Türkiye 16. Madencilik Kongresi / *$16^{th}$ Mining Congress of Turkey,* 1999, ISBN 975-395-310-0

# APPLICATION OF THE CAVEABILITY CONCEPT TO PILLAR DESIGN IN LONGWALL MINING (ABU - TARTUR MINING CONDITIONS)

W. A. Gomma
Professor, Mining dept., Faculty of Engineering Assiut University , Assiut Egypt

S. S Imbaby
Associate Professor, Mining dept., Faculty of Engineering Assiut University, Assiut Egypt

ABSTRACT: The stability in longwall faces depends mainly on the interaction between the roof strata , face and roadway supports and the dimensions of rib pillars. If the rib pillar is too narrow, very high stresses act on the pillar resulting high rates of roadway closure, in the immediate vicinity of the face.

The main aim of this paper is to apply the caveability concept to longwall rib pillar design at Abu - Tartur mining area . The pillar load is estimated taking into account the physical and mechanical properties of phosphate deposit and roof rock , panel width, mining height, depth below surface and pillar width. It is found that the safe rib pillar widths in case of longwall face widths 60,100 and 120m are 25, 33 and 39m respectively when factor of safety is about 1.8 and extraction ratio equals 75% .

## INTRODUCTION

The caving characteristics of the gob are the principal factor to be considered when designing a longwall system . Caveability prediction methods have been developed to assist the mining engineer in the mine planning stage. The roof conditions significantly influence the process of roof caveability. Generally, soft roof conditions signify good caving characteristics, e.g. thin laminated shales with probable problems in roof stability. On the other hand ,hard roof conditions signify difficult caving , e.g. hard sandstone with good roof conditions in the entries. Loading exerted on the pillars depend on the competence of the surrounding strata. Longwall pillars perform the essential function of protecting the entries. The entries must be maintained in good conditions throughout the life of the longwall face production for the transport of ores, miners and materials and efficient coursing of mine ventilation (Josien, 1980; Szwilski, 1983; Unrug and Szwilski, 1982).

To predict pillar stability, a design method must identify and quantify the variables involved in pillar design. The significant variables in pillar design are the resistance of pillar material to fracturing and crushing, degree of competence or stiffness of roof strata, geometry of pillars and panels , virgin vertical pressure and geological structures such as faults and joint sets ( Mark, 1991;Potvinetal., 1989).

There are two basic approaches to guide longwall pillar design. The conventional design approach uses large pillars that are sized to carry all the induced abutment loads, (provided factor of safety greater than 1.0) . The other approach is the yield pillar technique using small pillars which may be designed to fail in a stable manner and transfer loads to the abutment pillars ( provided factor of safety about 1.0) (Sheorey et al, 1995) . The technique of leaving yield pillars in the goaf is eminently suitable for depillaring under air blast - prone uncaveable strata, when stowing or inducing caving by artificial means are not adopted . It is also possible to obtain acceptable extraction recovery unless the seam is very thick or very deep. The conventional pillar design has great attention of most researches because of its wide application in mining excavations.

Design formulae of longwall pillars consist of relatively simple equations whose output is a stability factor or a required pillar width . Although they represent simplified models of the actual problems, they are extremely useful in practical design. Numerical models are more complex methods, especially if the real rock conditions e.g.

nonlinearity, anisotropy,...etc. are taken into consideration. They can be effectively used in panel design and provide valuable insight control problems . Much efforts are required to apply them. So they are often less attractive than the design formulae (Mark, 1991). Bieniawski, 1984; Carr et al, 1982; Choi et al., 1980; Mark et al., 1986 developed methods for sizing rib pillars in longwall mining applying King's approach (King et al., 1970). The only difference between these methods is the choice of the angle of shear ($\phi$) at the side of the goaf. However, it is difficult to measure the angle of shear over the goaf which is the principal factor for determining pillar load. The caveability concept which depends on certain rock classification system is applied to facilitate the problem of pillar design .The obtained results are correlated with field measurements . Good agreement between these results and the field measurements is observed(Imbaby, 1992).

The principal aim of this paper is to apply the caveability concept to rib pillar design in longwall mining at Abu-Tartur phosphate mines . Safe pillar dimensions can be evaluated at different face lengths.

## 2.PILLAR FAILURE MECHANISMS

Pillar failure can be divided into two basic modes , stable (progressive) failure and unstable (bursting) failure. Stable failure is characterized by gradual deterioration of rock mass in a relatively slow and non violent manner. Unstable failure is associated with the violent release of energy in sudden bursts causing instantaneous failure of a rock mass. In progressive failure mode the fractures at the pillar boundaries are developed, relieving some of original confinement. Under increasing load, later expansion of the pillar will increase, slabbing may initiate and the fracturing will propagate to the pillar core .The loss of load bearing capacity is associated to the loss of pillar confinement. The failure of conventional pillars is in the form of progressive failure mode. Different methods for conventional pillar design include the following three basic elements :

a) estimation of the load applied to the pillars.

b) estimation of the load bearing capacity of the pillar material i.e. pillar strength.

c) a design criterion usually recommended safety factor F.S= pillar strength over pillar load.

The relationship between safety factor and percentage of the failed pillars is studied. It is found that the percentage of the failed pillars decreases as the safety factor increases. When the safety factor is equal to 1.0 the probability of failure is about 50% (Coates, 1981).

## 3.GEOLOGICAL AND MINING SITUATION OF ABU- TARTUR MINES

Longwall panels under investigation is located within Abu-Tartur plateau in the south - west of Egypt, in the Western desert . The plateau has a semi-oval shape and is exposed to the north - west direction. Its area comprises about 1200 $Km^2$ . The phosphate layer is of 3.5m. average thickness and located at a depth ranges from 50 m in the east to 260 m in the west , averaging about 155 m . The phosphate layer is nearly horizontal with an angle of inclination (0.0° 30" to 3°) averaging about 1° 30 ". The immediate roof is composed of 7.5 to 15 m of papery clayey shales overlain by a layer of argillaceous sand of 6.6 to 16 m . The stratigraphie column and rock properties are given in Fig. ( 1 )

Mine layout shows three ring galleries , main and tailgates as well as rib pillars between the panels as shown in Fig . (2). The width of rib pillar equals 25 m . The width of the pillars is determined on the basis of experimental mine observations. The maximum face length equals 120 m and panel extension is about 1000 m . The annual face advance is 760-800 m . Regular spacing about 0.75m. between the sets of steel supports in main and tailgates is maintained (Russian Techanical Proposals, 1989&1990).

## 4.DESIGN PROCEDURE

Pillar layout must be designed so that the possibility of pillar instability does not arise. Traditionally, mining engineers have thought to achieve this aim by ensuring , through the use of safety factors, that the load acting on individual pillars is always smaller than the corresponding pillar strength . Naturally , it is difficult in practice to predict the exact pillar load and pillar strength. For determining the strength of pillar material, Salamon approach has been applied(Salamon, 1967).

The methodology used in this paper for the development of pillar design guidelines is based on the application of caveability concept to assess the state of stress in the pillar i.e. pillar load . The significant variables which are taken into consideration can be grouped as follows:

a) uniaxial compressive strength of phosphate rock (pillar).
b) uniaxial compressive strength of papery clays (roof).
c)face length
d) mining height (pillar height).
e) depth below the surface.
f) specific weight of overburden rocks.

In Abu- Tartur area the longwall mining method is applied to exploit the phosphate ores. The proposed face lengths are 60,100 and 120 m with rib pillars of 25 m. in width. Excessive convergence occurred in the tailgate after extracting the panel which was supported by double channels face to face ( square cross section) steel sets as posts with regular spacing about 75 cm . Caps are double channels back to back (I - beam cross section)

To maintain the tailgates at good conditions to serve the next panel, supplemental supports must be installed thus increasing the cost of roof supports. The efficient design of rib pillars will improve the roof conditions in the main and tailgates.Consequently the cost of supports will decrease.

The physical and mechanical properties of phosphate rock (pillar material) papery clays (immediate roof)and the technical data in Abu-Tartur conditions are as follows:

Compressive strength of phosphate rock $a_c$=15.8Mpa
Compressive strength of roof rock $\sigma_r$ = 17.8 Mpa
Average depth below surface H =155m
Average specific weight of overburden rock Y=19.7KN/m$^3$
Mining height (pillar height) h =3. 5m
Longwall face length Wo =60,100 and 120m
Width of rib pillar Wp= 25m.

To apply the caveability concept in longwall pillar design, the caving height $h_c$ must be firstly determined according to certain rock classification system (Mark, 1991).To ensure the roof will cave behind the face the caveability index I is calculated from the following equation (Singh et al., 1990)

$$I=\frac{\sigma_c t^{0.5} L^n}{5} \qquad (1)$$

Where
I = caveability index
$\sigma_c$= compressive strength of roof rock Kg/cm$^2$
t = bed thickness (m)
L= average core length , cm
n= factor equals 1.0 for R Q D < 80 and 1.2 for R Q D > 80
R Q D= rock quality designation

It has been observed that good caveability can be expected when :
I = 400-2000

Then in the condition of Abu Tartur area the caveability index is calculated according to Eq.(l).

$$I = 178 \times (3.5)^{0.5} \times \frac{10}{5} = 666$$

The value of I (caveability index) is 666 which means that the roof rock is easy to cave .
The caving height will be (Peng et al., 1984) :

$$h_c=\left(\frac{100h}{6.2h+32}\pm 1.5+\frac{100h}{3.1h+5}\pm 4\right) \qquad (2)$$

$h_c$ = 28.6 ±5.5 m

The average pillar stress $\sigma_p$ according to caveability concept is :

$$\sigma_p=\frac{\gamma}{Wp^2}\{Wp[H(Wo+Wp)-h_c.Wo]\} \qquad (3)$$

When $W_p$ = 25 m. the factor of safety is calculated at different face lengths and the results are shown in table (1).

Table 1. Factors of safety at $W_p$ = 25 m

| $W_o$ ,m. | $\sigma_{p}$,Mpa | F.S. |
|---|---|---|
| 60 | 10.3 | 1.8 |
| 100 | 15.16 | 1.19 |
| 120 | 17.58 | 1.02 |

From table (1) the factor of safety in case of Wo = 60 m is sufficient but insufficient in case of Wo = 100 and 120 m. The width of pillar is changed and the pillar load is calculated again and the results are shown in table(2).

Table 2. Factors of safety at different face lengths.

| $W_0$, m. | $W_p$, m | $\sigma_{p,Mpa}$ | F.S. |
|---|---|---|---|
| 60 | 25 | 10.3 | 1.8 |
| 100 | 33 | 10.27 | 1.81 |
| 120 | 39 | 10.38 | 1.8 |

## 5.CONCLUSIONS

The main conclusions of this study can be summarized as follows:

1- Efficient extraction of ores by longwall mining cannot be achieved without taking into consideration the stability of the workings . If a pillar layout is perfectly stable then uncontrolled pillar collapse and excessive convergence in the roof of tailgates cannot occur.

2-The pillar width of 25m. is unsafe for longwall face length larger than 60 m.

3- The face lengths have been changed from 60m at the beginning of the panel to 120m after the face advances 200m .The safe pillar widths in case of Wo = 60,100 and 120 m are calculated by the application of caveability concept and have values 25,33 and 39m respectively and factor of safety about 1.8 with extraction ratio equals 75% .

## 6. REFERENCES

All-Union research and design institute of sulfur industry. 1989-Egyptian phosphate mines of Abu- Tartur deposit. Technical proposal Lvov .

All-Union research and design institute of sulfur industry. 1990-Egyptian phosphate mines of Abu- Tartur deposit. Technical proposal Lvov .

Bieniawski, Z.T. 1984. *Rock mechanics design in mining and tunneling. A.A Balkema.*

Carr, F. and Wilson , A. H. 1982. A new approach to the design of multi-entry developments for retreat longwall mining . 2 nd Conference on Ground Control in Mining ,W. V. Univ., Morgantown, W.V.

Choi, D. S. and Mc Cain, D. L.1980. *Design of longwall systems . Trans, of the Soc. Min. Eng. AIME, V. 268,pp. 61-64.*

Coates, D. F. 1981. *Rock mechanics principles . Monograph 874, Ottowa Information Canada.*

Imbaby, S.S. 1992. Analysis of different concepts of pillar loading formulae. 3rd Int. Conference on Mining Engineering, Cairo University, Faculty of Engineering, Cairo, Egypt.

Josien, J . P. 1980 .*Methods of investigating in longwall faces. Int. J. Rock Mech . Min . Sei. vol. 23, pp. 341-355.*

King , H. J and Whittaker, B. N.1970. A review of current Knowledge on roadway behavior. " Proc. On Roadway Strata Control, Nottigham, pp. 73-87.

Mark, C. and Bieniawski, Z. T. 1986. An empirical method for the design of chain pillars in longwall mining . 27th Symposium on Rock Mechanics, soc. Min Eng. AIME.

Mark, C1991 . Practical aspects of longwall pillar design . 10 th. Int. Conference on Ground Control in Mining, Morgantown , W.V., pp. 1-12 .

Peng, S.S.and Chiang, H.S. 1984. *Longwall mining " John Wiley&Sons.New York.*

Potvin, Y. Hudyma, M. and Miller H.D.S .1989. *Rib pillar design in open stope mining . CIM Bulletin, Vol. 82, No. 927. pp 31-36.*

Salamon , M . D. G. 1967. *A study of the strength of coal pillars. J. S. Afr. Ints. Min. Metall.*

Singh, R., Singh, T.N. and Dhar, B.B.I990. *Coal pillar loading in shallow mining conditions . Int. J. Rock Mech . Min.Sci & Geomech. Abstr. Vol. 33, No. 8.*

Sheorey, P.R., Barat, D. and Das, K. K.1995. *Application of the yield pillar technique for successful depillaring under stiff strata. Int. J. Rock. Mech. Min Sei & Geomech. Abstr. Vol. 32, No. 7pp. 699-708*

Szwilski, T. B. 1983. Sizing of chain pillars around longwall panels First Int. Conference on Stability in Underground Mines . New York .

Unrug, K. and Szwilski, T. B.1982 .Methods of roof caveability Predictions . Int. Symposium on Ground Control in longwall Mining and Mine Subsidence, AIME, Honolulu.

|  | Thickness | Description | Rock properties |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| Column | m |  | $\gamma$ Kn/m$^3$ | $\sigma_c$ Mpa | $\sigma_t$ Mpa | E Gpa | c Mpa | P degree |
|  | 20-120 (70) | Kurkur for. Limestone | 22.2 | 65.1 | 7.5 | 14.4 | 17.5 | 33.5 |
|  | 80-130 (105) | Dakhla for. Clayey-Car. | 19.8 | 46.8 | 5.1 | 7.6 | 14.1 | 31.4 |
|  | 4.2-8 (6.1) | Phosphate argillaceous | 21 | 43.4 | 3.1 | 6.0 | 11.2 | 30 |
|  | 6.6-16 (11.3) | Argillaceous sand | 17 | 20.6 | 2.6 | 6.7 | 6.3 | 35 |
|  | 7.5-15 (11.250 | Papery clays | 18.3 | 17.8 | 4.2 | 7.2 | 6.6 | 34 |
|  | 0.75-7.3 (4.25) | Phosphorite | 20.6 | 15.8 | 1.5 | 8.2 | 4.2 | 34 |
|  |  | Nubia for variegatet clay. | 18.2 | 2.3 | 1.9 | 4.8 | 6.7 | 33.5 |

Fig. (1): Rock properties and stratigraphie column along Abu-Tartur plateau

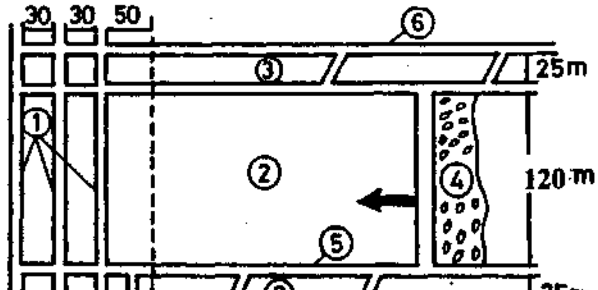

Fig. (2): Layout of underground mine in Abu-tartur site.

1 - ring galleries 2- panel 3- rib pillars
4- goaf 5- maingate 6- tailgate