

# APPLICATION OF THE ROCK MASS CLASSIFICATION SYSTEMS TO PILLAR DESIGN IN LONGWALL MINING FOR ABU-TARTUR LONGWALL PHOSPHATE MINING CONDITIONS

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## ABSTRACT

Pillars are designed to ensure regional stability or local support in stopes and along drifts, or to yield under a measure of control. In all cases, the strength of the material and the variations in strength must be known both for the pillar and for the roof and floor. The stability in longwall faces depends mainly on the interaction between the roof strata, face support, roadway support and dimensions of pillars. The main aim of this paper is to apply rock mass classification systems to longwall 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.

Two methods from classification systems are used in calculation pillars stress and strength to pillars design namely Geological Strength Index (GSI) and Rock Mass Rating (RMR) systems. GSI values for immediate, main roof rocks and phosphate ores are determined from geological conditions, as lithology, structure of the interlocking of rock blocks and the conditions of the surfaces between these blocks. RMR value can be determined by correlation it with GSI system. The pillar widths calculated by applying rock mass classifications (GSI& RMR) are 49m and 64m at a factor of safety 2 and panel width 100m with extraction ratios of 70 and 64 % respectively.

The data used in calculations are collected from geological reports of the company and from laboratory tests of phosphate ores and shale rocks in the roof.

*Keywords:* Rock Mass Classification (RMC) - Geological Strength Index (GSI) - Rock Mass Rating (RMR) - Abu-Tartur longwall phosphate mine - Pillar width.

## 1. Introduction

Rock mass classification systems have emerged as a powerful tool which can be used for assessing ground conditions and determining support requirements in underground mines [1]. Studies of pillar performance and strength in phosphate mines highlighted the need for pillar design guidelines that specifically address pillar stability in Abu-Tartur phosphate mines. At present, pillar dimensions are either based on rock mechanics science or on strength equations that were developed for metal or non-metal mines. This paper presents a pillar design based on rock mass classification systems that will assist in the design of safe pillar action in Abu-Tartur longwall phosphate mines.

There are many empirical methods to determine pillar designs each of these methods "classic" pillar design formulas consisted of three steps [2]:

- a) Estimating the pillar load using tributary area theory
- b) Estimating the pillar strength using a pillar strength formula

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### c) Calculating the pillar safety factor

Two methods from classification systems are used in calculation of pillars stress and strength to design pillars namely GSI and RMR systems. GSI values for immediate, main roof rocks and phosphate ores are determined from geological conditions, as lithology, structure of the interlocking of rock blocks and the conditions of the surfaces between these blocks [3,4]. RMR value can be determined by correlation it with GSI system [5].

The methodology used in this paper for the development of pillar design guidelines is based on the application of the rock mass classification systems to assess the optimum pillar dimensions in Abu-Tartur longwall mines. The significant variables which are taken into consideration can be grouped as follows:

- a) Uniaxial compressive strength of phosphate ore (pillar)
- b) Uniaxial compressive strength of papery clays (roof)
- c) Face length (panel width)
- d) Mining height (pillar height)
- e) Depth below the surface
- f) Specific weight of overburden rocks

The data used in calculations are collected from geological reports of the company and from laboratory tests of phosphate ores and shale rocks in the roof.

## 2. Empirical Approach to Pillar Design

When pillar strength is estimated, both size and shape effects must be considered. The size effect related to the presence of discontinuities within ore mass. Therefore rock mass strength is less than strength of intact laboratory sized samples. The shape effect describes the increase in the strength of the pillar when the width ( $W_p$ ) to height (h) ratio increases. This is due to the increase in confining pressure within the pillar [6].

## 3. Pillar Strength

Pillar strength can be defined as the maximum resistance of a pillar to axial compression [7]. In flat lying deposits, pillar compression is caused by the weight of the overlying rock mass. Empirical evidence suggests that pillar strength is related to both its volume and its shape. Numerous equations have been developed that can be used to estimate the strength of pillars in coal and hard rock mines, and have been reviewed and summarized in the literature [5,8,9,10,11]. These equations are generally empirically developed and are only applicable for conditions similar to those under which they were developed. More recently, numerical model analyses combined with laboratory testing and field monitoring have contributed to the understanding of failure mechanisms and pillar strength [8].

$$\sigma_s = k \frac{W_p^\alpha}{h^\beta}$$

A pillar strength  $\sigma_s$  equation that captures both the pillar shape and volume effect is a power equation of the following form, where k is a parameter related to the rock strength,  $W_p$  and h are the pillar width and height and  $\alpha$  and  $\beta$  are parameters related to the geomechanical conditions of the rock mass and different empirical equations are given in Table (1) [8,12].

**Table 1.**

Summary of empirical strength formulae for hard rock pillars where the pillar width and height is in meters.

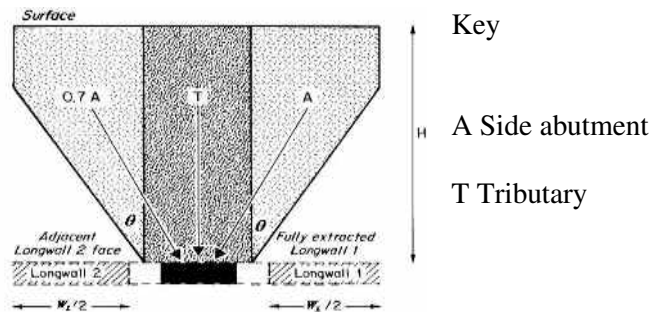
| Pillar strength formulae (MPa)      | $\sigma_c$ (MP) | Rock mass       | Reference |
|-------------------------------------|-----------------|-----------------|-----------|
| $133 \frac{W_p^{0.5}}{h^{0.75}}$    | 230             | Quartzites      | [13]      |
| $65 \frac{W_p^{0.46}}{h^{0.66}}$    | 94              | Metasediments   | [14]      |
| $35.4(0.778 + 0.222 \frac{W_p}{h})$ | 100             | Limestone       | [15]      |
| $0.42\sigma_c \frac{W_p}{h}$        | -               | Canadian Shield | [16]      |
| $74(0.778 + 0.222 \frac{W_p}{h})$   | 240             | Limestone/Skarn | [17]      |
| $0.44\sigma_c(0.68 + 0.52k)$        | -               | Hard rocks      | [18]      |

**4. Pillar Stress**

The average pillar stress ( $\sigma_p$ ), in regular layouts of square one chain pillars, can be estimated by the tributary area method as follows and as shown in Fig(1) [8,19].

$$\sigma_p = \frac{\gamma \left[ (W_L + W_p + 2B)H - \frac{(W_L + B)^2}{4 \tan \theta} \right] (W_p + B)}{W_p^2}$$

Where  $\gamma$  is the specific weight of the overlying rocks, H is the depth of cover,  $W_p$  is the pillar width,  $W_L$  is the panel width,  $\theta$  is the abutment angle and B is the heading.



**Fig. 1.**Conceptual model of the side abutment load.[19]

**5. Pillar Strength Based On a New Failure Criterion**

Sheorey and et al, 1985 suggested a formula to estimate pillar strength  $\sigma_s$  based on a new failure criterion represented by the following equation [20].

$$\sigma_s = 0.66kh^{-0.35} + 5[\gamma H(1 - e^{(-0.15W_p/(25+0.1H))})]^{0.8} \quad \text{MPa}$$

Where:

k =  $\sigma_{cm}$  = in-situ rock mass strength of the phosphate ore, MPa

h = mining height, m

Another equation is used Sheorey's failure criterion was chosen to determine  $\sigma_{cm}$  as a function of the RMR (Sheorey, 1997) [21,22,23]. This criterion is expressed by the following relationship.

$$\sigma_{cm} = \sigma_{ci} e^{\frac{RMR-100}{25}}$$

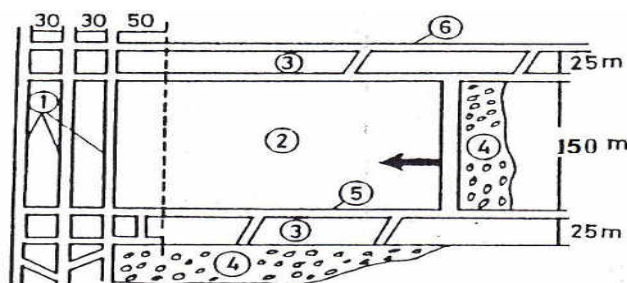
Where:

$\sigma_{ci}$  = compressive strength of intact rock, Mpa.

RMR = Rock Mass Rating

## 6. Geological and Mining Situation of Abu-Tartur Mines

Longwall panels under investigation are located at 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<sup>2</sup>. The phosphate layer is of 3.5m average thickness and is located at a depth ranges from 50 m in the east to 260 m in west and average about of 200 m. The phosphate layer is nearly horizontal with an angle of inclination (0° to 3°) averaging about 1.5°. The immediate roof is composed of 17.5 m of papery clayey shales overlain by a layer of argillaceous sand of 6.6 to 16 m thickness. The stratigraphic column and rock properties are given in Table(2) [4,24,25]. Mine layout shows three ring galleries, the 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 150m and panel extension is about 1000 m and the annual face advance is 760-800 m [24].



**Fig. 2.** layout of underground mine in Abu-Tartur site.

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

**Table 2.**

Rock properties and stratigraphic column along Abu-Tartur plateau

|       | Column | Thickness, m | Description                         | Rock properties             |                           |                       |                            |               |                                     |                            |
|-------|--------|--------------|-------------------------------------|-----------------------------|---------------------------|-----------------------|----------------------------|---------------|-------------------------------------|----------------------------|
|       |        |              |                                     | Density, K N/m <sup>3</sup> | Compressive strength, Mpa | Tensile strength, Mpa | Modulus of elasticity, Gpa | Cohesion, Mpa | Bending strength kN/cm <sup>2</sup> | Angle of internal friction |
| Roof  | Main2  | 20-120       | Kurkur formation (limestone)        | 22.2                        | 65.1                      | 7.5                   | 14.4                       | 17.5          | 195                                 | 33.5°                      |
|       |        | 80-130       | Dakhla formation (clayey-carbonate) | 19.8                        | 46.8                      | 5.1                   | 7.6                        | 14.1          | 64.5                                | 31.4°                      |
|       |        | 4.2-8        | Phosphate-carbonate                 | 21                          | 43.4                      | 3.1                   | 6                          | 11.2          | 130                                 | 30°                        |
|       | Main1  | 6.6-16       | Argillaceous sand                   | 17                          | 20.6                      | 2.6                   | 6.7                        | 6.3           | 61.8                                | 35°                        |
|       | Imm.   | 7.5-30       | Papery clay shale                   | 21.4                        | 14                        | 4.2                   | 7.2                        | 6.6           | 53.3                                | 30°                        |
| Ore   |        | 0.75-7.3     | phosphorite                         | 20.6                        | 70                        | 3.1                   | 8.2                        | 11.2          | 12.8                                | 34°                        |
| Floor |        | —            | Nubia formation (variegated clay)   | 18.2                        | 20.5                      | 2.6                   | 4.8                        | 6.7           | 67.3                                | 33.5°                      |

Pillar layout must be designed to decrease the possibility of pillar instability. 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 [24].

In Abu-Tartur area the longwall mining method is applied to exploit the phosphate ores. Proposed face lengths are 60,100 and 120 m with rib pillars of 25m in width. Excessive convergence occurred in 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).[24,25]

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.[24]

The physical and mechanical properties of phosphate ore (pillar material), papery clays (Immediate roof) and the technical data in Abu-Tartur conditions are as follows: [24,25]

Compressive strength of phosphate ore from laboratory tests  $\sigma_c = 40$  Mpa and in-situ mass strength  $\sigma_{cm} = 15.760$  Mpa. [3].

|  |                                |
|--|--------------------------------|
| Compressive strength of roof rock          | $\sigma_r = 20.6 \text{ Mpa.}$ |
| Average depth below surface                | $H = 200 \text{ m}$            |
| Average specific weight of overburden rock | $\gamma = 25 \text{ KN/m}^3$   |
| Mining height (pillar height)              | $h = 3.5 \text{ m}$            |
| Longwall face length                       | $W_L = 100 \text{ m}$          |
| Abutment angle                             | $\theta = 30^\circ$            |
| Heading                                    | $B = 3 \text{ m}$              |
| Factor of safety                           | $F.S = 2$                      |

## 7. Calculation of Dimension of Pillar By Rock Mass Classification Systems

$$F.S = \frac{\sigma_s}{\sigma_p} = 2$$

$$F.S = \frac{(0.66kh^{-0.35} + 5[\gamma H(1 - e^{-1.5w_p/(25+0.1H)})]^{0.8}) W_p^2}{\gamma \left[ (W_L + W_p + 2B)H - \frac{(W_L + B)^2}{4 \tan \theta} \right] (W_p + B)} = 2$$

$$2 = \frac{(0.66 \times 15.76 \times 3.5^{-0.35} + 5[0.025 \times 200(1 - e^{-1.5w_p/(25+20)})]^{0.8}) W_p^2}{0.025 \left[ (100 + W_p + 2 \times 3)200 - \frac{(100 + 3)^2}{4 \tan 30} \right] (W_p + 3)}$$

$$2490.923W_p^{-2} + 860.308W_p^{-1} - 18.119(1 - e^{-1.5w_p/45})^{0.8} - 3.291 = 0$$

$$\therefore W_p = 49.1 \text{ m} \approx 49 \text{ m}$$

## 8. Pillar Strength by RMR

$$\sigma_{cm} = \sigma_{ci} e^{\frac{RMR-100}{25}}$$

GSI value for phosphate ore is determine in work [3,4], GSI = 55 and by correlation between RMR and GSI from this relationship [5] as flows:

$$RMR = GSI + 5 \quad \therefore RMR = 55 + 5 = 60$$

$$\text{Pillar strength} \quad \sigma_s = \frac{\sigma_{cm} \times W_p^{0.46}}{h^{0.66}}$$

$$\sigma_s = \frac{\sigma_{ci} \times W_p^{0.46}}{h^{0.66}} e^{\frac{RMR-100}{25}}$$

Pillar stress for square one raw chain pillar

$$\sigma_p = \frac{\gamma \left[ (W_L + W_p + 2\mathbf{B})H - \frac{(W_L + \mathbf{B})^2}{4 \tan \beta} \right] (W_p + \mathbf{B})}{W_p^2}$$

$$F.S = \frac{\sigma_s}{\sigma_p} = 2$$

$$2 = \frac{\sigma_{cm} \times W_p^{0.46} \times W_p^2}{\gamma \left[ (W_L + W_p + 2\mathbf{B})H - \frac{(W_L + \mathbf{B})^2}{4 \tan \beta} \right] (W_p + \mathbf{B}) h^{0.66}}$$

$$2 = \frac{\sigma_{ci} e^{\frac{RMR-100}{25}} \times W_p^{2.46}}{0.025 \left[ (100 + W_p + 6)200 - \frac{(100 + 3)^2}{4 \tan 30} \right] (W_p + 3) \times 3.5^{0.66}}$$

$$70.654W_p^{2.46} = 21200W_p + 200W_p^2 - 4593.832W_p + 600W_p + 49818.505$$

$$70.654W_p^{2.46} - 200W_p^2 - 17206.168W_p - 49818.505 = 0$$

$$\therefore W_p = 64.3m \approx 64m$$

## 9. Conclusions

From this study, the following conclusions can be drawn:

- 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 may not be occurred.
- 2) The value of RMR is determined by correlation with GSI value and equal to 60
- 3) The pillar widths calculated by rock mass classifications are 49m and 64m at a factor of safety = 2 and panel width 100m with extraction ratios of 70 and 64 % respectively.

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## تطبيق أنظمة تصنيفات الكتل الصخرية في تصميم أعمدة المناجم بطريقة الحائط الطويل بمناجم فوسفات ابوظرطور

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### الملخص العربي

يتم تصميم الأعمدة في المناجم لضمان أمان منطقة المنجم بالكامل أو للتدعيم المحلي مثل واجهة الحش و الممرات و في كل الحالات، فإن قوة التحمل والخواص والتغيرات التي تحدث فيها لا بد أن تكون معروفة للمادة المكونة للعمود وكذلك صخور السقف والأرضية ويعتمد أمان واجهات الحش أساساً على التوازن بين صخور السقف ودعامات الواجهة و الممرات وكذلك ابعاد الاعمدة وهي الهدف الأساسي من هذا البحث الذي يهدف الي تطبيق أنظمة تصنيفات الكتل الصخرية لتصميم أعمدة المناجم في منطقة مناجم فوسفات ابوظرطور. مع الأخذ في الاعتبار الخواص الفزيائية والميكانيكية لرواسب الفوسفات وصخور السقف وطول واجهة الحش و ارتفاع العمود والعمق من السطح عند حساب الحمل الواقع على العمود.

و قد تم استخدام طريقتان من أنظمة تصنيفات الكتل الصخرية هما Geological Strength Index (GSI) and Rock Mass Rating (RMR) systems في تحديد قوة تحمل الصخر في الحقل لتعيين ابعاد العمود و قد تم تعيين قيم GSI لصخور السقف ورواسب الخام من الخواص الجيولوجية و كذلك RMR عن طريق علاقة ترابط بين RMR و GSI.

و ابعاد العمود التي تم حسابها عن طريق أنظمة تصنيفات الكتل الصخرية (RMR&GSI) هما 49 متر و 64 متر بعامل أمان قدره 2 مع طول واجهة حش مقدارها 100 متر بنسبة استخراج 70 و 64 % علي الترتيب.

والبيانات التي استخدمت في الحسابات تم الحصول عليها من التقارير الجيولوجية لدي الشركة ومن الاختبارات المعملية لخام الفوسفات وصخور السقف.