DEVELOPMENT OF COMPUTATIONAL SOFTWARE TO DETERMINE THE 'FACTOR OF SAFETY' OF BORD AND PILLAR WORKING AS PER TRIBUTARY AREA APPROACH

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

By

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DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY,

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National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled **"DEVELOPMENT OF A COMPUTATIONAL SOFTWARE TO DETERMINE THE FACTOR OF SAFETY OF BORD AND PILLAR WORKING AS PER TRIBUTARY AREA APPROACH"** submitted by Abinash Dash in partial fulfilment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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CONTENTS

ABSTRACT

Factor of safety (FOS) plays an important role in mine planning. Various factors/parameters are necessary to determine the FOS by tributary area approach especially in bord and pillar working. Investigations have been carried out to determine the parameters affecting the selection of bord and pillar method in underground coal mines. The data are entered according to the Indian mining conditions and requirements to exhibit the planning of a mine to determine the best fit result. This dissertation emphasises on to develop a software for the mine planners and administration to take ameliorative measures in advance to design a stable bord and pillar working based on relation between pillar dimensions and FOS.

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INTRODUCTION

INTRODUCTION

1.1. GENERAL

Mining is the exploitation of useful and valuable minerals present underneath the earth surface. Many Geological factors determine the ease with which an ore can be extracted. The primary methods of extraction of coal include methods like long wall mining and bord and pillar working. Pillars in coal mines serve various purposes e.g., protection of gate roadways or entries, panel isolation to guard against spontaneous heating, protection of mine shafts and surface subsidence control[2]**.** Considering the fact that the structural integrity of a coal mine largely depends on pillars, considerable research in the area of pillar strength and design has been done over the last few decades. The study provides a calculative approach to determine safe underground working when the coal is extracted by the bord and pillar pattern. It essentially evaluates the safety of a pillar and hence can be assumed approximately to be that for a mine. The method used for calculating FOS is the tributary area approach for safety analysis .Usually, the percentage of extraction is around 60% for bord and pillar working in Indian mines [1]. This dissertation also deals with the pillar strength through empirical formulas designed by different researchers or academicians etc. and the determination of FOS**.**

1.2. OBJECTIVES

1. Study of different parameters and empirical pillar strength formulas responsible for evaluating the FOS in underground coal mines using bord and pillar method.
2. Development of software for calculation of FOS of coal pillar in underground mines using bord and pillar method as per Tributary area approach.

1.3. METHODOLOGY

In order to achieve the above said objectives, the following methodology was adopted.

- ✓ **Literature review:** All the past research work carried out by researchers, academicians, scientists etc. related to present topic was reviewed to gain some knowledge.
- ✓ **Study of parameters:** All the parameters which are found to affect FOS are thoroughly studied.
- ✓ **Development of software:** Software was developed in Microsoft Visual Studio for the calculation of FOS. The coding language used was c#.

- ✓ **Collection of data:** Data was collected from 2 different mines and FOS was calculated using developed software

Chapter-2

LITERATURE REVIEW

LITERATURE REVIEW

2.1. BORD AND PILLAR WORKING METHOD

Bord and pillar method of working is generally adopted for seams with thickness greater than 1.5 m, at moderate depth and seams that are not very gassy. The method of working consists of driving a series of narrow roads, separated by blocks of solid coal, parallel to one another and connecting them by another set of narrow parallel roadways driven nearly at right angles to the first set[1].The stage of formation of a network of roadways is known as development. The coal pillars formed are extracted after the development of the mine and this later stage of extracting coal from the pillars is known as depillaring. Some of the problems associated with Bord and Pillar method of working are high extraction losses compared to other methods and sluggish ventilation [3]. At greater depths this method becomes uncontrollable as effects of roof pressure are not easily predictable [1].

2.2. DIFFERENT APPROACHES TO DETERMINE FOS OF A PILLAR

There are basically two different approaches used to determine the stresses experienced by a pillar and relating to the FOS of the pillar in bord and pillar working. Among them, Pressure Arch Theory and Tributary Area Approach are popular. Generally, tributary area approach is used to determine the FOS in bord and pillar working of Indian mines.

2.2.1. Tributary Area Approach:

A pillar takes the weight of overlying rock up to a distance of half the opening width surrounding it. For square pillars width of pillar is taken as same as length of pillar

This approach carries with itself the following assumptions [2]:

- The seam is subjected only to vertical pressure, which is constant over the mined area. However, stress transfer occurs where stiff abutments exist in underground workings. Thus this vertical pressure may be relieved partially.
- Each pillar supports the pillar of rock over an area that is the sum of the cross-sectional area of the pillar plus a portion of the room area, the latter being equally shared by all neighbouring pillars. However, this is certainly not valid if the area of development is small since the pillars in the centre of the excavation are under more stress than the pillars near the sides. It is usually only accepted as valid if the mined-out area is greater than the depth below surface.
- It is assumed that the load is uniformly distributed over the cross-sectional area of the pillar.

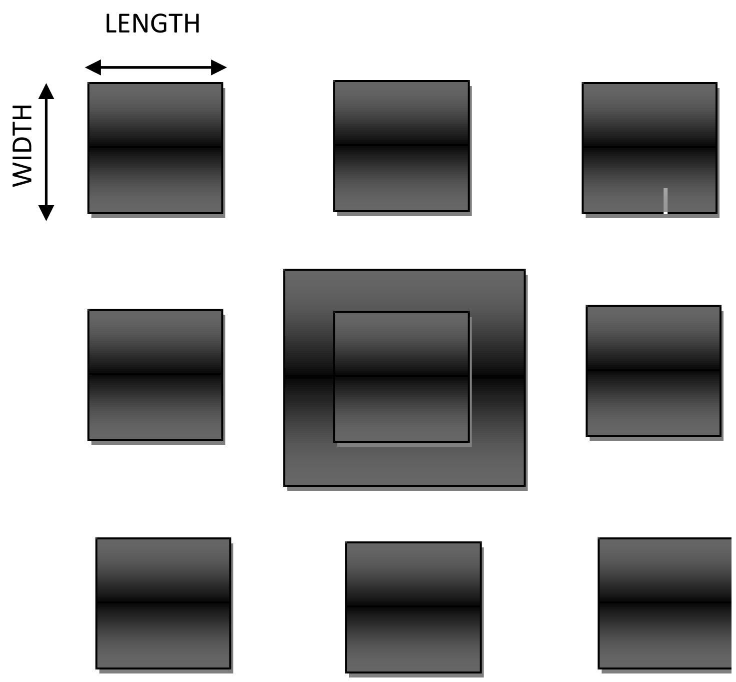

Fig.1. Pictorial view of Tributary area pillar loading

2.2.2. Pressure Arch Theory [6]:

This theory explains that the formation of an opening makes the stresses to shift outward on both sides of pillar thus leaving behind a de-stressed zone just like an arch shape surrounding the pillar. The stress levels along with the shape and size of the opening and other strata conditions determines the exact shape and size of the arch formed around the pillar. Subsidence occurs when the arch formed reaches the surface. The de-stressed zone inside the arch is called intradosal ground, while the zone outside is called extradosal ground. The stratum at the fringe of the intradosal ground gets compressed as part of the vertical stress is transferred to the abutments. The height of the intradosal ground is about 2- 4 times the width of the extraction.

2.3. BASIC DESIGN CRITERIA

The basic approach for designing coal pillars is to determine the strength of the pillar and to compare it with the stresses acting on the pillar. The design procedure is to change the dimensions of the pillar until the maximum stresses acting on the pillar is equal to the strength of the pillar reduced by a safety factor.

The different criteria followed in designing coal pillars are [4]:-

2.3.1. Strength of pillar

Since the strength of a pillar is a reflection of the material quality and the distribution of stresses in the pillar, it is essential to look at the variables that impact the distribution of the stresses in the pillar. Presumably, the most essential factors are the vertical and horizontal components of the stress vector at the contact between the pillar and the encompassing strata. The distribution of these components and their magnitudes are influenced strongly by the friction and cohesion in the contact plane and by the deformation characteristics of the pillar material and the surrounding the strata [4] .The strength of a pillar has a tendency to increase with an increase in its ratio of width, w, to height, h. This increment in strength is because of the lateral confinement given to the pillar by the lateral component of the contact stress.

2.3.2. Strength of Roof and Floor

One critical perspective in bord-and-pillar mining is the quality of the roof and the floor. Weak roof and floor strata in the vicinity region of the coal seam can influence the following in bord-and-pillar mining: (i) roof support in the bords, (ii) the working conditions and the equipment's used for mining and (iii) stability in a long term aspect of the system. As far as roof control in bord-and-pillar workings is concerned, the problems tend to increase as the density of the bedding planes in the immediate roof strata increases. On a basic level, there are two methods for enhancing the behaviour of a good roof [4]: (a) by enhancing the apparent strength of the roof, (b) by lowering the burden in the roof. The previous can be attained by the use of supports, while the latter concerns mine outline and design. The most critical parameters that control the size of the induced stresses are the dimensions of the pillars and the bord width.

2.3.3. Pillar Load

The determination of pillar load is the most challenging thing while surveying the condition of pillar. The main technique sufficiently effective to compute the pillar burden is the tributary area approach. This theory applies to horizontal workings of which the lateral extent is very large in relation to the depth below surface [4]. The pillar stress calculated shows the upper range of the average pillar stress or pillar stress in any level working of fixed height upheld by uniform pillars.

[4]In order to maintain the equilibrium, the weight of the unsupported roof strata above the panel will be redistributed in the form of abutment stresses. The objective of the pillars is to restrict the merging of roof and floor that will happen otherwise. Most likely, these pillars will be more reliable if they have a high stiffness - that is a high width-to height proportion.

2.4. TYPES OF PILLARS AND THEIR FUNCTIONS IN COAL MINES

In coal mining industry, especially in any underground mine working, two unique classifications of pillars are found namely: support pillars and protective pillars. The distinguishing criteria between the two sorts of pillars are difficult to find and there are number of cases when pillars satisfy both the necessities i.e. protective as well as supportive. The various critical contrasts in the two types of pillars are: [4]

2.4.1. Support Pillars:

Support pillars can be isolated into two classes: pillars that give regional support (support to the surrounding pillars within its zone of influence), and pillars that give local support. Be that as it may, pillars regularly give both regional and local support. A decent illustration of this is a pillar in bord and pillar working having a high degree of FOS. Regional support pillars are briefly utilized and are extracted once they have finished their role. One of the interesting aspects of local-support pillars is that their useful function is often limited to the time when actual mining takes place in their immediate vicinity. Consequent damage to these pillars can happen given the mode of failure is stable. The concept of yielding support pillars falls into this category. Barrier and wide inter-panel pillars are typical examples of pillars that provide regional support.

2.4.2. Protective Pillars:

Over the span of mining, it regularly gets crucial to shield or protect underground and surface structures from the impacts of mining. One of the viable methods for accomplishing this is to leave segments of the coal seam unmined to get protective pillars. The important criteria for designing these pillars depend generally on the nature of the structure that needs to be secured. On account of underground structures, for example as bunkers, pump stations, etc, it is generally the strength and magnitude of stress that decides the size of protective pillars.

2.5. PILLAR FAILURE

Pillars which are left in underground working as remnants or pillars which act as supporting elements in underground working need to be strong and large enough to support the weight of the overburden material and its load [5]. Pillar failure still possesses a great risk in spite of so many researches going on in this topic. The load that a pillar is likely to take so that it maintains a high degree of FOS is an important aspect and needs to be given attention during pillar making. There are various methods to know the pillar load including numerical and empirical methods but the most difficult part is to determine the in situ pillar strength. Salamon Munro was the first author who was able to give an empirical relation between pillar dimensions and the respective pillar strength by observing a series of cases in South African coal mines [5]. The pillar strength can be attributed to the intact strength of material and the (w/h) ratio or the width to height ratio. Faults, cracks, joints can have an effect on the pillar strength and thus an important aspect to observe but are out of mathematical calculation.

When the pillars are loaded they undergo the following phases before failure [5]:

- Stress at the pillar side and at the centre
- Fracturing of sides and stresses make the fracture zones grow larger while the core approaching yield conditions.
- Fractured zones convergence
- Ground distressing around failed pillar.

2.6. SIZE OF PILLARS

The size of the pillars is affected by the following [6]:

1. The depth from the surface and rate of extraction in the workings or advancement.
2. Strength of the coal- Seams with weak feeble coal feel the need of large pillars. Impact of environment and emission of gas from pillars additionally impact the strength of pillars.
3. The nature of the roof and floor-It causes the risk to crush. A solid roof has a tendency to crush the pillar edges whilst a delicate floor inclines it to creep and both calls for large sized pillars.
4. Geological Considerations- In the region of faults, large pillars are needed. Dip and water in the vicinity additionally impacts the choice as to the requirement of size of pillars.
5. Time dependant strain- With time the strain continues expanding, the force (load) staying consistent and if the size of the pillar is not sufficiently high, then it may fall flat under the time dependant strain, albeit at first it may ,with the progression of time, weathering takes place which decrease the strength of coal pillars.

In India, the measurements of coal pillars and the width and height of galleries are directed by Regulation 99 of Coal Mines Regulation 1957. It is stipulated that the width of galleries should not surpass 4.8 m and the height of the galleries should not surpass 3 m. For width running from 3 m to 4.8 m, the measurements of pillars for different kind of working are given underneath [6].

Table 1: Minimum distance between centres of adjacent pillars according to regulation 99 of CMR 1957

Depth of the seam from the surface	Where the width of galleries does not exceed			
	3m	3.6m	4.2m	4.8m
	The distance between centres of adjacent pillars shall not be less than (in m)			
Not exceeding 60m	12	15	18	19.5
Between 60-90m	13.5	16.5	19.5	21
Between 90-150m	16.5	19.5	22.5	25.5
Between 150-240m	22.5	25.5	30.5	34.5
Between 240-360m	28.5	34	39.5	45
Exceeding 360m	39	42	45	45

2.7. FACTOR OF SAFETY (FOS)

The factor of safety (FOS) is a very simple ratio used to calculate how safe a pillar or working in normal working conditions. It is given as:

Safety factor = $\frac{S_\rho}{\sigma_p}$

Where, σ_p = Stress on pillar

S_ρ = Strength on pillar

2.7.1. Stress on pillar:

The mathematical equations used to calculate the stress on a pillar for a bord and pillar working on the basis of tributary area approach are as follows[6]:

$$P = (L_P + W_0)(W_P + W_0) \times \gamma \times g \times h \quad (1)$$

Where, γ is the weight of the rock per unit volume, P is the load and h is the depth of mining.

L_P - Length of pillar,W_0 and W_P are the width of gallery and pillar respectively

The stress on the pillar,$\sigma_p = \frac{P}{\text{Area of Pillar}} = \frac{(L_P+W_0)(W_P+W_0)\times\gamma\times g\times h}{(L_P+W_0)}$

$$= \frac{(L_P + W_0)(W_P + W_0) \times \sigma_v}{(L_P + W_0)} \quad (2)$$

In case of inclined seam the formula for stress on the pillar is:

$$\sigma_p = \frac{(L_P+W_0)(W_P+W_0)\times\sigma_v}{(L_P+W_0)} \times (\cos\theta + m\sin\theta) \quad (3)$$

Where, θ = angle of inclination, m = poison's ratio, and σv = vertical stress = γgh

2.7.2. Strength of pillar

The strength of a pillar is determined by the empirical formulas or equations given by famous researchers based on numerous case studies taken by them of different mines and geo mining conditions:

2.7.2.1. CMRI formula [2]

A formula was proposed by CMRI taking into account the criteria of w/h ratio, the compressive strength of a pillar, the seam height and the material cover.

$$S_\rho = (0.27 \times \sigma_c \times h^{-0.36}) + \left\{\frac{H}{160}\left(\frac{w}{h} - 1\right)\right\} \quad (4)$$

Where, S_ρ- Pillar strength (MPa)

σ_c - Uniaxial compressive strength (UCS) (MPa)

h - Working height or seam height (m)

H - Depth of cover (m)

2.7.2.2. Obert-Duvall/Wang Formula [2]

According to *Obert and Duvall*, the equation is valid for w/h ratios of 0.25 to 4.0.

$$S_\rho = \sigma_1\left(0.778 + 0.222\frac{w}{h}\right) \quad (5)$$

Where, S_ρ is pillar strength, σ_1 is uniaxial compressive strength of a cubical specimen (w/h =1), and w and h are pillar dimensions.

2.7.2.3. Salamon-Munro Formula [2]

Salmon and Munro (1967) tested numerous pillars in South Africa. On the basis of the survey conducted on 98 standing pillars and 27 failed pillars, they generated a formula:-

$$S_\rho = 1.32\frac{w^{0.46}}{h^{0.66}} \quad (6)$$

Where, S_ρ is the pillar strength in psi, and the pillar measurements w and h are in feet.

Chapter-3

DEVELOPMENT OF SOFTWARE

DEVELOPMENT OF SOFTWARE

3.1. SOFTWARE REVIEWS

The Microsoft Visual Studio 2013 is used for the development of the software, and coding was written in C# language.

3.2. MICROSOFT VISUAL STUDIO

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop computer programs for Microsoft Windows, as well as web sites, web applications and web services. Visual Studio uses Microsoft software development platforms such as Windows API, Windows Forms, Windows Presentation Foundation, Store and Microsoft Silver light. It can produce both native code and managed code

3.3. C SHARP (PROGRAMMING LANGUAGE)[7]

C# (pronounced as C sharp) is a multi-paradigm programming language encompassing strong typing, imperative,declarative, functional, generic, object-oriented (class-based),andcomponent-oriented programming disciplines. It was developed by Microsoft within its .NET initiative and later approved as a standard by Ecma (ECMA-334) and ISO (ISO/IEC 23270:2006). C# is one of the programming languages designed for the Common Language Infrastructure.

3.4. SOFWARE APPROACH

- The program consists of a single screen where all data should be entered and the result appears in the same page too when the button “calculate” is clicked.
- The program consists of ten text boxes which are to be entered by an integer or float value and a drop down list for selection of pillar strength model or formula.
- After entering all the data, click on “calculate” button to know the FOS.
- Figure 2 represents the flowchart of the program.

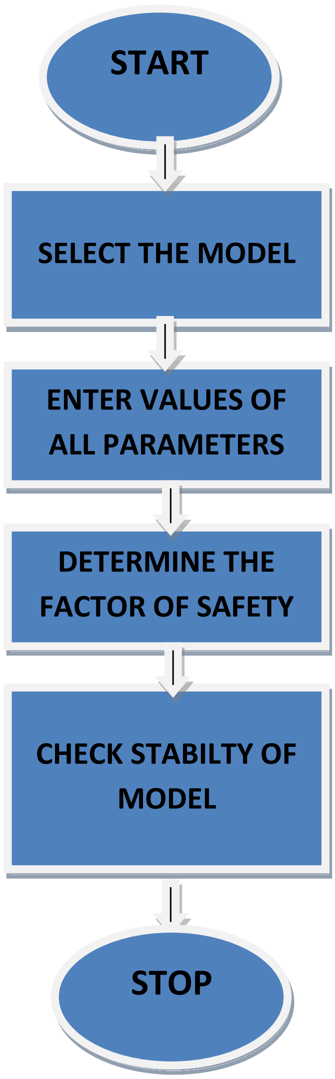

Fig.2. Flowchart of the program

3.5. INTERFACE OF THE SOFTWARE

Software was designed to calculate the factor of safety of the pillars in bord and pillar methods under Indian mining conditions and the pictorial view of the developed software using different models to calculate the strength of the pillars has been depicted in Figure 3 and 4.

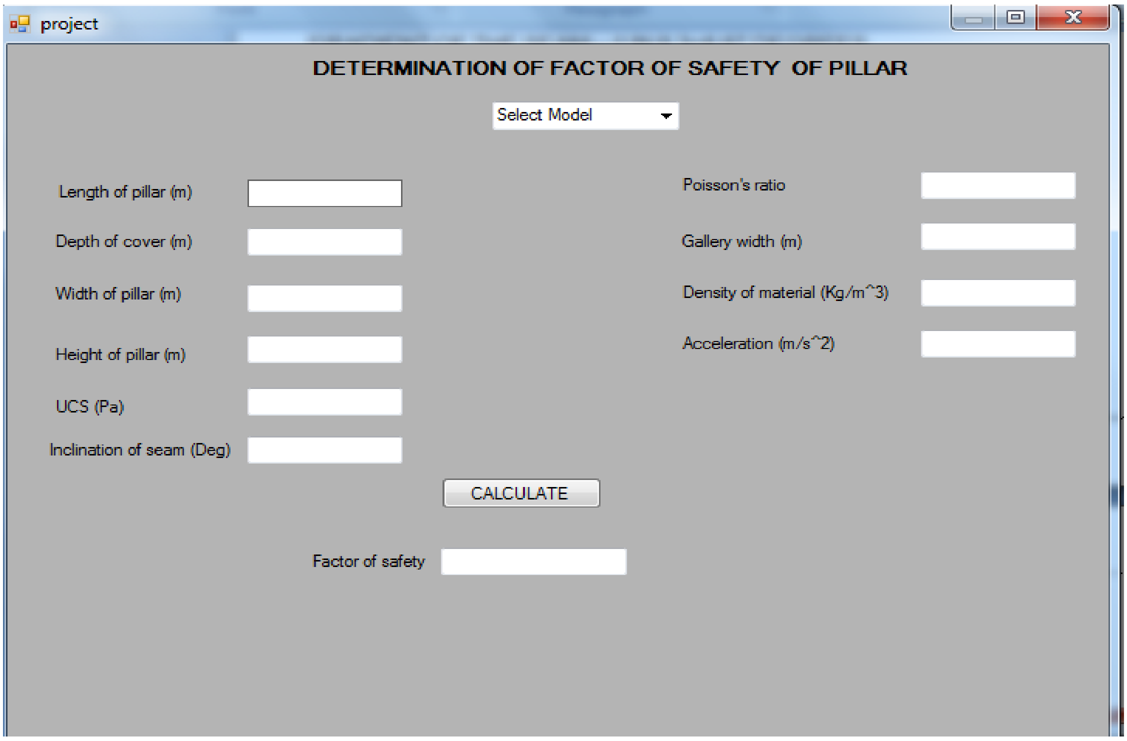

Fig.3. Pictorial view of software interface

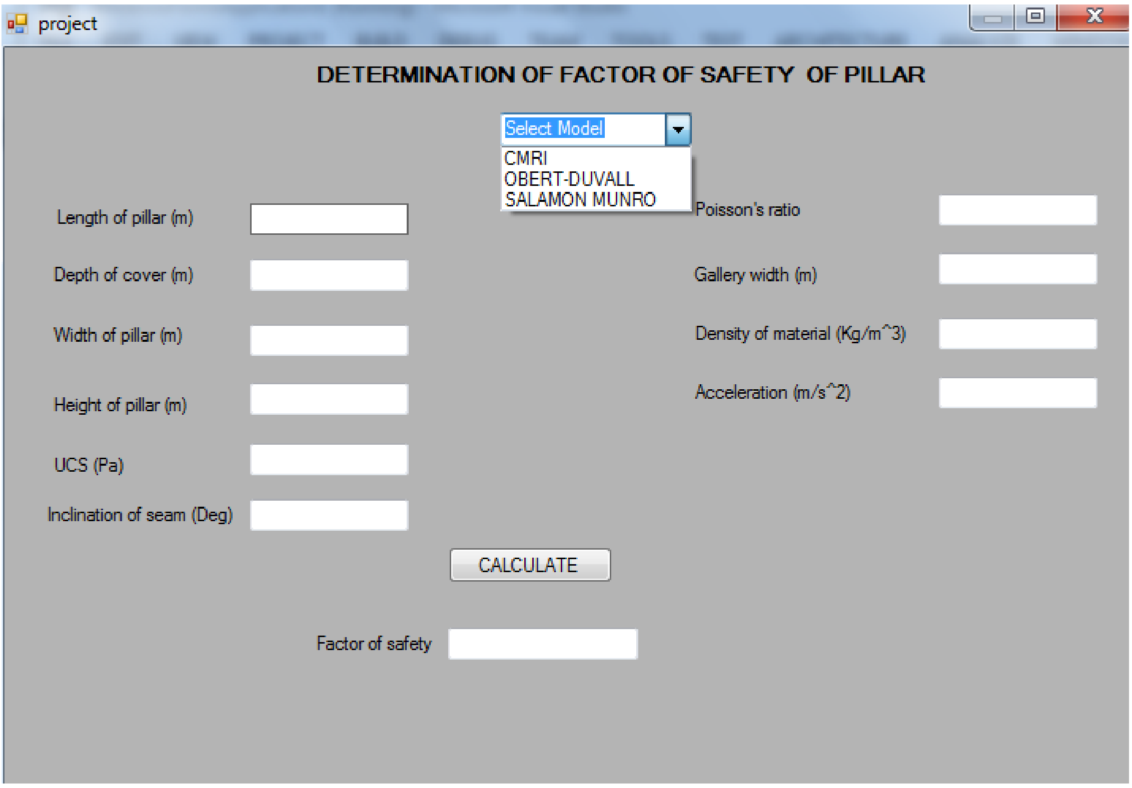

Fig.4. Pictorial view of different models

Chapter-4

CASE STUDIES

CASE STUDIES

The developed software was applied on two different underground coal mines namely GDK-8 incline, SCCL and Hingir Rampur Seam-III, Orient -2 mine, Brajrajnagar, MCL. The summary of parameters of these two mines has been presented in Table 2&3

Table 2: Data collected from GDK-8 incline (SCCL)

Sl. No.	Parameters	Data
1.	Seam (IV) Thickness	3.1m
2.	Gradient of the Seam	1in 8.3=6.87^0
3.	Width of Galleries	4.5m
4.	Height of Pillar	3m
5.	Length of pillar	30.5 m
6.	Depth of cover	270m

Table 3: Data collected from Orient mine-2 (Brajrajnagar, MCL)

Sl. No.	Parameters	Data
1.	Seam (III) Thickness	3.3m
2.	Gradient of the Seam	1in 6=9.46^0
3.	Width of Galleries	4.2m
4.	Height of Pillar	2.5 m
5.	Length of pillar	30 m
6.	Depth of cover	135 m

Chapter-5

RESULTS AND DISCUSSIONS

5.1. RESULTS

All the above data are entered into the software and found that FOS was around 1.10 in GDK-8 incline (SCCL)and 3.01in Hingir Rampur Seam-III, Orient -2 mine, Brajrajnagar, MCL which represents that the working are safe and stable as they have their FOS above 1. Since this software provides the FOS, pillar dimensions that can respond to the stresses induced on them can be decided prior to the commencement of the development phase in a bord and pillar working. The pictorial view of calculation of FOS of both the coal mines have been represented in Figures 5&6.

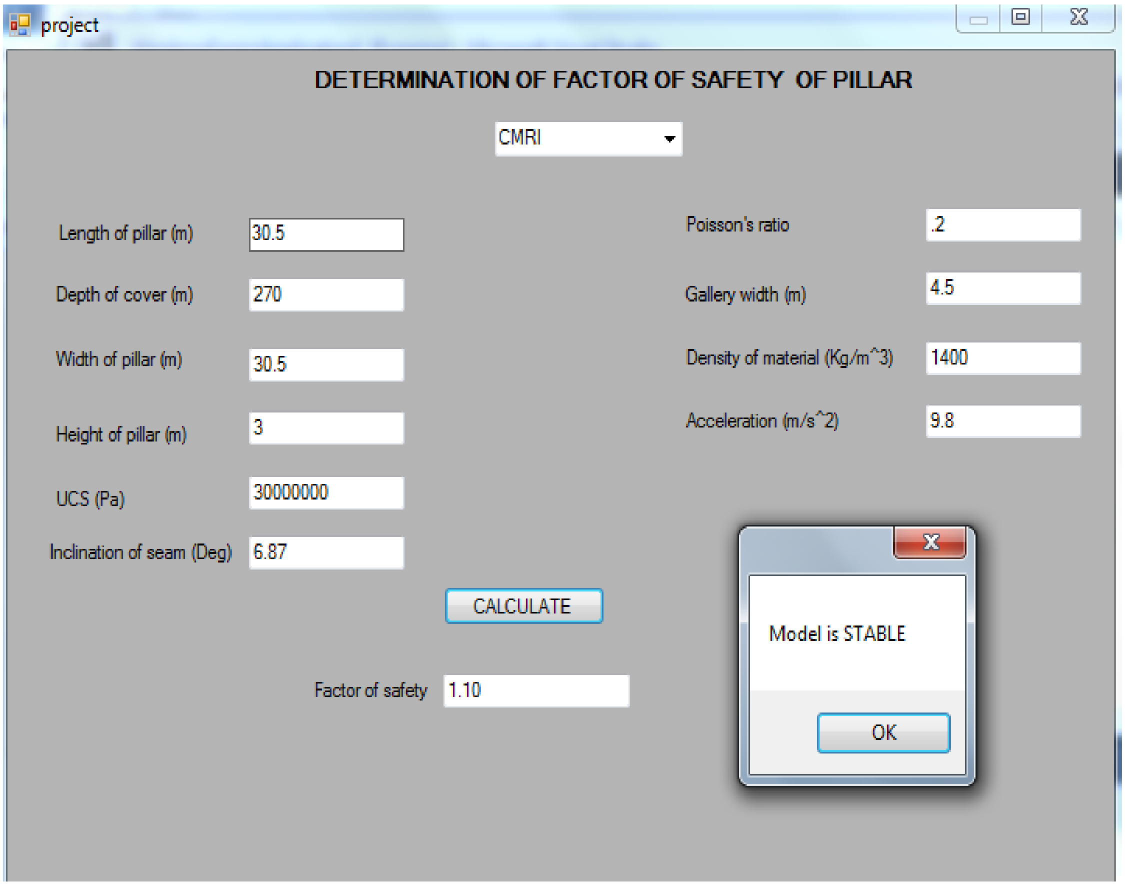

Fig.5. Calculated FOS for GDK-8 incline

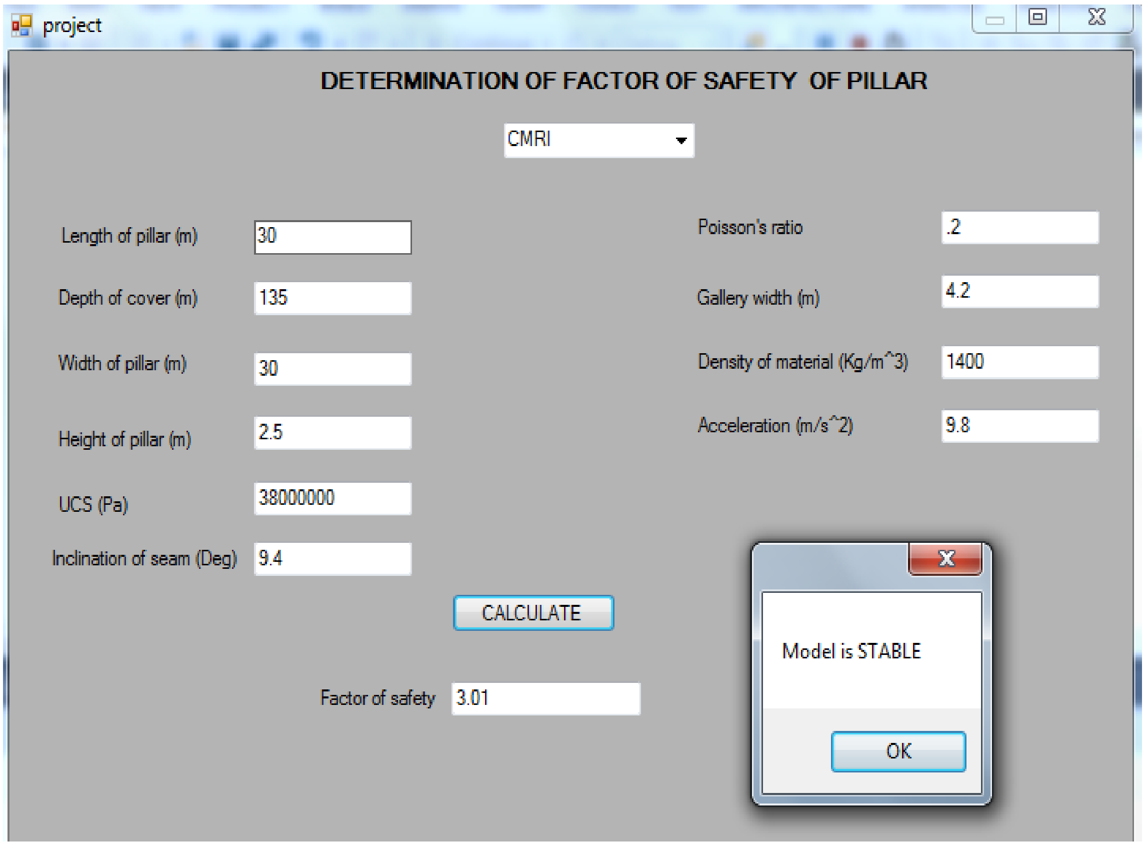

Fig.6. Calculated FOS for Orient -2 mine, Brajrajnagar, MCL

5.2. DISCUSSIONS

The factor of safety (FOS) depends upon the pillars and galleries dimensions and it is crucial to select the correct dimensions of pillars and galleries during pillar design. FOS has been calculated with the varying pillar and gallery dimensions in the tables 4-6 and the trend has been represented in Figures 7-9.

Table 4: FOS wrt. Length of a square pillar (keeping other parameters same)

Length of pillar	10m	14m	16m	24m	27m	28m	30m	34m	35m
Factor of safety	0.686	0.82	0.879	1.024	1.06	1.071	1.09	1.126	1.133

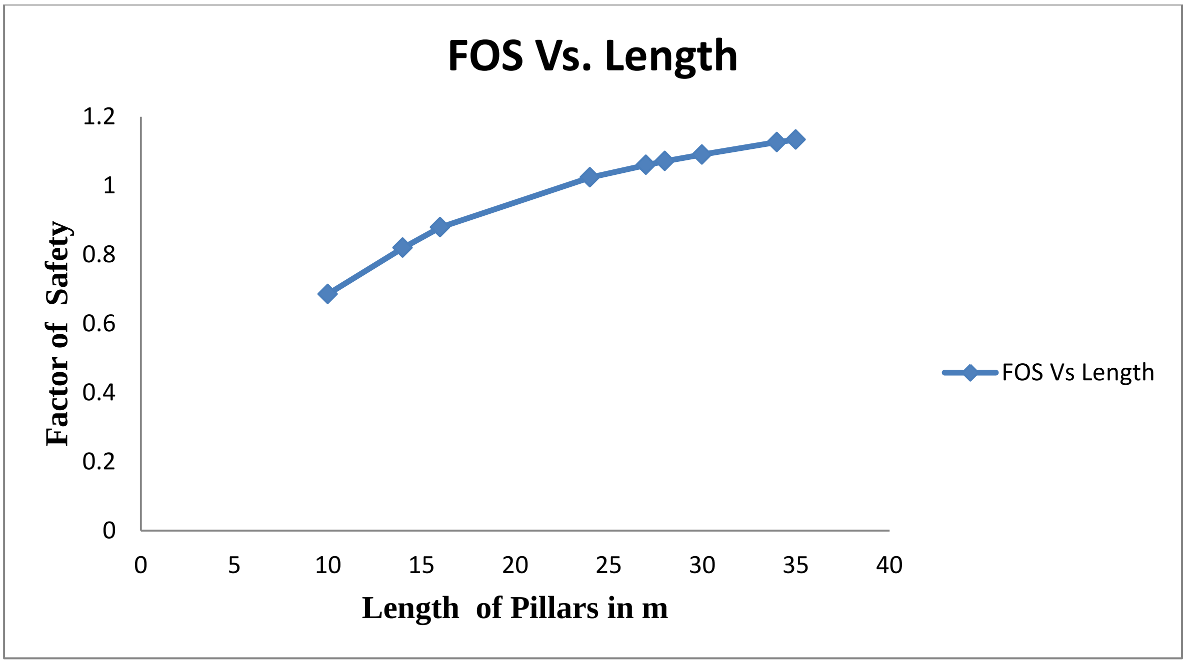

Fig.7. Variation of Factor of safety wrt. Length of a square pillar

The factor of safety (FOS) increases with the increase in the length of the pillar. For the square pillars, the length equals the width of a pillar and hence similar trends like Length vs. FOS getting for the width. Figure 7 shows that the FOS initially tends to increase linearly until a certain point. Further increase in the length of the pillar shows a small variation in FOS.

Table 5: FOS wrt. Width of a gallery (keeping rest parameters same)

Width of gallery	2m	3m	3.5m	4m	4.5m	4.8m
Factor of safety	1.269	1.193	1.158	1.124	1.09	1.07

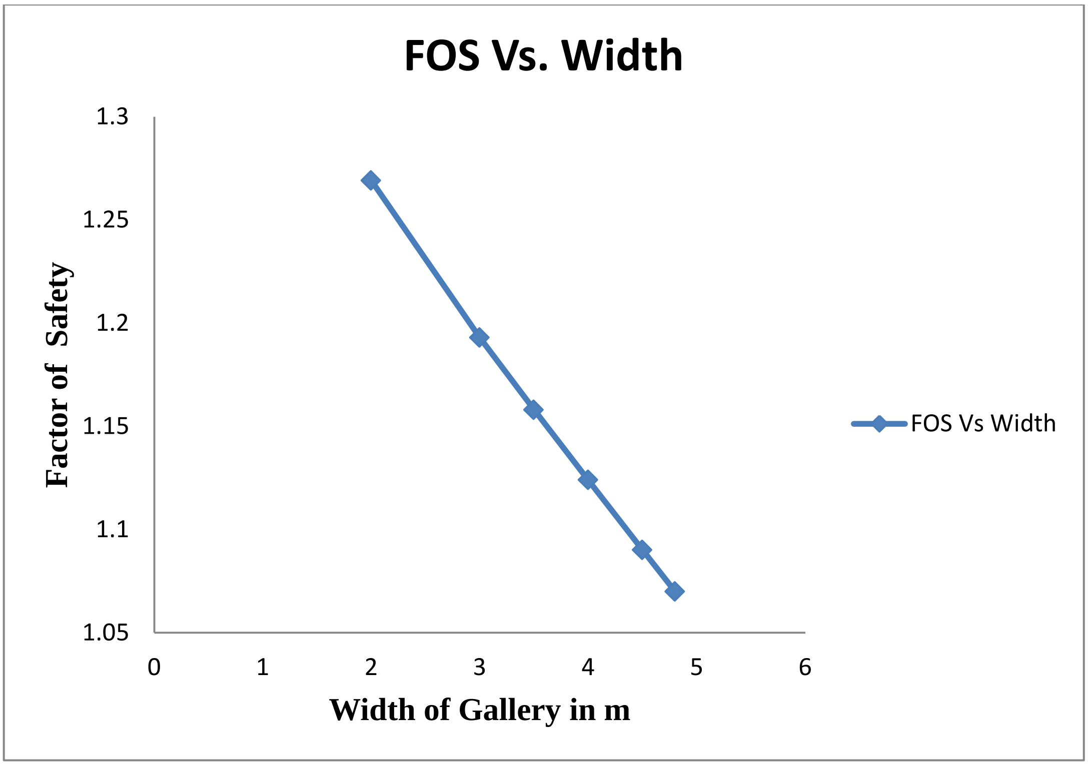

Fig.8. Variation of Factor of safety wrt. Width of a gallery

The FOS decreases linearly with the increase in the width of the galleries. The reasons behind this can be attributed to the load that the sides of a pillar bear when an opening is made and larger the opening, larger would be the load experienced by the pillar and hence the FOS decreases.

Table 6: FOS wrt. Height of a square pillar (keeping rest parameters same)

Length of pillar	1.2m	1.8m	2.1m	2.4m	2.6m	2.8m	2.9m	3m
Factor of safety	1.52	1.31	1.24	1.18	1.12	1.11	1.10	1.09

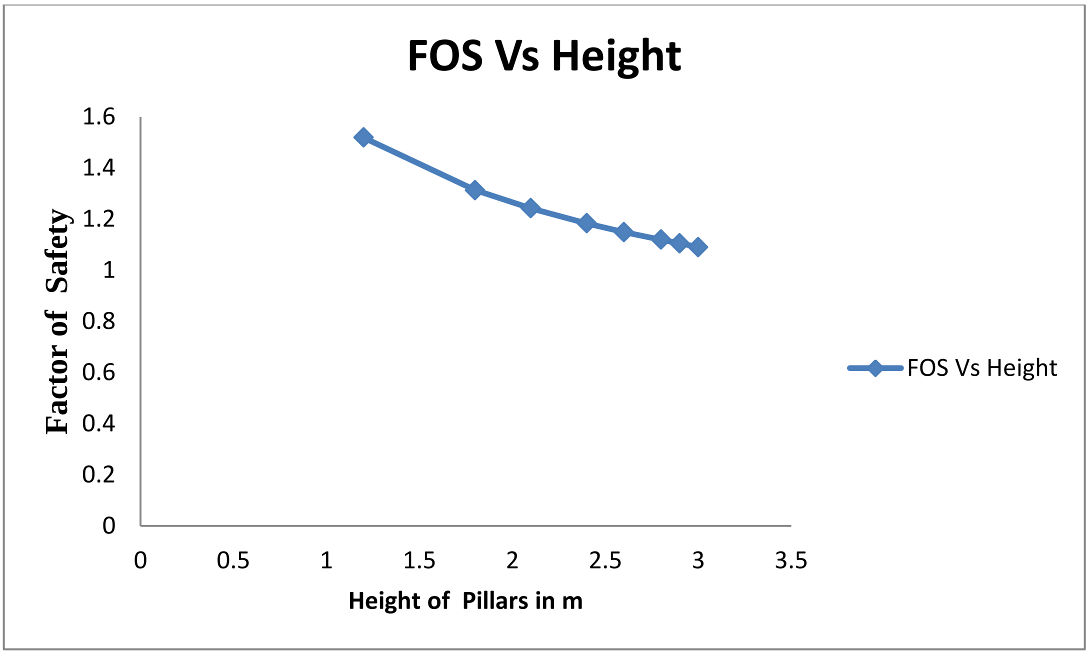

Fig.9. Variation of Factor of safety wrt. Height of a square pillar

The FOS shows a decreasing trend with the increase in the height of the pillars. The trend initially decreases linearly to a certain point. Beyond that point, the slope of the graph decreases FOS in a faster rate.

Chapter-6

CONCLUSIONS

CONCLUSIONS

Pillar failure is one of the most prominent forms of accidents in bord and pillar working in coal mines. The software is used for determination of FOS of a pillar during the pillar designing process for checking the stability of the pillar in coal mines. Different parameters that include the pillar and gallery dimensions can be so chosen that it gives safe FOS during pillar designing process. From the graphs, it was concluded that the FOS increases with increase in length of pillar while it decreases with the increase in the height of pillar and width of gallery excavated during development phase. So we can take preventive measures in advance by choosing appropriate dimensions of pillar and gallery with the proposed software to reduce risk of pillar failure to a certain extent following Regulation 99 of CMR 1957. For the determination of FOS of the pillars of Indian coal mines worked under bord and pillar method, the pillar strength calculated using proposed CMRI formula stands out among all other pillar strength formula due to the consideration of certain parameters like Indian geology and nature of coal.

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