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# Coal Pillar Strength Formula in Indonesian coal mines

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**Abstract**
In underground coal mines, coal pillars play a major rule in sustaining the weight of the overburden and protecting the stability of the entries and crosscut during mine development and production, allowing the miners to safely extract the coal[1]. The determination of a coal pillar size is adjusted to the expected load and strength of the coal seam. It needs to consider several factors such as pillar load (stress within the pillar), pillar strength, and safety factors. In this determination, an analysis will be conducted using five similar coal pillar strengths including; Obert-Duvall Equation (1967), Holland Equation (1964), Holland-Gaddy Equation (1956), Salamon-Munro Equation (1967), and Bieniawski (1983). Using AirLaya seam as an example, we can combine the results of various equations. The coal used in the Airlaya research area has a value of k = 425.75, thus the strength of Airlaya insitu seam coal is estimated to be 161,607 Psi.

## 1. Introduction

In underground coal mines, coal pillars play a major rule in sustaining the weight of the overburden and protecting the stability of the entries and crosscut during mine development and production, allowing the miners to safely extract the coal [1]. Due to these vital functions, the coal pillar has become one of the most fascinating subjects in the field of rock mechanics, particularly in the field of ground control. Ground control engineers seek to design coal pillars cost-effectively by minimizing their dimensions without sacrificing the stability of the entries or gate roads. A few meter reduction of a typical chain pillar width in longwall mine may be an attractive incentive in today's high production longwalls[2]. Insitu test on underground pillars can reduce the size problem and the results are more representative, but more expensive and requires a long time. [2] made measurements in situ and obtained the results that for a cube-shaped pillar example, strength would decrease with the size of the sample and become constant when it reaches a critical size, which is about 1.5 meters.

The types of pillars that are often found in underground longwall coal mining are barriers, chains, and ribs. The determination of the dimensions of the Barrier pillar is very important in the design of coal underground mines because the barrier pillar is a coal pillar whose main function is to protect from the effects of deformation and excessive subsidence [3]. Also, another function of the barrier pillar is as a dividing zone between the two work areas (roadways and gateways) to limit the voltage that works in each area and is a barrier to fight incoming air currents, gas migration, and spontaneity combustion. If the determination of the barrier pillar is not under the conditions of the rock mass and the expected stress distribution, a collapse will occur [4]. The determination of a coal pillar size is adjusted to the expected load and strength of the coal seam. It needs to consider several factors such as pillar load (stress within the pillar), pillar strength, and safety factors. In this determination, an analysis will be conducted using five similar pillar strengths including; Obert-Duvall Equation, Holland Equation, Holland-Gaddy Equation, Salamon-Munro Equation, and Bieniawski by paying attention to stress factors [1], physical properties and mechanical properties of intact rock, rock mass characteristics, pillar size (scale effect) and pillar shape (shape effect) and coal condition (depth, slope, and thickness of coal) [4].

*1.1Empirical coal pillar strength formulae*

For the past few decades, ground control researchers developed many coal pillar strength formulae, with general agreement that the strength of a coal pillar increases with the pillar's width-to-height (*w/h*) ratio. There are two general types of expressions for predicting the strength of a cubical coal pillar: the linear formula in Eq (1) and the power formula in Eq. (2):

$$S_p = S_{cube}\ (A + B\ \frac{W_p}{H}) \quad (1)$$

$$S_p = S_{cube}\ \frac{W_p^{\alpha}}{H^{\beta}} \quad (2)$$

Where $S_p$ is the coal pillar strength, $S_{cube}$ is the strength of a cubical coal pillar at *w/h* = 1, w, and h are the width and the height of the coal pillars, respectively, and α, A, and B are constants. There is also an exponential form of the pillar strength formula based on a linear logistic regression model from coal pillar stability data.

According to [2], from all calculations of the existing pillar strength, it shows five pieces of evidence that are suitable to be applied by the U. S coal mining:

1. Obert – Duvall *formula* [2]

$$S_2 = S_1\left(0{,}778 + 0{,}222\frac{W_p}{H}\right) \quad (3)$$

2. Holland *formula* [2]

$$S_2 = S_1\sqrt{\frac{W_p}{H}} \quad (4)$$

3. Holland – Gaddy *formula* [2]

$$S_2 = k_1\ \frac{\sqrt{W_p}}{H} \quad (5)$$

4. Salamon – Munro *formula* [2]

$$S_2 = \frac{k_1\ W_p^{0{,}46}}{12\ H^{0{,}66}} \quad (6)$$

5. Bieniawski *formula* [2]

$$S_2 = S_1\ \left(0{,}64 + 0{,}36\ \frac{W_p}{H}\right) \quad (7)$$

Using the Pittsburgh seam as an example, we can combine the results of various equations like Figure 1. [2].

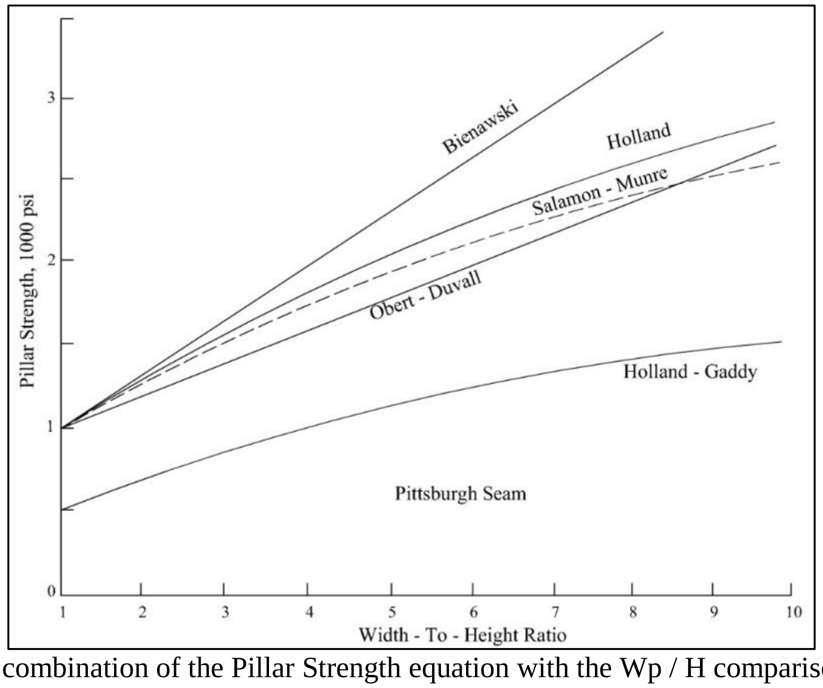


**Figure 1.** The combination of the Pillar Strength equation with the Wp / H comparison approach at Pittsburgh Seam [2].

*1.2. Pillar Failure*
Pillar failure occurs when the load on the pillar is more than the strength of the pillar. The eradication of the pillar is due to an increase in the existing burden, chemical oxidation of coal, mine fire, and excessive amounts of water entering the mine. In addition to pillar strength, a wide pillar with height ratio (w / h) is also important [5]. For the Slender pillar (w / h <4), the resulting collapse often approaches the value of the load capacity, sometimes suddenly or immediately collapsing. Pillars with w / h between about 4 and 10 are mostly elastic with the possibility of plastic properties at the core, and collapse tends to occur gradually with a collapse at a constant value residual strength. Pillar damage occurs until the pillar has issued enough weight to stop the collapse process. Pillars with w / h greater than 10 (known as "squats") have a plastic core and significant strain occurs after an initial loss of strength due to collapse or yield of elastic parts on the outside of the pillar. After this initial damage, the pillar gains strength due to the damage factor. The implication for surface structure in the collapse of the pillar slender with a shorter and far more significant envelope compared to collapse in the pillar squat at a greater depth. Different formulas for analyzing pillar strengths have been developed, and computer programs for carrying out pillar analysis are available.

## 2. Data and Methodology

*2.1. Classification Rock Mass*
Rock mass classification is needed as important initial information to be used later in the design of opening holes, non-tunnel dimensions, systems, and mounting methods. Data collection for rock mass classification in the Air Laya coal mine.

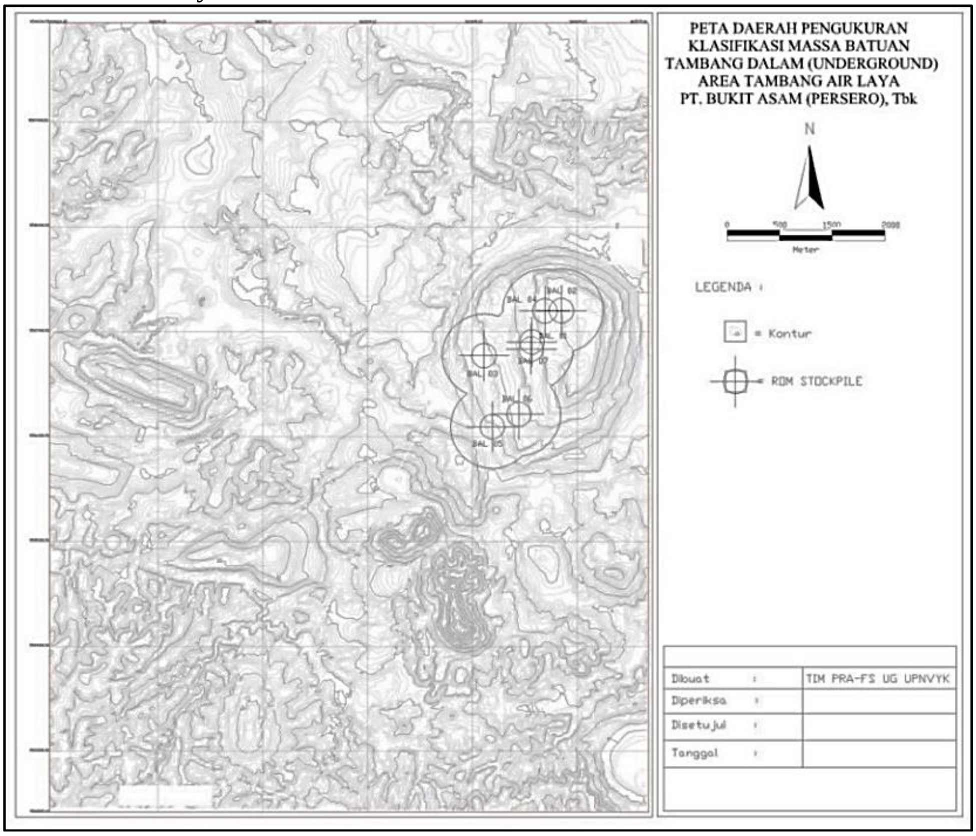


**Figure 3.** Map of Study area

Calculation of rock mass classification / Rock Mass Rating (RMR) according to [2] consists of 5 main parameters, namely: Compressive strength value, RQD (Rock Quality Designation) value, muscular distance, muscular condition, and groundwater. In addition to using the RMR, classifying rock masses using the Q-System with RQD parameters, the number of set heights, degree of alteration, water flow, and the voltage reduction factor. The selection of the measurement area used to calcify the rock mass in the area around the BAL borehole at the Air Laya mine is due to the BAL area having complete RMR parameter data especially RDQ and considered homogeneous. The results of rock mass classification are average rock class III-IV (moderate-weak).

**Table 1.** Data Define Material

| Properties | *Coal Seam D* | *Coal Seam E* | *Sandstone* | *Siltstone* | *Claystone* |
|---|---|---|---|---|---|
| **Ukuran Sample (cm) silinder** | ***6*** | ***6*** | ***6*** | ***6*** | ***6*** |
| **Ukuran Sample (in) silinder** | ***2.362*** | ***2.362*** | ***2.362*** | ***2.362*** | ***2.362*** |
| **Ukuran Sample (cm) cubical** | ***5.3172831*** | ***5.317283141*** | ***5.317283141*** | ***5.317283141*** | ***5.317283141*** |
| *Unit Weight* (MN/m$^3$) | 0.023 | 0.023 | 0.021 | 0.024 | 0.026 |
| *Cohesion* (MPa) | 0.344 | 0.419 | 1.18 | 0.59 | 0.37 |
| *Friction Angle* ($^O$) | 11.82 | 24.33 | 34.47 | 27.79 | 19.25 |
| *Tensile Strength* (MPa) | 1.03 | 1.03 | 0.71 | 0.42 | 0.34 |
| *Young Modulus* (MPa) | 139 | 348.19 | 504.47 | 505.85 | 302 |
| | 0.321 | 0.3 | 0.31 | 0.33 | 0.28 |
| *Intact Compression Strength* (MPa) silinder | 1.91 | 4.35 | 5.1 | 3.79 | 1.91 |
| *Intact Compression Strength* (psi) silinder | 277.023 | 630.915 | 739.694 | 549.694 | 277.023 |
| *Intact Compression Strength* (N/cm$^2$) silinder | 191 | 435 | 510 | 379 | 191 |
| *Intact Compression Strength* (MPa) cubical | 1.528 | 3.48 | 4.08 | 3.032 | 1.528 |
| *Intact Compression Strength* (N/cm$^2$) cubical | 152.8 | 348 | 408 | 303.2 | 152.8 |
| *Intact Compression Strength* (psi) cubical | 221.618 | 504.732 | 591.755 | 439.755 | 221.618 |
| *Intact Compression Strength* (psi) cubical | 70.958 | 161.607 | 189.470 | 140.802 | 70.958 |
| *Intact Compression Strength* (psf) cubical | 31912.943 | 72681.310 | 85212.571 | 63324.636 | 31912.943 |

## 3. Result and Discussion

Five similar pillar strengths have been widely applied to coal mines. The coal used in the Airlaya research area has a value of k = 425.75 which will be used in equation (3.11). Thus the strength of Airlaya insitu seam coal is estimated to be 161,607 psi. This value is used for equation (3.4). (3.5) and (3.6). (3.7) Based on the five pillar strength equations, the strength of the coal pillar from Airlaya seam can be estimated as follows:

1. *Obert and Duvall Formula*

$$\sigma_p = 161{,}607\left[0{,}778 + 0{,}222\left(\frac{w}{h}\right)\right]$$

2. *Holland and Gaddy Formula*

$$\sigma_p = 425{,}75\left[w/h^{1/2}\right]$$

3. *Holland Formula*

$$\sigma_p = 161{,}607(w/h)^{1/2}$$

4. *Salamon and Munro Formula*

$$\sigma_p = \frac{425{,}75w^{0{,}46}}{12H^{0{,}66}}$$

5. *Bieniawski Formula*

$$\sigma_p = 161{,}607\left[0{,}64 + 0{,}36\left(\frac{w}{h}\right)\right]$$

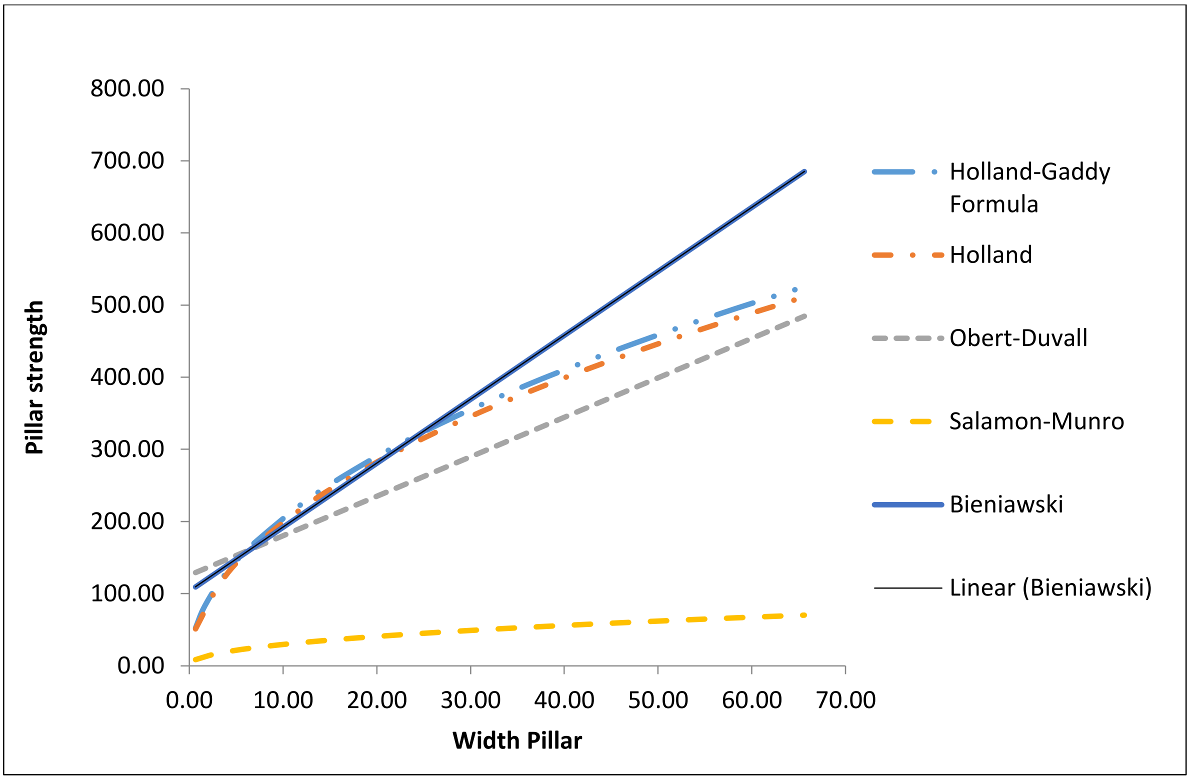


**Figure 4.** The combination of the Pillar Strength equation with the Wp / H comparison approach at Air Laya Seam

## 4. Conclusions

The conclusion from the results of the design plan and pillar stability on Airlaya's coal seam is as follows:

– Based on the analysis of the pillar strength equation, the Bieniawski equation predicts the highest pillar strength value in the Airlaya seam condition so that the obtained Airlaya seam strength equation is σp = 161,607 [A + B (w / h)].
– In Airlaya's seamless condition which has a depth of more than 500ft, so the suitable pillar strength equation used to predict the value of pilate strength is the Bieniawski and Obert-Duvall equation.

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## References

[1] S. S. Peng, “Topical areas of research needs in ground control - A state of the art review on coal mine ground control,” *Int. J. Min. Sci. Technol.*, 2015, doi: 10.1016/j.ijmst.2014.12.006.
[2] Z. T. Bieniawski, “A review of coal pillar strength formulas by W. A. Hustrulid,” *Rock Mech. Felsmechanik Mécanique des Roches*, 1977, doi: 10.1007/BF01261805.
[3] A. Majdi, F. P. Hassani, and P. Cain, “Two new barrier pillar design methods for longwall mining,” *Min. Sci. Technol.*, 1991, doi: 10.1016/0167-9031(91)90600-H.
[4] J. Lu, A. Ray, K. Morsy, and S. S. Peng, “Effects of Rock/Coal Interface Property on Coal Pillar Strength,” *Int. Conf. Gr. Control Min.*, 2008.
[5] W. A. Hustrulid, “A review of coal pillar strength formulas,” *Rock Mech. Felsmechanik Mécanique des Roches*, 1976, doi: 10.1007/BF01239762.