changes at a range of 0.4 to 3.5 0 (*Peng, 1984*) i.e. 2.6 to 22.75 MPa from the 1101 face line to the adjacent chain pillars. The width of the side abutment pressure is related to the overburden thickness. The relationship can be expressed as follows (*Peng, 1986*):

$Ws = 9.3\ h$ .... (5)

Where, Ws = Width of the side abutment pressure;

h = Overburden thickness.

From the above stated calculation, it is estimated that the width of the side abutment

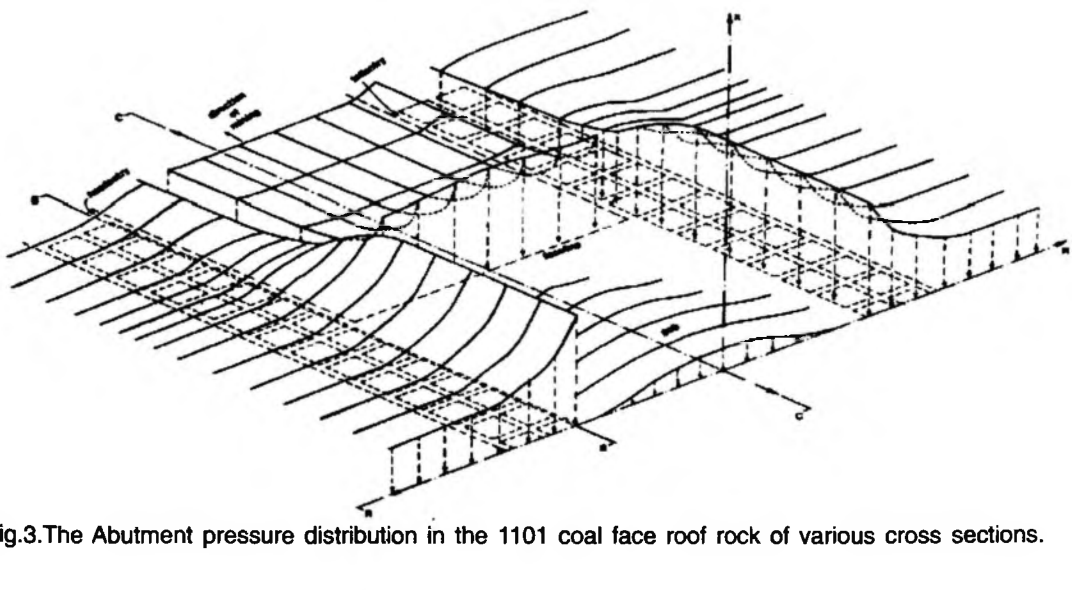

Fig.3.The Abutment pressure distribution in the 1101 coal face roof rock of various cross sections.

pressure may range in depth from 1101 coal face up to 147.04 m, which indicates that due to the mining of 1101 coal face the Gondwana Formation may be severely disturbed and ultimately affect the Belt gate and Track gate roadway tunnel geometry. According to the mine development plan of BCMC, adjacent 1103 coal face will be mined out after 1 to 1.5 years later than the complete extraction of 1101 coal face. The bigger interval of time is required for the successive coal face due to settling down and stabilization of the surrounding mining induced disturbed rock mass.

So, when the adjacent 1103 coal face is to be scheduled for mining, response of the strata behavior due to mining of 1101 coal face must be taken into consideration. From the analysis of the front and side abutment pressure distribution, it is clear that due to mining of 1101 coal face, a wide range of stresses may redistribute around the rock mass i.e. an interaction problem may arise due to disturbance to the upper strata. The acute problem should be taken into consideration by the mine authorities for the safety and long life of the mine of BCMC.

Gob Pressure Estimation

The resulting non-linear stress distribution is approximated by a triangular distribution of forces in the coal mine gob harsh environment, shown in Fig.3. *Wilson (1981)* proposed a number of equations for calculating the redistribution of vertical stress, the peak abutment stress, the width of the rib side yield zone and the total vertical force carried by the yield zone for the specified strata condition of 1101 coal face of BCMC. Following are the relations forth estimation of stresses in the roof and various cross sections in the coal mine face (*Wilson, 1981*) :

Vertical stress

$$\sigma_{zz} = b\ p\ \exp\left(\frac{xF}{m}\right) \quad ...(6)$$

Peak abutment or yield stress,

$$\sigma_y\ c_o = +b\ p \quad ...(7)$$

Width of yield zone,

$$\frac{m}{F}\ \text{in}\left(\frac{p}{p^*}\right) \quad ...(8)$$

Vertical force carried by yield zone,

$$A_b = \frac{m}{F}\ b(p - p^*) \quad ...(9)$$

Where,

σ_z = vertical stress

σ_y = Peak abutment or yield stress

P = γ h = vertical stress remote from the excavation

c_o= In-situ uni-axial Compressive Strength of the strata.

b = Constant in the principal stress form of the coulomb shear strength equation,

$$\sigma_1 = c_o + b\sigma_3 = +b \quad ...(10)$$

m = Height of the extraction

x = Distance from the rib side

xb = width of the yield zone

P* = Support pressure p_i plus unconfined compressive strength of the broken material at the rib side, taken as 0.1

i.e. p* = p_i + 0.1; MPa

$$F = \frac{b-1}{\sqrt{b}}\left(1 + \frac{b-1}{\sqrt{b}}\tan^{-1}\sqrt{b}\right) \quad ...(11)$$

Where, $\tan^{-1}\sqrt{b}$ is expressed in radian.

The stress in the zone beyond the peak stress decays asymptotically towards the overburden stress, P. The stress decay curve is assumed to be in the form of

$$(\sigma_{\approx} - p) = (\sigma_y - p)\exp\left(\frac{X_b - x}{c}\right) \quad ...(12)$$

Where, 'C' is a constant having the units of distance (m).

Where, is the load deficiency associated with each rib side pillar. For, W > 0.6h

= 0.15 h 2 ... [14 (a)]

And, for W < 0.6h,

Aw = 1/2 w (h -) ... [14 (b)]

Where, W is the width of the longwall face. In the case of BCMC, the width of coal face is 105 m and the overburden depth above the coal seam is 250 m. Hence the condition 14 (a) is applicable for the 1101 coal face.

For the calculation of redistribution of stresses around the longwall coal face of 1101, the following parameters are used, Δ = 0.026 MN/m3, h=250 m, m = 2.5 m, b = 2.82, 1 = 18.3924 MPa, 3 = 0.465 MPa, Co = 17.08 MPa, and Pi = 0. Here the prevailing condition for the calculation is that the coal seam VI is located between the strong roof and floor. Substitution in the appropriate equations, it is found that, p = 6.5 MPa, p* = 0.1, = 35.41 MPa = 4.53 m, Ab = 20.23 MN/m, Aw = 243.75 MN/m and C = 8.75 m. The stress analysis by the above stated method shows that there is a discernible stress rise up to 45 m from the face line. For the detailed analysis, a computer program Turbo C++ run is given in Appendix -1, from which it can be seen that there is a dynamic change of pressure from the face line up to the solid abutment coal measures, as shown in Fig.4.

Conclusions

The complete extraction of coal from the 1101 longwall face induces a series of activities, including movements of the rock strata between the roofline and the surface, surface subsidence, abutment pressure on both sides of the face, and roof - to - floor convergence in the entries and face end area. The redistribution of stresses due to the mining of 1st slice (1101 face) is relatively large; the magnitude of front and side abutment pressure ranges from 1.3 to 6.92 MPa and 2.6 to 22.75 MPa respectively, and

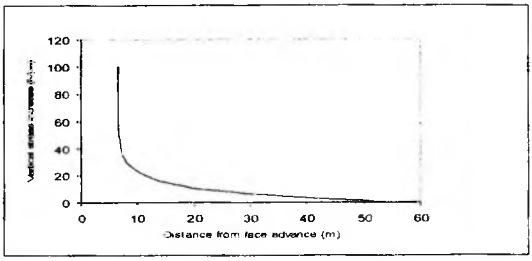

Fig.4. Vertical stress redistribution ahead of the 1101 coal face line with face advance.

the side abutment pressure may affect the surrounding rock mass up to 147.04 m from the face line. As a consequence of stress redistribution, the surrounding rib pillars may start to deform, which ultimately impacts the gate road geometry and overall stability of the 1101 coal face. In the process of caving, each of the strata sags downward as soon as it is under the direct effect of advancing 1101 coal face. When the downward sagging exceeds the maximum allowable limit of the strength of the rock mass, the stratum started to break and fall. As it falls, its volume increases; therefore the gap between the top of the rock pile and sagged stratum continues to decrease as the caving process propagates upward, and when the gap between the successive strata vanishes, the caving process stops. However it is recognized that it might eventually be necessary to control strata movements and reduce mining problems which might arise from multi slicing mining conditions in the very thick seam like Barapukuria condition.

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Appendix

Computer program (Turbo C++) for distribution of vertical stress around the longwall face of 1101, BCMC (after Wilson, 1981)

```
#include<stdio.h>
#include<conio.h>
#include<math.h>
#include<graphics.h>
#include<stdlib.h>
void main( )
{
float m=2.5, f=2.3, p=6.5,p1=0.1;
float xb;
clrscr( );
xb=(m/f) * log (p/p1);  //p*=p1
printf("Xb=%f",xb);
float sigmay, c0=17.08,b;
float sigma3=0.465,sigma1=18.3924;
b=(sigma1-c0)/sigma3;
printf("\n\n b=%f",b);
//f=((b-1)/sqrt(b)) * ( 1+ ((b-1) / sqrt(b)) * atan(sqrt(b)) );
//printf("\n\nf=%f",f);
sigmay=c0+(b*p);
printf("\n\nSigmay=%f",sigmay);
float Ab=(m/f) * b *(p+p1);
printf("\n\nAb=%f",Ab);
float Aw, neu=0.026,h=250;
Aw=0.15*neu* h*h;
printf("\n\nAw=%f",Aw);
float C=(Aw+(p*xb)-Ab)/(sigmay-p);
printf("\n\nC=%f",C);
for(int x=0.0; x<=480.0; x=x+5.0 )
{
float sigmazz=p+ ( (sigmay-p)* exp((xb-x)/ C) );
printf(" \n when x=%d    sigmazz= %.4f ",x,sigmazz);
}
getch();
}
```