MANUAL ON PILLAR
EXTRACTION IN NSW
UNDERGROUND COAL MINES

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INTRODUCTION AND PURPOSE OF MANUAL

During the period May 1990 to June 1991 seven mineworkers were fatally injured during pillar extraction operations within N.S.W. These figures represent the worst period for fatalities in pillar extraction for over 10 years.

Investigations and reviews conducted after these accidents highlighted the need for all pillar extraction operations to be carefully managed and controlled. Further there is a need for fundamental principles governing strata movement around goaf edges, together with proven mining practices, to be collated and disseminated throughout the industry.

This manual provides the basis for achieving these objectives.

The manual is formulated on the notion that a plan of management is essential for the design, implementation and control of any pillar extraction method. Such a plan has the elements of:-

Data Collection
Design
Implementation
Control
Review

These elements are displayed within the manual and provide a guide for Colliery Managers and Mining Engineers in developing a management system to safely develop and practice pillar extraction. Designers of pillar extraction systems must address all the issues identified in the management plan process, in a sequential manner, when developing an extraction layout.

Contained within the management plan is the vital element of design. This section forms a library of theory, principles and practice from which a pillar extraction method can be developed to operate under specific physical conditions. In order to provide designers with a clear and consistent precis of the principles involved in pillar extraction, a synopsis of Basic Theory has been developed, and is included in the design element. These principles form the platform from which all pillar extraction operations must be designed.

Safe Management of pillar extraction is an ongoing process as knowledge is updated and expanded, and more experience is gained. Accordingly the Manual has been designed to cater for additions, alterations or deletions from each element.

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CHAPTER 1

GEOTECHNICAL CODE OF PRINCIPLES

1.1 INTRODUCTION

The purpose of this chapter is to provide coal industry management and Inspectorate personnel with a concise summation of geotechnical principles as they relate to planning and operation of pillar extraction panels. It is intended to provide the basis for a geotechnical understanding to be gained, so that pillar extraction operations can be planned and operated safely, taking account of the prevailing geotechnical environment.

It is not the authors' intention that this chapter be regarded as either a standard code of practice, or as a definitive design handbook with extensive design parameters, equations and nomograms. Rather, it is intended that the code of geotechnical principles outlines the importance of various components of the mine geotechnical environment, to safe and efficient pillar extraction planning and operation.

It should also be noted that the level of understanding of rock mechanics principles, and how they apply to mining practice in general, and pillar extraction in particular, is continually expanding and developing. There are certain aspects of pillar extraction rock mechanics which currently are not fully understood. An increased level of the coal industry knowledge base, with respect to pillar extraction experience, will undoubtedly assist in furthering the development of the rock mechanics understanding in relation to pillar extraction.

1.2 BASIC THEORY AND PRINCIPLES

1.2.1 STRESS

Stress is a term equivalent to pressure, in solid materials, i.e. a force per unit area. In the earth's crust every component of the crust, or piece of rock, is in an equilibrium state of compressive stress as a result of the weight of overlying material. Consequently stress generally increases, approximately linearly with depth, as the weight of overlying rock increases. This is analogous to carrying a pile of books. The greater the height of the pile, the heavier they are. In the case of the earth's crust, the books are represented by layers of rock. Stress is a measure of that weight, divided by the area on which it acts.

Vertical stress, σ_v, can therefore be defined as

$$\sigma_v = \rho g H \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where ρ is rock density (typically 2500 kg/m^3 for sandstone)
g is the gravitational constant (9.81 m/s^2)
H is depth in metres
(This equates to approximately 2.5 MPa per 100m depth)

Generally, horizontal stress is equal in all directions, and is a constant ratio, k, of the vertical stress. Refer to Figure 1.1.

Horizontal stress, σ_H, can therefore be defined as,

$$\sigma_H = k\sigma_v \quad \ldots\ldots\ldots\ldots\ldots (2)$$

At mining depths, k can range from 0.3 to 2.0, with σ_H generally equal to, or less than σ_v.

However, in some sections of the earth's crust, such as is evidenced in many areas of the Sydney Basin coalfields, σ_H is often greater than σ_v. This is the result of geological disturbances, locked-in stresses from previous greater depths of burial, tectonic effects etc.

1.2.2 STRAIN

What is strain?

Strain is probably the more important parameter to understand, as it, and its associated parameter, displacement, is the major effect of stress in a mining environment.

Strain is a measure of the displacement of a material, per unit length, caused by an applied stress (or stress change).

$$\varepsilon_1 = \frac{l_1}{L_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where L_1 is the original length,
l_1, is the change in L_1, due to a stress applied in that direction.

When stress is applied in a certain direction, the material deforms and is strained in that direction and the magnitude of that strain is determined by the elasticity of the material, in this case the rock mass.

The relationship between stress (σ), strain (ε) in the same direction is defined by the elastic constant, Young's Modulus, (E), as

$$\sigma = E.\varepsilon \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where σ and ε are both in the same direction. Refer to Figure 1.2.

When a block of material is compressed in one direction (say vertically), it will expand in the other (horizontal) direction. The amount of lateral expansion or strain, ε_2, is defined by what is known as Poissons Ratio υ. Typically, the amount of lateral expansion is 0.25 to 0.5 times the amount of vertical compression, i.e. υ ranges from 0.25 to 0.5.

The amount of lateral expansion, or tensile strain, is defined as

$$\varepsilon_2 = \frac{l_2}{L_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

and so the relationship between the vertical compressive strain, ε_1, and the lateral expansion, or tensile strain, ε_2, is

$$\upsilon = \frac{\varepsilon_2}{\varepsilon_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

These relationships are shown on Figure 1.3.

1.2.3 STIFFNESS

Stiffness is an important parameter in the design of any support system (whether the support is artificial, or in situ coal such as a pillar). Stiffness is a property of every structure and is defined as the applied load divided by the deformation created by that load.

$$K = \frac{\text{Force}}{\text{deformation}} = \frac{F}{l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

What this means is that under a given load (or weight) a stiffer material will deform (or compress) less than one with a lower stiffness as shown on Figure 1.4. The concept of relative stiffness is simply illustrated by placing the same weight on two separate coil springs. The stiffer spring deforms far less than the less stiff spring. This is shown diagramatically on Figure 1.5.

By substituting in the above equation, using the relationships of stress and strain, stiffness, K, can also be defined as

$$K = \frac{F}{l} = \frac{\sigma.A}{\varepsilon.L} = \frac{E.A}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

> where E is the Young's Modulus, A is the area over which the load is applied and L is the original height or length in the direction of applied load.

In terms of understanding, this means that for a given block of material (or a coal pillar), the larger the area, the higher the stiffness, but the larger the height, the lower the stiffness. Refer to Figure 1.6.

1.2.4 IMPACT OF MINING EXCAVATIONS

Prior to mining, a rock mass is in a state of equilibrium; that is, stresses are equal and opposite (or balanced), in all directions.

The effect of any excavation whether it be a notch in the surface (a foundation trench, or open-cut mine strip), or an underground excavation, is to remove material which was providing balancing stresses around the boundary of that excavation.

Therefore, upon mining, the balancing stresses are removed causing the boundary to move inwards. The movement of that boundary continues in a form dictated by the stiffness of the surrounding material, until such time as a new state of stress equilibrium has been reached. Refer to Figure 1.7. This ground movement generates changes in the direction and magnitude of the pre-mining stresses in all the surrounding rock mass. As a result of these induced stresses, the material will either be capable of sustaining the increased stress level and hence deform accordingly, then reach a new equilibrium, or it will fail, if strained beyond its capacity.

1.2.5 STRENGTH

Strength of any material is a measure of its capacity to carry stress (or load per unit area). There are a number of different strength parameters, according to the applied stress regime. In the simplest case, uniaxial compressive strength (UCS) is defined as the maximum compressive stress, applied in one direction only, which a material can carry before failure.

Strength of a material is often illustrated using the Stress-Strain characteristic curve for that material. Depending on the nature of the material, after it has passed its peak strength it can fail suddenly in a brittle fashion, or, at the other extreme, it can behave almost plastically - continuing to deform under load - in a ductile manner. This is shown on Figure 1.8. How the material behaves post-failure depends on the material and the loading system.

Triaxial strength is the compressive strength of the material subjected to a lateral confining stress. In most underground situations, except at excavation boundaries, the rock is actually confined and exhibits significantly greater strength due to this confinement. This effect is demonstrated on Figure 1.9.

Confining stresses allow the material to carry far greater stresses before failure and so the triaxial strength of a material generally increases significantly with increasing levels of confinement.

Confining stresses can modify the post-failure behaviour of materials to a more ductile behaviour from a brittle one. So there is an element of change from 'brittleness' towards 'ductility' associated with the effect of confining stresses on material behaviour in addition to the increase in material strength.

Strength of a structure is the load that this structure can sustain before failure. For large structures, like coal pillars, parts of the structure may have failed locally, that is at its edges, but overall the pillar can accommodate greater load. The lateral confining stress in a coal pillar is the prime reason why localised edge failure does not extend well into the pillar.

1.2.6 ROCK PROPERTIES

The preceding sections described some of the basic parameters of stress, strain, stiffness and strength of materials which are relevant to determining the geotechnical response of a rock mass to mining excavations - leading to design principles.

There are numerous other properties which are relevant, but those mentioned above are essential for the following reasons.

1. To understand the basis of any geotechnical design guidelines.

2. To appreciate the importance of measuring the relevant rock properties to assist in the design.

It is also important to point out that the geotechnical environment associated with coal mining is a stratified, sedimentary deposit. There are numerous, often very different materials which make up the material surrounding the excavation (including the coal seam) and the role of discontinuities such as bedding planes, laminations, joints, cleats etc. is as important (if not more important) as the inherent properties of each individual component of the rock mass. Therefore rock mass properties on scales that include these features are critical for sound geotechnical design.

Stress is a parameter which can rarely be measured directly and when a 'stress measurement' is undertaken, it is usually done by strain relaxation techniques and stress changes are inferred from strains, by a knowledge of the stress-strain characteristics of the material.

1.2.7 EFFECT OF DEPTH

There are two main components to the effect and significance of depth. The first and most obvious one is that increasing depth, increases pre-mining or virgin stress levels in the rock mass, both vertically, and horizontally.

The second component is the influence of the surface on shallow depth excavations. Beyond a certain depth, the underground excavation is sufficiently far from the surface, so that the surface has no effect on the excavation. However, at shallower depths, there is a point at which the proximity to the surface starts to influence the stress redistribution around the excavation. This is shown on Figure 1.10.

It is this influence which can lead to the observation of underground conditions being more adverse at shallow depths than at slightly greater depths with a transition zone as depth increases. The depth at which the surface influences underground conditions is dependent on rock properties, discontinuities, structure etc., but most importantly it is a function of excavation width and this is discussed in the next section.

At the very shallow depths, many overburden rock types are subjected to minimal confinement within the rock mass. This leads to a tendency for brittle or sudden failure, with poor predictability and reliability of warning signs.

1.2.8 EFFECT OF EXCAVATION WIDTH

Excavation shape plays a major part in determining the distribution of stresses around an excavation. A mine roadway, and an extraction panel are both essentially rectangular excavations, with width being the only major, and dominant variable.

In general, the wider an excavation is, the greater the level of mining induced tension that exists in the roof (and floor) strata, normal to the excavation boundary. Refer to Figure 1.11. These induced tensile stresses reduce pre-mining compressive stresses, giving rise to large zones of rock at very low confining stress which exhibit low compressive strength. This leads to greater propensity for failure to occur, particularly when discontinuities are present.

Increasing width also leads to increasing abutment stresses on adjacent pillars or solid coal on either side of the excavation. It is these regions which have to carry the vertical load which was previously carried by the coal in the excavation. This redistribution of stresses through the overlying strata is the cause of overlying goaf failure, aided by the low confining stresses set up by the roof. Therefore increasing excavation width leads to a propensity to form extensive overburden failure - as is deliberately engineered in a longwall or pillar extraction section, as goaf failure.

As mentioned in Section 1.2.7, there are a number of other factors which are involved in generating detrimental interaction with the surface. However, the effect of excavation width relative to depth is a dominant factor in that it generates induced tensile stresses above the excavation, and when the composite beam of overburden strata reduces to a thickness where mining induced stresses are extending to the surface, and the majority of the overburden strata is in a zone of induced tensile stress, then surface interaction should be anticipated.

As a guide, whenever excavation width W, is equal to or greater than twice depth D, then surface interaction should be anticipated.

i.e. $W/D \geq 2$ .... (9)

It is important to note that such a situation merely indicates that surface interaction could occur (and to a progressively greater extent as W/D increases) with the likely consequences of:

- heavier than normal weighting on abutments and supports and general conditions underground, due to lack of spanning across panel causing more loading on support elements within a panel;
- potential 'dead weight' loading;
- generally less strain within the overlying rock prior to failure, as a result of lower stress levels and less confinement, creating more brittle rock behaviour, hence less warning signs.
- overburden strata integrity less predictable, with greater detrimental effects of discontinuities leading to sudden failures without warning.
- greater potential for fracturing extending to surface (potential for water inflow, ventilation short-circuiting etc).

1.2.9 EFFECT OF PILLAR WIDTH AND HEIGHT

The role of pillars in controlling the underground geotechnical environment is often grossly under-estimated. Pillars - whether they be barrier, development/chain, yield pillars or fenders - are the key load bearing elements of an underground coal mine. A later section addresses pillar design as such; this section is intended to simply highlight the importance of the geometric factors of width and height, for any type of pillar.

A pillar of coal should be regarded as a block of material, or column, loaded vertically from either end, with a varying degree of horizontal constraint applied at each end also. The horizontal constraint may vary from zero to the full value of resultant horizontal stress in the adjacent strata. Depending on the interface between roof/floor and the coal pillar, that horizontal constraint will be distributed into the coal pillar also, providing a degree of confinement to the coal in the pillar, as shown on Figure 1.12.

The extent to which the horizontal constraint can confine elements of the coal pillar, and particularly achieve overlapping constraint from roof and floor, is clearly a function of both the width (w) and the height (h) of the pillar.

Similarly, the vertical stress profile across the width of the pillar is such that in the centre of the pillar there is a lower applied vertical stress and higher horizontal confining stress than there is on the pillar edges. This results in a much stronger, confined 'core' of material in the pillar centre, which carries the majority of the load, while the pillar edges are subject to more uniaxial loading and possible failure, but still provide essential constraint to the pillar core. Refer to Figure 1.13a and 1.13b. (It is for this reason that apparently yielding or fractured pillar ribsides should not be continually cleaned away from pillars, as they are fulfilling a vital pillar core constraint role, even when in a broken state).

Therefore the ratio of pillar width (w) to height (h) is a critical one in pillar design.

Width: Height Ratio (w/h) is the main geometrical consideration in determining a pillar's strength, hence stability, not simply width, as is all too often the case. w/h Ratios of 10 or above are generally regarded as indestructible pillars, although coal properties, surrounding strata and the loading environment must always be carefully examined.

It is worth noting that, for a given pillar height, as the width is progressively reduced, it is the pillar core which reduces in width first, while the 'yield' zones on either side of the core remain roughly constant in width. There comes a point when the core becomes too narrow to sustain load, and eventually for narrower pillars, the core disappears altogether and the two yield zones intersect, resulting in a fully yielding pillar.

It is imperative to recognise the role of roof and floor strata stiffness, relative to the coal pillar. If the floor, for instance, is a very low stiffness claystone, then even the best engineered pillar geometry will not prevent the pillar from punching into the floor under any reasonable pillar loading. The pillar coal itself may not fail, but the floor may, and the consequences in terms of control and support of overlying strata could be just as serious as if the coal pillar itself had failed.

1.2.10 ROADWAY & PILLAR DESIGN PRINCIPLES

Roadway design is a peripheral issue to pillar extraction, however, for completeness it needs to be included here. Roadway design issues include roadway width, height (especially as this effects pillar Width/Height) and support requirements.

Excavation width has been discussed earlier in terms of principles. It is important to recognise the effect on stress distribution and the significance of roof type particularly, in order to determine roof support requirements. It is not intended in this chapter to address the application of geotechnical principles to roof or rib support, as these are two quite distinct and separate issues.

The other points to remember are that in dealing with old headings which are being re-accessed for extraction, or developing roadways which will stand for a long time, any fretting of the ribs which has inevitably taken place has effectively increased the roof span and therefore increased the likelihood of roof instability.

The principles of confinement of pillar cores, and w/h ratio as a strength design criteria have been discussed in section 1.2.9. In terms of design principles, the different types of pillars and their different roles must firstly be clarified and design principles applied accordingly.

1.2.10.1 BARRIER PILLARS

Barrier pillars are an essential component of any partial extraction system, and even in many total extraction systems where total, complete and continuous caving cannot be guaranteed, or where some additional degree of protection or isolation for certain areas of the mine is required.

A barrier pillar must be designed to remain stable for the life of the mine (or region within the mine), which means a considerable safety factor should be inbuilt in its design.

$$\text{Factor of Safety} = \frac{\text{Pillar Strength}}{\text{Pillar Stress (max)}} \qquad \ldots\ldots\ldots\ldots (10)$$

There are a number of methods of estimating strength and stress and it is not the intention of this chapter to go into these. However, it is important to point out that in determining strength, a method which takes account of width and height (hence triaxial strength condition) be used. In determining stress, it is important to consider that caving adjacent to the barrier is likely to be incomplete, even with the best total extraction practice, and so it must be assumed that the barrier pillar may carry a large proportion of load abutment diverted from the adjacent excavations.

In any partial extraction or high extraction first workings panels, it is essential to leave regular, straight barriers between effective panels of small w/h ratio pillars, as shown on Figure 1.14.

1.2.10.2 PANEL/CHAIN PILLARS

There are a range of practices with respect to chain pillar layouts such as including a stable development pillar adjacent to a narrow yield pillar (for development conditions). The main points to make are similar to those for barrier pillars, although the life of the pillars is possibly shorter, and so lower safety factors can be adopted.

Chain pillar design (and use of appropriate safety factors) must consider the changing roles of a chain pillar on development, then extraction on one side, then both sides. Some designs require the pillar to crush (or yield) once the second extraction panel has passed, while others require the pillar to maintain a role of providing regional overburden stability, particularly at depth. In particular, where massive roof strata (sandstone, conglomerate) exists, strata bridging can also cause major abutment loads to be thrown over large areas, hence the importance of appropriate pillar design.

Pillar design for later secondary extraction must also take into account length, because pillars need to accommodate suitable multiples of the basic split centre distance. Also it has to be decided whether pillars are to be split once or twice (or more) and if lifting one side or both sides ("lefting and righting") is to be planned.

1.2.10.3 FENDERS

It must be recognised that a fender is a pillar in every sense of the word, albeit one with a very short lifespan. The issue with fenders is that the support offered to the roof is systematically reduced during the lifting sequence.

The most recent geotechnical evidence, as shown on Figure 1.15, suggests that the fender is not positioned in a stress-relieved zone, as previously believed, and it is only at the very inbye end, during lifting, that there may be any degree of yield and/or stress relief occurring. It is therefore prudent to design for maximum fender width to ensure stability and safety while working in the split, with the upper fender width being determined by operational capabilities in terms of:

- reach of machine
- remote control capabilities
- ensuring that men are not working under unsupported roof

A further principle to remember is that of w/h ratio. A fender width of 7.5m in a 2.5m working section is roughly equivalent in strength to a fender width of 9m, if the height is increased to 3.0m . Fenders with a w/h ratio of at least 2.5 to 3 are usually advisable.

The most common fender widths are currently in the 7m - 10m range, for working depths down to 450m, in a typical 3m seam section.

1.2.10.4 OTHER CONSIDERATIONS

Any irregularity in pillar shape will lead to non-uniform induced stress redistribution from the adjacent excavation and hence reduced stability for that region of the pillar. Areas of extreme irregularity should be omitted from consideration when calculating pillar strength.

A rectangular pillar is generally going to be slightly stronger than a square pillar of the same width. However, a narrower rectangular pillar may be a lot weaker, even if it has the same area as a square pillar, since the width of pillar core (reduced by constant width yield zones on all sides) will be significantly reduced. Refer to Figure 1.16. Therefore it is prudent in situations where guaranteed stability is essential, to use the minimum dimension of the pillar as a guide (and for w/h ratio analysis), as well as taking into account the additional support capacity of the pillar in its "long" direction.

Once again, as for roof support, the topic of detailed pillar design methods and principles should be addressed separately.

1.2.11 ROLE OF ROOF SUPPORT

Roof support in coal mines - in the form of roadway support, longwall support or goaf edge support - is not the primary means of roof control. The coal and roof strata itself is the primary control means and the role of artificially introduced roof support elements is therefore not to hold the roof up, but to assist the strata to be self supporting.

This can be achieved by various means. In the context of roadway and longwall support, the role of the support element is generally to resist convergence and bed separation in the immediate roof layers and provide sufficient contact friction and reinforcement such that the immediate composite roof beam is self supporting (in the case of a roadway), or is sufficiently stiff to resist and control the overlying strata in the case of a longwall.

In a pillar extraction section there are several components of roof support.

1) In the split headings and any outbye intersections the support is critical for maintaining roof integrity, just as in a gate road - particularly when any additional abutment loads develop as a result of the retreating goaf edge.

2) On the goaf edge the role of roof support (apart from any means of signalling accelerated roof closure prior to a goaf fall) is similar to that of a longwall, but to a far lesser extent (and negligible extent in the case of many timber breaker props). That is, it provides some degree of local control of the immediate roof plies, and also serves as a fulcrum for the immediate roof plies, (which are acting as an open ended cantilever) to bend on, and subsequently to control fracture initiation. Similarly breaker props set along outbye edges of an active goaf serve to control the roof and prevent the goaf edge caving beyond the breakers. However, breaker props in any environment must be seen for what they are, and that is a relatively low stiffness support, by comparison to solid coal.

3) Some form of roof support may also be required within lifts, for safety reasons, if the miner driver is required to operate within the lift.

1.2.12 ROLE OF TIME

It is vital to the whole understanding and application of geotechnical principles in underground coal mining, to recognise the importance of time.

The behaviour of rock under load changes within time. As described earlier, at both the micro and macro scales rock mass failure occurs progressively and as such is a time related phenomenon. Arising from this are the facts that:

1. No rock mass surrounding an excavation is ever likely to be in absolute equilibrium, and so design safety factors need to take this into account.
2. Particularly in the vicinity of high abutment and marginal stability regions, the rate and extent of migration of induced strains and potential failure zones is extremely time-dependent, hence the need to maintain a continuous speed of mining extraction to minimise this migration process. (This is especially the case in areas of abutment and failure migration ahead of a face which will subsequently have to be mined through). It is for this reason that fenders should not be left partially extracted, nor should pre-splitting of pillars ahead of lifting be adopted as standard practice.

1.3 SUMMARY

STRESS

- *Stress in rock is a form of pressure, and is a unit of force (or load) per unit area (usually measured in Megapascals (MPa).*
- *In the earth's crust prior to mining, the state of stress is in a state of equilibrium in all directions.*
- *Vertical stress increases with depth, due to the weight of overlying strata.*
- *Horizontal stress can exceed vertical stress and the entire pre-mining and virgin stress field can be changed in magnitude and direction due to geology, structure, tectonic influences etc.*

STRAIN

- *Any change in stress (induced stress) generates strains which are the change in length, per unit length (dimensionless),* ε.
- *Strain is related to stress, via the elastic constant, Young's Modulus, E, of the particular material.* $E = \sigma / \varepsilon$ *(in MPa or GPa).*
- *When a material is loaded vertically, the ratio of lateral expansion* (ε_2) *to vertical compression* (ε_1), *is defined by Poissons Ratio,* υ.

$$\upsilon = \frac{\varepsilon_2}{\varepsilon_1}$$

EFFECT OF EXCAVATIONS

- *A mining excavation disturbs the stress equilibrium in the ground resulting in 'induced stresses' and a resultant stress redistribution around the excavation.*
- *The effect of the excavation is to generate stress abutments (redistributing the pre-mining stress away from the excavation).*
- *Induced stresses resulting from stress redistribution cause strains within the rock near the boundary, resulting in deformation towards the opening from all directions (roof, rib and floor).*

STIFFNESS

* *Stiffness, K, is the parameter which relates deformation of the structure to applied load.* $K = F/l$*, or* EA/L *(MegaNewtons/metre, MN/m).*

STRENGTH

* *Strength is a measure of the load-bearing capacity of a material, in the units of stress (load per unit area), MPa.*

* *Uniaxial compressive strength, UCS (MPa), is the maximum compressive stress sustainable by a material subjected to loading in one direction.*

* *Triaxial strength (MPa) varies according to the degree of confining pressure applied, which results in significant increases in strength.*

* *Under triaxial conditions, axial strain levels also exceed uniaxial strains at failure, and materials generally become less brittle and more ductile/plastic as triaxial confinement increases.*

ROCK PROPERTIES

* *Basic parameters of stress, strength, stress-strain and stiffness characteristics are important parameters for geotechnical design, however the role of discontinuities, structure etc. can be equally if not more important in determining the behaviour of coal measure strata.*

DEPTH

* *Increasing depth generates increasing pre-mining stresses in the ground.*

* *At shallow depth, surface interaction can occur leading to 'heavy' mining conditions, 'dead weight' loading, and possible fracturing through to the surface.*

* *Shallow depth can also result in goaf failure occurring in a more brittle fashion, with much less warning of impending failure and a far greater degree of unpredictability.*

EXCAVATION WIDTH

- *Greater width generates higher levels of induced tension in roof and floor.*
- *Greater width leads to higher levels of vertical abutment stresses adjacent to the excavation (and resultant rib problems due to induced horizontal strain).*
- *Greater width generates compressive and shear stress failures above the abutment and ribside edge, causing goaf formation.*
- *At increasing Width: Depth (W/D) ratios, there is an increasing likelihood of surface interaction. This can often occur with W/D>2.*

PILLAR WIDTH AND HEIGHT

- *Pillars are the main load-bearing elements in an underground mine.*
- *Horizontal stresses can be directed into the pillar via the roof and floor contact and influence the pillar stability. Induced horizontal stresses can also be generated within the pillar, creating confinement.*
- *Pillars generally are designed to form a confined core of lower stressed material in the centre, with less confined, but higher stressed yield zones around the edges.*
- *The critical geometric parameter influencing pillar strength is the Width: Height Ratio, w/h. w/h ratios in excess of 10 are usually regarded as indestructible.*

ROADWAY AND PILLAR DESIGN

- *Roadway height is a consideration in terms of pillar or fender w/h ratios.*
- *Increased roadway width naturally leads to greater propensity for roof instability (and hence support requirements).*
- *Due to rib fretting in old workings, effective roof span will increase with time and may require remedial attention.*
- *Pillars are the principal load-bearing members in an underground mine and so their correct design is an integral part of good, safe, mining practice.*
- *Barrier pillars must be designed for 'life of mine' stability.*

- *Barrier pillar loading calculations should allow for carrying the major abutment loading from adjacent panels.*

- *Barrier pillars should be incorporated within any high production partial extraction or first workings layout.*

- *Any pillar design approach for estimating pillar strength must take account of the w / h ratio of the pillar.*

- *Fenders needs to be designed as pillars, with a very short lifecycle.*

- *Fenders should be designed to remain stable at least until the coal is being lifted off at the inbye end.*

- *Typical fender widths are in the 7-10m range for 450m depth, for up to 3m working height, but should be designed according to local conditions and requirements, having regard for w / h ratio also.*

- *Pillar shape irregularities can create excessive induced stresses and increased instability.*

- *Minimum pillar dimensions (in the case of non-square pillars), or a composite determination of effective width, should be used for design purposes.*

ROOF SUPPORT

- *The role of roof support is to assist the strata to be self-supporting (or in the case of weak material below a competent member, to suspend the immediate roof). Artificial roof support elements, in their own right, will not hold the roof up.*

- *Support serves to confine and prevent bed separation and form a beam of increased stiffness in the immediate roof, capable of bridging roadway spans, or constraining overlying cantilevering roof strata in a goaf edge situation.*

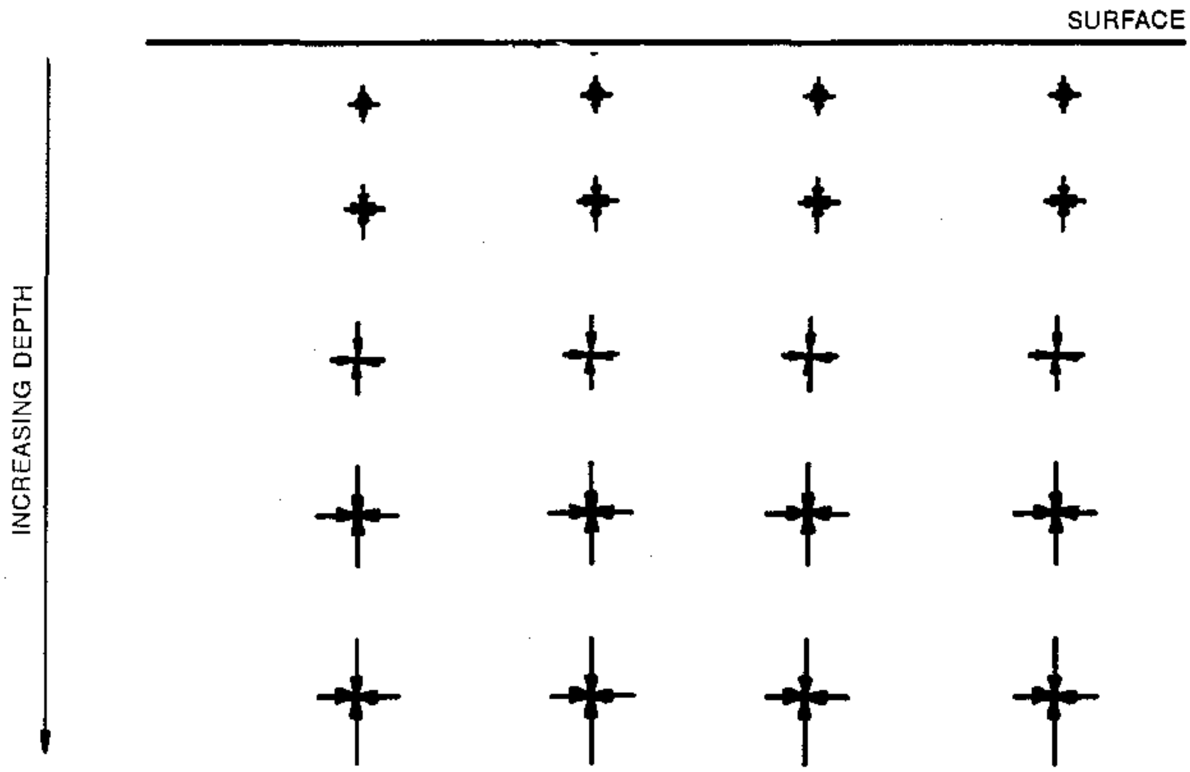
- *Breaker prop support as used in pillar extraction is a relatively low stiffness support, and can be ineffectual as a roof support (though it can be a very effective early warning device). However it can provide a fulcrum for limiting, controlling or even initiating failure in the immediate roof strata.*

TIME

- *All rock deformation/failure is time-related, to a greater or lesser extent.*
- *Even in apparently stable equilibrium conditions, there will be a progressive time-based degradation of conditions, albeit insignificant in many situations.*
- *In high stress, marginal stability areas (such as in the vicinity of a retreating face line) the rate and extent of migration of induced strains and potential failure zones can be very time-dependent and can create extremely adverse conditions if the rate of mining is slowed or disrupted significantly.*

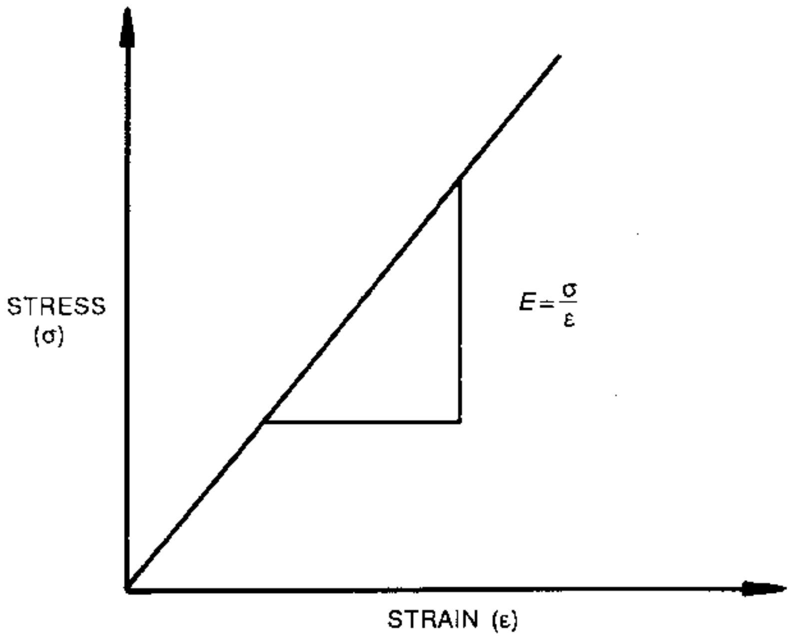
1.4 ACKNOWLEDGMENTS

Chapter 1 and components of chapter 2 of this manual have been prepared by Drs Bruce Hebblewhite, John Shepherd and Bernard Madden of ACIRL Ltd, in conjunction with Dr Jim Galvin and Mr Ian Anderson of the Pillar Extraction Industry Committee.



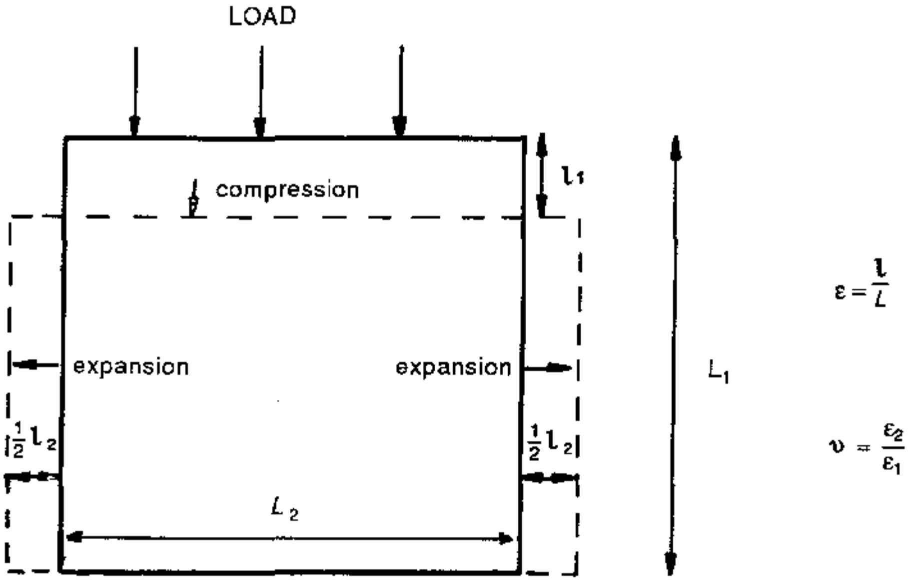
PRE-MINING STRESSES (HORIZONTAL AND VERTICAL) INCREASE WITH DEPTH

FIGURE 1.1



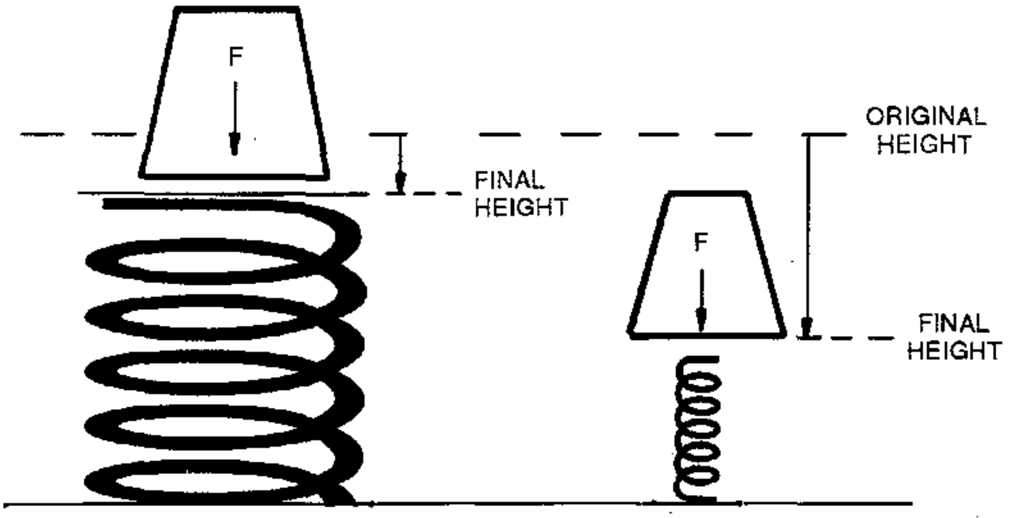
ELASTIC CONSTANT — YOUNG'S MODULUS

FIGURE 1.2



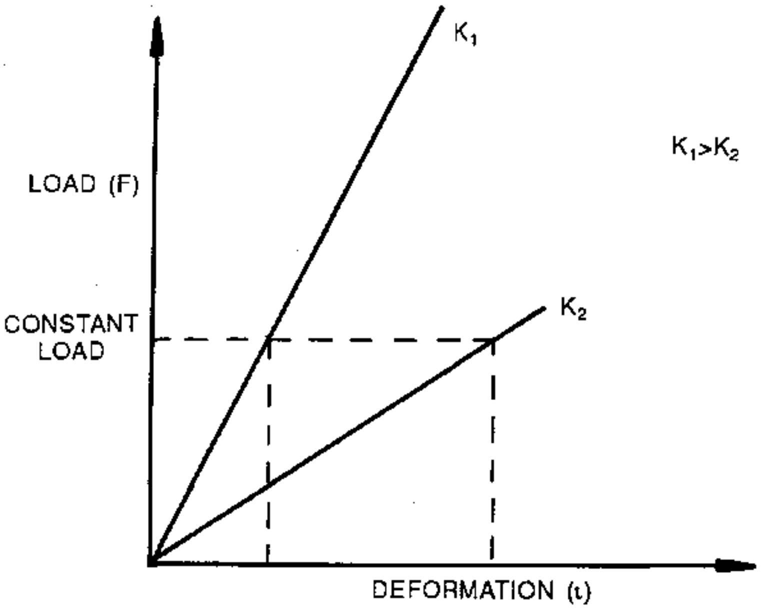
STRAINS INDUCED IN A BLOCK UNDER LOAD — POISSON'S EFFECT

FIGURE 1.3



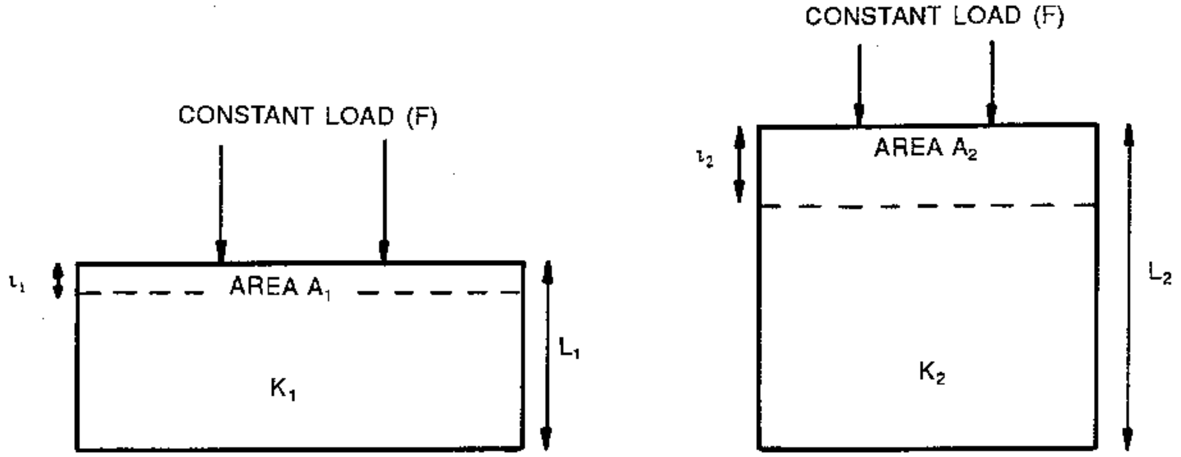
EFFECT OF CONSTANT LOAD ON TWO SPRINGS OF DIFFERENT STIFFNESS

FIGURE 1.4



RELATIVE STIFFNESS (K) OF TWO MATERIALS UNDER CONSTANT LOAD

FIGURE 1.5

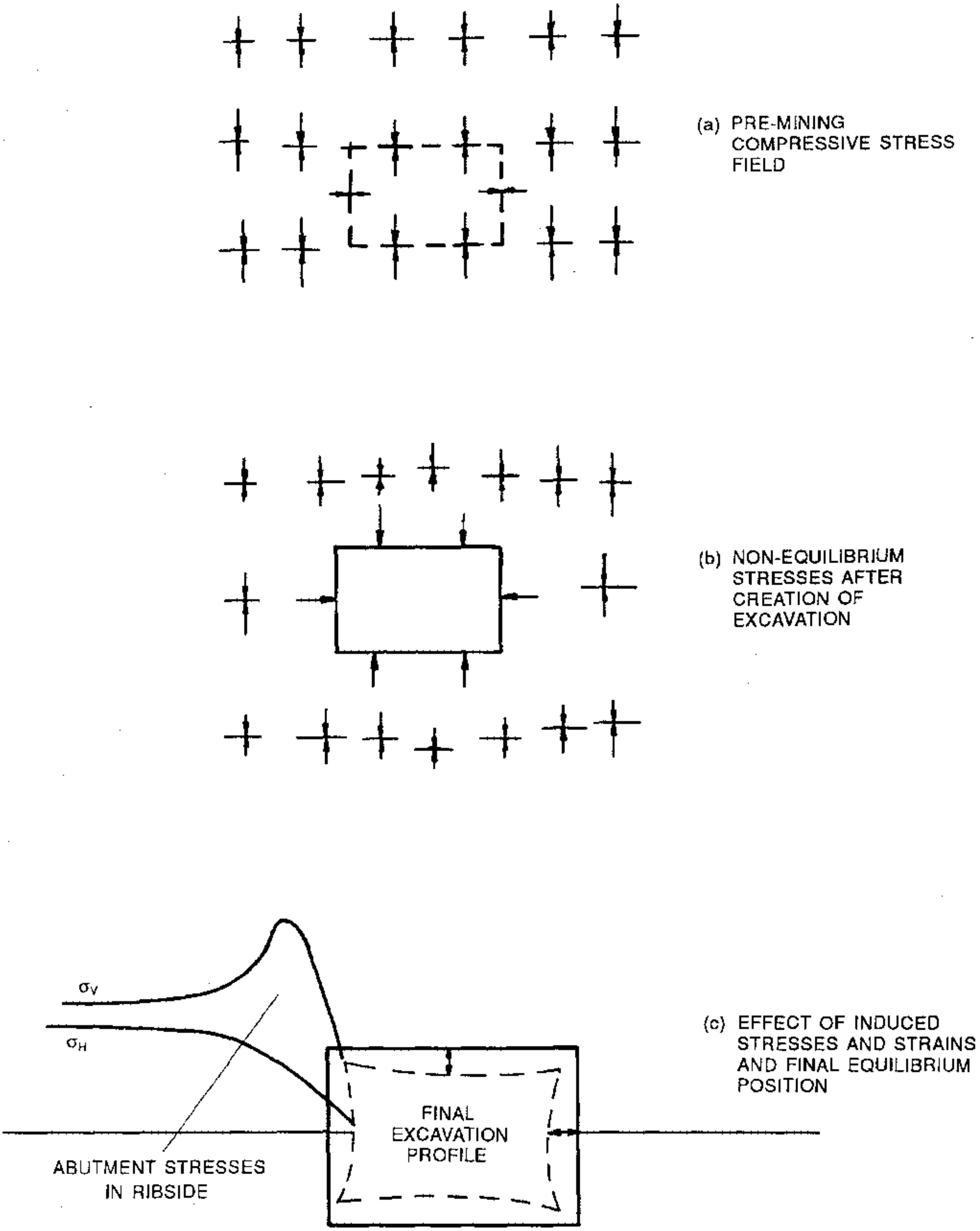


$E_1 = E_2$
$L_1 < L_2$
$A_1 > A_2$
$l_1 < l_2$
$K_1 > K_2$

$$K = \frac{EA}{L}$$

EFFECT OF AREA (A), AND HEIGHT (L), ON RELATIVE STIFFNESS OF TWO BLOCKS (OR PILLARS)

FIGURE 1.6



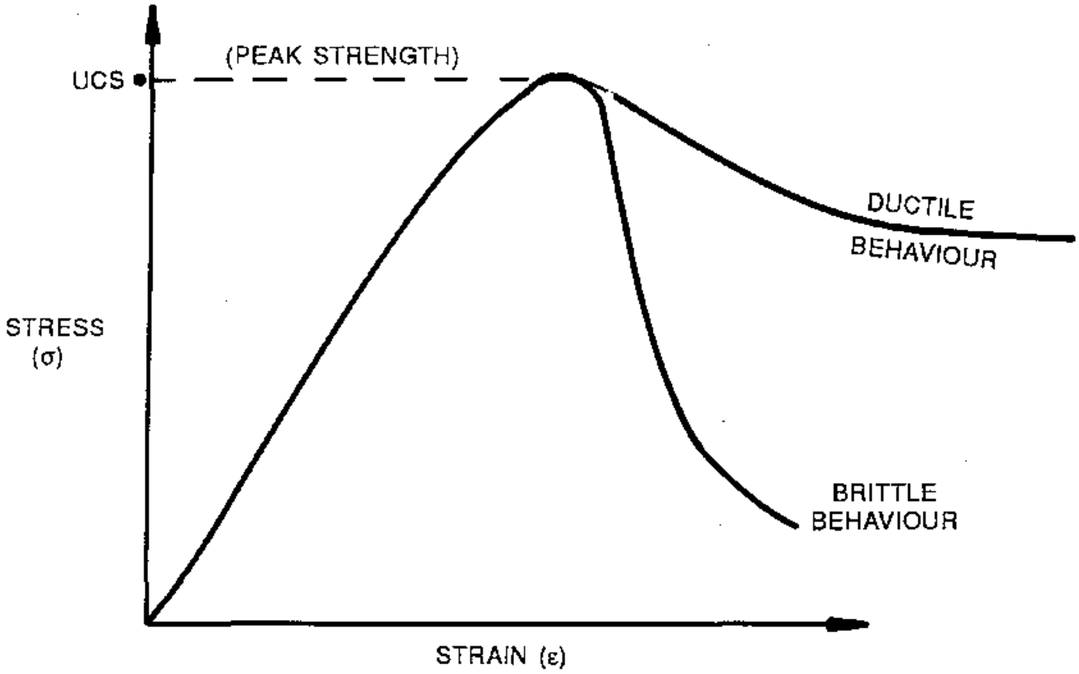
(a) PRE-MINING COMPRESSIVE STRESS FIELD

(b) NON-EQUILIBRIUM STRESSES AFTER CREATION OF EXCAVATION

(c) EFFECT OF INDUCED STRESSES AND STRAINS AND FINAL EQUILIBRIUM POSITION

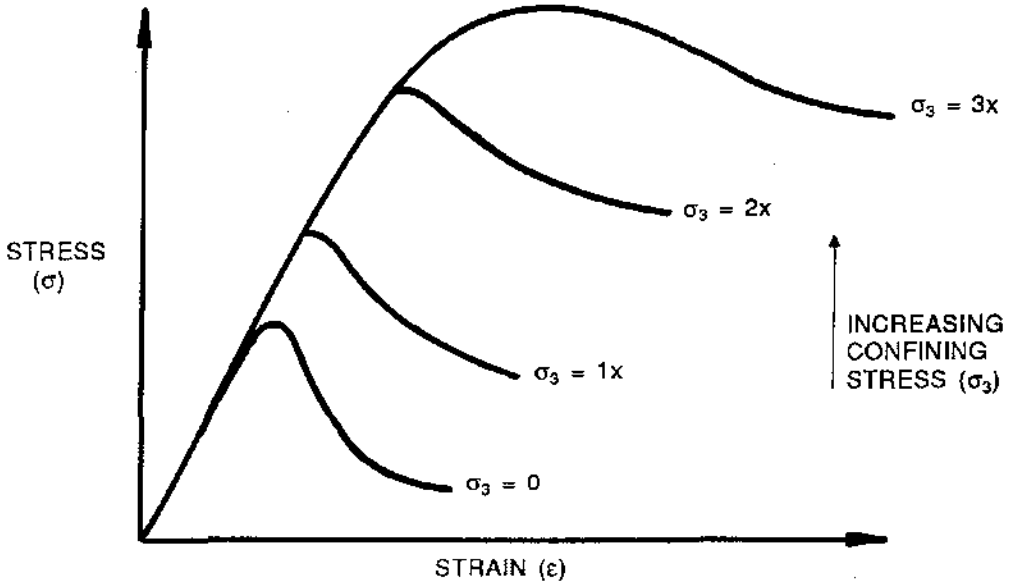
CREATION OF AN EXCAVATION IN PRE-MINING STRESS FIELD

FIGURE 1.7



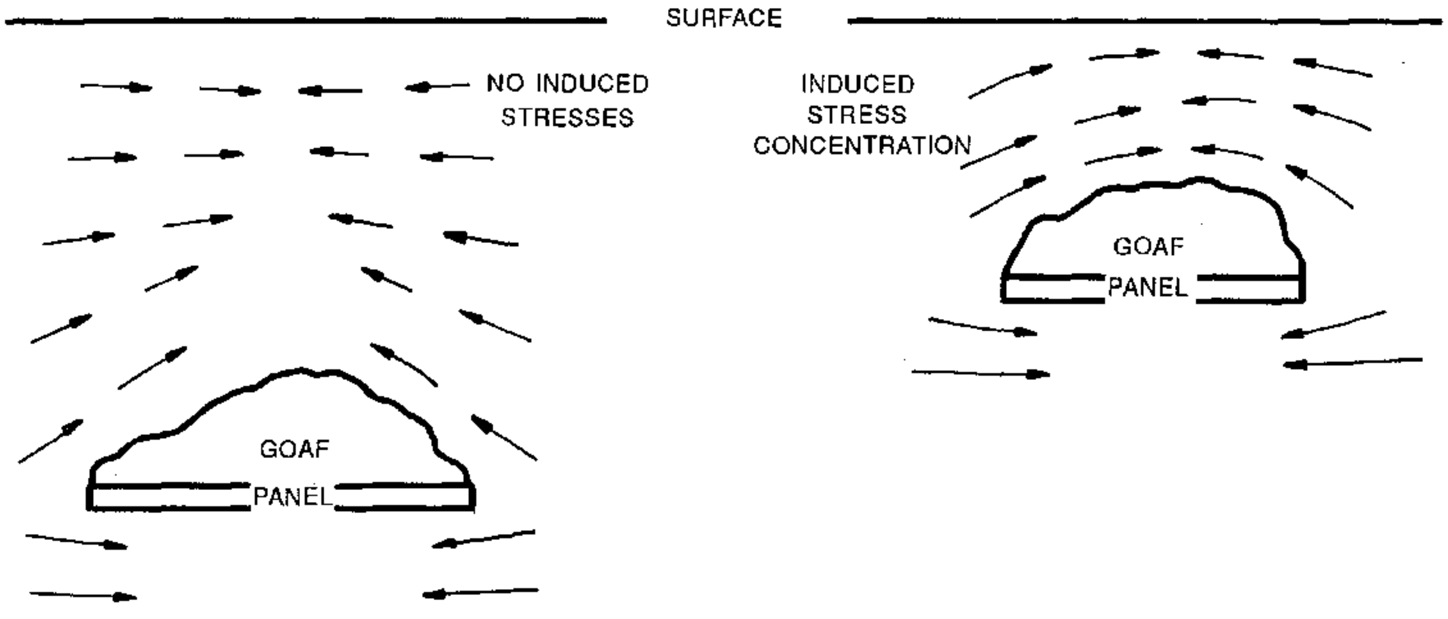
TYPICAL STRESS — STRAIN CURVE ILLUSTRATING UNIAXIAL COMPRESSIVE STRENGTH (UCS) AND RANGE OF POST-FAILURE BEHAVIOUR

FIGURE 1.8



TRIAXIAL COMPRESSIVE STRENGTH CURVES FOR INCREASING CONFINEMENT

FIGURE 1.9

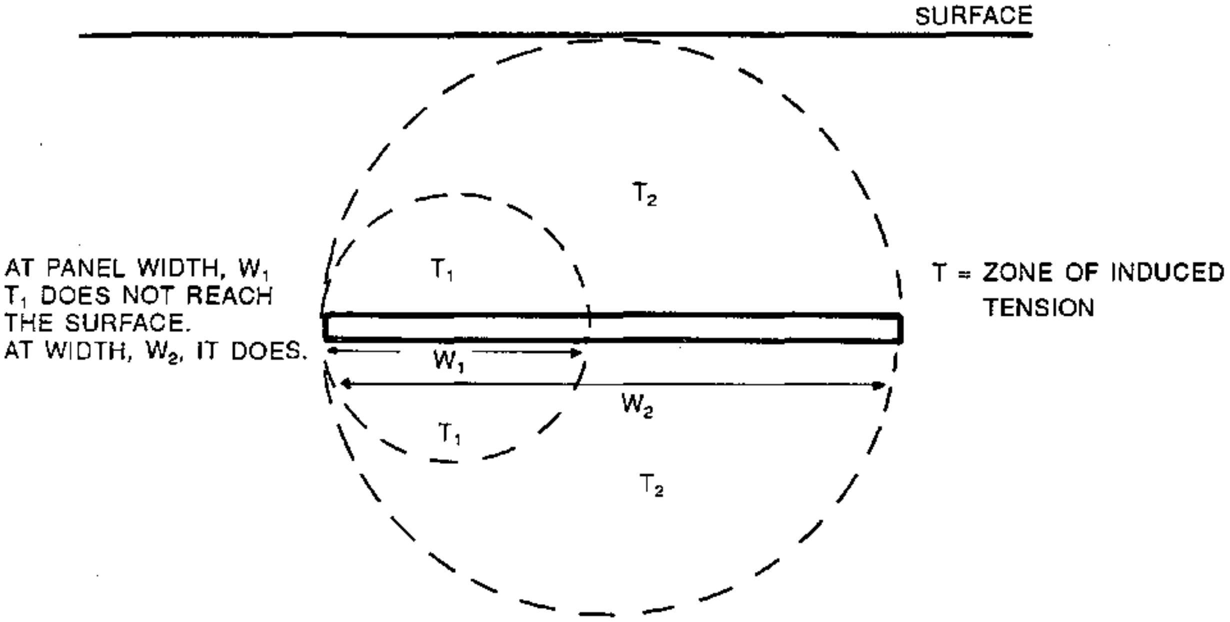


DEEP (NO SURFACE INTERACTION)

SHALLOW (SURFACE INTERACTION)

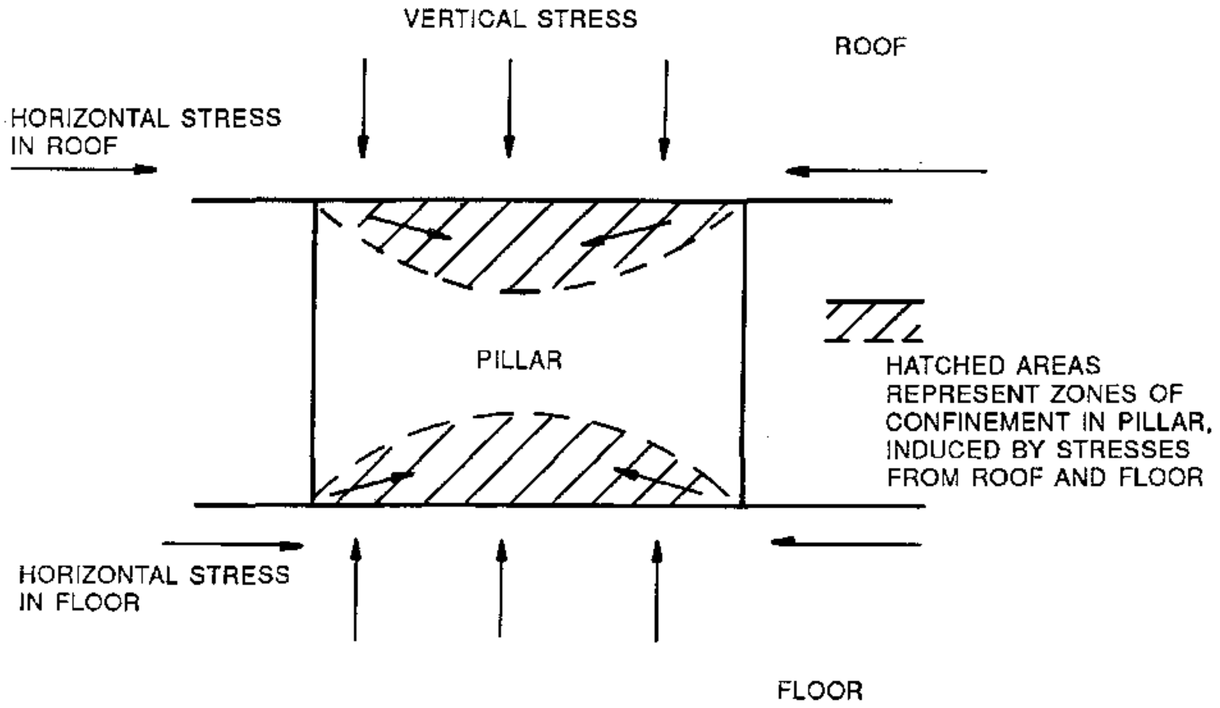
EFFECT OF DEPTH ON HORIZONTAL STRESS RE-DISTRIBUTION

FIGURE 1.10



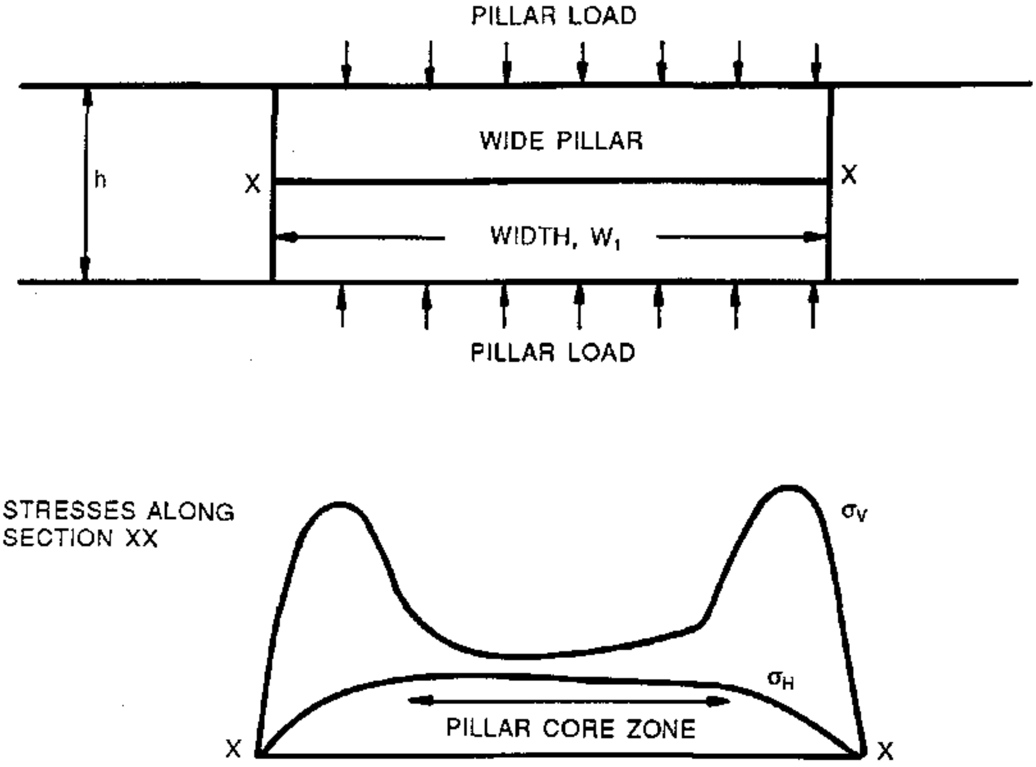
EFFECT OF PANEL WIDTH ON SURFACE INTERACTION

FIGURE 1.11



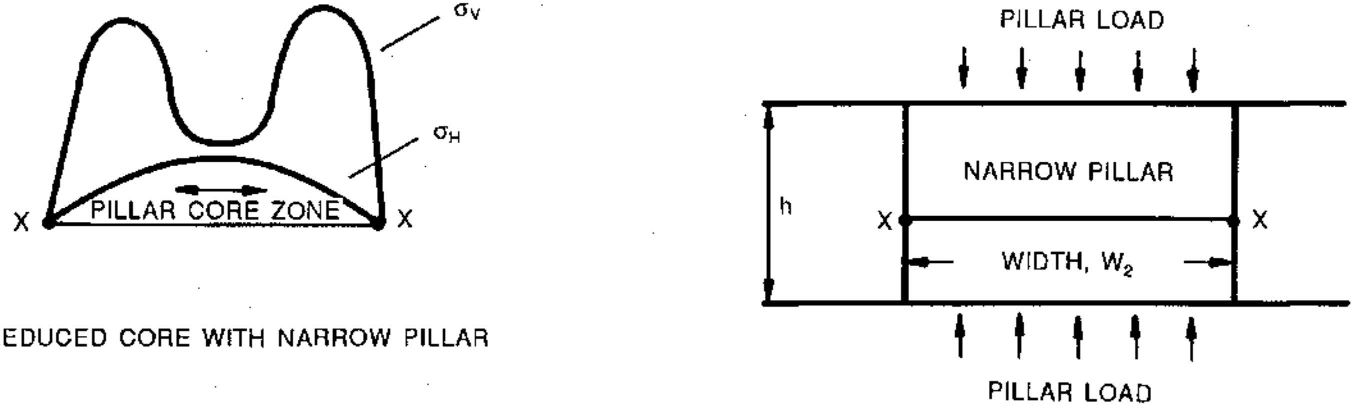
EFFECT ON PILLAR OF HORIZONTAL CONFINEMENT WITHIN ROOF AND FLOOR

FIGURE 1.12



CONFINED CORE WITH WIDE PILLAR

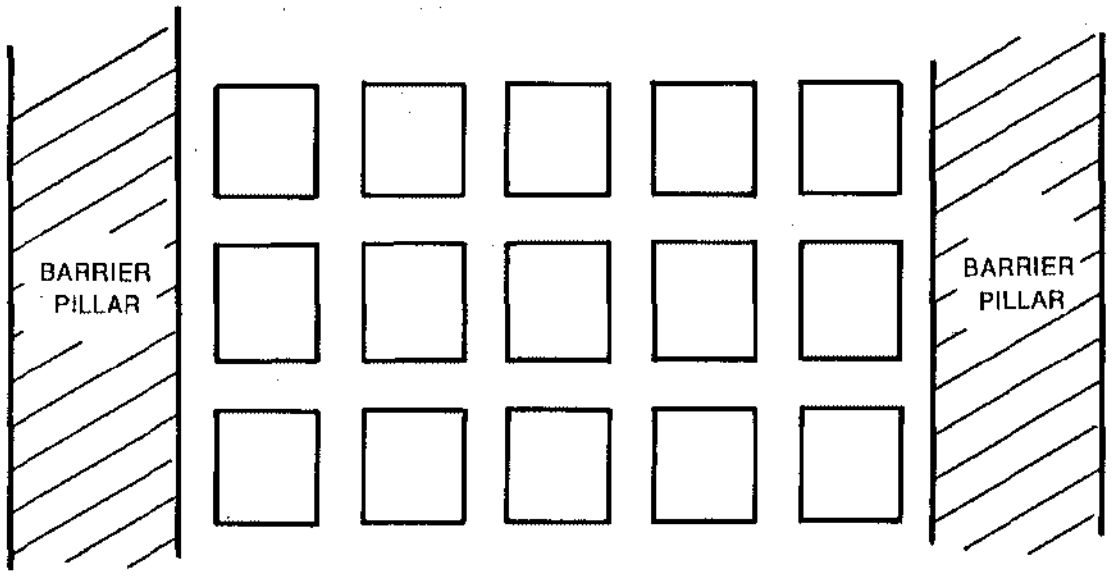
FIGURE 1.13(a)



REDUCED CORE WITH NARROW PILLAR

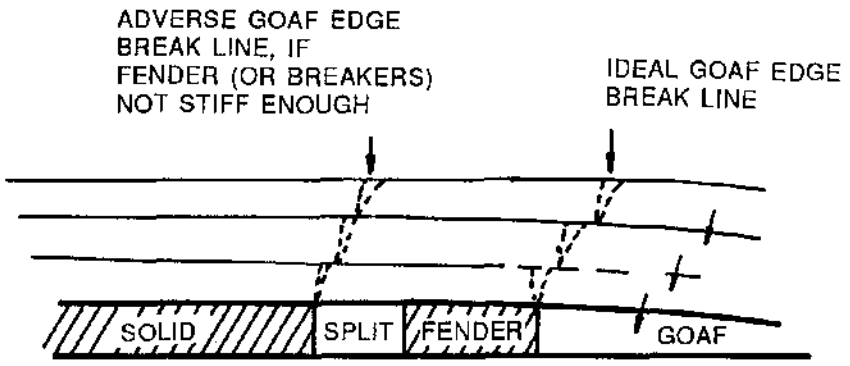
EFFECT OF PILLAR WIDTH ON INDUCED STRESSES AND PILLAR CORE

FIGURE 13(b)



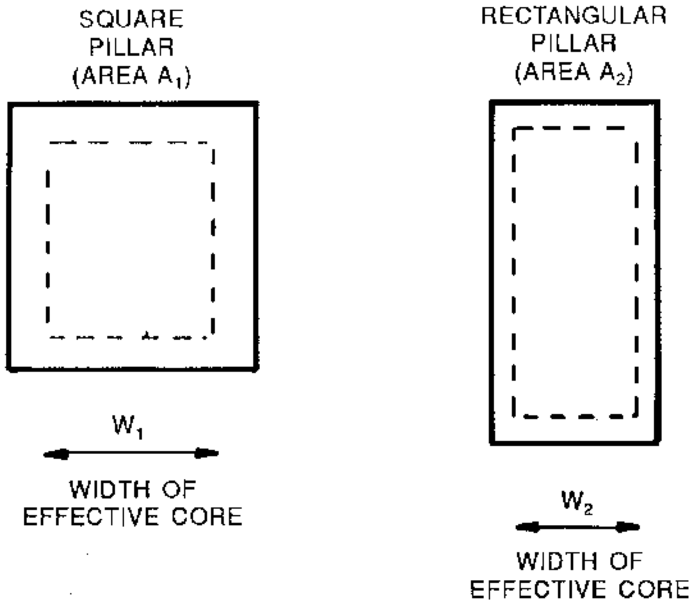
USE OF BARRIER PILLARS BETWEEN PANELS OF HIGH EXTRACTION (PARTIAL OR TOTAL)

FIGURE 1.14



GOAF EDGE FAILURE CONTROL — EFFECT OF FENDERS AND/OR BREAKER SUPPORT

FIGURE 1.15



$$A_1 = A_2$$

$$W_1 > W_2$$

A NARROWER RECTANGULAR PILLAR WILL HAVE A NARROWER EFFECTIVE LOAD-BEARING CORE (HENCE LOWER STRENGTH) THAN A SQUARE PILLAR OF THE SAME AREA

FIGURE 1.16

CHAPTER 2

DESIGN ISSUES

2.1 INTRODUCTION

When considering a design appropriate for the physical conditions in a proposed extraction panel, the designer must take into account the influence that the following issues may have on the extraction system. The final extraction layout must have successfully incorporated principles and practice enunciated.

2.2 PANEL COMMENCEMENT

It can be advantageous to commence a goaf adjacent to a geological weakness, e.g. a dyke or fault, to help induce a quick initial cave. However, this is not always the case and every panel design must be treated on its merits, taking into account the nature and geometry of the structure, and associated roof conditions.

Wherever safely possible and practical a panel should be commenced by extending an existing goaf edge, thus assisting in creating an early cave, and maintaining goaf continuity.

As a general rule, goaf formation should always retreat away from existing goaf lines and not approach an existing goaf, where excessive loading and unpredictable caving may occur. This relates to the presence of abutment loading adjacent to any excavation, either old or current. When abutment stresses interact, their magnitudes are superimposed on each other with the potential for major loading and damage.

Care must be taken when extracting in the vicinity of major structural features (faults, dykes) which may act as a well lubricated weakness plane through the overburden strata. This is particularly the case where such structures intersect the seam, outbye the working face and current goaf edge.

Particular care must be exercised when retreating towards a known geological weakness. It may be necessary to either leave a protective barrier of coal adjacent to the structure, or extract the panel such that the goaf line is not parallel or sub-parallel to the structure.

Previous sections have made repeated references to the importance of knowledge of geological information, in particular the micro and macro discontinuity data. Coal cleats and roof joints are especially important.

Prior to a panel being driven some consideration should be given to the orientations of cleats and roof joints. If possible, adverse heading and split directions where roof joints may be parallel to splits or fenders should be avoided.

Further, it is important that any panel earmarked for extraction be mapped, prior to finalisation of the extraction planning process. This mapping should identify any structure or other anomalies within the panel (roof or seam) which may affect the geotechnical performance of that rock mass. Once identified, such areas may require additional remedial roof support, or variations to sequences or extraction geometry to cope with the variation in anticipated geotechnical behaviour.

2.3 CONTINUITY OF EXTRACTION

The principle outlined in section 1.2 was that all rock responds to induced stresses, undergoing progressive strain and possible failure in a time-dependent manner. Due to this time dependent behaviour of both coal and the surrounding strata it is extremely important to maintain continuity during pillar extraction. Partially extracted fenders should not be left standing for extended periods. Fenders should be completely extracted during the last shift before a weekend or other extended non production period.

Time dependent behaviour also has implications when extraction of old pillars is undertaken. It must be recognised that both roadway and pillar conditions may have deteriorated since mining first occurred. This deterioration may require considerable remedial work, as well as an accurate knowledge of current positions of pillar edges.

2.4 RATE OF EXTRACTION

When the roof collapses adjacent to a pillar at the goaf edge, stresses on that pillar are reduced considerably. During subsequent extraction of this pillar, stresses increase, as the pillar size diminishes, until a maximum level is reached prior to caving. The longer it takes to extract the pillar, the more time the pillar has to deteriorate. During this time hazardous mining conditions may develop.

Therefore the rate of extraction should be as fast as is practically possible.

2.5 EXTRACTION WIDTH

Extracted widths of any panel should be that necessary to ensure complete goaf caving, consistent with a speedy retreat rate. Caving width varies with strata type and the critical extraction width required to ensure complete caves should be determined preferably by past practice, supported by analytical design.

Where it is not possible to have a panel extraction width capable of inducing complete caving, a partial extraction layout should be designed leaving stable abutments. In this case care must also be taken to maintain mine-wide regional, as well as local stability.

It is not recommended to plan a panel to be just on the critical width, as it could lead to some areas being incompletely caved, with resultant load transfers onto abutments.

Therefore total extraction panels should have a width above the critical width and partial extraction voids well below the critical width.

2.6 PANEL UNIFORMITY

Irregular panel shapes interfere with stress levels over goaf edge pillars, sometimes resulting in inconsistent or unpredictable goaf formation.

Once a complete cave has been established, that goaf width should be maintained to ensure regular, controlled caving.

A continuous, open goaf edge should be maintained wherever possible once caving has been initiated, as caving of an open-ended cantilever is far more predictable and controllable than initiating the primary goaf fall.

2.7 FENDERS

2.7.1 MAXIMUM FENDER WIDTH

a) WITHOUT RADIO REMOTE CONTROL

Suggested width is such that the miner driver does not go beyond the rib line.

Venturing beyond the rib line will involve erecting support in the lift which is potentially hazardous and the setting of these supports slows the extraction rate. The issue of rib spall becomes more critical when the miner driver proceeds beyond the rib line.

It should be noted that excessive fender width may slow the extraction process down to such an extent that time-dependent deterioration occurs at the outbye end of the split and fender.

b) WITH RADIO REMOTE CONTROL

Suggested width is such that no operator is under unsupported roof.

Issues to be considered are the position of machine operator and other face workers. How will the machine be recovered if power trips etc?

2.7.2 MINIMUM FENDER WIDTH

It is suggested that minimum fender width be 5m or w/h ratio of at least 2, whichever is the greater. It must be recognised that once below a certain width, coal fenders have little effective stiffness and will crush out when loaded. If a large fall were to occur on an excessively small fender, the fender would yield, thus putting the working split effectively in the goaf.

2.8 GOAF EDGE STRAIGHTNESS

It is suggested that the goaf edge be maintained as straight as possible, perpendicular to the direction of retreat. Where preformed pillars are being extracted, it is recommended that one pillar be extracted at a time.

Where more than one goaf line abuts onto a panel of standing pillars to be extracted, consideration should be given to the additional loads acting on pillars influenced by the intersection of these goaves. See Figure 2.1.

Where three (3) goaf lines abut onto a panel of standing pillars to be extracted, it is strongly recommended that consideration be given to protecting the standing pillars from abutment pressures by having barrier (or interpanel) pillars between the standing pillars and the additional goaf edges. For example successful layouts are shown on Figures 2.2 and 2.3.

Avoid arrow head layouts as depicted in Figures 2.4 and 2.5.

The problem with goaf lines lagging back into the goaf is that this may induce a goaf fall to over-run the working face, which is lagging into the goaf, and cause roof failure in areas outbye the working face.

Where an existing goaf edge is irregular, consideration should be given to leaving some coal in order to maintain a constant panel width.

2.9 COAL LEFT IN GOAF

Any coal left in the goaf may hold up the roof and delay caving. In particular, large stooks left can behave as small pillars due to excessive w/h ratios relative to their loading, which then prevent them being crushed out as intended. The caving process becomes extremely unpredictable due to the loading distributions on these stooks, which are then susceptible to sudden failure as a result of minor loading changes. In some cases the stooks can lead to incomplete caving which generates excessive loading on the surrounding solid coal area. Recent information suggests that even quite small stooks of <20m^2 can slow down roof caving by several hours, particularly under a sandstone roof, and particularly at shallow depths where stook loading is minimal.

Therefore as much coal as possible should be extracted consistent with safe extraction principles (e.g. fender size and support rules).

If large stooks do remain and inhibit caving, their presence and impact on caving needs to be known by colliery management who must be prepared to modify extraction plans and, if necessary, leave a row of effective barrier pillars and commence a new goaf line outbye.

Shape and size details of remnant stooks should be part of standard pillar extraction reporting on a shift by shift basis. This information should be used in the ongoing review of the extraction process.

Where standing pillars are being extracted, pillar dimensions may be such that, formation of a fender less than the minimum dimension could occur. In this case consideration should be given to either:-

i) forming this fender on the inbye end of the pillar being extracted and leaving it unmined, (providing it will crush out) as shown in Figure 2.6(a) or

ii) dividing the fender dimension equally onto other fenders and leaving that extra coal unmined, as shown in Figure 2.6(b).

2.10 PRE-SPLITTING OF STANDING PILLARS NEAR THE GOAF EDGE

As previously demonstrated in section 1.2, a rock of given area will deform (strain) when load (stress) is applied to it. If however the load remained constant, but the load bearing area of the rock were reduced, then the rock would deform much more than it originally did. This principle applies directly to pillar splitting.

Pre-splitting of pillars can markedly reduce the confining core of the pillars, that is, their load bearing area. The load that the strata applies onto the pre-split pillar remains constant, hence pre-split pillars will compress (deform) much more than the original pillar. Such movement may be measured in centimetres only but it can be sufficient to weaken joint, bedding planes etc. and help reduce strata integrity at the goaf edge.

Where relatively small pillars are pre-split the compression of the pre-split pillars may result in excessive rib spall, further reducing these pillars ability to accept goaf loading. The end result can be a less competent mining system with respect to control of the goaf edge and roof near the goaf edge.

Therefore splitting of pillars outbye the extraction line should be delayed until as late as practical in the extraction process and the number of such splits should be kept to a minimum.

2.11 ROADWAY AND SPLIT SUPPORT

2.11.1 WIDTH - wherever possible these should be kept to a minimum. In old workings, roadway widths of 8m or more are not uncommon. Support in roadways must be consistent with physical conditions and likely loadings placed on the area during extraction.

2.11.2 BREAKER PROPS - whether they be timber or mechanised, provide a relatively low level of resistance to convergence of the immediate roof strata - they will not hold up the entire overlying goaf edge overburden sequence. That is the function of the surrounding pillars and solid coal.

Breaker props can generate small induced stresses in the roof strata and provide a fulcrum to assist in breaking off the immediate roof strata which is cantilevering out from above solid coal.

Timber breaker props can provide warning of impending goaf falls.

A discrete standard for breaker props must be set, including such matters as number of props per set, frequency of breaker sets and also minimum acceptable diameter.

2.11.3 LEAD IN TIMBER - support rules should include lead in support to tighten face areas up during extraction.

2.11.4 ROOF BOLT BREAKERLINES - there is evidence to suggest that roof bolt breakers can arrest feather edges where timber breakers may fail. In roof conditions subject to feather edging it is suggested that consideration be given to installing roof bolts and straps at inbye goaf edges to supplement timber breakers.

2.12 TAKING TOP AND BOTTOM COAL

Careful consideration must be given to how or if top and/or bottom coal are to be recovered during extraction. The extraction plan must consider the extra time spent in any area in order to remove tops or bottoms and the exposure of personnel to goaf edge conditions, e.g. location of workmen, and time and frequency spent at that location.

The issue of stook stability (w/h ratio) must be addressed when extra coal is removed, thus effectively reducing its capacity to bear load. The reliability of props set on canches is also an issue to be considered. As effective pillar height is increased problems with rib spall may become apparent. As discussed in section 1.2.3, the effective stiffness of a pillar reduces as height increases, resulting in greater convergence (or compression).

Taking of top or bottom coal must be seen as an integral part of an extraction process and catered for during design and sequencing. By significantly increasing the time required to extract any portion of coal, top or bottom coaling, also increases the likelihood of roof instability at the goaf edge.

2.13 LIFTING LEFT AND RIGHT

Generally this form of extraction is only considered when:-

i) the condition of the original access roadway to a pillar is so poor, that reclaiming the old road is impractical on both cost and mining parameters, or

ii) in a regular extraction sequence, positive goaf edge control can be maintained by the use of mobile breaker line supports.

Unless positive control of the goaf edge can be maintained this form of extraction is not recommended.

2.14 SHALLOW COVER

Section 1.2.7 has outlined the geotechnical principles associated with surface interaction and some of the likely consequences when such interaction occurs.

It is clearly important to know the depth of cover (rock head) above any panel, as accurately as possible (as well as type and variability of rock material).

The risk of a sudden, unpredictable goaf collapse is considerably increased with shallow cover. These collapses occur with virtually no warning and are therefore regarded as uncontrolled.

The increased level of unpredictability in goaf caving with shallow cover must be taken into account in terms of panel layout, operational procedures and discipline. It is also essential to minimise the number of new goaf formations (which is when the maximum unpredictability in caving occurs), by establishing one goaf. Having established that goaf it is vital to maintain good caving conditions which allow the overburden strata to fail as controlled, open-ended cantilever beams.

2.15 FEATHER EDGES

The phenomenon of feather edge roof failures in headings running perpendicularly into a goaf is a characteristic, generally, of massive (not necessarily strong) roof strata types. There is also some evidence that feather edge failures are prone to occur at depths <50m. In these cases the roof strata bridging across pillars and stooks extends up to the ground surface assisting some form of blocky caving mechanism.

Feather edging is a phenomenon that is not yet fully understood, although a range of theories has been postulated. The evidence suggests it is a function of bending mechanisms and stress distribution. The relative effects of stress initiation, and geological contribution, can also be factors.

It warrants caution and effort to develop greater understanding. Any operation with massive immediate roof (sandstone, conglomerate etc.) should be conscious of it, both in terms of placement of men, and steps to provide additional goaf edge support. (Refer to section 2.11.4).

2.16 HIGHLIGHTING OF ROOF STRATA ANOMALIES

Where it is possible to trace features in the roof strata, stonedust should not be applied to the roof and the feature(s) highlighted by painting. Position and trend are then readily apparent to all officials and workmen. The potential influence of these features can be continuously assessed.

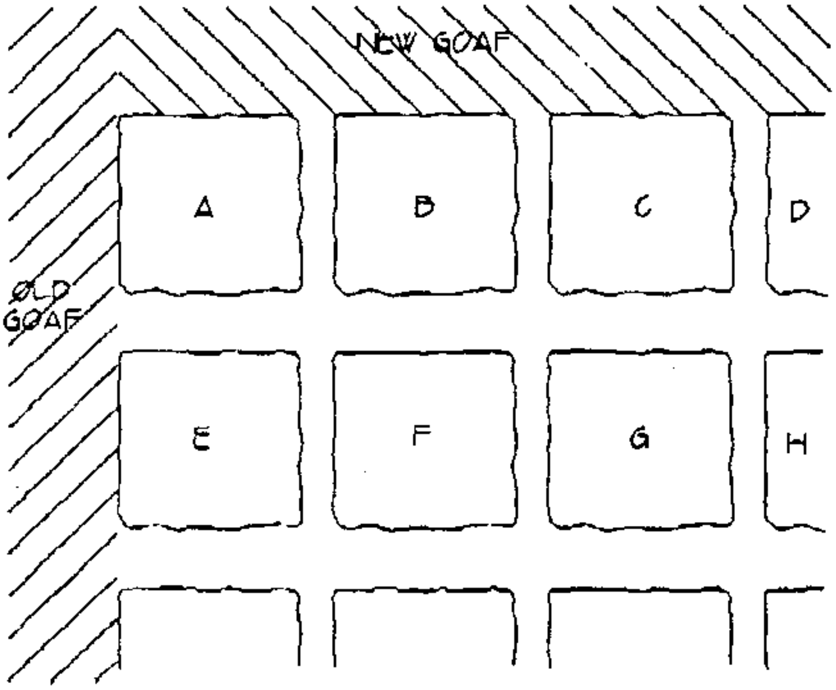


FIGURE 2.1(a)

PILLAR "A" ESPECIALLY SUBJECT TO ADDITIONAL LOAD

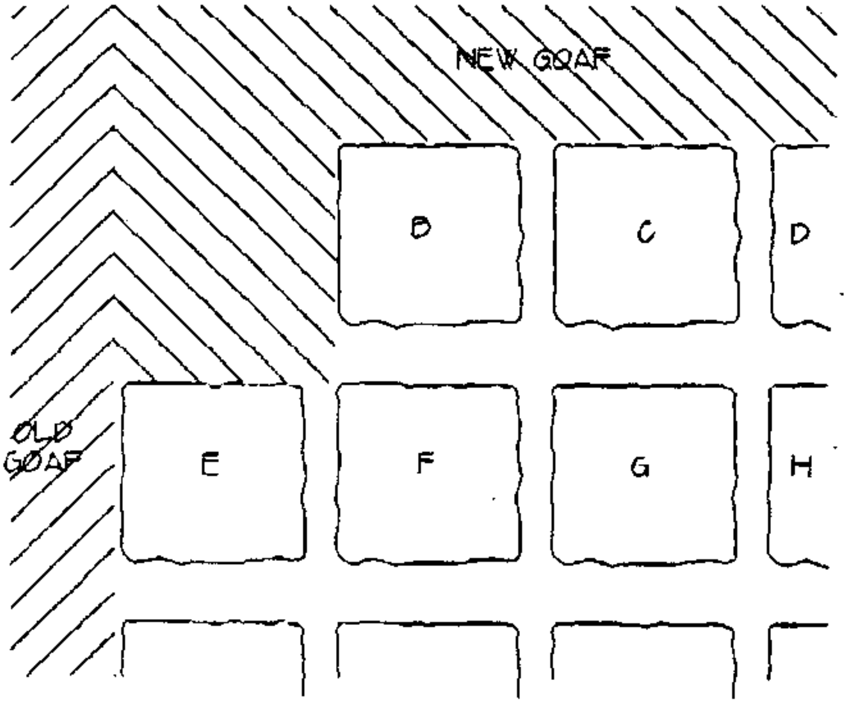


FIGURE 2.1(b)

PILLAR 'A' REMOVED

PILLARS 'B' & 'E' SUBJECT TO ADDITIONAL LOAD

NOT TO SCALE

FIGURE 2.1

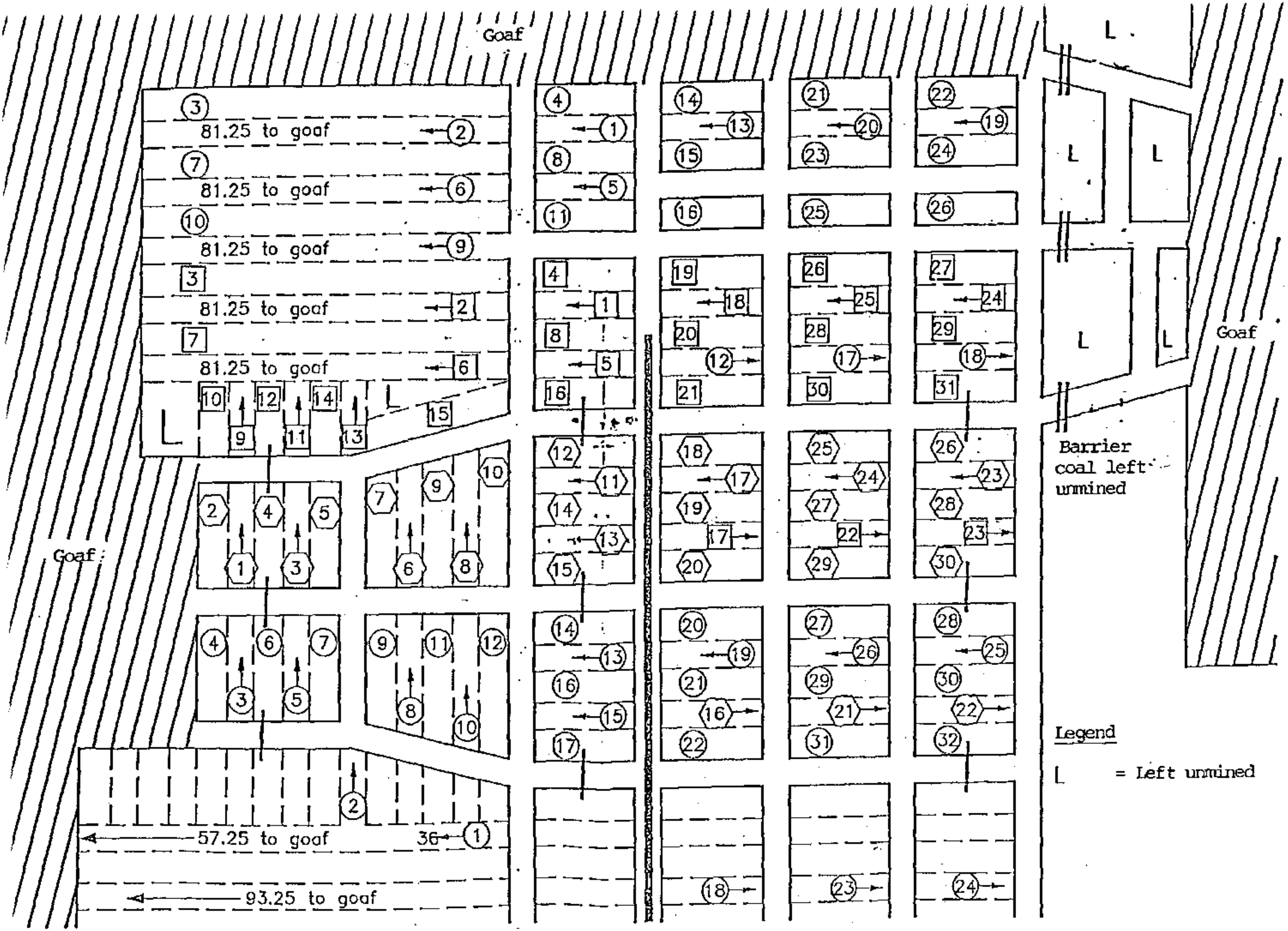

Goaf
Goaf
Goaf
81.25 to goaf
81.25 to goaf
81.25 to goaf
81.25 to goaf
81.25 to goaf
57.25 to goaf
36
93.25 to goaf
Barrier coal left unmined
L
Legend
L = Left unmined

FIGURE 2.2

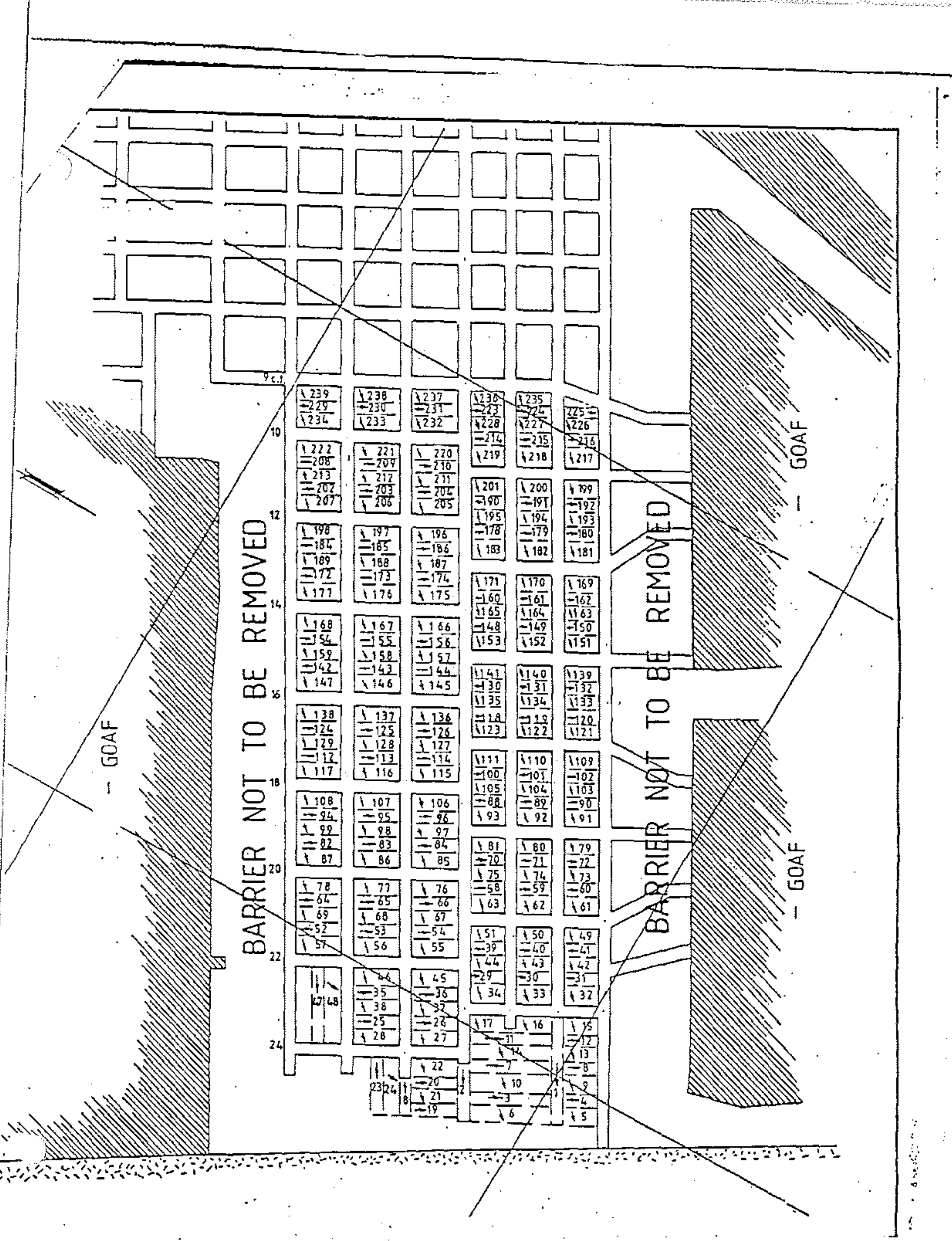
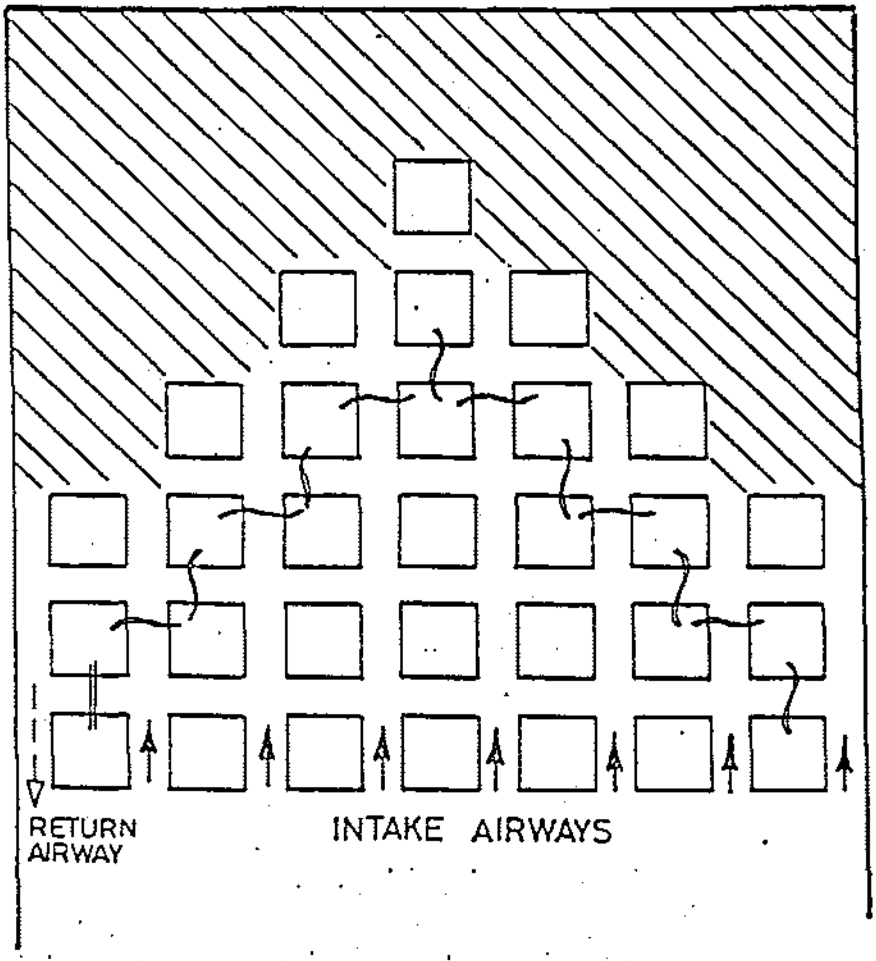
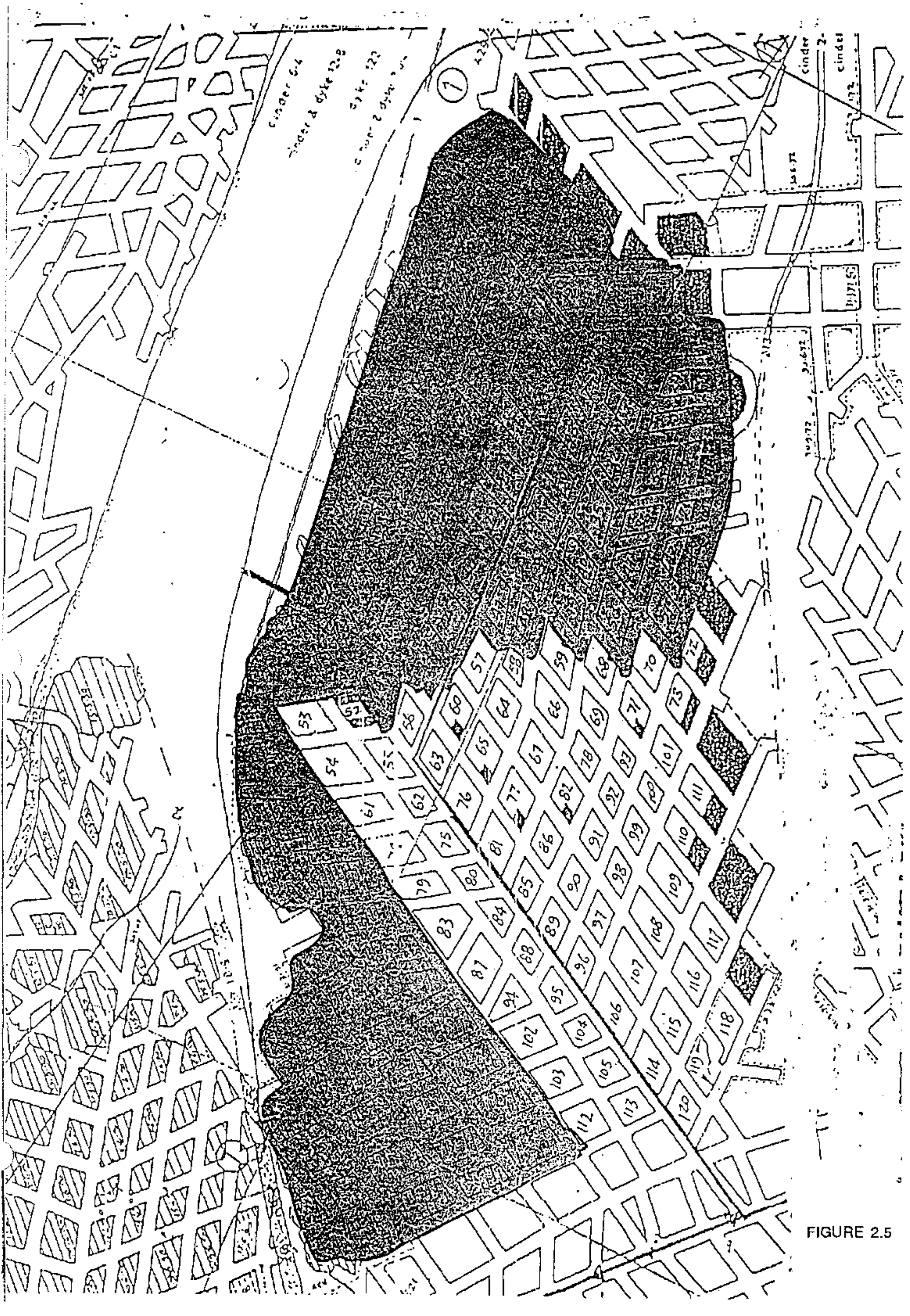

BARRIER NOT TO BE REMOVED
BARRIER NOT TO BE REMOVED
GOAF
GOAF
GOAF

FIGURE 2.3



PILLAR EXTRACTION SEQUENCE - ARROWHEAD

FIGURE 2.4


cinder 6.4
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dyke 12.2
cinder & dyke
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FIGURE 2.5

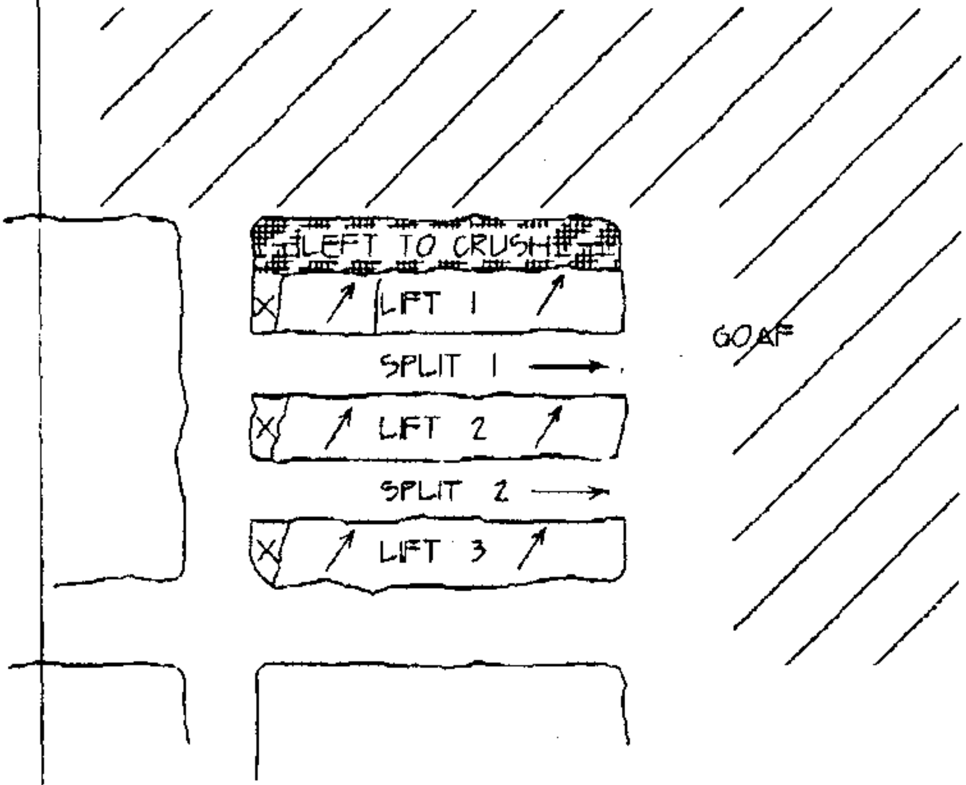

FIGURE 2.6A

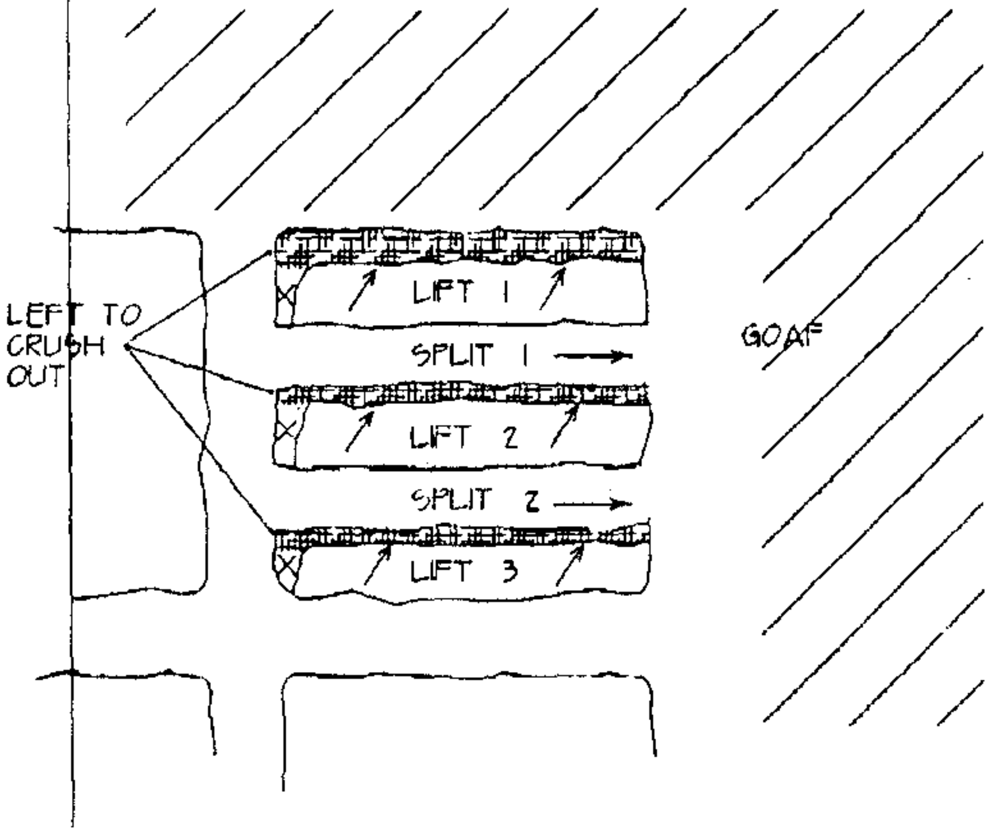

FIGURE 2.6B

NOT TO SCALE

CHAPTER 3

DATA COLLECTION

3.1 INTRODUCTION

Before any design process can commence it is essential that the planner has a detailed knowledge of the environment within which the extraction operation is to operate.

Information collection can be based on exploration or geotechnical methods e.g. surface or underground boreholes, or actual mine observations, e.g. underground surveys, inspections.

All sources of information are important and the knowledge and experience gained at neighbouring collieries can be particularly useful.

It is recommended that the following information be sought prior to extraction design:

3.2 REGIONAL DATA COLLECTION

(a) SEAM DEPTH - including variations across the proposed extraction area and also along its length.

(b) SEAM THICKNESS - including significant variations

(c) UPPER STRATA CHARACTERISTICS

Strata type, thickness, strength and structural integrity.

(d) IMMEDIATE ROOF STRATA - up to 20m above the seam

Strata type, thickness, strength and structural integrity (including microfracturing or laminations), and effect of time and weathering on above.

(e) IMMEDIATE FLOOR STRATA - up to 10m below the seam

Strata type, thickness, strength and structural integrity (including microfracturing or laminations), and effect of time and weathering on above.

(f) COAL

Strength, thickness, structural integrity:

- Joints
- Cleats
- Banding
- Soft bands
- Stone bands
- Rib spall caused by bands

Nature of roof/floor contacts, floor structure contours

(g) REGIONAL GEOLOGY

Faults

- type
- throw
- direction

Dykes

- nature
- thickness
- direction

Channels/Washouts

Non-Conformities

Dip

- direction
- rate

Rapid depth changes due to surface Topography

Waterbodies

3.3 OPERATION SPECIFIC DATA COLLECTION

The following issues apply to all pillar extraction operations, however for the extraction of old standing pillars a high level of confidence is required and items 3.3.1 - 3.3.6 inclusive are of crucial importance.

3.3.1 RELIABILITY OF EXISTING PLANS

An assessment must be made of veracity and completeness of information shown on existing plans, e.g. are all roadways shown. Any deficiencies highlighted must be completely addressed and an up to date and accurate plan employed for extraction design.

3.3.2 EXISTING PILLAR AND ROADWAY LAYOUT

It is extremely important during the design phase to have an accurate layout of existing pillars. Precise pillar shape and dimensions are fundamental to enable a proper extraction sequence to be developed. The width of roadways surrounding pillars is also particularly important to the designer. Unless the shape and dimension of pillar and roadway widths can be guaranteed to 500mm a re-survey of the existing workings will need to be undertaken.

3.3.3 EXISTING SUPPORTS - ROOF AND RIB

All existing pillar areas should have been supported, to some extent, during development. This support may have been considered adequate for first workings but support type and density need to be re-assessed prior to pillar extraction commencing. During this re-assessment the reliability of existing support needs to be assessed to determine if -

1) it was adequate in the first instance

2) it is still functioning effectively

3) it is adequate for pillar extraction.

3.3.4 EXISTING STABILITY

A critical assessment must be made of existing stability of pillars, intersections and roadways in the subject area.

Pillar strength needs to be evaluated taking into account:

- effective size of the pillars and roadways
- loads acting on pillars, especially abutment loads adjacent to goaf edges
- the possibility of high pillar abutment loads induced by extraction initiating a pillar collapse "run" outbye the working face.

Intersections and Roadways require evaluation in terms of:

- loss of strength over time
- deterioration of existing jointing planes etc.
- size and shape
- signs of intersection sag which is an indication of bed separation. (In this case consideration has to be given to the effectiveness of support measures chosen.)
- floor stability

3.3.5 GEOLOGICAL FEATURES

The underground location, magnitude, nature and direction of all geological features needs to be established. From this information the impact of these features on Pillar Extraction operations can be evaluated and an appropriate system for supporting and working around such anomalies can be developed.

3.3.6 PREVIOUS TOTAL EXTRACTION EXPERIENCE

Previous behaviour of strata around goaf areas can be invaluable in estimating the likely behaviour of future extraction workings. Therefore a thorough compilation of total extraction experience needs to be prepared and should include such items as:-

- critical goaf span to induce caving
- goaf edge behaviour e.g. feathering
- goaf edge support requirements
- stook and fender behaviour
- seam and immediate roof/floor behaviour
- frequency and spans of goaf falls
- expression of surface subsidence (stepping may indicate plug failures)

3.3.7 INFLUENCE OF OTHER SEAM WORKINGS

Workings in other seams can interact if they are in close proximity to the active seam. This can result in high stress concentrations, pillar punching of floor or roof strata and in unpredictable goaf behaviour. Apart from these concerns the issues of gas and/or water accumulations migrating to the active seam must also be considered.

3.3.8 IMPACT OF MINING CONSTRAINTS ON THE EXTRACTION

The following matters all have the potential to influence the manner of extraction.

- gas liberation
- liability to spontaneous combustion
- ventilation method
- windblasts
- water inflows

Close consideration of the potential impact of these mining constraints needs to be made when deciding upon an appropriate extraction layout. For example, internal coal barriers may be necessary for a seam liable to spontaneous combustion. The impact of these barriers on goaf formation must be included in the extraction design.

3.3.9 TYPE OF EQUIPMENT AVAILABLE

The type and size of equipment available can impact on overall panel layout including -

> pillar shape, fender size, roadway width, breakaway angles, rib stability.

Whilst not specifically addressed within the above areas it is recognised that constraints on underground mining may be imposed by surface subsidence limitations. These constraints need to be addressed and assessed in a similar manner to matters outlined in Section 3.3.8.

CHAPTER 4

IMPLEMENTATION

4.1 INTRODUCTION

Once developed, it is essential that the plan be implemented in such a manner that design objectives are fully achieved. Implementation is heavily dependent upon the commitment to and understanding of the plan by workmen and supervisors. The following issues need to be addressed for successful implementation of the plan.

4.2 SKILLS AUDIT OF EMPLOYEES

Selection of deputies and workmen, for pillar extraction operations should be based on experience, training and previous performance. The potential hazards involved in pillar extraction must be balanced by the capability of persons extracting pillars.

4.3 TRAINING/COMMUNICATION

It is vital that employees involved in pillar extraction are fully conversant with the plan and their role in implementing the plan.

4.3.1 STRUCTURED OVERVIEW OF THE PLAN AND ITS DESIGN

Persons involved in implementing the plan must be made aware of the critical design issues addressed and the basic principles employed. Extra training must be given to officials charged with the responsibility of approving variations to the original plan. These officials must be in a position to comprehend the significance of any variation they allow.

Pre-mining training sessions structured to cater for the needs of:

- Undermanagers
- Deputies
- Workmen

should be established. On-going training for alternations, additions and deletions to the plan (for successive extraction panels) should also be established.

4.3.2 PROCEDURES GOVERNING CHANGES TO APPROVED PLAN

Procedures outlined in section 5.3 need to be clearly defined prior to extraction commencing.

4.4 POSTING OF EXTRACTION PLANS

In addition to the requirements of the C.M.R.A. 1982 arrangements must be established to cater for replacing and up-dating plans as and when required.

CHAPTER 5

CONTROL

5.1 INTRODUCTION

Control of the extraction operation is essential to ensure that:-

1. The plan is practiced as designed, and
2. Physical conditions, at and around the face are carefully observed and any deviation from expected behaviour is promptly communicated to all appropriate personnel.

The following issues need to be addressed for successful control of the plan.

5.2 SUPERVISION

5.2.1 INSPECTION FREQUENCY

5.2.1.1 Deputies

Inspection frequency for deputies controlling mining operations are specified within the Coal Mines Regulation Act - Managers and Officials Regulation.

5.2.1.2 Undermanagers

Inspection frequency for undermanagers, responsible for supervising pillar extraction operations,, should be consistent with the appropriate provisions within the Coal Mines Regulation Act - Managers and Officials Regulations. It is recommended that over a 24 hour period of continuous pillar extraction, the operation be inspected at least once by an undermanager.

5.2.1.3 Manager, Deputy Manager, Undermanager-in-Charge

Inspection frequency of pillar extraction operations by these officials should be consistent with the appropriate provisions within the Coal Mines Regulation Act - Managers and Officials Regulation.

It is recommended that at least one of these officials inspect every pillar extraction operation at the colliery at least once every week.

5.2.2 INSPECTION PURPOSE

Any requirement within this section is in addition to that specified within the Coal Mines Regulation Act 1982.

5.2.2.1 Deputies

The prime purpose for control by face deputies is to monitor and observe extraction operations and then provide an accurate report of details encountered and knowledge gained during each shift.

This detail and knowledge must be then transferred to oncoming deputies and other senior mining officials. Formal reporting of this knowledge is essential. Verbal communication between deputies is to be encouraged. It is recommended that formal reporting, either by a specific report or within an existing statutory report, include these matters:-

- goaf falls - number, time, size
- geology encountered during shift
- nature, location and size
- weightings - when and where
- evidence of breakers being overridden.

5.2.2.2 Undermanagers

Inspections by undermanagers have four purposes:-

1) To audit actual face operations against the approved plan,

2) to monitor panel conditions with a view to pre-empting mining problems and thereby limiting the need for on-the-spot variations to the approved plan,

3) to develop an understanding of Pillar Extraction behaviour and thereby recommend, if necessary, any variations in future pillar extraction planning and,

4) to report to more senior mining officials instances where all design conditions are complied with, but nevertheless, goaf behaviour is not as planned.

5.2.2.3 Managers, Deputy Managers, Undermanagers-in-Charge

Inspections by these officials have the purpose of auditing face operations against the approved plan as well as monitoring the overall effectiveness of the plan.

5.3 VARIATION TO THE APPROVED PLAN

5.3.1 WHEN

The approved plan should only be altered where continued compliance with that plan would:-

1) create an unsafe situation

or 2) create conditions which make further mining impractical.

5.3.2 WHO AND HOW

The decision to alter the approved plan must not be left to the sole discretion of the face deputy, but must be made by at least an Undermanager after an on-site inspection.

Where a variation in plan has been decided upon by an undermanager, then inspections on a shift by shift basis must be made by on-coming undermanagers until at least the undermanager-in-charge has reviewed that variation.

Should the need for a variation to the plan be pre-empted and approved by the undermanager-in-charge or a higher mining official, then that alternation can be implemented when required without an onsite inspection of an undermanager.

The deputy must continue to have the right to stop an operation or withdraw machinery if, based on his judgement, continued mining would create an unsafe condition. If such a decision leads to the need for a variation to the approved plan then production should not re-commence until at least an undermanager has inspected the site.

5.3.2.1 Review of Variation Decision

Once a variation to the approved plan has been made an overall review of the modified sequence must be conducted by either the Manager, Deputy Manager or Undermanager in Charge with the aim of:-

1) Determining if the variation was justified.

2) Determining the effect of the variation on:-
   a) the immediate sequence
   b) the general extraction plan
   c) future mine planning.

5.3.3 COMMUNICATION OF CHANGES TO THE PLAN

The manager must establish processes to cater for:-

1) prompt amendments to be made on all appropriate plans.

2) communication, in writing, to other appropriate mining officials outlining the reasons for the change to plan.

3) documentation of all changes in a central register for optimizing future mine planning and for general reference.

5.3.4 UNWARRANTED DEVIATIONS TO THE APPROVED PLAN

If, during an audit inspection conducted by a mining official senior to a deputy, it is found that an unapproved/unwarranted variation has been made to the plan then this fact must be brought to the attention of either the Manager, Deputy Manager or Undermanager-in-charge, as soon as is practicable and an assessment made of the impact the variation may have on:-

a) the immediate sequence
b) the general extraction plan
c) future mine planning.

The issue of disciplinary action is left to the discretion of the Colliery Manager.

CHAPTER 6

REVIEW

6.1 INTRODUCTION

An essential element in the management of pillar extraction is the review process. Reviewing the impact of events, changes and performance are essential to modify and optimise the design of pillar extraction plans for both immediate and future workings.

It is recommended that a review process be established to scrutinize the plan whenever the following issues arise:

6.2 UNPLANNED INCIDENTS

These are unexpected incidents that occur when extraction is taking place within the parameters of the approved plan.

Examples of such events are:-

1) Buried continuous miners
2) Excessive or unusual floor heave
3) Creation of a "feather edge"
4) Excessive or unusual rib crush
5) Serious injury to a workman.

6.3 VARIATION TO THE APPROVED PLAN

As mentioned in Sections 5.3.1 and 5.3.4, reviews of approved or unwarranted variations of plan must be made to determine the effect such variations may have on:-

a) the immediate sequence
b) the general extraction plan
c) future mine planning.

6.4 ROUTINE REVIEW

Regular and on-going appraisal of the extraction plan, especially when standing pillars are being worked, should be made with a view to pre-empt problems and to refine the extraction process for subsequent panels at the colliery.

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CHAPTER 7

BREAKER LINE SUPPORTS

7.1 INTRODUCTION

Breaker Line Supports (BLS) were introduced into pillar extraction in New South Wales during the 1980's. Their initial introduction was aimed at achieving three targets:-

a) IMPROVED SAFETY

By providing greater support at the goaf edge, fewer falls would flush into the work place, thus reducing the risk to workmen and also reducing the number of continuous miners buried.

It was also hoped that much less timber would be used therefore reducing the number of slips, trips and strains to workmen associated with the transport and placement of timber.

b) INCREASED PRODUCTION

By mechanising goaf edge control, the fluency of mining would increase, allowing for a greater proportion of cutting time.

Less production would be lost from down time associated with recovery of buried machines.

c) REDUCED COSTS

A reduction in timber consumption and better utilisation of support labour would result in cost savings.

A saving in repair costs to damaged continuous miners should occur.

Increased safety should result in savings on insurance premiums.

Industry wide statistics have not been kept on the performance of BLS, however anecdotal evidence from workmen and Colliery Managers suggests that positive gains have been made in all three target areas.

To date over ten collieries have employed BLS whilst extracting pillars.

Use of BLS is also consistent with the Chief Inspector of Coal Mines philosophy that....

> *"By the year 2000, all workmen associated with the extraction of coal pillars will be protected by a barrier between their work place and the goaf..."*

It is therefore likely that increased usage of BLS will occur in the future.

The purpose of this chapter is to collate experience gained to date with BLS and hence provide a knowledge base for the design of future BLS operations.

7.2 STRATA CONTROL AT THE GOAF EDGE

Experience has shown that whilst BLS can improve face safety they do not eliminate buried continuous miners, indeed there are several instances where BLS have been buried (some irretrievably). To understand why BLS are being buried it is necessary to consider the mechanisms controlling goaf edge behaviour.

7.2.1 ROLE OF FENDERS

Control of strata cantilevering out into the goaf is determined by goaf edge pillars and goaf edge fender. Fig. 7.1a shows a typical extraction cross-section, where the goaf is hanging up prior to caving. Fig. 7.1b shows a simplified concept of the forces involved.

The outbye coal pillar, if designed to be stable, acts effectively as a rigid clamp on the beam.

This clamp is sufficiently strong as to prevent movement of the beam.

The overhanging strata is represented by the beam, whilst the weight on the beam represents goaf loading on the strata.

The fender is represented by a static support under the beam between the clamp and the weight.

The weight (goaf load) is bending the beam (overhanging strata). As mining progresses the cantilevered beam will ultimately reach a point where it will be so loaded that it will fail.

Provided the static support is sufficiently large the beam should break at point A (Fig. 7.lb). If the static support is inadequate, that is, the fender collapses, and deflects under the beams cantilevering action, the beam may fail at point B (Fig. 7.1b). If the clamp were to slip as well that is, a goaf edge pillar collapse, failure could occur as far back as point C (Fig. 7.1b). Referring back to Fig. 7.1a, it becomes obvious that control of the goaf depends heavily on:

1) Stable pillars
and 2) Adequately Dimensioned Fenders.

Generally speaking pillar size in New South Wales Coal Mines are of such dimension as to ensure stability in the majority of cases. Therefore design of the fender becomes the critical element in goaf edge control.

7.2.2 ROLE OF BLS

When compared to a stable coal fender, BLS carry relatively low loads. Hence BLS can only be expected to control a small portion of the goaf, such as an area shown on Fig. 7.2a.

It is the fender and immediate outbye pillar that govern overall goaf edge stability. Should the fender fail, BLS will be inadequate to prevent goaf flushing into the working face and fender roadway.

Fig. 7.2b illustrates a typical goaf break line, highlighting the influence of BLS. By acting as a positive support to the roof (adjacent to the fender) BLS effectively push the goaf break line away from the face.

7.3 LESSONS LEARNT FROM OPERATING BLS

7.3.1 PROXIMITY TO THE CONTINUOUS MINER AND FENDER

If BLS are to achieve maximum impact they need to be as close as possible to the fender and continuous miner, thereby reducing the span of roof the BLS need to control. In this position BLS are working within the "shadow" of the fender. The further BLS lag back along the split, the greater load they will be subjected to. Deflection of the roof will occur as the BLS accept this load. The greater the deflection, the greater the risk of a fall extending above or ahead of the BLS.

This potential danger is at its greatest when the final lifts are being taken from a fender. Fig. 7.3a illustrates the spans required to be supported during normal lifting whilst Fig. 7.3b shows significantly greater spans developed whilst the last lift of a fender is being mined.

EXAMPLE

Fig. 7.4, taken from an overseas Colliery, illustrates a goaf collapse which buried three BLS. Significant factors in the incident were considered to be:-

a) The BLS were not staggered, and
b) The BLS were 3 - 5m distant from the continuous miner

KEYPOINT - KEEP BLS AS CLOSE AS POSSIBLE TO THE FENDER AND CONTINUOUS MINER AT ALL TIMES

7.3.2 BLS ADVANCE

7.3.2.1 ADVANCE DISTANCE

Most operations limit BLS advance to 2m (or approximately 1/2 chock advance) for any cycle. In poor roof conditions even these distances may be reduced. Where roof conditions are good (massive sandstone) and overall loads from the goaf are considered low, a limited number of operations allow 4m (or approximately 1 chock advance) for any cycle.

KEYPOINT - LIMIT BLS ADVANCE TO SUIT ROOF CONDITIONS.

7.3.2.2 ADVANCE SEQUENCE

Advancing BLS in a sequence different from that specified can affect the manner of support to the roof and may lead to unpredictable strata collapses.

KEYPOINT - DON'T ADVANCE BLS OUT OF SEQUENCE.

7.3.3 BLS POSITIONING

To fully utilize the potential of BLS most operations involve lifting both sides of a split. Fig. 7.5a illustrates a typical layout. If 9m fenders are formed then the span from the goaf edge to the outbye fender line would be around 23 - 24m. With these spans there is the potential for goaf flushing around the BLS, onto the miner and into the workplace. To counter this hazard BLS are "spread" out from the confines of the split and positioned into the lifts for some distance. Maximum separation between supports is generally 1.5 - 2.0m as shown onFig. 7.5b. Separation distances are primarily a function of fender widths e.g.

- 9m fenders may have 2m BLS separation.
- 6.5m fenders may have 1m BLS separation.

A potential danger with spreading BLS is that their areas of support influence may cease to overlap, greatly reducing their effectiveness.

The middle BLS is generally located on the split centre line, whilst flanking supports are located at varying distances into the fender. Positioning of the flanking BLS is related to either the fender rib line or the closest roof support to the rib line.

Despite these precautions flanking BLS are occasionally buried by goaf material. Recovery can be difficult if the BLS is at right angles to the fender as shown onFig. 7.5b. Some collieries address this difficulty by angling their flanking BLS to allow for "straighter pull" during recovery as shown in Fig. 7.5c.

Similar issues need to be considered when lifting only to one side of a lift as shown on Fig. 7.5d.

KEYPOINT - WHEN LIFTING BOTH SIDES FROM A SPLIT BLS MAY BE SPREAD TO PROVIDE MAXIMUM GOAF EDGE PROTECTION BUT MUST REMAIN CLOSE ENOUGH TOGETHER TO PROVIDE MUTUAL SUPPORT.

7.3.4 WEAKENING STOOK "X"

Extraction designed around 8 - 10 m wide fenders, results in relatively large final stooks (stook X). Whilst these larger and stronger stooks assist in maintaining temporary stability near fender ends and intersections, they may delay caving.

Careful use of BLS may permit the weakening of these stooks, in a controlled manner, allowing for early and consistent goaf formation.

Fig 7.6 illustrates a method used for weakening final stooks.

KEYPOINT - REDUCTION OF LARGE FINAL STOOKS IS POSSIBLE USING BLS.

7.3.5 BLS HYDRAULICS

7.3.5.1 OPERATING PRESSURES

If BLS operating pressures are excessive for the environment they work in then it is possible for the following problems to occur:-

i) Strata may be fractured by the BLS punching into the roof, thus reducing strata integrity at the face and increasing the potential for falls ahead of the BLS.

ii) Rapid destruction of roof bolt heads which then can act as projectiles endangering workmen.

EXAMPLE BLS operating pressure of 380bar at 400m depth of cover had to be reduced to 200bar when depth of cover reduced to less than 100m.

KEYPOINT - MATCH OPERATING PRESSURES TO THE IMMEDIATE ENVIRONMENT.

7.3.5.2 HYDRAULIC PERFORMANCE

Just as longwall support performance is a function of hydraulic efficiency, so BLS need to be properly maintained and tested to ensure that actual support performance meets design expectations.

KEYPOINT - MAINTAIN HYDRAULIC SYSTEMS.

7.3.5.3 USING BLS PRESSURE GAUGES TO PREDICT GOAF FALLS

Where the immediate roof is massive some operators claim to have been able to predict goaf collapses by monitoring the rise in pressure on BLS pressure gauges.

Massive strata has the ability to cantilever, as a single beam, from the goaf edge out into the goaf. As the strata is stiff, only small deflections occur before failure but these deflections occur along the length of the beam. This small amount of movement translates to extra load on BLS leading to increased BLS leg pressure.

Where the immediate roof is laminated and/or jointed, there is no correlation between goaf behaviour and BLS leg pressures.

KEYPOINT - BLS PRESSURE GAUGES, MAY UNDER CERTAIN CONDITIONS, WARN OF IMPENDING GOAF FALLS.

7.4 MINING AND SAFETY ISSUES

7.4.1 PRE-SPLITTING OF PILLARS

Due to operational problems and delays in installing and flitting BLS, efficient extraction is often achieved from long splits.

Where standing pillars are being extracted there is the temptation to pre-split across the entire panel and extract fenders from the end of each pillar. Reference to section 2.10 highlights the issues associated with this style of mining. Pre-splitting should be minimised and delayed as long as possible.

7.4.2 USE OF 2 OR 3 BLS

Where extraction is limited to one side of a split generally 2 BLS are used. Where extraction takes place on both sides of a split generally 3 BLS are used. A detailed examination of strata and BLS loads would need to be conducted prior to installing only 2 BLS when lifting both sides of a split.

7.4.3 LOCATION OF WORKMEN

Unlike longwalls, BLS do not provide designed walkways or riding compartments for workmen. It is common practice to establish rules or procedures whereby workmen are located away from the goaf edge in case goaf material flushes over or around BLS.

7.4.4 CONTROL OF FENDER DIMENSIONS

If extraction is occurring as shown on Fig. 7.5a, then the depth of extraction on the solid side needs to be carefully controlled. If the depth of extraction exceeds the design limit then the next goaf side will be less than design width. At least one continuous miner has been buried as a result of inadequate fender size, formed by excessive extraction of solid side coal.

REMEMBER - BLS, LIKE ALL MINING SYSTEMS, CAN FAIL WHEN INFLUENCED BY ADVERSE GEOLOGY.

EXAMPLE

Fig. 7.7 illustrates a tightly controlled BLS operation where very poor roof conditions led to burial of the continuous miner.

REMEMBER - BLS, LIKE ALL MINING SYSTEMS, CAN FAIL WHEN INFLUENCED BY UNAUTHORISED VARIATIONS TO THE APPROVED EXTRACTION PLAN.

EXAMPLE

Fig. 7.8 illustrates the consequences, when an unauthorised variation was made to recover "easy" coal from a pillar left to protect a fault.