# Optimization of Pillar Sizes in Underground Coal Mines

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***Abstract* - Prospecting for ore bodies, analysing the feasibility of extraction, determining the operation's profitability, and extracting the needed resources are all operations involved in mining. Different strategies have been approached for mining effectiveness while keeping output and safety in mind. The Bord and Pillar method of mining is one among them. The most important aspect of successful Bord and Pillar mining is choosing the right pillar size.**

**Around 60% of the coal in Indian mines is obstructed in the form of pillars. This study examines the various pillar design procedures used around the world in general and analyses the existing practises of an Indian mine in particular. The mine will collapse if the pillars are too small. If the pillars are excessively large, substantial amounts of valuable material will be left behind, lowering the mine's profitability. The durability of pillars and successful extraction from them has become a serious problem in recent years. The safety factor is the most critical criterion to consider while building a pillar. The major goal of this article is to raise the extraction ratio of Bord and Pillar workings while maintaining a high level of safety.**

***Index Terms* - Bord and Pillar; safety factor; extraction ratio; pillar design; ore body.**

## 1.INTRODUCTION

Let us begin with a quick historical overview of the issue to help us get our bearings. Mining is one of the world's oldest industries. Prospecting for ore bodies, analysing the economic potential of a proposed mine, and extracting the needed resources are all part of the mining process. Mined materials are those that cannot be cultivated by agricultural operations or created artificially.

Opencast mining and underground mining are the two types of mining practices. Longwall mining and Bord and Pillar mining are the two most popular underground mining processes. Because of its antiquity and ease of operation, the Bord and Pillar technique of mining is most commonly used in Indian underground mines. One of the earliest methods of mining is the Bord and Pillar method. The key to Bord and Pillar mining success is choosing the right pillar size. Before building an underground coal mine pillar, the mineral resource must be turned into a mineral reserve. This may appear to be quite rational, however there has been a circumstance in the past when the coal pillar has failed and the ore body has been discovered later, with some pretty clear economic ramifications. If the pillars are too big, the extraction ratio drops, resulting in reduced production and profit, and if the pillars are too small, human safety is jeopardised.

The durability of pillars and successful extraction from them has become a serious problem in recent years. Uniaxial compressive strength represents a coal pillar's real strength. Other confirmatory tests for Uniaxial compressive strength include tensile strength and tri-axial strength.

Current coal pillar research (in rock engineering) is aimed at bettering our understanding of the surrounding strata's behaviour as well as the application and limitations of Indian coal pillar design methodologies. The extraction of existing pillars becomes more likely when virgin reserves are depleted; pillars produced today could be extracted at a later date; in certain circumstances, well into the twenty-first century. As a result, understanding the long-term stability of pillars becomes increasingly important, both in terms of worker safety during extraction methods and as a significant national resource.

The pillar design influences not only the support of the overburden, but also the percentage of extraction and the ventilation network design. The pillar's shape and size have a significant impact. For a fixed gallery width and height of working, square pillars are typically preferred. When designing a pillar, several geotechnical considerations such as mining depth, seam inclination, in-situ coal characteristics, working height, and gallery width are taken into account. The tributary area approach is used to compute the load on the pillar, and the pillar strength is obtained using several empirical formulae. The safety factor is calculated by dividing the pillar's strength by the pillar's stress. The feasibility of working is determined by an optimal correlation between the safety factor and the extraction percentage. The safety element is a significant consideration in pillar design.

## 2. AIM OF THE STUDY

In fact, five types of pillar were recognised;

- Barrier pillars between mining panels
- Entry pillars protecting the main entries
- Panel pillars formed during the development of mining panels
- Split pillars, formed by splitting panel pillars prior to depillaring, and
- Remnant pillars, the diminishing remnants of split pillars formed during depillaring operations.

The goal of this paper is to go through some of the factors that must be addressed while designing a pillar for an underground coal mine.

The purpose of this study is to assess the pillar design of a local colliery's Bord and Pillar working, to assess the extraction ratio of the Bord and Pillar working, to identify the safety factor as used elsewhere, and to analyse the same in regard to a specific mine.

The process of data gathering and data analysis is used to fulfil the above purpose and specific objectives.

## 3.METHODOLOGY

The above goals could only be achieved if they were pursued in a methodical manner. Knowing everything there is to know about a goal is always the first step. As a result, we must begin with a literature review. In this regard, books, journals, and articles will supply a wealth of information that should be properly researched and learned.

This can be approached by two ways:

- Data collection
- Data analysis

This will be followed by mine visits & collection of data from the field.

- Location of seam, depth of seam, seam thickness, and other geological data will be collected, while borehole data, pillar dimensions, and other mining data will be obtained.
- Mine samples will need to be gathered, safely packaged, and delivered to a lab for analysis.
- Different types of experiments will be carried out, including estimating the strength qualities of coal.
- It will be used to compute the safety factor.
- The extraction ratio will be assessed based on the safety factor.

We can achieve the experiment's goal by approaching it in the manner described above.

### 3.1 Pillar Strength Formulas

#### 3.1.1 CMRI formula

The pillar w/h ratio, the pillar's uniaxial compressive strength, the height of the seam, and the depth of the cover were all factors considered by CMRI when developing a formula for pillar strength.

$$S = (0.27 * \sigma_c * h^{-o.36}) + \left(\left(\frac{H}{250} + 1\right) * \left(\frac{w}{h} - 1\right)\right)$$

S = Pillar strength (MPa)

$\sigma_c$ = Uniaxial compressive strength (UCS) (MPa)

h = Working height or seam height (in m)

H = Depth of cover (in m)

w = Pillar width (in m)

Numerous pillar strength formulas have been proposed, but five formulas are used most commonly (*Bieniawski*, 1984; *Peng*, 1986). Each formula specifies its own appropriate factor of safety. These are given below.

#### 3.1.2 Obert-Duvall/Wang Formula (*Obert and Duvall*, 1967)

This formula is given as:

$$\sigma_p = \sigma_1(0.778 + 0.222\frac{w}{h})$$

The pillar strength is p, the Uniaxial compressive strength of a cubical specimen is 1 (w/h = 1), and the pillar dimensions are w and h.

This equation, according to Obert and Duvall, is applicable for w/h ratios ranging from 0.25 to 4.0, assuming gravity loading.

#### 3.1.3 Holland - Gaddy Formula

*Holland & Gaddy***,** Holland (1964) extended the work by Gaddy (1956) and proposed the following formula:

$$\sigma_p = k\frac{\sqrt{w}}{h}$$

The Gaddy factor is k, the pillar dimensions are w and h, and the pillar strength is psi. For the design of coal pillars, Holland advised a safety factor of 2.0, with a range of 1.8 to 2.2.

3.1.4 Holland Formula

In a 1973 publication, Holland proposed a new way of expressing the strength of coal pillars, namely:

$$\sigma_p = \sigma_1 * \sqrt{\frac{w}{h}}$$

Where $\sigma_1$ is the strength of cubical pillars (w = h = 1). In fact, it can be understood as the strength of coal specimens at crucial sizes, and it needs to be determined. A safety factor of 2.0 is recommended.

3.1.5 Salamon-Munro Formula

The following formula for pillar strength was proposed:

$$\sigma_p = k * R * \frac{w^{0.46}}{h^{0.66}}$$

Where, $\sigma_p$ the strength is in psi, and the pillar dimensions w and h are in feet. For this calculation, the suggested safety factor is 1.6, with a range of 1.31 to 1.88.k is the UCS of a 1ft3 coal sample (in lb/in2), and R is the long-term Strength factor.

In SI units, the above equation becomes:

$$\sigma_p = 0.79 * k * R * \frac{w^{0.46}}{h^{0.66}}$$

Where, $\sigma_p$ the strength is in MPa while w and h are in meters. K is the UCS of $1m^3$ coal sample (in MPa) and R is the long-term Strength factor.

3.1.6 Bieniawski Formula

This formula is based on in situ tests on coal pillars on a massive scale. All of these studies looked into different pillar-strength formulas.

The pillar-strength formula can be stated in a normalised form to make the in-situ test results more widely applicable (i.e., not just to the location where the testing were performed).

The Bieniawski equation in its generalised form is:

$$\sigma_p = \sigma_1 \left[0.64 + 0.36\frac{w}{h}\right]$$

Where $\sigma_p$ is pillar strength, w is pillar width, h is pillar height, and $\sigma_1$ is the strength of a cubical specimen of critical size or greater (e.g., about 3 ft or 1 m for coal). *Bieniawski (1969) and Bieniawski and van Heerden (1975) used large-scale in situ testing on 66 coal specimens with width-to-height ratios ranging from 0.5 to 3.4 to confirm this association.*

*For w/h ratios up to 10, the formula is extremely accurate, beyond which it produces conservative estimations.*

3.2 Pillar Load Determination

There are several methods for calculating the pillar load or, more accurately, the average pillar stress. The tributary area technique and the elastic deflection theory are the two most common. The tributary area hypothesis is the simplest method for determining the pillar load. The pillar load can be computed using a number of well-known simplification assumptions:

$$S_p = \left[1.1H\frac{(w+B)(L+B)}{w*L}\right]$$

Where Sp pillars load or the average pillar stress in psi, H is is depth below surface in ft, w is pillar width in ft, L is pillar length in ft, and B entry width in ft. The term 1.1 H can be replaced by the virgin vertical pressure Sv derived from the overburden weight above the seam $\gamma$H, where $\gamma$ is the unit weight of the overburden. The pressure can be considered to increase at a rate of 1.1 psi/ft of depth.

For square pillars, that is, when w = L, Eq. becomes:

$$S_p = H\left[\frac{(w+B)^2}{w^2}\right]$$

For inclined seams:

$S_p = H\left[\frac{(w+B)^2}{w^2}\right]$(Cos$\theta$+msin$\theta$)

Where,

$\theta$= angle of inclination of seam

m = Poisson's ratio

If the term extraction e is used (percentage extraction is 100e), which is defined as the ratio of mined-out area to total area, then the extraction e for rectangular pillars is

$$e = 1 - \left[\frac{w}{(w+B)}\right]\left[\frac{L}{L+B}\right]$$

This may also be rewritten as:

$S_p=\left[\frac{H}{(1-e)}\right]$

3.3 Factor of Safety

Factor of Safety= $\frac{\sigma_p}{S_p}$.

Where,

$\sigma_p$= Strength of pillar

$S_p$= Stress of pillar

The above approach of pillar design incorporates the following assumptions:

1. Only vertical pressure, which is continuous throughout the mined region, is applied to the seam. Stress transmission, on the other hand, happens in

underground workings with stiff abutments. As a result, some of the vertical pressure may be eased.

2. Each pillar supports the rock column over an area equal to the pillar's cross-sectional area plus a fraction of the room's area, with the latter being shared equally by all neighbouring pillars. However, if the developing area is tiny, this is not true since the pillars in the centre of the excavation are under higher stress than the pillars towards the sides. It is normally only considered valid if the mined-out area exceeds the depth below the surface.

3. The weight is expected to be evenly distributed across the pillar's cross-sectional area.

However, study has revealed that:

a) Stress is not evenly distributed across the cross section of a single pillar, with the highest stress occurring at the corners formed by the intersection of three orthogonal planes, notably the pillar's two sidewalls and the roof or floor.

b) As the percentage of extraction is increased, the tension on the pillars increases.

c) The ratio of pillar width to pillar height affects the stress distribution in pillars.

3.4 Laboratory Techniques

The tests used for the analysis are Uniaxial compressive strength testing.

Uniaxial compressive testing:-

This is the most popular test for determining the characteristics of any sample. After coring, cutting, and polishing, samples were prepared. The diameter of the sample obtained was 53.2 mm, while the length of the sample used for testing was 78 mm. It was indicated at what load the sample failed. The failure pattern was investigated.

Protodyakonov Test

The Impact Strength Index (ISI) is a method of assessing coal strength that has a lot of potential for use in coal cutting and drilling. It also gives a sense of the rock's uniaxial compressive strength.

**1.** Method

The impact strength index test was first developed by Protodyakonov to provide insight into the rock's strength, cutability, and brittleness, and was further enhanced by Evans and Pomeroy (1966).

- This technique is based upon the crushability of rock under standard experimental condition.
- This test is performed by a vertical cylinder apparatus which is 30 48 cm in height and has a steel plunger.
- 100 gm of sample is taken of size -4.75 mm to + 3.35 mm is taken in the cylinder.
- 50 gm of sample is taken if the sample is coal.
- A plunger is dropped from a height of 65 cm into the cylinder in which the sample is kept.
- The weight of the plunger taken is around 2.4 kg.
- The plunger is dropped 20 times in the cylinder if the sample is rock and 15 times if the sample is coal.
- The crushed sample is collected and is sieved through 0.5 mm sieve.
- The -0.5 mm sample is collected and filled in the volumeter.
- The height "h" in the volumeter is measured.
- Protodyakonov impact strength index is found out by using the following formulae.

P.S.I = (20 × n)/h

Where,

P.S.I = Protodyakonov strength index

n = no of blows

h = height in the volumeter

Typical Protodyakonov Test setup: Volumeter

4. METHOD OF CALCULATION

- Initial weight of sample =50 g for coal
- Initial weight of sample =100 g for rock
- Height in volumeter = h
- No of blows = n = 15 for coal
- No of blows = n = 20 for rock
- P.S.I = 20 × n/h

4.1 Point Load Test

The point-load strength index, which is obtained underground on unprepared rock cores, can be used to determine the Uniaxial compressive strength of rock. The ratio of the applied load to the square of the core diameter is used to determine the point-load strength index. The uniaxial compressive strength and the point-load strength index have a strong relationship.

The relationship is as follows:

Point Load Index:

$I_s = P/d^2$

Where d= equivalent core diameter in mm.

$\sigma_c = 24 I_s$

Where $\sigma_c$ is the Uniaxial compressive strength and $I_s$is the strength index obtained on NX core (54 mm in diameter).
It should be emphasised that the examined point-load strength index is for NX core, hence the results are only applicable to 54 mm core diameters.

### 4.2 Tensile Test

The maximal stress created in a specimen during a tension test to rupture it is known as tensile strength.
Making a rock specimen in the shape of a dumbbell or a dog bone is quite tough.
Another option is to use some type of fixing agent, such as epoxy cement/glue, to hold the cylindrical sample at two ends and then apply tensile force to the two ends.
$\sigma_t = P_{max} / A$
Where, $\sigma_t$= Tensile strength,
$P_{max}$= load at failure,
A= area

## 5.MATERIALS AND METHODS

Data collection
Bararee Colliery, Dhanbad, Bharat Coking Coal Limited provided the samples (BCCL). They were then sealed in plastic bags to keep them dry and safe for laboratory examination.
Sampling Procedure

## 6.STORAGE & TRANSPORTATION OF SAMPLES

- The samples taken at the site are preserved in a separate location.
- Plastic bags are used to store some of the samples that will be taken to the lab for testing.
- Samples are typically transported in trucks, lorries, and other vehicles.
- Wooden boxes are used to store samples gathered in plastic bags that prevent the samples from interacting with the outside environment.
- When transporting coal samples, wooden boxes are frequently recommended because they protect the samples from sunlight.
- If the coal samples are exposed directly to the sun's heat during transit, they may catch fire. As a result, wooden boxes effectively safeguard the samples.

The samples are expected to reveal important information about the subsurface's geological, physical, and engineering characteristics.
Coring was done prior to doing laboratory research. Suitable cores with the appropriate L/D ratio were obtained for several investigations. The cores were then polished with corundum powder and prepared for testing.

## 7.LABORATORY DATA ANALYSIS

1.Uniaxial compressive strength test
The length of the sample used for testing was 78.4 mm, and the sample diameter was 54.2 mm. As the sample goes off before showing any reading on the scale, the average UCS value of the sample was not able to be determined.

2.Point Load test
The sample length used for testing was 72.9mm and the diameter of the sample taken was 54.2mm. The $\frac{l}{d}$ ratio is 1.345. The breaking load (P) was 1kN. Therefore,
$I_{50}= \frac{1000}{54.2^2} = 0.340 N/mm^2$.
Therefore, $\sigma_c=24*I_{50}$
$=24* 0.349 = 8.16 MPa$.

3.Brazilian Test
The sample length used for testing was 31.8mm and the diameter of the sample taken was 54.2mm. The $\frac{l}{d}$ ratio is 0.586. The breaking load (P) was 3kN. Therefore,
Tensile Strength,
$\sigma_t= \frac{2P}{dt}$
$= \frac{2*3000}{3.14*54.2*31.8} N/mm^2. = 1.10 N/mm^2$.

4.Moisture Test
This test was carried out on three samples of varying weight. The presence of moisture in the sample taken from mines was determined by baking it at 1050°C to 1100°C for 5 hours. By interacting with mineral/coal surfaces and changing their surface characteristics and bonding nature, moisture in rock can affect uniaxial compressive strength.
Moisture-induced reduction in Uniaxial compressive strength has been documented by a number of

researchers. Because the amount of reduction varies depending on the rock type and test settings, it's best to figure out the Uniaxial compressive strength of rock under the moisture conditions that will be faced in the field.

This test was done on Nov. 1, 2013.

Table 1 for moisture test result:-

| Sample No. | Weight of sample before putting in oven (in g) | Weight of sample after putting in oven (in g) | % loss in moisture |
|---|---|---|---|
| A | 851 | 848 | 0.352 |
| B | 733 | 731 | 0.272 |
| C | 611 | 610 | 0.163 |

%loss in moisture=

$$\frac{Weightofsamplebeforeputtinginoven(ing) - Weightofsampleafterputtinginoven(ing)}{Weightofsamplebeforeputtinginoven(ing)}$$

Average % loss in moisture = 0.262%.

The entire pillar design procedure will depend on this much moisture content.

## 8. TEST RESULTS & DISCUSSIONS

The results of the numerous tests performed on the produced sample reveal that the coal sample is extremely soft.

### 8.1 COMPRSSIVE STRENGTH TEST RESULT

This test fails because the coal was too soft, and it fails before any value is revealed.

### 8.2 POINT LOAD TEST RESULT

Table 2 for point load test result:-

| S. No. | Length of Sample L(in mm.) | Diameter of Sample D (in mm.) | L/D | Failure load (in KN) | $I_{50}$ (in N/mm$^2$) | $\sigma_c = 24 * I_{50}$ (in MPa) |
|---|---|---|---|---|---|---|
| 1. | 72.9 | 54.2 | 1.345 | 1 | 0.340 | 8.16 |

Because the compressive strength test failed due to the soft nature of coal, only one sample was subjected to a point load test. The average strength obtained was 8.16 MPa.

### 8.3 TENSILE STRENGTH TEST RESULT

Table 3 for tensile test result:-

| S. No. | Length of Sample L(in mm.) | Diameter of Sample D (in mm.) | L/D | Failure load (in KN) | $\sigma_t$ |
|---|---|---|---|---|---|
| 1. | 31.8 | 54.2 | 0.586 | 3 | 1.10 |

The coal sample's average tensile strength was found to be 1.10 MPa. This discrepancy in compressive and tensile strength appears to be related to the fact that during coring, a fracture in the coal sample may have occurred.

According to the aforementioned test results, the coal we're working with is soft and friable. As a result, we must be extremely cautious when planning and deciding on pillar sizes.

### 8.4 MOISTURE TEST RESULT

Table 4 for moisture test result:-

| Sample No. | Weight of sample before putting in oven (in g) | Weight of sample after putting in oven (in g) | % loss in moisture | % Average |
|---|---|---|---|---|
| A | 851 | 848 | 0.352 | 0.262 |
| B | 733 | 731 | 0.272 | |
| C | 611 | 610 | 0.163 | |

At this moisture content, the different calculations have been completed. The moisture content in the mine, on the other hand, does not remain consistent and might fluctuate. As a result, consideration must be exercised when designing a coal pillar.

### 8.5 FURTHUR EXTRAPOLATION FROM RESULTS

The table below was created using the CMRI formula to calculate the Factor of Safety.

This is an Indian method for determining the safety factor of coal pillars.

$$S = (0.27 * \sigma_c * h^{-0.36}) + \left(\left(\frac{H}{250} + 1\right) * \left(\frac{w}{h} - 1\right)\right)$$

The Strength value calculated from this formula is compared with the original strength values and the Factor of Safety has been calculated. The graphs for factor of safety versus width of the pillar have been plotted for various dimensions of gallery width.

P1= Load on the pillar if gallery width is 3m.

P2= Load on the pillar if gallery width is 3.6m.

P3= Load on the pillar if gallery width is 4.2m.

P4= Load on the pillar if gallery width is 4.8m.

F1= Factor of Safety at gallery width 3m.

F2=Factor of Safety at gallery width 3.6m.

F3=Factor of Safety at gallery width 4.2m.

F4=Factor of Safety at gallery width 4.8m.

Table 5 for Load bearing capacity and factor of Safety for various widths

| *S.No.* | *WIDTH (in m)* | *STRENGHT (in MPa)* | *P1(B=3.0) (in MPa)* | *P2(B=3.6) (in MPa)* | *P3(B=4.2) (in MPa)* | *P4(B=4.8) (in MPa)* | *F1* | *F2* | *F3* | *F4* |
|---|---|---|---|---|---|---|---|---|---|---|
| | 05 | 2.859 | 17.024 | 19.673 | 22.514 | 25.546 | 0.167 | 0.145 | 0.127 | 0.111 |
| | 10 | 6.299 | 11.238 | 12.299 | 13.409 | 14.566 | 0.560 | 0.512 | 0.469 | 0.432 |
| | 12 | 7.675 | 10.390 | 11.238 | 12.119 | 13.034 | 0.739 | 0.683 | 0.633 | 0.588 |
| | 15 | 9.739 | 09.579 | 10.225 | 10.895 | 11.586 | 1.013 | 0.952 | 0.893 | 0.840 |
| | 17 | 11.115 | 09.204 | 09.764 | 10.341 | 10.935 | 1.207 | 1.138 | 1.074 | 1.016 |
| | 18 | 11.803 | 09.053 | 09.576 | 10.115 | 10.669 | 1.304 | 1.232 | 1.166 | 1.106 |
| | 20 | 13.179 | 08.794 | 09.259 | 09.736 | 10.225 | 1.498 | 1.423 | 1.353 | 1.288 |
| | 22 | 14.555 | 08.587 | 09.004 | 09.431 | 09.868 | 1.695 | 1.616 | 1.543 | 1.475 |
| | 24 | 15.931 | 08.416 | 08.794 | 09.181 | 09.576 | 1.892 | 1.811 | 1.735 | 1.663 |
| | 25 | 16.619 | 08.341 | 08.703 | 09.072 | 09.448 | 1.992 | 1.909 | 1.831 | 1.759 |
| | 26 | 17.307 | 08.273 | 08.619 | 08.971 | 09.332 | 2.092 | 2.008 | 1.929 | 1.854 |
| | 27 | 17.995 | 08.209 | 08.541 | 08.879 | 09.224 | 2.192 | 2.106 | 2.026 | 1.950 |
| | 28 | 18.683 | 08.151 | 08.469 | 08.794 | 09.125 | 2.292 | 2.292 | 2.124 | 2.047 |
| | 30 | 20.059 | 08.046 | 08.341 | 08.642 | 08.948 | 2.492 | 2.492 | 2.321 | 2.241 |
| | 31 | 20.747 | 07.999 | 08.284 | 08.574 | 08.868 | 2.593 | 2.504 | 2.419 | 2.339 |
| | 32 | 21.435 | 07.955 | 08.230 | 08.510 | 08.794 | 2.694 | 2.604 | 2.518 | 2.437 |
| | 33 | 22.123 | 07.914 | 08.180 | 08.450 | 08.725 | 2.795 | 2.704 | 2.618 | 2.554 |
| | 34 | 22.811 | 07.875 | 08.132 | 08.394 | 08.660 | 2.896 | 2.741 | 2.717 | 2.634 |
| | 35 | 23.499 | 07.838 | 08.088 | 08.341 | 08.599 | 2.997 | 2.905 | 2.817 | 2.732 |
| | 36 | 24.187 | 07.804 | 08.046 | 08.292 | 08.541 | 3.099 | 3.006 | 2.916 | 2.831 |
| | 37 | 24.875 | 07.772 | 08.007 | 08.245 | 08.487 | 3.200 | 3.106 | 3.017 | 2.931 |
| | 37.5 | 25.219 | 07.756 | 07.988 | 08.223 | 08.461 | 3.251 | 3.157 | 3.075 | 2.980 |
| | 38 | 25.563 | 07.741 | 07.969 | 08.201 | 08.436 | 3.300 | 3.207 | 3.117 | 3.030 |
| | 40 | 26.939 | 07.684 | 07.900 | 08.119 | 08.341 | 3.505 | 3.410 | 3.318 | 3.229 |
| | 45 | 30.379 | 07.566 | 07.756 | 07.999 | 08.144 | 4.015 | 3.916 | 3.821 | 3.730 |

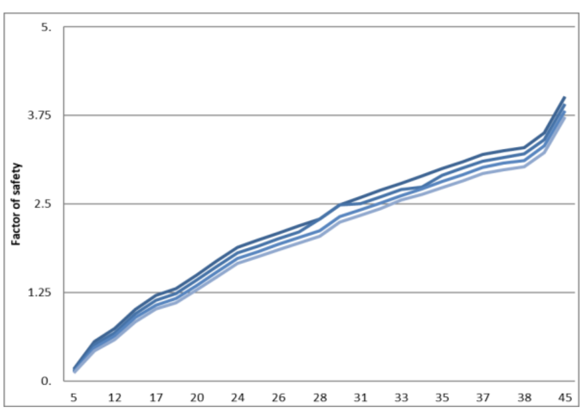


Fig 1: Graph showing comparisons for various FOS with width of pillar.

The investigation's goal was to assess the pillar design in an underground coal mine. The following conclusions have been reached as a result of this research.

- The CMRI pillar design formulas were assessed, and the best width/height ratio of the pillar was determined, resulting in maximal extraction and a sufficient safety factor for workings.

- The standard Bord and pillar approach was used, with all pillars assumed to be square in shape. Throughout the mine, the gallery width and working height remained constant, and the safety factor was assessed by adjusting other geotechnical factors.
- When compared to the typical safety factor of 1.5 -2 for Indian mining circumstances, the safety factors computed using the CMRI technique were found to be on the higher side.
- When safety factors were calculated using the DGMS criteria for minimum pillar dimension for all approaches, they ranged from 0.70 to 4.02 at various depths and aperture widths.
- For each strategy, simple linear equations were created to aid the mine operator in determining the economic extraction percentage for a sufficient safety factor while maintaining overall safety.

## 9.CONCLUSION

The most important aspect of successful Bord and Pillar mining is choosing the right pillar size. The mine will collapse if the pillars are too small. If the pillars are excessively large, substantial amounts of valuable material will be left behind, lowering the mine's profitability. The safety factor is the most critical criterion to consider while building a pillar.

According to the CMRI technique, the observed safety factor for the coal pillar is 3.17. 18.10 percent was calculated as the extraction percentage. Due to panelling, the average life span of a coal pillar is 3-4 years. As a result, the suggested safety factor for coal pillars is 1.5-2. The observed safety factor, however, is 3.17.

So it gives a possibility of decreasing the safety factor to around 2. This would increase the extraction percentage without compromising the safety factor.

## 10.DISCUSSIONS

The following conclusions were drawn from the study:

- For all techniques, the safety factor of a fixed width to height ratio diminishes as depth increases.
- For a fixed depth of mining of 266 m, the safety factor falls and the extraction percentage increases for all techniques as the w/h ratio lowers.
- At various w/h ratios, the Obert – Duvall technique revealed the maximum safety factor for a depth of cover of 120 m.
- When the width to height ratio of the pillar was reduced from 18.292 to 11.504, the extraction percentage increased from 16.3 percent to 25.64 percent for all approaches at 200 m depth cover.
- The safety factor increases as the w/h ratio grows for all approaches at a given depth of cover.
- The safety factor for CMRI formula is maximum at a depth of 266 m, with a width to height ratio of 13.33, with a value of 3.168, as the pillar strength is calculated as 25.76 MPa, while the load on the pillar is 8.13 MPa.
- For various width-to-height ratios and varied depths of cover, the Bieniawski technique yields a safety factor ranging from 0.697 to 1.4936.
- Using the CMRI technique, the safety factor ranged from 1.84 to 6.84 for various width-to-height ratios and different depths of cover.
- The safety factor for the CMRI approach ranged from 2.78 to 3.60 when using regulation 99 of the CMRI regulations 1957 for a minimum width to height ratio at various depths of cover. The Bieniawski technique had a safety factor of 0.70 to 1.35.
- The safety factors produced via CMRI and the Obert-Duvall technique are on the upper side when compared to the stability conditions in Indian mines, which require a safety factor of 1.5–2.

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