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Case Study on Stability Analysis of Highwall Mining in India by using Combined Finite Element Modelling and Statistical Approach.

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Abstract
The paper describes the stability analysis of High Wall Mining in south Deccan region of India. In the year (1983-2002) around 620 incidents happened under the working operation of high wall mining due to improper planning and design structure at high wall face. The main objective of this paper is to design safety by increasing the coal production of High Wall Mining using Numerical Modelling. The Numerical Modelling prepared using a Finite Element Method (FEM) of an Ansys Software was applied to the critical parameter of high wall mining as web cut to access the stability analysis of high wall mining. The Mathematical method employs exiting using the CIMFR and Mark Bieniawski for analysis of Factor of Safety at high wall face. The output of the result review to compare the factor of safety data with Numerical Modelling vs Mathematical Approach to conclude the best dimension pattern for web cut of high wall mining to achieve maximum production of coal at face seam of the high wall in dip direction.

Keywords:*High Wall Mining, Factor of Safety, Ansys Software.*

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I. INTRODUCTION

The word High Wall Mining defines as a mining strategy to recover coal from a surface mine that has arrived at its economic limit. The coal accessed at the base of the high wall from where a progression of parallel entries crashed into the coal seam in dip direction. The sections mined by utilizing two types of high wall mining frameworks to be specific, Continuous high wall mining (CHM) and Auger drill mining. CHM framework uses a seam by digger typically creating 3.5 m wide rectangular entries. In contrast, the auger drill framework uncovers a single or twofold circular hole regularly from 1.5 to 1.8 m in width. The depth extends from 50 to 500 m contingent upon the high wall mining frameworks and mining conditions. It is a remotely controlled mining technique that concentrates coal from the base of an uncovered high wall.

1.1 Working Operation

The first step of mining has to creates the formation of the bench with a platform to extract the coal. The method of extraction of coal in High Wall Mining is bottom to the top of the seam. After the installation of CHM at platform bench from the bridgeof the high wall miner, an operator advances acutter head into an uncoveredcoal seam as Shown in Figure 1.1. The machine rests on a crawler track at the bench under the high wall. Coal extracted in parallel rectangular (the width of the cutter head) entries spaced at diverse durations. The Cutter (Continuous miner) pushed into the seam through a string of push beams that use a set of dual-screw conveyors to clean the coal from the cutter arms and to ship it to the rear of the device. A slewing conveyor stockpiles coal inside the bench and the front-end loader places the coal in the dumper truck. The process repeated as cycle operation for cutting the coal in the entire panel, as shown in Figure1.2.

Figure 1.1: The Layout of Continuous High Wall Mining (CHM).

Method of Cycle Operation

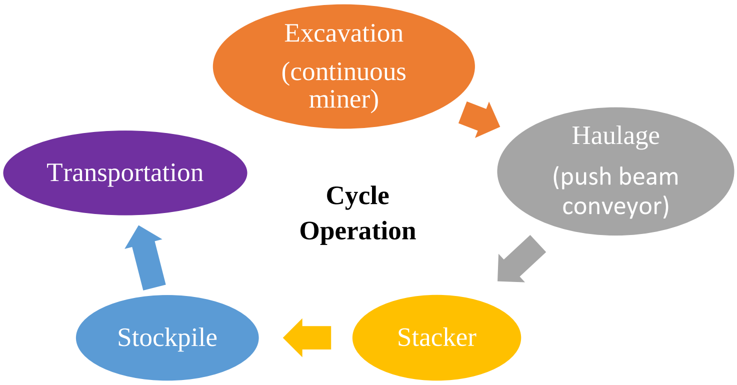


Figure 1.2: The Method of Cycle Operation of Continuous High Wall Mining (CHM).

1.2 Statement of The Problem

There is a critical need in High wall panel design for improved guidelines in sizing a high wall mining parameter such as web cut, web pillars & Barrier pillar.

High wall pillar design should satisfy two criteria.

- **i.** Maintain the required degree of web cut/ entry, & web pillars, stability during all the phases of the service life of high wall face.
- **ii.** Minimize the web pillar sizes, resulting in better resources management and faster development.

The main approaches for issues to the design of a high wall pillar such as

i) Stiff pillar.

ii) Pillar stress.

The"Stiff pillar" approach requires a large panel pillar that sized to support the overburden without failure. **Pillar stress** is also known as Normal stress which defines as the stress that takes place when an axial pressure/force loads occur on a coal ore body reserve. Pillar stress, on the other hand, uses a narrow coal pillar that designed to transfer the Load to nearby solid coal abutment such as a web pillar.

1.3 Application

- The high wall mining system is capable of handling coal seam thickness from 26 to 16 ft with a dip up to 16^0.
- Low mining cost.
- Low labour requirement.
- Roof bolting & ventilation system not required for High Wall Mining.

II. METHODOLOGY

There are two methods required for analyzing the Factor of Safety of High Wall Mining. First is the theoretical approach which is needed to study and collect data from a field visit to analysis the failure that occurs at the High wall. Second is the numerical model required to investigate the Factor of Safety of the high wall by designing the numerical model of the high wall with increasing the variant parameters such as Web Cut and Web Pillar for studying and concluding the best dimension pattern.

Methodology Layout of High Wall Mining

Theoretical Approach — Numerical Modelling

III. CASE STUDY OF MINE A

Mine 'A' is an open cast mine from south Deccan region of India. Around 600 m length of the high wall is accessible for extraction in every one of the seams in Mine A. Penetration depth of each seam is restricted by deficiency F4 on Fault side having an up throw of 10 – 15 m as appeared in Figure 3.1. The working of high wall mining varying from 58 to 220 m of depth. The web cut of the high wall miningdipping the gradient at around 9.5^0. Details of extractable coal seamsat Mine 'A' explained in Table 3.1. The overall Slope angle of the high wall slope is around 44^0. The lithology of the coal measure rocks and the seams at the site from an agent borehole section data has appeared in Table 3.1. delegate borehole section area indicating the seams in the proposed Physic-mechanical properties of the coal measure rocks. The test includes uniaxial compressive Strength, Brazilian tensile Strength, Density, Young's modulus, Poisson's ratio, and slake durability. These tested properties for intact rock, for the rock types, including the coal seams and their roof & top and floor, are given in Table 3.1.

Table 3.1: - Seam Details of Mine "A" With Physical -Mechanical Properties of Rock

Strata	Depth (m)	σc (*MPa*)	*E* (*GPa*)	€	Density (kg/m3)	σt (*MPa*)	Slake durability Index (%)
Top Section	1-77	32.7	2.26	0.27	2600	0.8	80
Coal Seam	77-81	33.0	2.7	0.19	1500	3.7	80
Bottom Section	81-190	45.1	5.7	0.25	2600	2.1	76

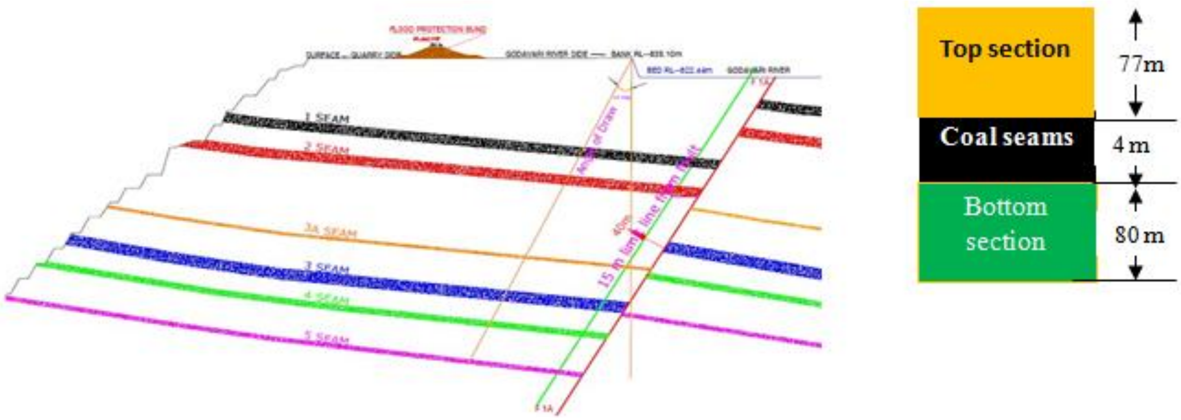


Figure 3.1: A Plan Showing the Proposed of Layout of High Wall Mining in Mine "A"

IV. MATHEMATICAL SIMULATION EQUATION OF HWM

4.1 Stability Factor/Factor of safety (FOS)

The ratio of the ultimate strength on coal pillar to actual working on coal pillar (or) Load acting on the pillar termed as the factor of safety (FOS)

$$\text{The factor of safety (FOS)} = \frac{\text{strength of coal pillar}}{\text{Load on coal pillar}}$$

Based on the beyond studies from Indian coalfields, it has been located,

- The safety factor is more than 2.0 is long term stability.
- The safety element is among 1.5 & 2 can be taken as a medium period strong, stable for a few years.
- If the stability factor is 1; it termed a short period stable, with the stand-up time of some week of the month.

4.1.1 Mark – Bieniawski Formula

i. Web Pillar strength: -

Sp = Si [0.64 + (0.36 (W/h)] .... (4.1)

Sp = Pillar strength, Mpa; Si = In situ Coal strength, Mpa. For India Coal Field Si = 6 Mpa (approx.). W = Width of Web pillar, h = Height of pillar.

4.1.2 CIMFR Formula

i. Estimation of pillar strength

$Sp = 0.27\ \sigma c\ h^{-0.36} + ((H/250) + 1)^{*} ((Wm/h)-1)$ …………. (4.2)

Sp= strength of the pillar, Mpa; σc = Compressive strength of 25mm cube coal sample

h = working height, m; H = depth of cover, m; Wm = equivalent width of pillar,

Wm = 2Wb for long pillar; Wb= width of web pillar, m.

4.1.3Estimation of Load (or) Stress on coal pillar for Mark – Bieniawski & CIMFR Formula

Load on pillars can be estimated using the Tributary area method, which reads as:

Lp = Sv (Wb + We) / Wb…………………………… (3)

Sv = in situ vertical stress (or) Normal stress= density of rock * overburden depth.

Wb = web pillar width ;We = high wall miner hole width(or) web cut.

Substitute the value of high wall parameter data in Equation (4.1, 4.2,4.3) enter the result of mathematical value in the table, as shown in Table 4.1.

Table 4.1: - Comparison of FOS as Mark – Bieniawski vs CIMFR Formula

Web Cut (m)	Web Pillar (m)	Strength		Load		FOS	
		Mark Mpa	CIMFR Mpa	Mark Mpa	CIMFR Mpa	Mark Mpa	CIMFR Mpa
3.5	10	9.24	10.874	3.088	3.088	2.99	3.52
4	10	9.24	10.874	3.203	3.203	2.88	3.39
4.5	10	9.24	10.874	3.32	3.32	2.78	3.275

V. NUMERICAL MODELLING APPROACHES

Today's mining technology prefers more complex problem issues it can analyze by using Numerical Modelling. Examining the different type of rock mass in the mining area are very complicated method. Numerical Modelling is tools which used to solve the problem for Engineering Structure. Various numerical modelling software was introducing in the market such as FLAC, Ansys, Surpac, Minex. The Numerical Modelling of high wall mining has done by using "**Ansys Software"** to analyze the Factor of Safety.

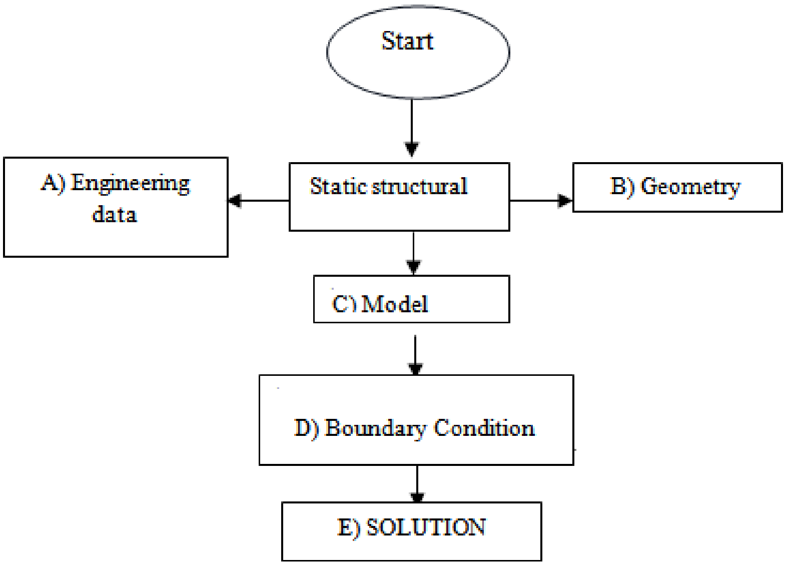
5.1 Application of numerical Modelling:

I. The finite element method has found wide application in ground control study of high wall mining. Generally, rock strata such as shale, sandstone, clay, and other geology body of sediment that occur with coal seam do not behave elastically in engineering problems. They may go into a plastic state after Load on them exceeds a specific limit which is called **elastic to a plastic state.**The General Solution Flow Chart Procedure Steps in Ansys Software, as shown in Figure 5.1.

II. Numerical Modelling used to solve the application in mining method such as

a) Board and pillar.
b) Longwall mining.
c) Drilling and blasting.
d) Roof bolting (strata control).

Figure 5.1: General Solution Flow Chart Procedure Steps in Ansys Software



5.2 Input Parameter Requiredfor Designing High Wall Miningin Mine A.

1) Height of bench: 10m 2) Width of web cut (We): - 3.5m
3) Width of bench: 5m 4) Width of web pillar (Wb): -10m
5) Face angle: 63^0 6) Width of barrier pillars: -20-30m
7) Length of cut hole =150-220 m 8) No of cut: - 44
9) Depth = 91.5m 10) Height of extraction (H) = 4m
11) Wm = 2* Wb
12)PMP data of High WallMining for Entering in Engineering data (Table3.1).

5.3 Engineering Data

Enter the PMP data (Table 3.1), in Ansys engineering toolbox, as shown in Figure 5.2.

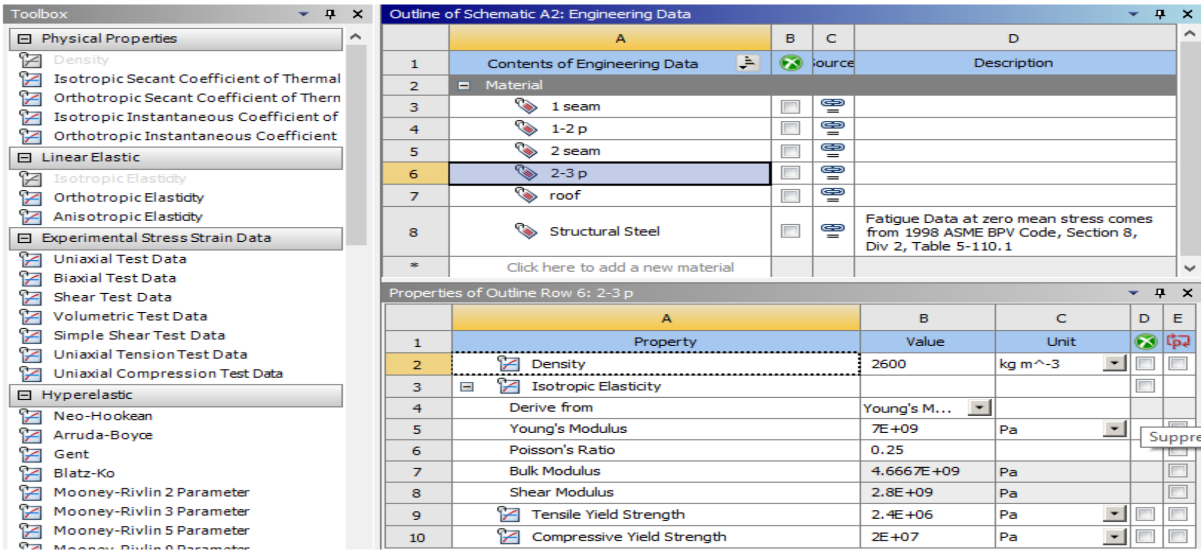


Figure 5.2: Analysis of Engineering Data Model of High Wall Mining from Ansys Software

5.4 Geometry

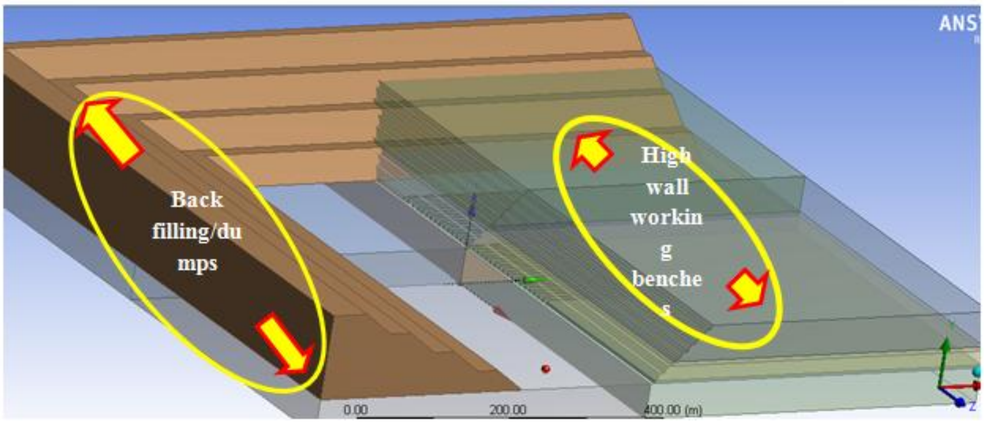


Figure 5.3: Top view of Geometry Model of High Wall Mining from Ansys Software

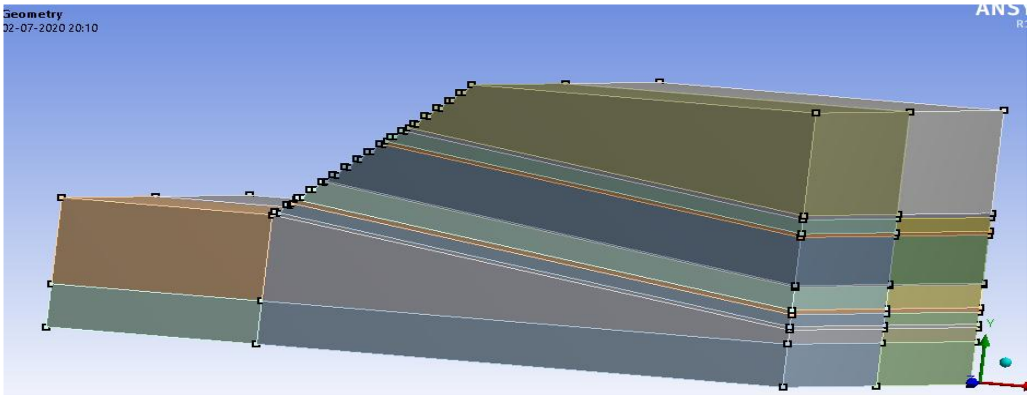


Figure 5.4: Side view of Geometry Model of High Wall Mining from Ansys Software

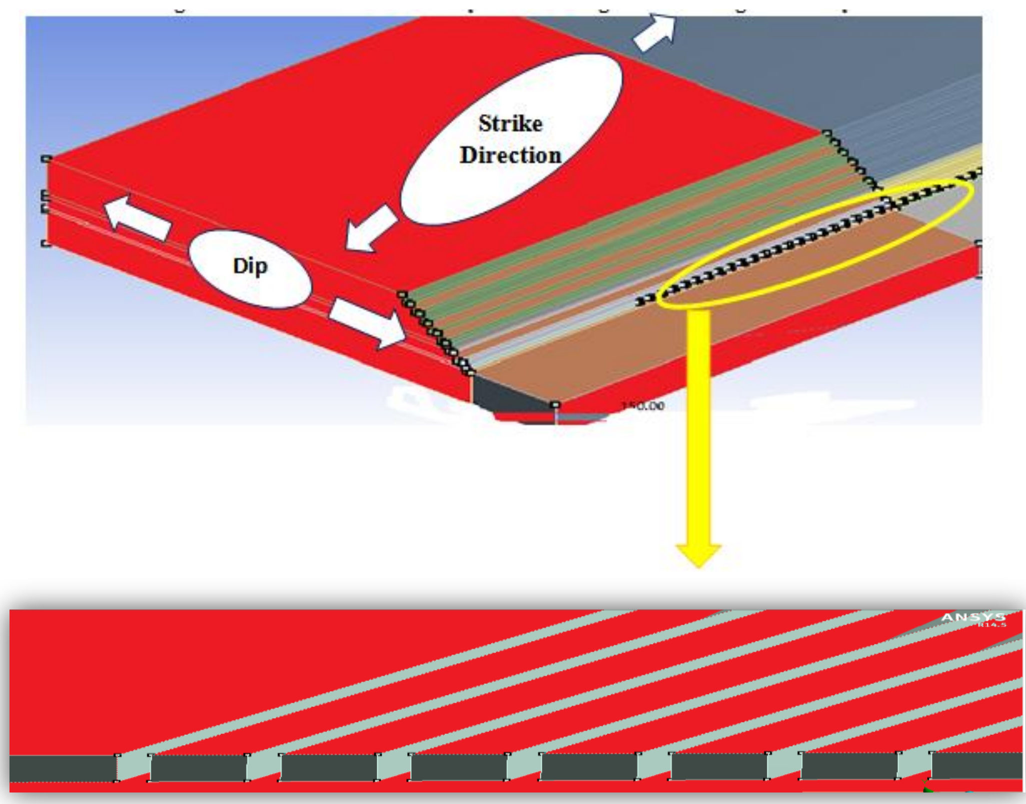


Figure 5.5: Strike and Dip Direction of Geometry Model of HWM from Ansys Software

5.5 Model

Meshing

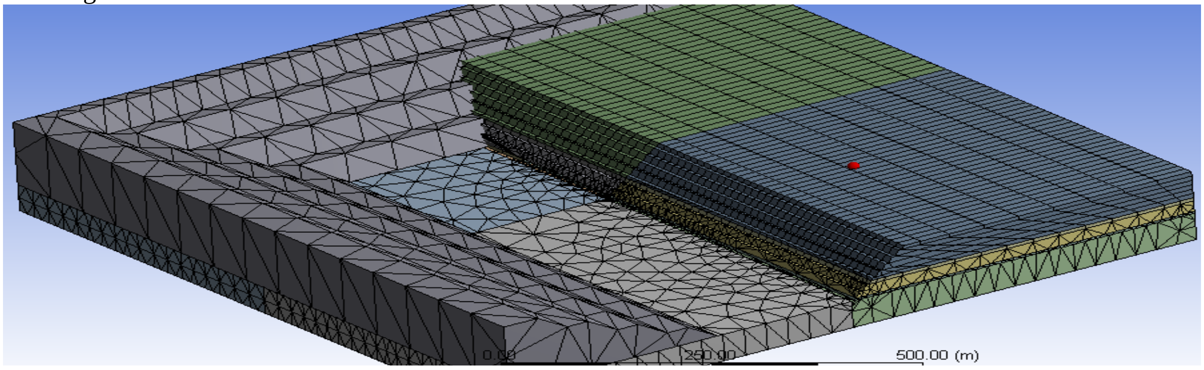


Figure 5.6: Meshing Model of High Wall Mining from Ansys Software.

5.6 Boundary Condition

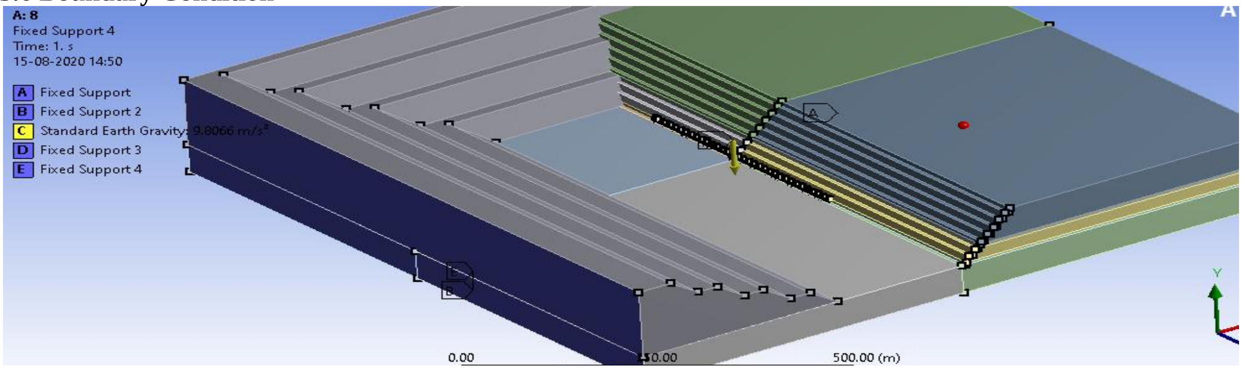


Figure 5.7 of Boundary Condition of High Wall Mining from Ansys Software.

VI. RESULT & DISCUSSION OF HIGH WALL MINING.

6.1 Normal Stress

From the Finite Element Model, the Normal Stress is calculated by creating the path on each coal roof pillar in the Dip and Strike direction, as shown in Figure 6.1. Noted and enter the value of Normal Stress of High Wall in each pillar in the table, as shown in Table 6.1.

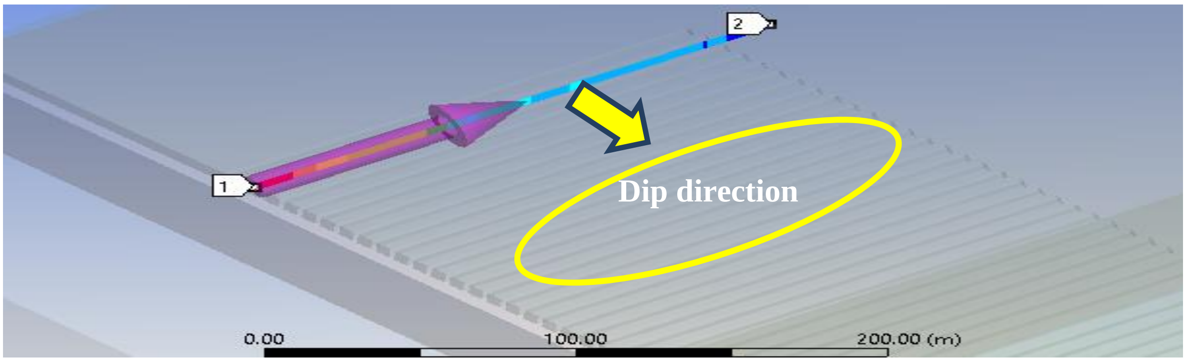


Figure 6.1: - Analysis of Normal Stress in Dip and Strike direction from Ansys Software

Table 6.1: Analysis of Normal Stress at Web Cut Variants from Ansys Software.

Pillar No.	AVG NORMAL STRESS AT		
	3.5 m	4 m	4.5 m
1.	1.53	1.94	2.10
2.	2.15	1.95	1.94
3.	2.42	2.34	1.85
4.	1.94	2.11	2.01
5.	2.20	2.14	2.94
6.	1.91	2.41	3.91
7.	2.09	2.45	3.04
8.	2.02	3.18	2.00
9.	2.29	2.53	2.91
10	2.63	2.32	1.84
11.	.2.00	2.26	2.05
12.	2.11	2.33	2.92
13.	2.65	2.33	1.87

14.	2.22	2.15	3.71
15.	2.44	2.72	1.76
16.	1.67	2.30	3.96
17.	1.92	1.94	2.34
18.	1.99	2.19	3.96
19.	2.11	2.22	2.94
20.	1.93	2.23	2.19
21.	1.91	2.58	2.03
22.	2.31	2.24	1.69
23.	2.08	2.27	2.82
24.	2.18	1.88	2.15
25	2.15	2.06	2.44
26	1.96	1.85	2.55
27.	2.25	1.89	2.08
28.	1.87	1.96	1.95
29.	1.84	2.77	2.84
30.	2.03	2.54	2.04
31.	2.40	2.53	2.32
32.	2.13	2.51	1.92
33.	1.53	1.94	2.10
34	2.15	1.95	1.94
35	2.42	2.34	1.85
36	1.94	2.11	2.01
37	2.20	2.14	2.94
38	1.91	2.41	3.91
39	2.09	2.45	3.04
40.	2.02	3.18	2.00
41.	2.29	2.53	2.91
42.	2.63	2.32	2.84
43	2.00	2.26	2.05
44	2.11	2.33	2.92
Avg	**2.1**	**2.28**	**2.42**

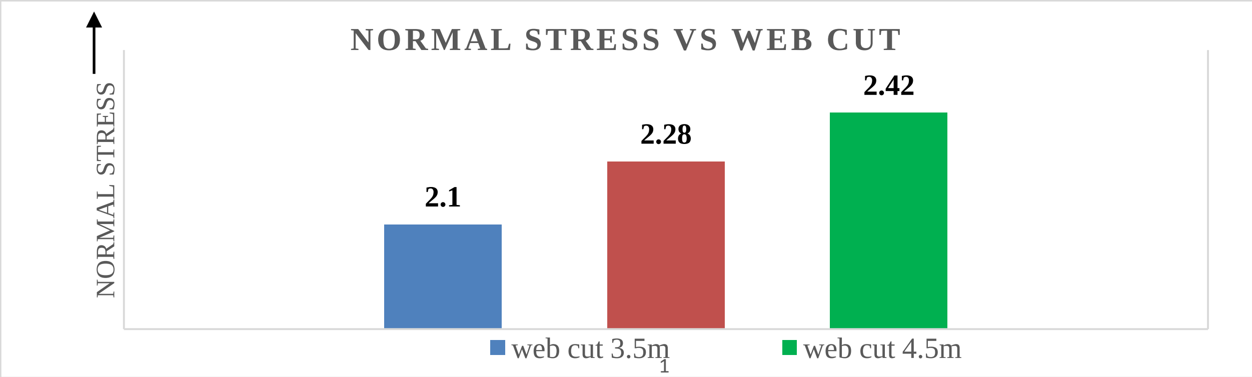


Figure 6.2: Normal Stress vs Web cut variants of Mine-A

Discussion of Result

From the result of Table 6.1 and Figure 6.2, it observed that as Web cut increases the normal stress acting on coal seam roof, it's expanding. Which trends that the stability factor is diminishing due to Factor of Safety is inversely proportional to Normal stress (FoS ɑ 1/ Normal stress) which causes a roof failure at high wall face.

6.2 STABILITY FACTOR (FOS)

i) Strength of pillar (Sp) at 3.5m, Sp at 4m, Sp at 4.5m

= $0.27 \times 33 \times 4^{-0.36}$ + [(91.5/250) +1] [(20/4)-1] = **10.874Mpa**.

ii) Load on pillar (Lp) = σn Avg x (Wb + We) / Wb

- ⇨ Lp at 3.5m = 2.1 x (10 +3.5)/3.5 = **2.835 Mpa**.
- ⇨ Lp at 4m = 2.28 x (10 +4)/4 = **3.192 Mpa**.
- ⇨ Lp at 4.5m = 2.42 x (10 +4.5)/4.5 = **3.51 Mpa**

iii) FOS: -

- ⇨ SP 3.5/ Lp 3.5 = 10.874 / 2.835 = **3.83**
- ⇨ SP 4/ Lp 4 = 10.874 / 3.192= **3.41**
- ⇨ SP 4.5/ Lp 4.5 = 10.874 / 3.51 = **3.09**

Table 6.2: - Comparison of Stability Factors (FOS) For Theory vs Modelling At Increasing Web Cut Variants.

S.no	Web cut (m)	Web pillar (m)	Strength (Mpa)	Load (Mpa)	FOS	
					Theory	Modelling
1	3.5	10	10.87	2.835	3.52	3.83
2	4	10	10.87	3.192	3.395	3.4
3	4.5	10	10.87	3.51	3.27	3.1

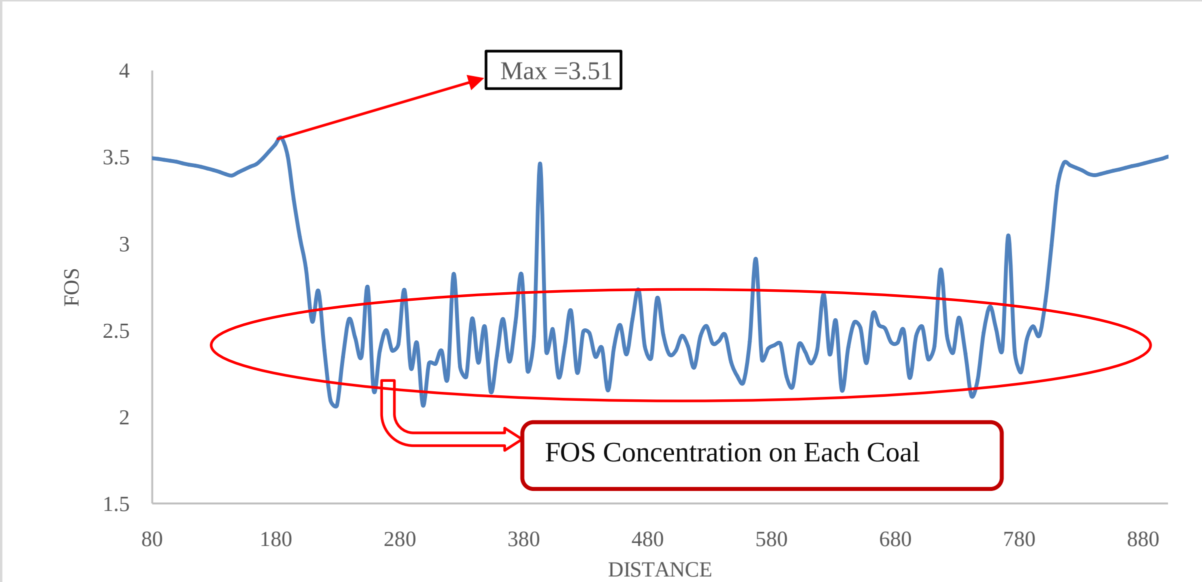
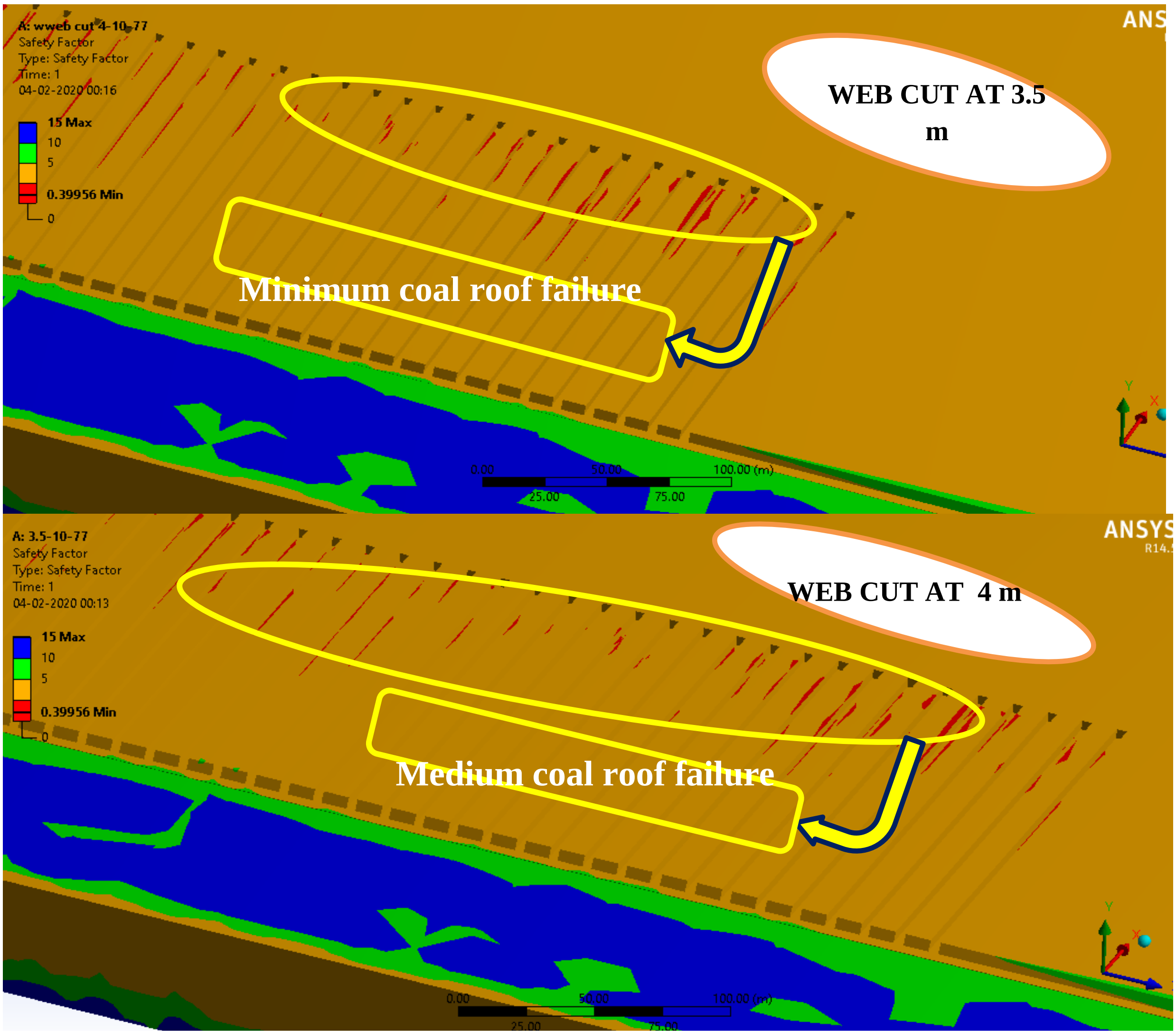


Figure6.3:- Plotting Graph Between FOS vs Distance at Web cut 3.5 m.



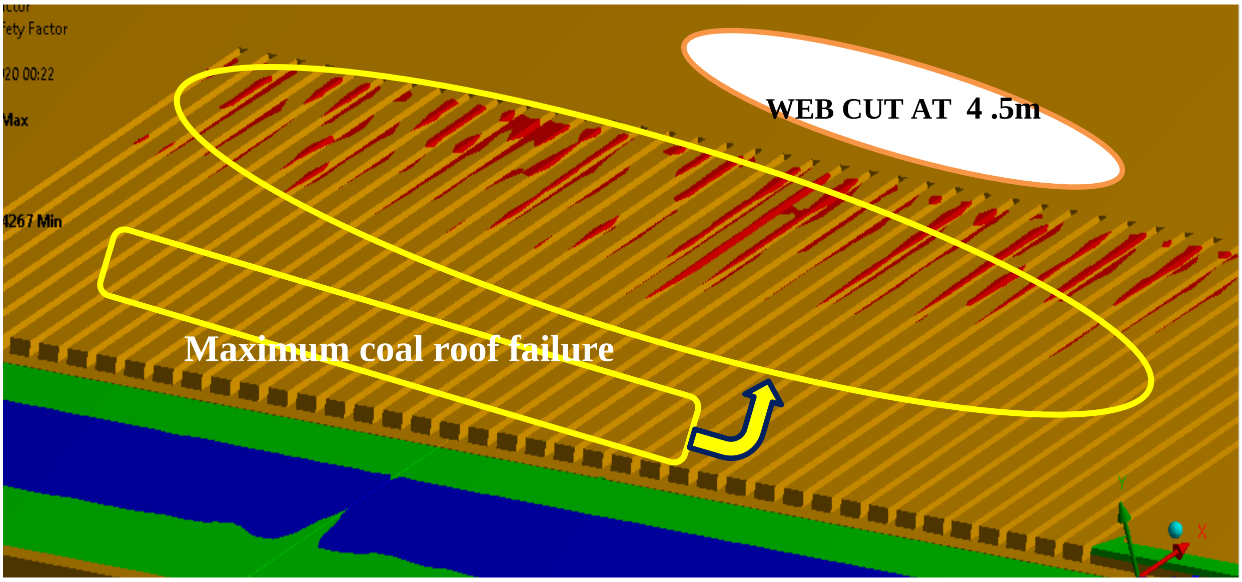


Figure6.4: - Analysis of Factor of Safety for Three Models of Web Cut Variants from Ansys Software at Coal Seams.

Discussion of Result

From above Figure 6.4,it's concluded that the web cut at 3.5m is the most safety operation method for High wall mining as compared to web cut at 4 and 4.5 m. which causes most roof failure for coal seam at web cut 4 and 4.5m. So, it's better to extract coal at a "**web cut = 3.5 m".**

6.3 Comparison of (Mark- Bieniawski, CIMFR, Numerical Modelling) Data

6.3.1 Web Pillar Strength

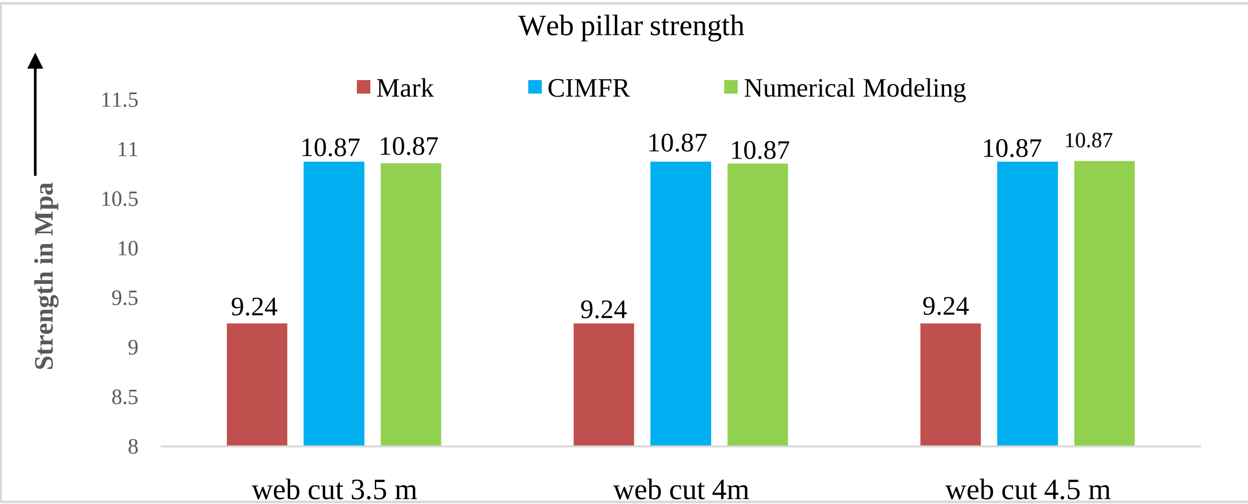


Figure 6.5: Plotting the Histogram Strength Graph Comparison of (Mark- Bieniawski, CIMFR, Numerical Modelling data) at Web cut (3.5m, 4 m, 4.5m).

6.3.2 Web Pillar Stress (or) Load Acting on Pillar

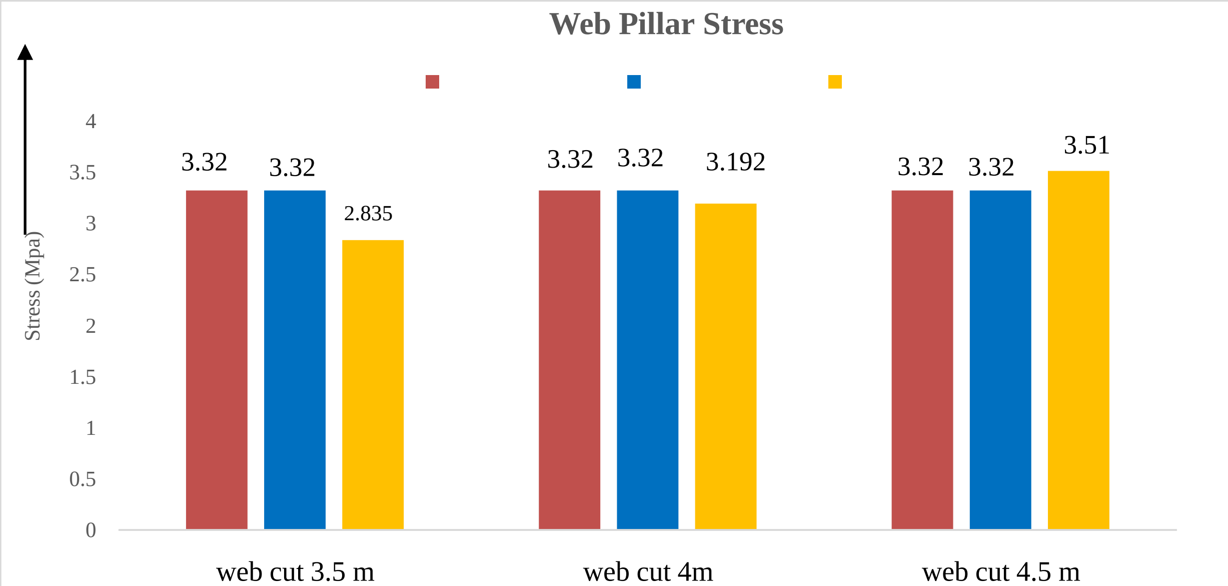


Figure 6.6: Plotting the Histogram Stress Graph Comparison of (Mark- Bieniawski, CIMFR, Numerical Modelling data) at Web Cut (3.5m, 4 m, 4.5m).

6.3.3 Stability Factor (FOS)

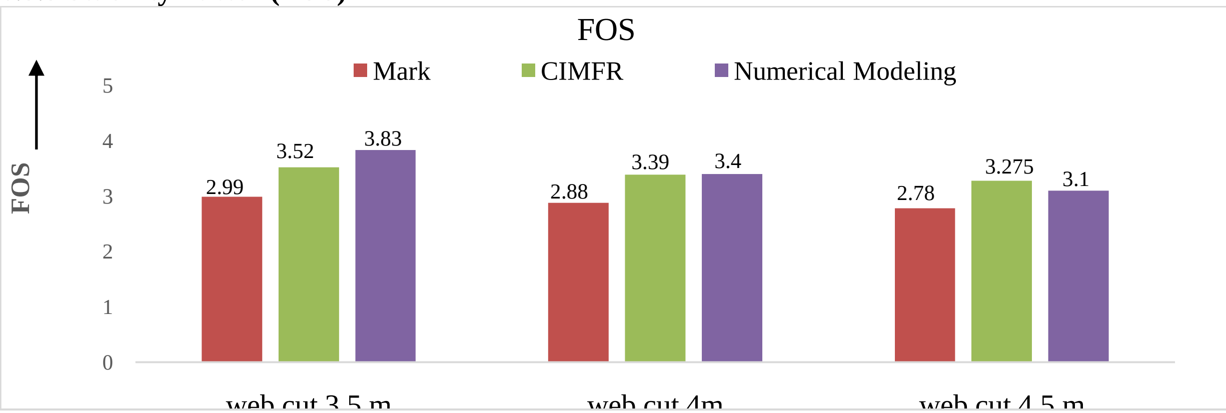


Figure.16: Plotting the Histogram FOS Graph Comparison of (Mark- Bieniawski, CIMFR, Numerical Modelling Data) at web cut (3.5m, 4 m, 4.5m).

Discussion of Result :

From Figure 14, 15 and 16, it observed that as the width of the Web cut increased then the stability factor of the column is diminishing. Due to as the width of the cut is increased then strength on a pillar is stay consistent during applying stacking/Load step by step the strength factor of high wall configuration cause failure and pattern to slant disappointment mishap.

VII. SUMMARY AND CONCLUSION

a) The factor of safety for Web pillars at high wall mine the primary recommendation from the steadiness thing evaluation is to maintain and design the web pillars with a minimal stability factor as **"2"** for safety working method during the cutting of coal in Dip Direction.

b) Empirical and Numerical Modelling techniques used to analyze the safe layout of web cut, web pillar, and barrier pillars.

c) For stability reasons, a web pillar with a W/H ratio should be above 2-3 has good sound geomechanics-primarily based on the extraction of coal.

d) Analysis of Stability Factor of high wall mining, we should have to compare all the Empirical web design (Strength & Load) equation from different authors as (Mark- Bieniawski & CIMFR). And study several Field tests at mine for concluding the final dimension of High wall mining.

e) The Normal Stress of high wall mining is varying from **2.1 Mpa to 2.42 Mpa** by increasing the width of the web cut from 3.5 m to 4.5m.

- **f)** Table 6.2, as concluded that as the width of the web cut is increasing from 3.5 m to 4.5 m, then the Stability Factor (FOS) of high wall mining from numerical Modelling is decreasing from **3.83 to 3**.
- **g)** In this study, the aim for Designing any High Wall Mining for coal seam is a plan to increases the strength of the coal pillar by reducing the stress that occurs on coal seams during the extraction of the high wall face.

VIII. RECOMMENDATION FOR FUTURE STUDIES

- a) The use of comprehensive Numerical Modeling (Ansys Software) can be a useful tool in assessing and comparing the performance of Mine -A' layout design.
- b) Final Studying from all the result of Ansys models for Mine -A, High wall mine parameter variants, The best preventive shape for extraction the final dimension of High wall mining under the geology situation for coal seams at mine "A."

  Width of web cut:Should not be greater than 3.5m.

  Width of the web pillar: Should not be greater than 3.5m.

  Friction (or) slope angle: Should not Exceed **45^o**, at workbenches. And for dump soil Should not Exceed **37.5^o**
- c) In an open-pit mine, most of the failure surface occurs slope at the crest line. Dump failures of this type frequently observed.
- d) The study is useful for the future design of High Wall Mining by using Ansys Software in various mine location.

Declaration of Competing Interest

There is no conflict of interest in the preparation of this manuscript.

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