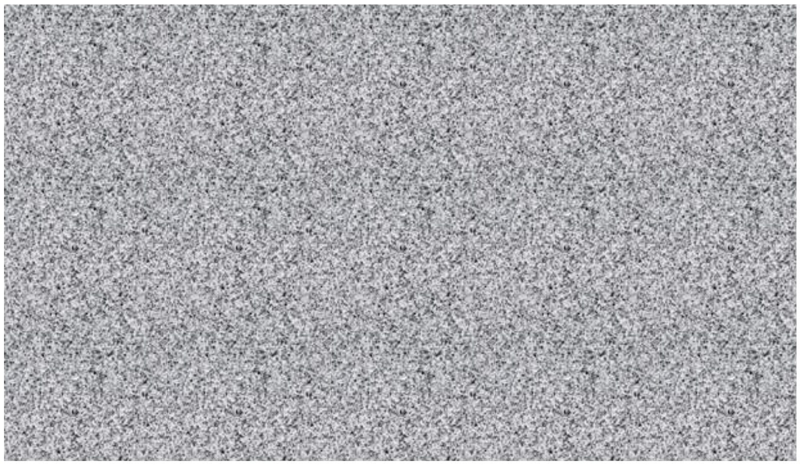
Pillar Design and Panel Stability in Coal Mines



- Coal pillars are to be left in the mine to support the overburden and to maintain the competence of the exposed roof.
- It also serves 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.
- Usually these pillars are in square or rectangle in shape.

Coal Pillars Design Approaches:

- **Ultimate Strength**: The design determines the strength of a pillar on the basis of its geometry, size and the compressive strength of the material.
  - This approach will compare the expected load of the pillar to its ultimate strength to determine its safety factor value.
  - The main assumption of this approach is that, once the ultimate strength is overcome the pillar will have zero strength, which is not strictly true in reality.

- **Progressive Failure**: The design assumes a non-uniform stress distribution within the pillar.
  - The failure of a pillar begin at the point of ultimate strength, and gradually progresses to ultimate failure.
    - Wilson Core Model
    - Diest Strain Softening Model

- Numerical Models can adopt both ultimate strength and progressive failure approaches.

Traditionally, all pillar design formulas employ the ultimate strength theory. Each of these "classic" pillar design formulas consisted of three steps:

- Estimating the pillar load
- Estimating the pillar strength
- Calculating the pillar safety factor.

Classic empirical pillar strength formulas usually follow one of two general forms.

$$\sigma_P = \sigma_{S'}\left(a + b\frac{W}{H}\right)$$

or

$$\sigma_P = K\frac{W^{\alpha}}{H^{\beta}}$$

where σp= pillar strength; σp = strength of insitu coal or rock; W = pillar width; H= mining height; α and β are regression constant and K = a constant depending on the field

Pillar strength formulas by Obert and Duvall (1967) and Bieniawski (1968), Sheorey follow the first form, whereas formulas by Salamon and Munro (1967) and Holland (1964) follow the second.

Load on the Pillars

The load on the pillar may be estimated using any of the following two approaches:

Tributary Area Approach

This relation is used to measure the distribution of load on the uniform sized excavations/pillars/stooks. The normal stress perpendicular to the seam,

$$\sigma_n = \gamma H(\cos^2\alpha + k \sin^2\alpha)$$

And the average stress on the pillar, P or σ p:

$$P = \sigma_p = \sigma_n / (1 - R) = \sigma_n [(B + w) / w]^2$$

Where,
H = depth of cover, m
B = width of the mined out area, m
γ= unit rock pressure = 0.025 MPa/m of depth
R = extraction ratio
w = width of the pillar, m
α = dip of the seam
The value of k, which is the ratio of horizontal to vertical in-situ stress, is taken as 1 in the absence of actual stress measurements.

$$\sigma_n = \gamma H$$

PILLAR LOADING

- **Estimation of loading on the pillar of Bord and Pillar mines based on tributary area loading concept.**

$$\sigma_L = \gamma g H \frac{(C_1 x C_2)}{(w_1 x w_2)}$$

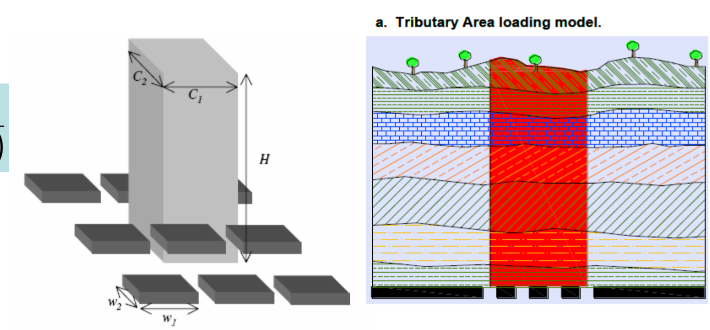
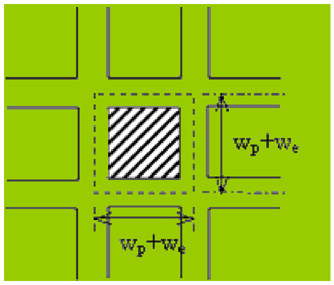


Fig: Tributory Loading Concept

Stresses in pillar by Tributary area Method

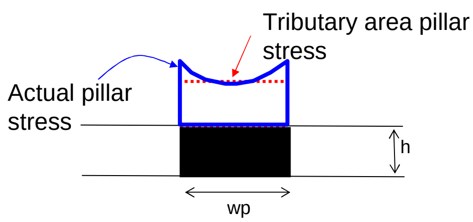


Pillar Stress

$$\sigma_p = \frac{\gamma H (w_p + w_e)^2}{w_p^2} = \frac{\gamma H}{1 - R}$$

where H = depth of cover, γ = unit weight of overburden ; Can be expressed in terms of extraction ratio R = total void/ total area

$$R = 1 - \frac{w_p^2}{(w_p + w_e)^2}$$



Safety factor during development

$$SF = \frac{Strength\ \ of\ \ pillar}{Stress\ \ on\ \ pillar} = \frac{S_p}{\sigma_p}$$

PILLAR LOADING

Tributary area loading concept It has certain following limitations:

- The attention of tributary load is being restricted to the normal pre-mining stress to apply to the vertical principle axis of the pillar support system. It assumes that all other stress components of the mining stress field have no effect on the pillar performance.
- Tributary estimates are valid only if the geometry of pillars is highly regular and it is repeat itself over a relative distance. So, any irregularity (i.e. solid ribs) will be relatively far away from the majority of the pillars, so its overall influence on the entire pillar structure can be neglected.
- Tributary is only applicable for support pillars under static load. For example, it cannot estimate the abutment load on a chin pillar.
- Tributary load is too conservative for longwall mining. It overestimates the pillar loads, because tributary load assumes the load is uniformly distributed over the pillars, which is not the case.

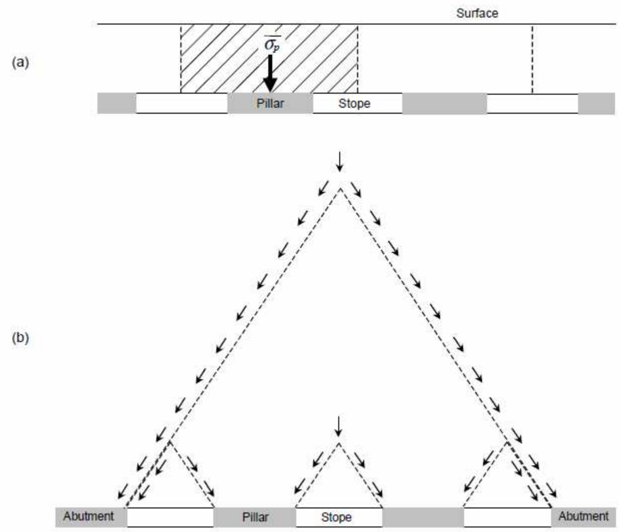


Figure Schematic cross-section illustrating the influence of depth on pillar load. (a) At shallow depths the pillars act in isolation and the tributary area theory approximation of average pillar stress is valid. (b) At great depths systems of pillars and stopes act as a single entity with the abutments carrying a greater proportion of the load. The arrows indicate the trend in the stress distribution.

Load on the Pillars

Wilson's Approach

The pressure (P in MPa) coming over the chain of pillars with goaf on one or both sides is estimated using the following relation:

$$P = \rho\ (W_2+B)\ \{ H^*(w_1+L) - (L^2/1.2) \}\ /\ (W_1{}^*W_2),\ \text{for } L/H < 0.6$$

Where,
ρ = unit rock pressure =0.025 MPa/m,
H = depth of cover, m
W1 = width of the pillar, m
W2 = length of the pillar, m
B = gallery width, m
L = extraction width, m
σ c = compressive strength of 2.5 cm cube coal, taken as 30 MPa
h = extraction height, m

Pillar Strength Equations

Overt-Duvall/Wang Formula

$$S_p = S_1\left(0.778 + 0.222\frac{w_p}{h}\right)$$

limitations: Developed for hard rock specimen but can also be applied to coal seams and found to be suitable for W_p/h ratio upto 8.

Holland-Gaddy Formula

$$S_p = \frac{K\sqrt{w_p}}{h}$$

Holland (1964) extended Gaddy's work (1956) and proposed this formula. K is Gaddy's constant and the units of w_p and h should be expressed in inches. This formula works well for a coal pillar safety factor of 1.8~2.2 with a w_p/h ratio between 2 to 8.

Holland Formula (1973)

$$S_p = S_1\sqrt{\frac{w_p}{h}}$$

Given different formula and recommended safety factor for using this formula is 2.0.

Salamon-Munro Formula (1967)

Based on the 125 case histories in South African coal fields. where Sp is expressed in psi and MPa and pillar dimensions are in ft and m in English and SI units respectively. Recommended safety factor for using this formula is 1.6, the range being 1.31 to 1.88

$$S_p = 1320\frac{w_p^{0.46}}{h^{0.66}}$$ (English units) or $$S_p = 7.2\frac{w_p^{0.46}}{h^{0.66}}$$ (SI units) w/h<5

$$Strength = \frac{19.05}{(w^{0.133}h^{0.066})}\left\{0.237\left[\left(\frac{w}{5h}\right)^{2.5} - 1\right] + 1\right\}$$ w/h>5

Bieniawski's Formula

based on large scale testing of insitu coal samples in South Africa and in USA . Recommended safety factor range 1.5 to 2.0

$$S_p = S_1\left(0.64 + 0.36\frac{w_p}{h}\right)$$

CMRI Formula (sheorey)

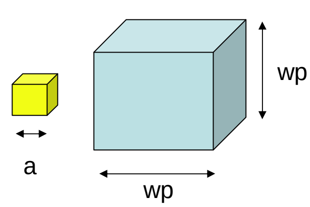
$$S = 0.27\sigma_c h^{-0.36} + \frac{H}{160}\left(\frac{W}{h} - 1\right) \text{ MPa}$$

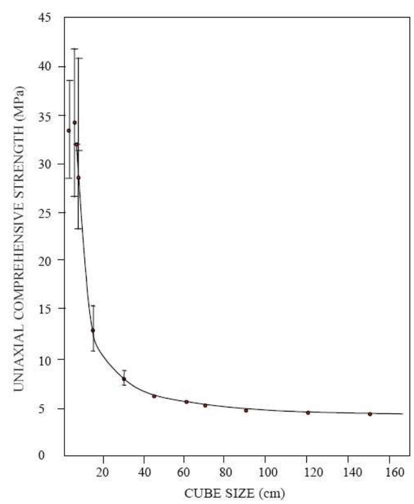
PILLAR STRENGTH

Size effect

- The relationship between the size and the strength of the specimen can be generalized by the equation given below:

$$S_1 = k_1 d^{-a}$$





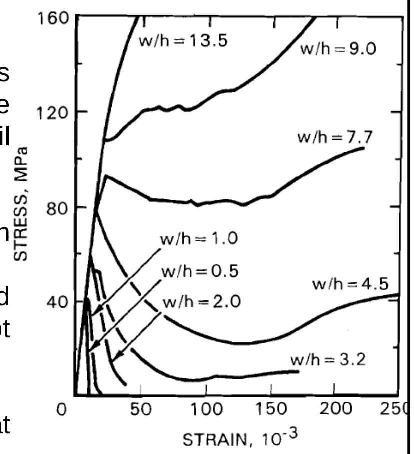
PILLAR STRENGTH

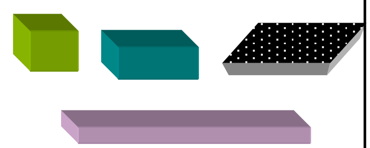
Shape effect (Das, 1986)

Slender pillars, whose w/h ratios are less than about 3 or 4. When these pillars are loaded to their maximum capacity, they fail completely, shedding nearly their entire load.

Intermediate pillars are those whose w/h ratios fall between about 4 and 8.
These pillars do not shed their entire load when they fail, but neither can they accept any more load.

Squat pillars are those with w/h ratios that exceed 10.
These pillars can carry very large loads, and may even be strain-hardening (meaning that they may never actually shed load, but just may become more deformable once they "fail.").

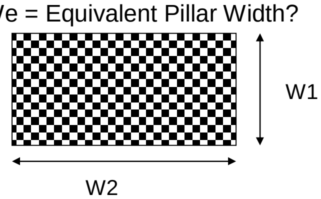


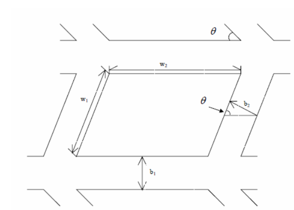


Strength of Rectangular Pillar

- **All strength formula were derived for square shaped pillar**
- **So, what is the strength for a rectangular or rhombus shape pillar which is being developed in longwall or Bord & Pillar mine?**

We = Equivalent Pillar Width?





$$w_e = \sqrt{w_1 w_2}$$

$$w_e = 4\frac{A_p}{C_p}$$

A= Area, C= Perimeter

$$w_{e\circ} = \Theta_\circ w \qquad \Theta_\circ = \frac{2w_2}{w_1 + w_2}$$

$$w = w_1 \sin\theta$$

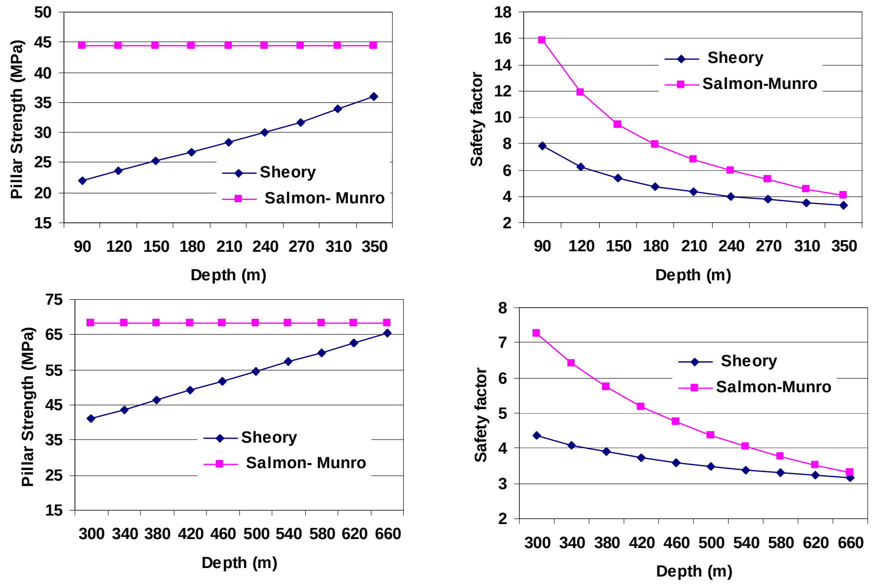
For rhombus shape pillars having sides W1<W2 and internal angle <90⁰

- **New Mark-Bieniawski's rectangular pillar strength formula**

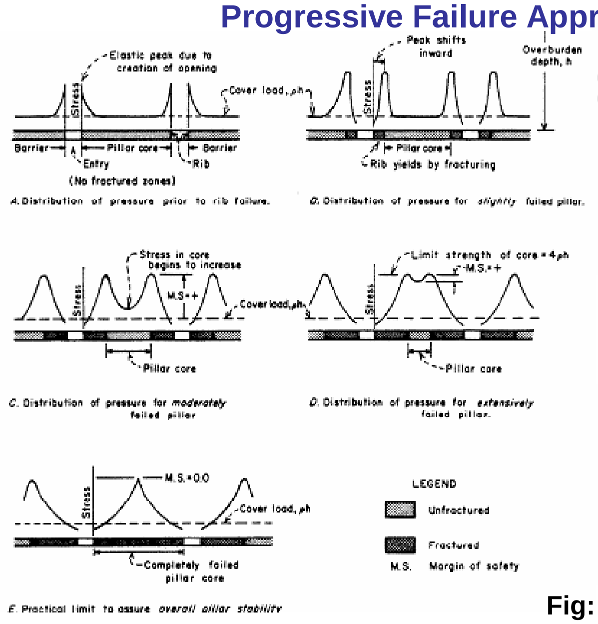
$$S_p = S_1\left(0.64 + 0.54\frac{w_p}{h} - 0.18\frac{w_p^2}{l_p h}\right)$$

where $l_p > w_p$

Comparison of Salmon and Sheorey Pillar Strength Formulae



Progressive Failure Approach



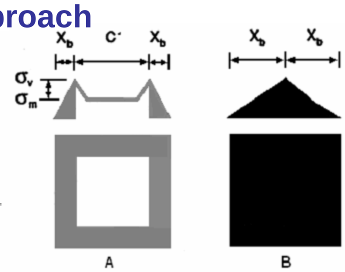


Fig. Yield zone confined core zone. - Wilson Core Model

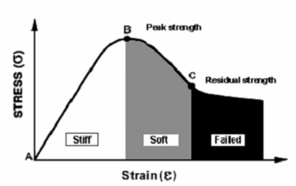


Fig: Idealized Pillar behaviour

Fig. Change in stress profile through pillar cross section as load increases.

Strain Softening Approach

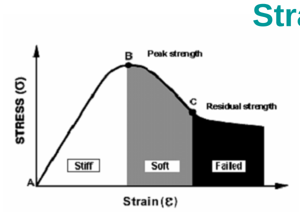
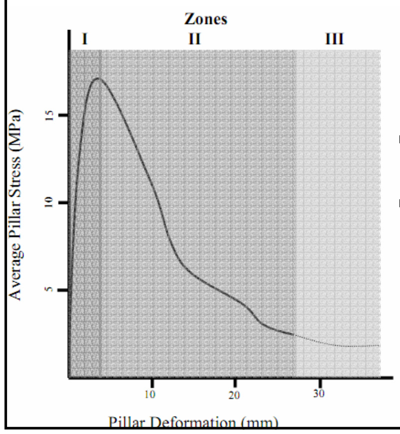
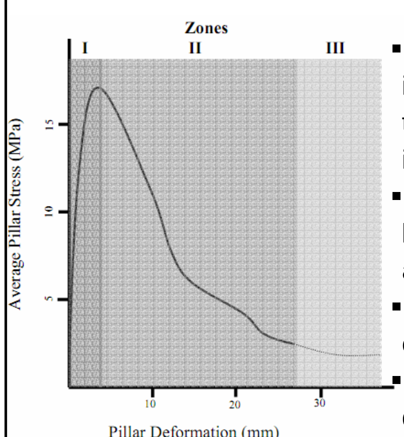


Fig: Idealized Pillar behaviour

- As a result of mining in the vicinity of the pillar, the pillar load, vertical stress gradually increases from the initial virgin value to maximum load bearing capacity or pillar strength.
- In this stage of loading, both the pillar load and the mean pillar deformation (or average vertical convergence) is increasing simultaneously, that is, the pillar's load deformation curve is in its ascending branch.
- This ascending portion of the pressure deformation curve is defined as **Zone I**.
- The pillar load is at its maximum when its value reaches the pillar strength.



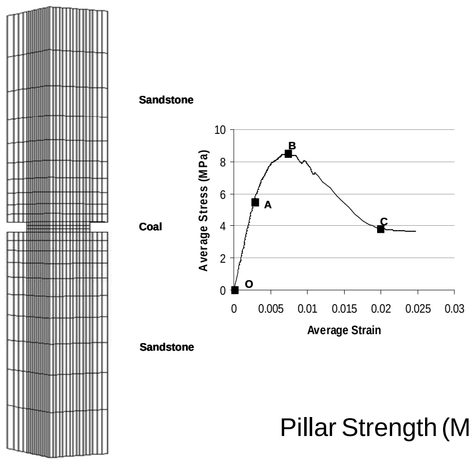
Fig; Load Deformation Curve of a Coal pillar

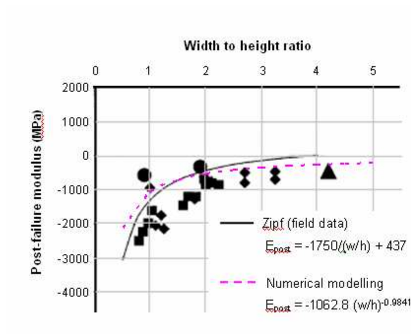


Fig; Load Deformation Curve of a Coal pillar

- If the pillar were to deform beyond this point, its load bearing capacity will diminish, that is, the load-deformation curve of the pillar moves into its descending branch or **Zone II**.
- If a pillar is in the descending branch of its load-deformation curve, then it is regarded as a yield or yielding pillar.
- Zones II and III are the strain softening portion of the load deformation curve of a yield pillar.
- Zone II is the area where strain energy can be dissipated rapidly and sometimes violently as in the case of a bump.
- Other than numerical modeling, virtually no in-mine observation exists as to the shape of Zone III.
- Zones II ands III are where load shedding occurs.

CURRENT APPROACH FOR PILLAR DESIGN BASED ON NUMERICAL MODELLING

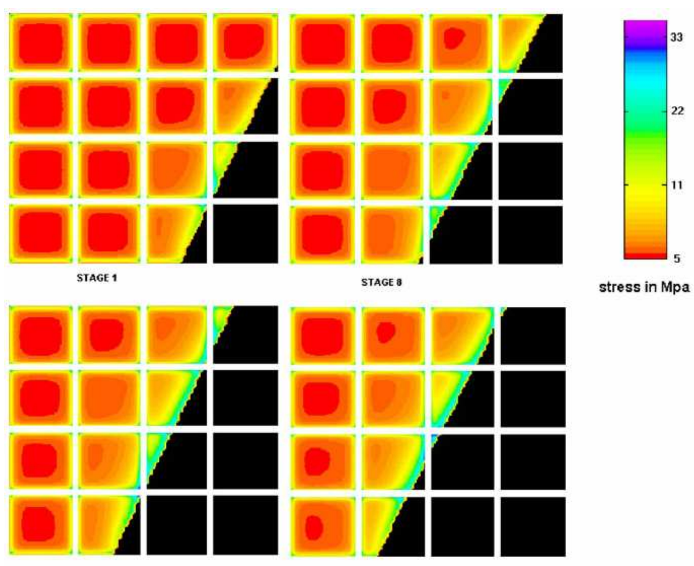




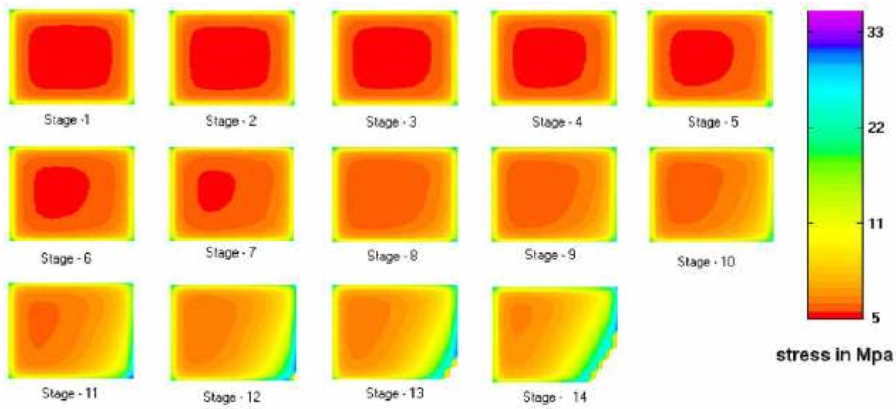
$$\text{Pillar Strength (MPa)} = \sigma_c^{0.66}[0.1514\,(w/h) + 0.2664]$$

$$E_{post}\ (\text{MPa}) = 1062.8\,(w/h)^{-0.9841}$$

Induced Stress Pattern on Pillars with Advancement of Goaf Line[2]

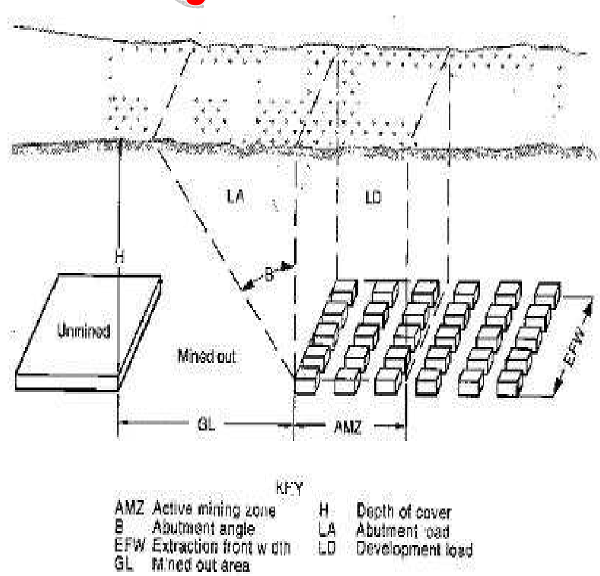


Induced Stress Pattern on the Specific Pillar in all Stages



Active Mining Zone

- This is new pillar design technique based on the concept of information of safety factor of the mining zone.
- AMZ includes all of the pillars on the extraction front (or "pillar line"), and extends outby the pillar line a distance of 2.76 times the square root of the depth of cover expressed in m.



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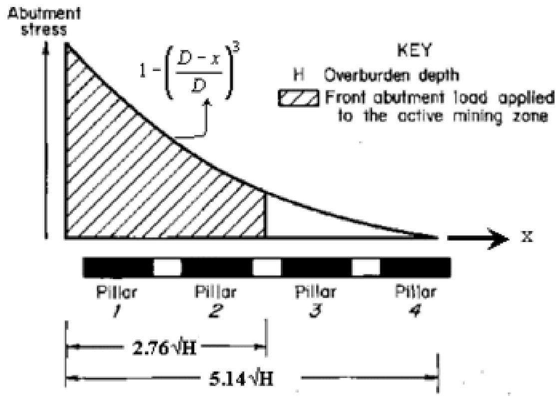
Distribution of Front Abutment Load

When a gob area is created by full extraction mining (depillaring), abutment loads are transferred to the adjacent pillars or solid coal;

The abutment stresses are greatest near the gob, and decay as the distance from the gob increases;



From experience and from numerical analysis it is found that the front abutment load reaches to zero at about a distance give by the following equation

$$D = 5.14\sqrt{H}$$

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Safety Factor of AMZ

$$SF = \frac{LBC}{TL}$$

$$LBC = nS_p A_p$$

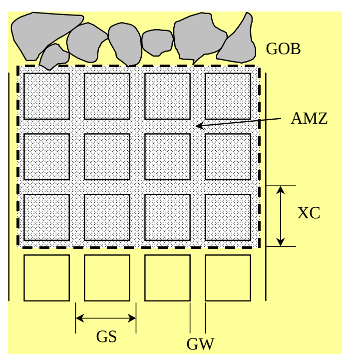
$$A_p = (XC - GW)\times(GS - GW)$$

Where,

LBC = load bearing capacity of AMZ and TL is the total load applied to AMZ.

The load bearing capacity of AMZ is determined using Mark-Bieniawski's equation for a rectangular pillar with dimension wp x lp x h m3

$$S_p = S_1\left(0.64 + 0.54\frac{w_p}{h} - 0.18\frac{w_p^2}{Lh}\right)$$



Panel layout with AMZ and other mining parameters

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Pillar Loading

There are mainly 4 cases of loading

- Development load;
- Development and front abutment load;
- Development, front abutment and one side load abutment load; and
- Development, front abutment and two side abutment load.

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Development Load Only

Development load is due to the weight of the overburden

$$L_d = H \times \gamma \times A_{AMZ}$$

$$A_{AMZ} = B_{AMZ} \times W_T = 2.76\sqrt{H} \times n \times GS$$

safety factor

$$SF = \frac{LBC}{L_d}$$

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Calculation for Front Abutment Load

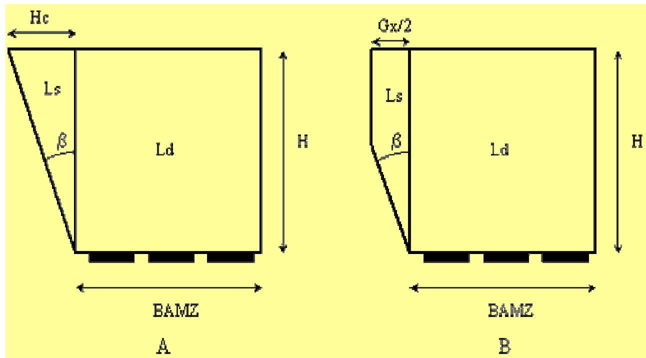
R-factor or the percentage of front abutment load applied to the AMZ can be estimated

$$R = 1 - \left(\frac{D - B_{AMZ}}{D} \right)^3$$

Where, $D = 5.14\sqrt{H}$

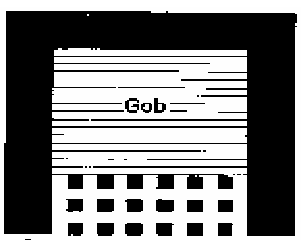
For, $B_{AMZ} = 2.76\sqrt{H}$

the R factor will be 0.90. That means about 90% of the front abutment load will be applied to the AMZ



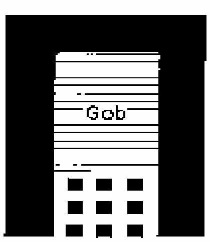
Two panel size conditions depends upon the supercritical and subcritical conditions

Supercritical and subcritical conditions of mine panels



Case 1: H tan B < GEXT/2 and H tan B < WT/2

Case 2: GEXT/2 < H tan B and GEXT/2 < WT/2



Case 3: WT/2 < H tan B and WT/2 < GEXT/2

KEY
H Overburden depth
B Abutment angle
WT Width of active mining zone
GEXT Gob extent

Calculation for Front Abutment Load <Cont.>

Super critical conditions

$$L_s = \frac{\gamma H^2 H_c}{2}$$

$$L_f = \left\{ \left[(W_T - 2 \times H_c) \times L_s \right] + \left[\frac{2}{3} \times H \times H_c^2 \times \gamma \right] \right\} \times R$$

Sub critical conditions

$$L_s = \left[\frac{H \times G_x}{2} - \frac{G_x^2}{8} \cot\beta \right] \times \gamma$$

$$L_f = \left\{ L_s \times (W_T - G_x) + \gamma \times \left(H - \frac{G_x}{2} \cot\beta \right) \times \left(\frac{G_x}{2} \right)^2 + \gamma \times \frac{2}{3} \cot\beta \times \left(\frac{G_x}{2} \right)^2 \right\} \times R$$

Critical conditions

$$L_f = \left\{ \left[(H - 0.5 \times W_T \times \cot\beta) \times 0.25 \times W_T^2 \right] + \left[\frac{2}{3} \times \left(\frac{W_T}{2} \right)^3 \cot\beta \right] \right\} \times R \times \gamma$$

Total load TL = Ld + Lf

Calculation for Side Abutment Load

Side abutment load is derived from the mined out gobs of nearby panel. Since there is a barrier pillar, most of the side abutment load will be carried by it.

$$R_{BAR} = 1 - \left(\frac{D - (W_{BAR} + GW/2)}{D} \right)^3$$

Side abutment load applied to the AMZ is estimated for both supercritical and subcritical case given as

$$L_{sd} = B_{AMZ} \times L_s \times (1 - R_{BAR})$$

Ls has to be taken according to the supercritical and subcritical conditions resp.

$TL = L_d + L_f + L_{sd}$ **and** $TL = L_d + L_f + 2L_{sd}$

DGMS Guideline for Pillar Dimension

According to DGMS Coal Mine Regulation 1957 No. 99, the pillar dimension is given based on depth of the cover only as shown in the following Table. This guideline ignores the insitu strength of the coal and thus probably over/under estimate the pillar dimension.

Depth of seam from surface	The distance between centers of adjacent pillars shall not be less than			
	Where the width of the galleries does not exceed 3.0 meters	Where the width of the galleries does not exceed 3.6 meters	Where the width of the galleries does not exceed 4.2 meters	Where the width of the galleries does not exceed 4.8 meters
(1)	(2)	(3)	(4)	(5)
	Meters	Meters	Meters	Meters
Not exceeding 60 meters	12.0	15.0	18.0	19.5
Exceeding 60 but not exceeding 90 meters	13.5	16.5	19.5	21.0
Exceeding 90 but not exceeding 150 meters	16.5	19.5	22.5	25.5
Exceeding 150 but not exceeding 240 meters	22.5	25.5	30.5	34.5
Exceeding 240 but not exceeding 360 meters	28.5	34.5	39.5	45.0
Exceeding 360 meters	39.0	42.0	45.0	48.0

Yield Pillar Approach

- Yield pillars are defined as a pillar that yields or fails upon isolation from the coal seam or yields during the longwall development cycle but retains residual strength.
- The yield pillar allows a general lowering of the roof and subsequent transfer of overburden load through the roof and floor after the peak strength is reached onto the neighboring pillar or abutments or unmined area.
- This mechanism often referred as pressure arch concept. This is possible as long as the width of the yield pillar mining (panel width) is less than critical width above which stresses can not be carried out by overburden.
- Yield pillars are employed in situations where stress concentrations are expected to be sufficiently high to cause unacceptable ground conditions.
  - High depth of cover,
  - High insitu stresses,
  - Presence of the fulcrum of cantilevering or bridging rock beds in the intermediate and upper roof or floor.

Yield Pillar Approach

- ❑Overburden stress transfer was visualized to occur through pressure arching onto side abutments.
- ❑It was deduced that the yield pillars support only the overburden weight below the arch, the higher its height and the higher the abutment loading.
- ❑ Arching occurs as long as the mining width does not exceed a critical dimension – the critical pillar arch width.
- ❑If this is exceeded, the pressure arch breaks and the yield pillars are subjected to full overburden loading, potentially leading to total pillar collapse and extensive surface subsidence.

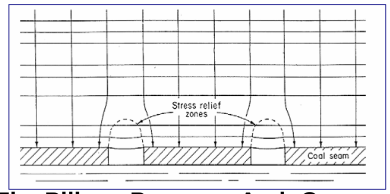


Fig. Pillar – Pressure Arch Concept

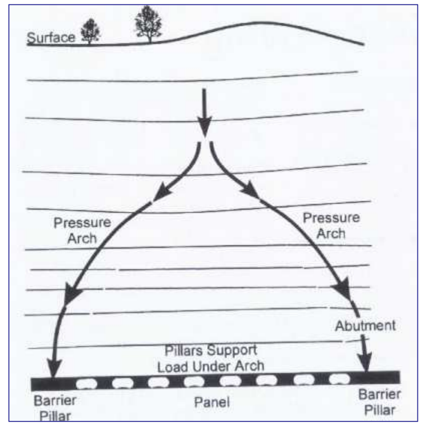


Fig. Yield Pillars – Pressure Arch Concept

Yield Pillar Approach

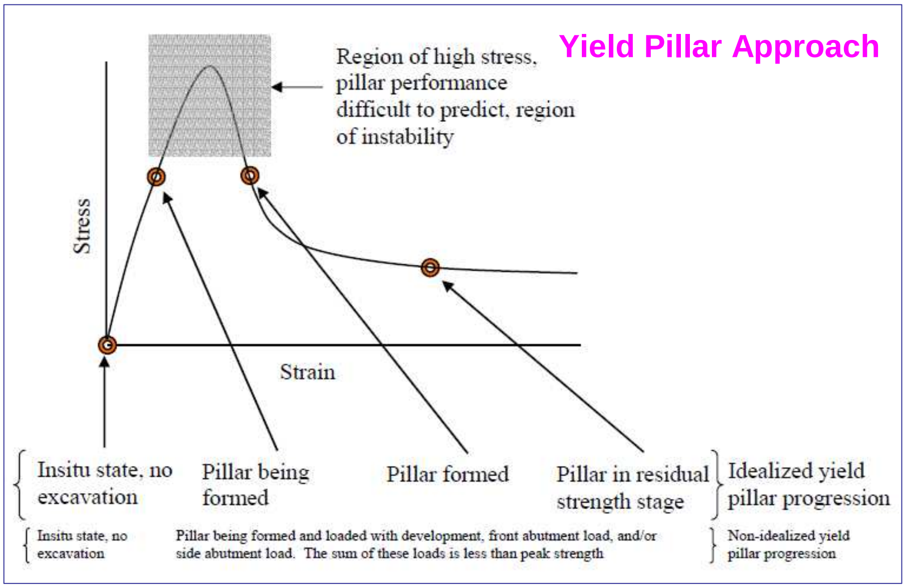


Fig: Idealized Yield Pillar versus non-idealized Pillar

Yield Pillar Approach

Benefits of Yield Pillar

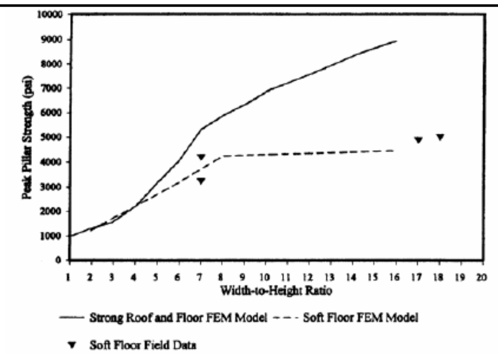
- Deep, bump prone lithology coal reserves can be mined safely only with yield pillars.
- Yield pillars increase the extraction ratio in a mine.
- Reserves formerly defined as unminable, become minable.

Yield Pillar Approach

Load shedding can take place if the following requirements are satisfied:

- There is nearby load-bearing area of unmined coal, standing or intrinsic supports, longwall shields to sustain the transferred loads.
- The roof and floor are sufficiently competent to facilitate the load transfer without a debilitating roof fall (termed room collapse in our case) or floor heave.
- The stiffness of the surrounding rock mass is sufficiently high to ensure that the equilibrium of the immediate and main roofs remain stable during and after the “load shedding and transfer” process.
- If one or more of these criteria is not satisfied, the pillar will collapse suddenly in an uncontrollable manner and the entire recovery room can be lost for the equipment removal.

Effect of Roof & Floor on Pillar Strength



- Su and Hasenfus (1999) employed finite element models (FEM) to explore the effect of various geologic conditions on pillar strength.
- They found that a rock parting may increase the pillar strength, while a clay parting could reduce it. A weak floor could reduce the pillar strength by as much as 50%.
- All of these effects were minimal for slender pillars, but became much more pronounced once the w/h exceeded 5.

The models also indicated that varying the uniaxial coal strength had almost no effect on pillar strength.

Gale(1996,1998) observed that pillar strengths seemed to fall into two groups, using FLAC:

- **Strong roof and floor rock** where confinement was easily generated within the pillar, and;
- **Weak rock or bedding planes,** which could fail either in compression or shear, and which limited the confinement that could be developed within the pillar, and thus limited the strength of the pillar system.

Modes of Pillar Failure (Mark):

- **Sudden, massive collapse**, accompanied by airblast, for slender pillars (width/height<4)
- **Squeezing**, or slow, non-violent failure, for most room and pillar applications (4<w/h<10)
- **Entry failure or bumps** for deep cover and longwall applications (w/h>10)

Massive Collapses
Massive collapses are pillar failures that take place rapidly and involve large areas. One effect can be a powerful, destructive airblast.

When large numbers of slender pillars are used over a large area, the failure of a single pillar can set off a chain reaction, resulting in a sudden, massive collapse accompanied by a powerful airblast.

Pillar Squeezes
Squeezes occur when the pillars are too small to carry the loads applied to them. As the loads are gradually transferred, the adjacent pillars in turn fail. The results can include closure of the entries, severe rib spalling, floor heave, and roof failure. The process may take hours or days, and can cause an entire panel to be abandoned.

Pillar Bumps
Bumps occur when highly stressed coal pillars suddenly rupture without warning, sending coal and rock flying with explosive force.

Cascading Pillar Failure (CPF)

- CPF is a potential problem faced by all Bord-and-pillar mining operations.
- CPF occurs when one pillar fails suddenly, which then overstresses the neighboring pillars, causing them to fail in very rapid succession.
- Within seconds, very large mining areas can collapse while giving little or no warning.
- The collapse itself poses **danger to miners**.
- In addition, the collapse can induce a **violent airblast or wind blast** that disrupts or **destroys the ventilation system**.
- Additional hazards to miners exist if the **mine atmosphere becomes explosive** as a result of a collapse.

EVALUATION OF PANEL STABILITY

Underground panel comprising coal pillars and overburden therefore, stability of a panel is dependent on the following parameters.

- **Strength of the coal pillar**
- **Interaction between coal pillar and superincumbent strata**

EVALUATION OF PANEL STABILITY

If a pillar fails in a panel either of two conditions occurs according to nature of failure.

- ***Violent (catastrophic) failure:***

  Pillar loses its strength completely and does not provide reaction (support) to the overburden. Thus, span of the unsupported roof increases and probably it may leads to overburden failure. This condition violate the requirements of panel stability (pillar and overburden must be stable).

- ***Non-violent (stable) failure:***

  Pillar does not fail completely and having some residual strength to provide the reaction to the overburden against the failure of overburden. In this situation, excess stress (pre-failure stress – residual strength) redistributes to the surrounding pillars and decrease pillar factor of safety. The amount of excess stress is dependent on the nature of overburden as well post-failure nature of coal pillar.

EVALUATION OF PANEL STABILITY

Nature of pillar failure can be understand by Salamon's Stability criterion (1970)

- **Stable, nonviolent failure** occurs when

  $|K_{LMS}| > |K_P|$ and

  unstable, violent failure occurs when

  $|K_{LMS}| < |K_P|$

  where $|K_{LMS}|$ is local mine stiffness and $|K_P|$ is post- failure stiffness at any point along the load-convergence curve of the pillar.

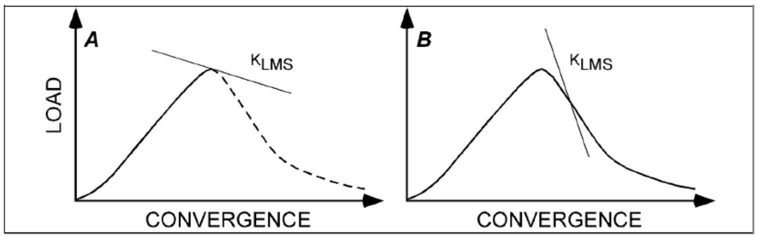


Fig.—Unstable violent failure versus stable nonviolent failure. *A*, Unstable failure in a soft loading system. Loading machine stiffness is less than post-failure stiffness.
***B*, Stable failure in a stiff loading system. Loading machine stiffness is greater than post failure stiffness. (Swanson and Boler, 1995)**

METHODOLOGY FOR ASSESSING PANEL STABILITY

Factor of stability is defined as ratio of Local mine stiffness **(KLMS)** to post failure pillar stiffness **(K_P).**

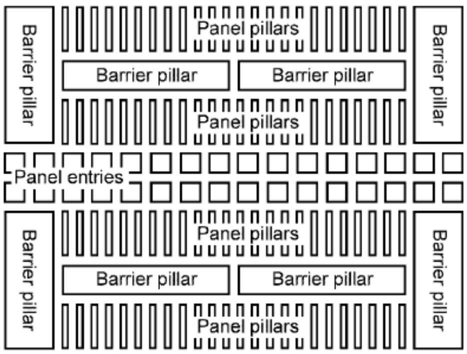
Factor of stability leads to three different approaches to control large collapses in room and pillar mines;

- Containment,
- Prevention, and
- Full Extraction

Containment Approach:

- In the containment approach, an array of **panel pillars** that **violate the local mine stiffness stability criterion** and can therefore fail in an unstable, violent manner if their strength criterion is exceeded are surrounded or "contained" by barrier pillars.
- The panel pillars have a factor of safety greater than 1, but the factor of stability is less than 1.
- The primary function of barrier pillars is to limit potential failure to just one panel.

- Barrier pillars have a high width-to-height ratio, typically greater than about 10, and contain panel pillars with a low width-to-height ratio, typically in the 0.5 to 2 range.
- It is a noncaving room-and pillar method in that panel pillars are not meant to fail during retreat mining.



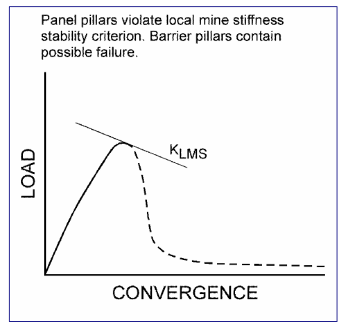
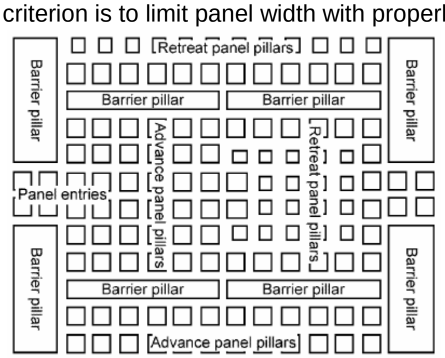


Fig: Containment Approach Layout

Prevention

- In contrast to the containment approach, the prevention approach "prevents" CPF (Cascading Pillar Failure) from ever occurring by using panel pillars that satisfy both the local mine stiffness stability criterion and a strength criterion.
- The factor of safety and the factor of stability for the panel pillars are both greater than 1. Therefore, panel pillars cannot fail violently, and CPF is a physical impossibility.
- To satisfy the local mine stiffness stability criterion, the panel pillars will usually have high width-height ratios (greater than about 3 or 4) and high strength safety factors as well (greater than 2).
- Another approach to increase local mine stiffness and satisfy the stability criterion is to limit panel width with properly spaced and sized barrier pillars.



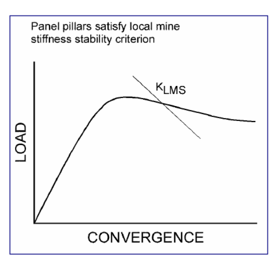
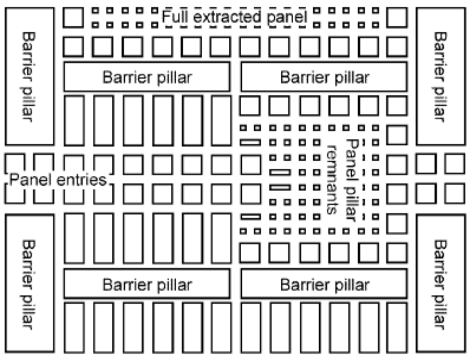


Fig: Prevention Approach Layout

Full-Extraction Mining

- The full-extraction approach avoids the possibility of CPF altogether by ensuring total closure of the opening and full surface subsidence on completion of retreat mining.
- This approach does not require barrier pillars for overall panel stability; however, they are needed to isolate extraction areas and protect mains and bleeders.
- The factor of safety for the panel pillar remnants is much less than 1 to force them to fail immediately after retreat mining.



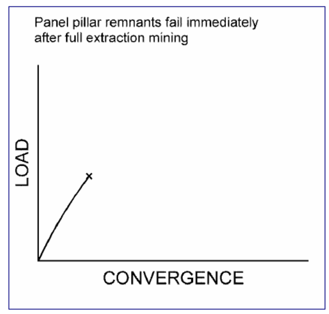


Fig: Full Extraction Layout

- Traditional strength-based design methods using a factor of safety are not sufficient to eliminate the possibility of CPF in room-and-pillar mines.
- Pillars that exhibit strain-softening behavior can undergo a rapid decrease in load-bearing capacity upon reaching their ultimate strength.
- The strain-softening behavior of pillars depends on both inherent material properties and geometry.
- Pillars with a low width-height ratio exhibit a greater degree of strain-softening behavior than pillars with a higher width-height ratio and typically elastic-plastic or strain-hardening material behaviors.
- Containment and full extraction options are the safest approaches to apply until good data on the post-failure behavior of pillars become available.
- Then, the prevention approach based on an evaluation of the factor of stability with the local mine stiffness stability criterion may enable safe room-and-pillar mining with higher extraction.