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AN APPROACH TO DESIGN ROOM -AND- PILLAR CLAY MINES (ASWAN -CONDITIONS)

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ABSTRACT : Mine pillar is the portion of deposit left in place to support openings. They may or may not be extracted after mining. Many major and relatively minor pillar collapses have been recorded in the history of mining. Therefore, design of room and pillar mines still deserves great attention.

In the present situation of ball clay mines at Aswan area (Abu - Reash mines) the extraction ratio reaches 40% and some problems in roof stability areencountered.

In this work, the physical and mechanical properties of roof rock(sandstone) and clay deposit are determined. Three different methods were applied to improve the design of this particular mine.namely, tributary area approach. Coates' theory and the authors proposed approach. This proposed approach is based on the beam deflection theory taking into consideration the deformational properties of the roof rock (sandstone) and clay deposit, immediate roof thickness, virgin vertical stress, room and pillar dimensions. The induced stresses over the pillars, factor of safety and extration ratio as well as the safe span are calculated. It is found that the pillars between the rooms at the extracted area(l .2 m^2) may be reduced from 5 x 5 m t o 3 x 3 m increasing the extraction ratio from 40% to 64% corresponding an increment and pillar stress is about 1.02 MPa with a factor of safety of 1.48.The increase in the maximum deflection in the middle of the roof span is 11 mm due to pillar splitting.

1.INTRODUCTION

(a) Basic Concepts

Room and pillar mining is commonly used in flat or gently dipping bedded deposits. Pillars are left in place in a regular pattern while the rooms are mined out. In many room and pillar mines, the pillars are recovered and the roof is caved. Room and pillar methods are used in deposits such as coal, potash, phosphate, salt, clay and bedded uranium ores.

A design code for room and pillar mining should fulfill two functions (i)to enable planning of new mines and (ii)to enable assessing the stability of current mining layouts and the effects of any improvement introduced(Bieniawski, 1982&1983).

While pillar stability is of much importance in the room and pillar mining method , the stability of mine roofs is a crucial aspect of strata control. Hence, selection of roof spans and their reinforcement must be addressed in any design code. Moreover, the design code should rely on certain geological data as well as the strength properties of the deposit and roof rock, which are considered as being available both from a site exploration program or obtained during mining. The geological data include stratigraphie log of roof strata, spacing or orientation of bedding and jointing, ground water conditions and faults (Bieniawski, 1975; Mohammed et al., 1997).

(b)Determination of Roof Span

Two main approaches were developed for roof span design. The first approach rely s on beam theory by considering the roof strata as a'single beam or a series of beams lying one on top of the other. Two types of beam models are conventionally used: namely simple beam and fixed-ends beam. Both are loaded uniformly by their own weight. The two ends of the simple beam are free to move. Roof strata in shallow mines resemble this model because smaller abutment pressures are present on the both sides. In contrast, the two ends of a fixed-ends beam are rigidly anchored and resemble most deep mines.

Comparing the results from simple and fixed-end beams shows that the roof span derived from the simple beam is shorter than that from the fixed -end beam (Alder et al., 1968; Peng, 1978).

The other approach supposes that estimating safe roof spans in U.S. coal mines may be achieved by means of engineering rock mass classification systems. Rock classifications are well known empirical methods for assessing the stability of underground openings in rock. They were developed primarily for the purposes of tunnel and chamber design in civil engineering. In mining, a detailed study of the application of rock classification to U.S. hard rock mining was initiated by the Bureau of mines in 1980. While in coal mining, researchers have been studying the rock classification approach systematically since 1978 (Choi et al., 1980). As a result, over 60 coal mining case histories have been compiled enabling estimating of safe roof spans in coal mines by means of Rock Mass Rating (RMR) system(Bieniawski, 1980).

The geomechanics classification provides guidelines for the selection of rock support to ensure long -term stability of various rock mass classes. Furthermore, for rock span selection in coal mines, practical experience and mining regulations should be used to assess the predictions from the geomechanics classification.

(c)Pillar Sizing

The design of mine pillars involves the determination of proper pillar sizes compatible with the expected load. Thus, in deciding the most suitable dimensions for mine pillars, the followings have to be considered : the pillar load (the stress on pillars), the pillar strength and the factor of safety. The first pillar strength formula was proposed in the USA as early as 1900 for coal pillars. After that research efforts have led to significant progress towards this aspect. Nevertheless, no single design approach or straight formulae have been accepted as the most reliable one, even for coal mine pillars which have been received the most research attention (Bieniawski, 1984).

There are two main approaches for pillar design. The first one is the ultimate strength approach which contends that pillars will fail when the applied load reaches the compressive strength of the pillars. It presumes that the load bearing capacity of the pillar reduces to zero the ultimate strength of the pillar is exceeded. The other one is the progressive failure approach which emphasizes the non-uniform stress distribution in the pillar. Failure starts at the most crucial point and propagates gradually to ultimate failure (Bieniawski, 1983).

A number of approaches are available for estimating the pillar load or the average pillar stress. The two major ones are the tributary area approach and Coates' theory (Coates, 1966&1981).

The tributary area approach assumed that :i) each pillar supports the column of rock over an area which is the sum of the cross-sectional area of the pillar plus a portion of the room areas, the latter being equally shared by the neighboring pillars. However, this is certainly not valid if the area of development is small since the pillars in the center of excavation are under stress than the pillars near the sides, ii) The load is uniformly distributed over the cross-sectional area of the pillar. However, researches carried out in the past has shown that this assumption is invalid. It should be noted that the tributary area approach represents the upper limit of the average pillar stress. In fact, measurements have shown that the approach overestimates the pillar load by about 40%.

(Coates, 1981;Oravecz, 1977) studied the concept of pillar load based on the elastic deflection theory. The most important consideration is that of seam compression between a relatively stiff roof and floor. The solution is based on the net deflection of the pillar , AS_p as a measure of the increase in the pillar stress resulting from mining. The factors taken into consideration are the deformational properties of pillar material and roof rocks, pillar width, length of mining panel, vertical and horizontal virgin stresses and pillar height. The main drawbacks of this approach are: i) the thickness of the immediate roof is neglected which has a great effect on the pillar load,ii) the mining zone besides the pillar was assumed in the form of an ellipse which does not usually happen.

(Singh et al., 1996) mentioned that the calculation of the actual load on the pillar is more complex than the determination of the pillar strength. The monitoring of stress redistribution around depillaring was done using vibrating wire sensors. An attempt was made to establish empirical relations to estimate the value of ultimate induced stress and its range of influence ahead of the face line which can be used for mine design strategies to optimize recovery and safety.

The purpose of this paper is to re-design the excavated area by decreasing the size of the pillars between the rooms taking strata control aspect into consideration.

2. GEOLOGICAL AND MINING SITUATION

Abu -EL-Reash mines is located at 1 km. east of highway road of Cairo-Aswan at Abu-Seberia Valley. The stratigraphie succession along the mine rock shows that the thickness of ball clay deposit ranges from 2.5 to 4 m. as shown in Fig. (1) (Technical Report, 1997). The immediate roof consists of medium hard sandstone of 3.3 m. thick and at some areas reaches 0.5 m. The clay deposit is nearly horizontal. Some normal faults exist with vertical throw about 6m and directed north-south. Numerous closed joints are found at the mine roof which have different directions and lengths. The thickness of the overburden ranges from 48.11m to 58.14 m with an average thickness of 53.14 m. The annual production is about 100,000 ton/year and the exploited clay is used in ceramic industry. The mine layout shows thirty three unsupported adits 3m. wide and 3.5m. height. A section from the mine layout is shown in Fig. (2). Pillars of rectangular cross - section (10 x 20m) are left to support the adits. The width of rooms is 2.5m and pillars of square cross section (5 x5m) are left to support the rooms. The excavated area is about 1.2km with extraction ratio of 40%. The mines extended into the mountain from 1 to 1.5km. from the cliff. There are different problems either in roof control especially at the areas of thin immediate roof thickness or in ventilation.

3.DETERMINATION OF ROCK PROPERTIES

Samples from ball clay deposit and sandstone from immediate roof are tested. Physical and mechanical properties are determined as shown in table (1).

4.DESIGN OF ROOM AND PILLARS

The tributary area approach , Coates' approach and the beam deflection theory are applied to estimate pillar loads. Four cases are solved. The length of the mining zone between the two adits is 45m. The first case represents the present situation of

B=5m.and B_0=2.5m. The other cases are of B=4,

$\mathbf{B_o=3.25\ \&B=3,\ B_o=4\ and\ B=2,\ B_o=4.25m}$

a)Tributary area approach: it is the simplest approach to determine the average pillar stress. The average pillar stress, σ_p for square pillars can be calculated as below:

$$\sigma_p = \sigma_v\,[(B+B_o)/B]^2 \qquad (1)$$

and the extraction ratio, R for a series of room and pillars as shown in Fig. (3) is :

$$R = A_m / A_t = (N+1)\,B_o/[(N+1)B_o+NB] \qquad (2)$$

Where,

σ_p =average pillar stress, MN/m^2
σ_v =virgin vertical stress, MN/m^2
B =width of pillar,m
B_0= width of room,m
R = extraction ratio,%
A_m=mined area,m^2
A_t=total area, m^2
N = number of pillars

b) Coates' approach: Coates derived a complicated equation to determine the incremental loading due to mining as following:

$$\sigma_p/\sigma_v = \Delta\,\sigma_p/\sigma_v\,\acute{y}+1 \qquad (3)$$

and $\Delta\sigma_p$ equals:

Table 1 .Physical and mechanical properties of ball clay and sandstone.

Rock type	γ KN/ m^3	σ_c MN/m^2	σ_t MN/ m^2	R_o MN/ m^2	μ	E GN/m^2
Ball clay	21.05	5.31		—	0.23	0.31
Sandstone	26.58	26.6	0.74	0.43	0.21	3.90

where,
γ = specific weight, KN/ m^3
σ_c = uniaxial compressive strength, MN/m^2
σ_t = tensile strength (Brazilian test), MN/m^2
Ro = modules of rupture, MN/ m^2
μ = Poissons' ratio
E =Young's modules, GN/ m^2

$$\frac{-2Ri-kh(1-\omega)(1-x2+h)-\omega p(khn)}{hn+\pi(1-Ri)(1+1/N)(1+h/L-x2)/2+2Rib(1-\omega)n} \quad ....(4)$$

where,
$\Delta\sigma_p$= incremental loading due to mining, MN/m^2
n= M/M_p
M = E(1- μ^2)
Mp = Ep(l- μ_p^2)
E = Young's modulus of sandstone,GN/m^2
μ = poisson's ratio of sandstone
μ_p = Poisson's ratio of ball clay
Ep= Young's modulus of ball clay, GN/m^2
$\omega = \upsilon / (1-\mu)$
$\omega_p = \mu_p (1-\mu_p)$
$K = \sigma_h / \sigma_v$
σ_h = horizontal stress, MPa
b, $= B_0/L$
L = breadth of the mining zone,m
Ri = radial distance from the center of pillar.m
X $= x^*/L^*$
h $= t,/L^*$
X* = displacement in x direction,mm.
ti = pillar height,m
L* = pillar length.m

c)The author's proposed approach :beam deflection theory is applied to determine the stress distribution over the pillars and deflection in the roof of the rooms. Overburden pressure, thickness of the immediate roof and its deformational properties, stiffness of the ball clay, pillar and room dimensions and height of extracted clay are the factors taken into consideration. The roof of room is unsupported in this analysis.

The, deflection curve of a beam acted upon by a distributed load over the pillar is estimated by the following differential equation (Timoshenko, 1956;Sheorey et al., 1974; Sheorey,1975).

$$EI\frac{d^4\delta}{dx^4} = \sigma v - kp.\delta \qquad (5)$$

where,
EI = flexural rigidity of sandstone rock
δ = roof deflection
Kp= pillar stiffness
The general solution of equation (5) over the pillar is:

$$\delta = \sigma v/kp + e^{-\alpha x}(x1 \sin \alpha x + x2 \cos \alpha x) + e^{-\alpha x}(x3 \sin \alpha x + x4 \cos \alpha x) \qquad (6)$$

where,

$$\alpha = \sqrt[4]{\frac{kp}{4EI}} \qquad (7)$$

Also the general solution of eq. (5) over the unsupported room is:

$$\delta = \frac{1}{EI}(\sigma v.X^4/24 + X^3/6.\ x5 + X^2/2.\ x6 + X.X_7 + X_8) \qquad (8)$$

From the boundary conditions at the edges between pillars and rooms, sixteen linear algebraic equations are obtained. A computer program is used to solve these equations and the roof deflection is obtained at any distance x over the rooms and pillars. The pillar stress σ_p is:

$$\sigma_p = \delta.\ K_p \qquad (9)$$

The safe span is determined to check the values of B_0 at each case.

Pillar strength is determined from uniaxial compressive strength a_c test carried out on cubic (5 x 5 cm) clay specimens having a width to height ratio of 1. The reduction factor in pillar strength due to volume effect based on Rock Mass Rating , RMR,(Mohammed et al., 1997) is,

$a_r$edin compression^. 5 exp (0.06 RMR) MPa (10)

Then,

$$\sigma_s = \sigma_c - \sigma_{red} \quad (11)$$

Factor of safety: A factor of safety is defined as the ratio of the pillar strength to the load acting on it. thus,

$$F= \sigma_s / \sigma_p \quad (12)$$

It is important to note that if the factor of safety is unity, the probability of failure is 50 %. The factor of safety should be greater than unity to achieve a low probability of failure.

5. RESULTS AND DISCUSSION

The stresses acting on pillars are calculated by applying equations (1), (3) and (9). The pillar strength is obtained from equation (11). For clay a_c is 5.31 MN/m^2, the equivalent RMR = 2 then,

σ_c = 5.31-0.56

σ_c = 4.75 MN/m^2

The extraction ratio R is calculated from eq. (2).

The factor of safety for each case is calculated and the results are given in table (2).

Where,

σ_{p1}, σ_{p2} and σ_{p3} are the pillar stresses calculated from tributary area, Coates and proposed.approaches respectively.

The relationship between extraction ratio and the induced pillar stress is shown in Fig. (4). It is obvious that the induced pillar stress increases as the extraction ratio increases for all approaches. The tributary area approach gives higher values of stresses than the other approaches. The smallest values of stresses are obtained by the proposed approach because the roof conditions are taken into consideration. Figure (5) shows an inverse relationship between the extraction ratio and factor of safety. When the extraction ratio reaches 64% the factors of safety in case of tributary area approach and Coates' approach are less than unity and equals 1.48 in case of the proposed approach. Fig. (6) shows the stress distribution. In the pfllar of width 5m and the roof deflection over the room of width 2.5 m. It is found that the maximum induced stress occurred at the pillar edge of 2.3 Mpa and 1.7 Mpa at the centre of pillar. The maximum deflection in the mid span is 2.24 cm. Fig. (7) shows the relationship between the extraction ratio and the induced maximum deflection at the mid span of rooms from application of the propsed approach. It is found that the increase in maximum deflection is 11mm when the extraction ratio increases from 40% to 64% with safe span of 3.9m.

To ensure stability during pillar splitting, six friction steel props of nominal load 400 KN as temporary supports are installed on the sides of the extracted pillar at the mid span of rooms at regular spacing 2.5m.as shown in Fig. (3). square caps of dimensions (0.5 x 0.5m) are used with each support. Splitting of pillars is extended towards the adits and has a retreat trend.

7.CONCLUSIONS

The characteristics of the roof strata have a strong influence upon the pillar stress and roof deflection in ball clay mines. Tributary area approach incorporates many assumptions and overestimates the pillar stress with respect to Coates and proposed approaches. In Coates' approach the thickness of the immediate roof is overlooked.

The thickness of the immediate roof and the deformational properties of sandstone(roof rock) and ball clay.room and pillar dimensions,virgin pressure are the main factors that taken into consideration in the proposed approach.The extraction ratio may be increased form 40% to 64% in the extracted area (1.2 Km^2) without any troubles.The splitting of pillars begins from the center of panel and directed towards the main adits in retreat method. Temporary friction supports are installed on both sides of the extracted pillar to ensure stability. Convergence between floor and roof of the adits must be measured by extensometer at definite stations. From the analysis of the measured convergence, it be will decided to support the adits or not.

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Table (2) pillar stress, extraction ratio and Factor of safety for different approaches

B m	Bo m	R %	σ_{p1} MN/m^2	F,	σ_{p2} MN/m^2	F_2	σ_{p3} MN/m^2	F_3
5	2.5	40	3.24	1.47	2.75	1.73	2.11	2.26
4	3.25	52	4.73	1.0	4.11	1.16	2.62	1.81
3	4	64	7.84	0.61	5.98	0.79	3.21	1.48
2	4.25	76	16.4	0.29	10.21	0.47	4.91	0.97

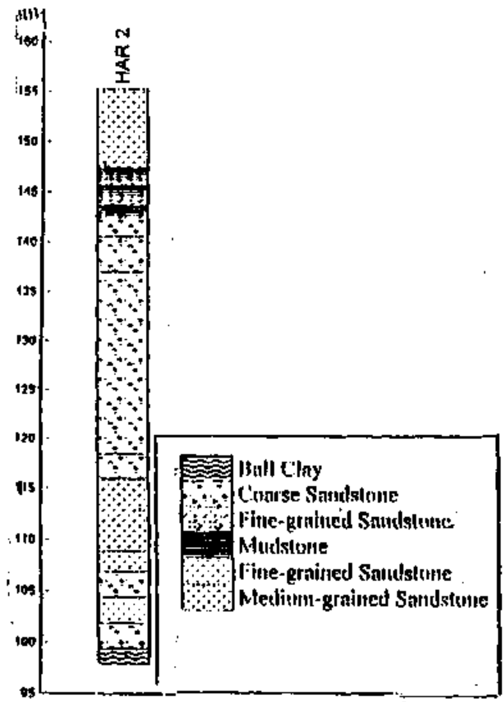

Fig. (1) Stratigraphic sequences along overburden of ball clay mine.

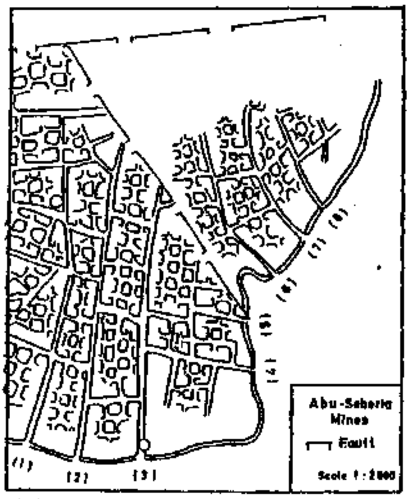

Fig. (2) Section from mine layout

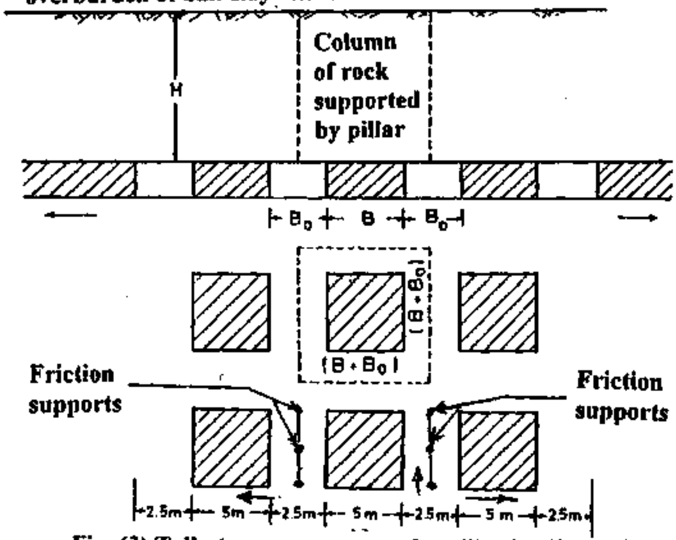

Fig. (3) Tributary area concept for pillar loading

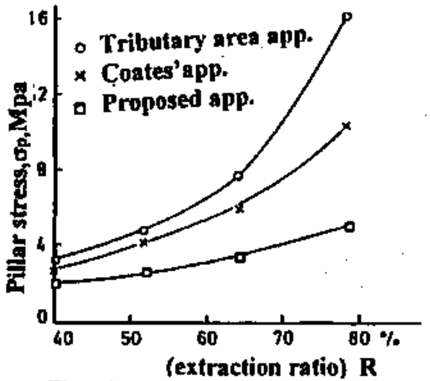

Fig. (4) The relationship between R and pillar stress σ_p.

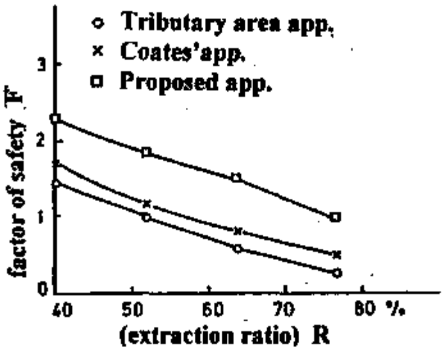

Fig. (5) The relationship between R and factor of safety F.

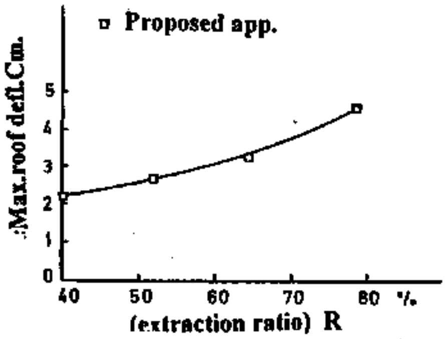

Fig. (7) The relationship between R and maximum deflection .

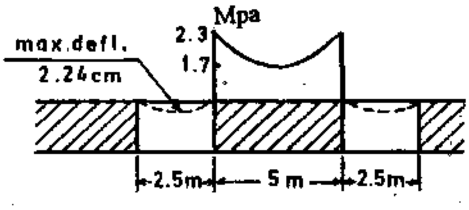

Fig.(6)Stress distribution over the pillar and the roof deflection