SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

# SIMRAC

# Final Project Report

Title: MULTISEAM DESIGN PROCEDURES

Author/s: R W HILL

Research
Agency: CSIR : DIVISION OF MINING TECHNOLOGY

Project No.: COL 026

Date: FEBRUARY 1994

## CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# MULTISEAM DESIGN PROCEDURES

## 1 INTRODUCTION

Many collieries in South Africa contain more than one seam which is economical to mine. If the seams are in close vertical proximity stress concentrations may arise during mining, which can result in difficult mining conditions when subsequent seams are extracted and which may impose restrictions on layouts. Marketing constraints and coal quality have meant that from a strata control point of view the ideal sequence of mining in a descending order has been difficult to achieve.

In the Witbank area mining takes place in the No 1, No 2, No 4 and No 5 Seams. The No 2 and No 4 Seams are relatively thick and have average depths of 85 m and 64 m respectively. The No 2 Seam has been extensively mined by bord and pillar methods. The No 4 Seam has been mined on a small scale with pillar superimposition being carried out depending on the parting distance. To prevent subsidence and destruction of upper seams, especially the No 5 Seam, pillar extraction has not generally been carried out. In order to maximize reserves pillar extraction will become more common in the Witbank coalfields.

In Natal the seams are rarely thicker than 2 m and the average depth in many parts is in excess of 150 m. As many as four or five superincumbent seams have been exploited. Since the area produces high grade anthracite and coking coal, total extraction methods are common. Coal reserves are usually limited and it is quite common to mine in areas that have been previously under or over mined.

Several combinations of mining multiple seams have been tried. Multiseam mining has been carried out at many collieries in the past and continues to the present day. Multiseam mining is likely to continue since the current trend is for brownfield rather than greenfield expansion. Since 1976 guidelines have existed for bord and pillar layouts (Salamon and Oravecz, 1976). The guidelines were formulated from field investigations and finite element modelling. Although the guidelines have been used successfully since, they only apply to bord and pillar mining and do not consider total extraction methods.

Many other coal mining countries in the world have multiple seams which are economic to mine. Investigations into multiseam mining practice have been carried out in a number of countries particularly the United States, India, United Kingdom, and Australia

## 1.1 Safety Hazard in Multiseam Mining

Table 1.1 shows the potential safety hazards associated with different multiseam mining sequences and extraction methods.

Table 1.1 Safety Hazards in Multiseam Mining

| METHOD OF MINING | | SAFETY HAZARD |
|---|---|---|
| Upper (U) Seam | Lower (L) Seam | |
| B&P | B&P | Spalling on pillars and parting collapse if P is thin and no superimposition. |
| PE (2) | B&P (1) | Roof falls in L seam, parting collapse if P is thin. |
| B&P (2) | HE (1) | Tensile zones and spalling in U seam when mining oversolid/goaf boundaries. Floor collapse over incomplete goafs. High safety risk if P/h ratio low. |
| Remnant Pillar (1) | B&P (2) | Intersection collapse in L seam when mining under remnant from HE panels. |
| PE (1) | PE (1) | Simultaneous mining in both seams - roof falls in working area of L seam. |
| HE (1) | HE (2) | Preferred method of mining safety hazard minimal, except where remnant pillars exist and water in U seam. |

Key

| | | | |
|---|---|---|---|
| B&P | Bord and Pillar | | |
| PE | Pillar extraction | | |
| HE | High extraction pillar extraction or longwall | | |
| P | Parting | | |
| (1) | Seam mined first | (2) | Seam mined second |
| U | Upper Seam | L | Lower Seam |

## 2 OCCURANCE OF MULTIPLE SEAMS

The Springs-Witbank Coalfield covers an area from Brackpan and Springs in the west to Belfast in the east. It is currently the most important coalfield in the country.

There is an intense concentration of mines in the central portion of the coalfield. A typical section of strata is as follows.

| SEAM | SEAM THICKNESS (m) | PARTING THICKNESS (m) |
|---|---|---|
| 5 | 1,8 | 25 |
| 4 | 2,5 - 6,5 | 15 - 20 |
| 2 | 6,5 | 2 - 3 |
| 1 | 2,0 | |

High underground extraction techniques have been restricted due to the differing qualities of the seams. High extraction can usually be obtained with shallow bord and pillar workings especially in the No 4 and No 5 Seams. The effect of undermining these bord and pillar workings at a later date with high extraction methods is unknown. The longterm stability of subsided and partially damaged workings can not easily be determined.

The seams in the Natal coalfields are generally thin, but of high quality so that high extraction methods are practised. A section in the Paulpetersburg area is shown below.

| SEAM | SEAM THICKNESS (m) | PARTING THICKNESS (m) |
|---|---|---|
| Alfred | 2,4 | 5,0 |
| Gus | 0,76 | 9,0 |
| Dundas | 2,6 | 19,0 |
| Coking | 1,0 | |

In the Vryheid area the parting between the Alfred/Gus and Gus/Dundas is usually between 15 and 17 m. The Gus and the Dundas Seams have been extensively mined. The Alfred Seam was the least marketable in the past. New markets have seen recent mining of the Alfred Seam being carried out over lower seam goafs.

In the Dundee area the Top Seam and Bottom Seam are separated by a parting of about 1,5 m. Several methods of mining have been carried out:

(i) bord and pillar with subsequent pillar extraction of the composite seams

(ii) simultaneous stooping in each seam

(iii) mechanised longwall mining in each seam.

The Vereeniging-Sasolburg Coalfield contains three mineable seams in a 40 m thick zone. The No 1 Seam has been mined to a limited extent in the Sigma and Coalbrook areas but extensively in the Cornelia area. The No 2 Seam has been the most extensively mined. It is split into a 2A and 2B Seam. The No 3 Seam has not been extensively mined owing to coal quality and poor roof conditions. Three extraction methods have been used in the area:

(i) pillar extraction under a previous longwall panel
(ii) longwall mining under pillar extraction panels
(iii) longwall mining under previously mined longwall panels.

All methods have generally been successful, however in method (ii) problems can occur due to snooks being left in the upper seam and in (iii) the location of the gate roads is of importance. In all methods caution must be given to water lying in the top seam.

## 3 PREVIOUS RESEARCH CARRIED OUT INTO MULTISEAM MINING

### 3.1 South Africa

Until the mid 1960's there was no rational design procedure available in South Africa for multiseam bord and pillar design, and neither had any investigations into interaction problems been instigated. The first field investigation into double seam mining was in 1967 at Coalbrook Colliery (Oravecz, 1968). Observations were continued until 1972 to examine the long term effects of double seam bord and pillar mining (Oravecz, 1972). Further investigations carried out culminated in a set of guidelines for multiseam bord and pillar design (Salamon and Oravecz 1976). Whether pillars are superimposed or not depends on the parting distance (P) in relation to the pillar centre distance (C) and the bord width (b).

The guidelines are as follows:

If $P < (0,75\ C \text{ to } 1,00\ C)$ panel pillars to be superimposed
If $P > 2b$ pillars can be designed to a safety factor of 1,6
If the pillars must be superimposed a minimum safety factor of 1,7 is recommended
If $P < (0,3b \text{ to } 0,5b)$, mining adjacent seams will only be practical if the parting contains a reasonable proportion of sandstone.
If $P < (1,5b \text{ to } 2,0b)$ the possibility of parting failure should be considered. The safety factor of individual workings should be $>1,8$. The safety factor of hypothetical pillars with a height equal to the combined height of the workings should be $>1,4$.

These guidelines were formulated from finite element modelling after determining the distance at which the alternating influence of bord and pillars is negligibly small. This distance was determined as 0,75 to 1,00 C. The lower value is the general criteria used by collieries.

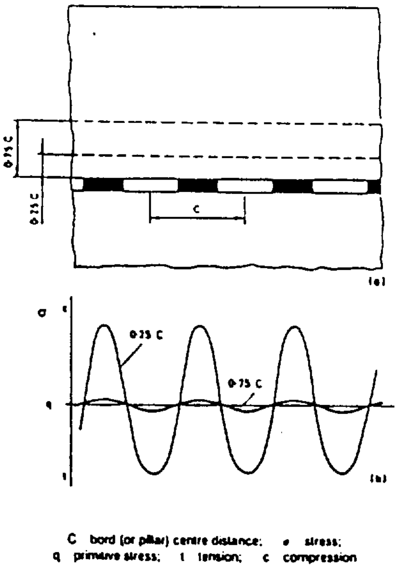


Figure 3.1 Stresses around Bord and Pillar workings (Salamon and Oravecz, 1976)

Bradbury and Lear (1984) investigated the validity of the superimposition criteria recommended by Salamon and Oravecz. Their investigation showed that the limiting distance at which stresses above or below bord and pillar workings return to primitive stress values decreases with depth and also with increased pillar size. For typical Khutala No 2 Seam conditions the limiting distance for the panel pillars is less than 0,7 C.

## 3.2 Other Coal Mining Countries

This review has been carried out by examining the literature pertaining to each country in turn, and has been limited to English language references only. Although it is known that multiseam mining occurs in many other locations, Eastern Europe and China for example, the paucity of references to non-English sources and the different geological conditions and mining methods justify this approach.

### 3.2.1 United States

Multiseam mining is common especially in the eastern US coalfields. It has been estimated (Webster et al,1984) that 156 of the 229 billion tons of coal reserves subject to underground extraction in the United States, are in areas where more than one mineable seam exists. Mine planning has been based on ease of access with little concern for ground control. Multiple ownership of seams has further complicated planning. The seam chosen for mining is usually the most accessible, has the best physical conditions and is the most marketable coal. Much research into multiseam strata control problems was carried out during the 1980's by three centres; Virginia Polytechnic Institute and State University, West Virginia University and the United States Bureau of Mines.

The first extensive review of the problems encountered in multiseam mining was by Stemple (1956). Many of the case studies reported have been used by later researchers.

Lazer (1965) documents observations made in the Pocahontas coalfields of southern West Virginia concerning mining seams above mined-out lower seams. Factors recognised as important in this situation were:

i) the structural characteristics and intervals between seams
ii) the method and care taken in mining, and
iii) the time elapsed following mining of either the upper or lower seams.

The partings between seams consist largely of shales, sandy shales and occasional beds of sandstone.

The conclusions from Lazer's observations were:

i) subsidence invariably occurs after complete mining - it extends to surface and is generally complete in two years

ii) an undeveloped upper seam can be mined successfully after a lower seam has been mined if the lower seam mining has been orderly and pillar extraction has been complete

iii) within normal limits the thickness of the lower mined out seam has little appreciable affect on the upper seam mining and the interval between the seams may be as little as 15 m

iv) if openings are first developed in an upper seam and then undermined, the openings in the upper seam will cave totally and the developed pillars will be lost

v) simultaneous and correlated mining with complete pillar recovery in vertical adjacent seams does not appear practical.

Peng and Chandra (1980) studied twenty West Virginia mining operations in multiple seams. It was recognised that exact quantitative specifications were not possible due to the varying geological conditions. Since pillar superimposition is a common method in multiseam design a model was developed of pressure interaction between superimposed pillars. Although stress transmitted to the pillars is uniform, the load transmitted to the floor is not. A high stress develops within the plane where the pillar meets the floor. This pressure decreases downwards and dissipates at a distance approximately four times the pillar width. According to Peng if the parting is less than eight times the pillar width the pressure contour lines interact with respect to two superimposed pillars.

From their findings, Peng and Chandra proposed the following guidelines:

i) if the parting is more than fifty times the larger of the expected mining heights, the interaction will be minimum

ii) extract multiple seams in descending order. If simultaneous extraction of several seams is necessary, the face of the upper seam should be kept ahead of the next lower seam such that it is out of the angle of draw from the lower seam

iii) pillar superimposition must be used in the development sections and over major long life entries

iv) if the interval between the seams is less than eight times the lesser dimensions of the pillars when they are superimposed the maximum possible stress should be determined for evaluating the integrity of the parting

v) remnant pillars should not be left behind in the goaf if mining is expected in the seams above and below. If remnant pillars are necessary, they should be uniformly distributed - not concentrated in one area. They should be small enough to gradually crush.

Haycocks et al (1981) list four major classes of ground control problems that can develop as a result of multiseam mining. Each of these must be avoided or minimised if optimum productivity is to be achieved. These problems are:

i) Pillar load transfer

Large pillars left in overlying seams may serve to concentrate stresses which can be transferred to workings below. The authors studied eighteen bord and pillar cases in the Appalachian region and found the maximum interactive distance was 33,5 m.

ii) Arching

The presence of a pressure arch and/or an abutment zone around a mine working was found to have two effects. Firstly, it forms a zone of high compressive stresses which can cause pillar and roof control problems. Secondly, a destressed zone may form which can be beneficial to mine openings.

iii) Subsidence

The main problems occur towards the edge of the subsidence trough where the strata is flexed. Both compressive and tensile stresses can exist which have been shown to have serious effects on roof stability.

iv) Interseam fracture

This is an alternative to the formation of a subsidence trough. Highly inclined shear or shear-tensile failures may develop which result in block movement of the ground to the excavation. The authors note that the mechanism is not understood.

The magnitude of stress at a given distance below a pillar can be calculated by means of the pressure bulb theory. The theoretical equations developed for soil mechanics tend to be inaccurate when applied to rocks. Ehgartner (1982) evaluated stress due to pillar loading using photoelastic models. It was found that the degree of layering had a significant influence on the size and shape of the pressure bulb below a remnant pillar. The relationship developed was

$$D = 2{,}07N + 16{,}76$$

where D = the minimum stable parting thickness in metres
N = the number of beds in the parting

Ehgartner found that the distance stress was transferred depended on the nature of the rock below the pillar. In particular it was found that low modulus stratified materials tended to increase the distance through which stress is transferred, while stiff isotropic materials had the opposite effect.

Webster et al (1984) describe the ground control mechanisms involved in mining through subsided zones. Data collected from case studies was used to construct empirical models to predict interaction problems and the type of damage that might occur. Their analysis showed that damage in upper seams due to subsidence above lower workings may be due to percentage extraction, the ratio of the parting to the lower seam height, the time elapsed and the percentage of sandstone or hardrock in the parting. The percentage extraction of the lower seam was found to be a dominating factor.

Grenoble and Haycocks (1985), and Haycocks et al (1987) incorporated the empirical models into a software package USEAM. The aim of the program was to provide engineers with a means of determining whether any difficulties will be encountered and of what type when mining under a remnant pillar or a solid/goaf interface. The program flow chart is shown in Figure 3.2. The program evaluates minimum stable parting thickness firstly from the number of layers in the parting (Ehgartner,1982), and then from the percentage of sandstone/hardrock in the parting. The equation used for this evaluation is

$$D = 33.52 - 0{,}198\ S$$

where S = the percentage hardrock/sandstone in the parting
D = the minimum stable parting thickness in metres.

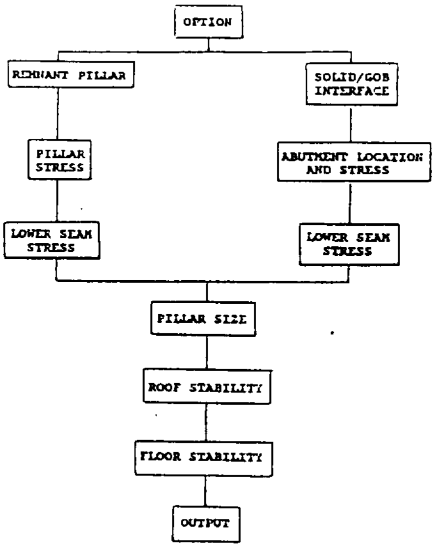


Figure 3.2 Flow chart for program USEAM

In the case of mining over a mined out seam Zhou and Haycocks (1986) proposed three methods of predicting upper seam damage due to trough subsidence. The three methods are based on statistical analysis and the authors state that any one can be used to evaluate upper seam stability depending on the application and the data available.

i) Damage factor

Based on previous work carried out by Webster et al (1984) a damage factor is calculated given the parting thickness, percent sandstone, extraction height of the lower seam, percent extraction and the time interval since mining the lower seam.

ii) Critical m-index

The ratio of parting thickness to lower seam height, defined as the index of undermining has been used in the Polish coalfields to evaluate the possibility of interaction due to undermining (Zhou and Haycocks, 1986).

iii) Subsidence factor

Holland (1951) stated that subsidence is responsible for most of the interaction effects on the overlying seam. From work reported by Webster et al (1984) a relationship was developed from the maximum predicted subsidence and the damage of the upper seam roof.

Case study analysis by Zhou and Haycocks (1986) has shown that the most frequent difficulty encounterd due to subsidence was damage to the upper seam roof. The authors considered the relative orientation of the upper seam with respect to the principle tensile stress direction of the subsidence trough to be an important factor affecting roof conditions. It is reported that workings in the direction of the maximum principle tensile stress will undergo more severe damage than those which are not.

The US Bureau of Mines has carried out a number of investigations into multiseam bord and pillar mining. Two problems were investigated, namely subsidence and pillar load transfer. Strata interactions due to subsidence were investigated at a coal mine in Pennsylvania. The depth to the upper seam was between 129 m and 176 m, and the parting to the lower seam between 27 m and 30 m. The lower seam was mined out by pillar extraction. The measurements showed that mining in the upper seam had little effect on the upper seam pillar stability, but had a more severe effect on the development and maintenance of entries.

Pillar load transfer has been investigated at a number of mines. At one mine in Pennsylvania pillar load transfer was used to explain excessive floor heaving and pillar loading that occured between two partially superimposed workings (Matetic et al,1987). The parting between the seams was approximately 12 to 13 m, which was less than the pillar width. The safety factors of the top seam pillars were low, between 0,77 and 0,44 depending on which American pillar strength formula was used. Two years after the lower seam was developed major floor heave and excessive pillar loading were observed. Three to four months later, the upper mine experienced excessive entry convergence and pillar loading. The investigators used the core and yield zone concept of pillar loading behaviour, developed by Wilson and Ashwin (1972). During pillar loading the core is the zone in the pillar center that behaves elastically and is confined by the yield zone that surrounds it. In the case of a low safety factor, or highly stressed pillar, the highest stress occurs towards the pillar core. It was concluded that a pillar loaded in this way is an unstable design and highly likely to transfer load.

At another mine where the workings were non-superimposed no pillar load transfer was observed (Matetic and Chekan,1988). In this case the depth was shallower at 169 m and the parting was approximately 33 m (or two pillar widths).

Field studies have shown the stability of bord and pillar workings can be related to the ratio of upper seam depth to parting thickness, independent of pillar design (Haycocks et al,1982).When the upper seam depth to parting thickness ratio reaches or exceeds 8:1, a potentially unstable condition may arise, especially for pillars with bearing capacities between 251 and 281 $m^2$ and partings less than 33,5 m. It is not clear how these criteria were established, and they are certainly contrary to experience gained in South Africa.

It is reported by Chekan and Matetic (1988) that in the case of rectangular pillars the interactive distance is controlled by the least width of the pillar. In general, rectangular pillars transfer less load a shorter distance than square pillars of equal load carrying capacity.

The Bureau of Mines has developed a three dimensional boundary element computer program MULSIM/BM, for analysis of single or multiple coal seams (Beckett and Madrid, 1986). The rockmass is assumed to be homogeneous, isotropic, and an infinite elastic body. Since the effect of surface is omitted, the program is only applicable to problems in which the seam depth is greater than the excavation width being analysed. Features of MULSIM/BM are:

(i) ability to specify up to 26 different property sets
(ii) ability to model a large mining area with a course grid and the area of interest with a fine mesh
(iii) ability to specify extraction ratios for the coarse mesh.

For the situation where upper seams overlie a goaf the program cannot accurately calculate the effect unless the parting is considerably greater than the expected caving height. It is recommended that MULSIM/BM is not used if an overlying coal seam is within 3,5 seam heights of a lower seam goaf.

Hsiung and Penn (1987a,1987b) have identified five types of ground control problems in multiseam mining.

(i) Pillar load transfer due to remnant pillars left in the goaf of the upper or lower seam.

Excessive load transferred from pillars will result in convergence, roof falls and floor heave.

(ii) Subsurface subsidence occurring when underlying seams are mined first

The effects of this subsidence is instability of entries and pillars in the upper seams. The zone of influence may extend as high as 60 m.

(iii) Longwall panel cutting across the goaf/solid coal boundary of the mined out seam.

The problems expected here depend on the sequence of mining and will be the same as (i) or (ii).

(iv) Fracture zone induced by longwall mining and bord and pillar mining with full extraction

The fracture zones (with tension fractures) and caving zone induced in the roof may extend thirty times the mining height, and the fracture zone in the floor as deep as ten times the mining height.

(v) Water problems

Water is an indirect cause to the ground control problems in the lower seam. This problem arises when plenty of water has accumulated in the top seam goaf, and the two seams are interconnected by fracture zones in the parting.

The authors present guidelines for multiseam mining especially for longwall mining where remnant pillars have been left (Appendix 3) . They are based on experience gained in multiseam mining in West Virginia over many years.

Using 65 data sets from a historical record of attempted multiseam mining in the eastern United States, Chanda (1989) developed a regression model for prediction of success probability. The model provides a measure of risk in a two seam mining situation. The variables found most significant in influencing success or failure were percent sandstone in the parting, time delay, minimum parting thickness, thickness of upper and lower seam, depth of cover to the lower seam, superimposed pillars and roadways and the leading seam. Chanda considered that the percentage extraction of the leading seam was not significant as a variable in the overall prediction of success probability. On that basis he concluded that there would be little difference between success or failure of multiple seam mining by bord and pillar and longwall systems.

Many of the problems that exist in multiseam mining operations in the United States appear to result from the inability to determine the correct pillar size. Overdesign is a common solution, underdesign a common fault. In the case of workings at depths greater than 300 m overdesigned pillars may result in unacceptably low extraction ratios. Checkan and Matetic (1988) have proposed an alternative design through the application of yield pillars.

### 3.2.2 India

The occurrence of coal seams in close proximity is a common feature of some of the important Indian coalfields in eastern India. There are 25 coal seams of thickness above 1,2 m in the Barakar measure of Jharia coalfield alone. In India such coal seam systems that are in close proximity and lie within 9 ,0 m of each other are termed contiguous seams (Coal Mining Regulations 1957). Geological conditions are similar to those in South Africa with partings consisting mainly of sandstone.

Superimposition of workings is seldom achieved aiming to inaccurate old survey maps and a lack of understanding of the effect of staggered longwall panels.

In bord and pillar mining an attempt has been made to establish a relationship between the variables governing parting stability (Bandopadhyay et al,1988). The factors affecting stress distribution in thin partings between contiguous pillar workings have been identified as depth of cover, parting thickness, lateral shift between pillars, percentage extraction and the ratio of the parting modulus to the seam modulus.

Two-dimensional finite element modelling was carried out in order to determine the effect of the different variables on the development of maximum tensile stress in the parting.

The effect of depth was shown to be approximately linear. The Young's modulus was found to have a negligible effect on development of tensile stress in the parting. The parting thickness had an inverse effect on tensile stress. The eccentricity, or the degree of superimposition showed that the highest tensile stress occurred when the centre of the lower roadway is exactly below the centre of the upper pillar.

The authors modelled the situation where superimposed pillars had been split and quartered. Two models were run, top seam small pillars with bottom seam large pillars and vice versa. The runs showed that the tensile stress in the parting remained nearly the same, whichever seam was split.

Using the US Bureau of Mines program BMINES four failed parting cases were modelled. The output principal stresses were used in a CMRS (Central Mining Research Station) failure criteria developed by Sheorey et al for obtaining the element safety number.

It was necessary for the authors to determine the rock quality using Bartons Q system in each case and they state that considerable engineering judgement is needed especially if geotechnical data is limited. Observations have shown that once parting failure is initiated it is difficult to arrest without the aid of supports. Therefore, for numerical modelling it was considered sufficient to identify only the failure initiation zone using the CMRS failure criteria rather than a more complex elasto-plastic analysis.

A study was carried out (Dhar et al,1988) into the effect of staggering of longwall panels in contiguous seams. Finite element modelling was used to assess the different stress environments for three different layouts (i) panels superimposed, (ii) panels staggered by half the width of the parting, (iii) staggering equal to the parting width. It was found that staggering increases the stress concentration for the advancing faces and decreases it in the lagging face. It was concluded that staggering of panels leads to instability of structures in contiguous seams.

### 3.2.3 Australia

Multiple seams occur in a few locations in New South Wales. Problems have been encountered mining under and over flooded goafs at collieries near Newcastle. Drainage from one seam to another has been practised.

Multiseam mining is carried out under the tidal waters of Lake Macquarie at Myuna Colliery. To produce a blended product, mining from three seams is carried out simultaneously. Subsidence control has an over-riding influence on the design of workings (Galvin and Anderson, 1986). While multiseam mining under large bodies of water is unlikely in South Africa it is worth evaluating the concepts and the design principals. It should be remembered that bord and pillar mining is usually carried out in South Africa either to prevent surface subsidence or to protect an upper seam. Workings are designed in accordance with the "Wardell Guidelines for Mining Under Tidal Waters" (Wardell 1975). The guidelines are based on criteria to minimise surface subsidence.

Three of Wardell's recommendations where bord and pillar workings are planned for both seams are:

i) bord widths should not exceed 5,5 m
ii) no pillar should have a width to height ratio of less than eight
iii) where the parting thickness between seams is not less than ten times the extracted thickness of the lower seam there is no necessity to superimpose pillars.

Galvin and Anderson (1986) argue that the mining height in any seam, let alone the lower, has no significance on the need to superimpose. They state that the primary criteria for determining whether superimposition is necessary are:

i) the magnitude and distribution of stress above and below pillars, and
ii) the quality of the parting between the seams.

A particular feature of Myuna Colliery is that the lease area is laid out on a grid system of 30 m squares with both panel and barrier pillars being 30 m wide. This is to accommodate the effects in variation of geological conditions in each seam on panel layouts. This provides the option of superimposing main developments in one seam with panel pillars in another seam.

### 3.2.4 United Kingdom

Interaction effects are a constant problem in the British coalfields. It was estimated (King et al, 1972) that every working face will be affected by interaction effects from previous workings at least once during its life.

The coal measures usually consist of soft sedimentary rocks such as shales, siltstones and mudstones. The predominant method of mining is by longwall, although some bord and pillar mining has been carried out in the north-east of England.

Transference of load in multiseam longwall conditions is often explained in terms of pressure arch theory (NCB,1954). As an excavation increases in width, increased stress is transferred to the abutments. Depending on the nature of the strata a maximum pressure arch width is reached with maximum stress on the abutments. The width of the maximum pressure arch is generally related to depth and is elipsoidal in shape. The height of the arch above the excavation is taken as twice the width. Inside the pressure arch a destressed area will exist.

The concept of a pressure arch assumes a back abutment in the goaf, however, it is now generally accepted that this back abutment does not exist. The value of a pressure arch concept is in determining whether other workings above or below will intercept the elipsoidal pressure arch and at what position.

King et al (1972) classified interaction as originating from three main causes:

i) stress fields due to old or current workings - static interactions
ii) active strata displacement in other workings due to current workings
iii) triggered interaction due to changes produced by current workings upon old workings.

Dunham and Stace (1978) attempted to define the principal factors controlling static interaction. They developed a mathematical model using linear regression analysis and convergence data collected from multiseam longwall operations in the UK. Their research showed a correlation between pillar geometry and ground stability in lower seams. The authors' main conclusions were:

i) the model developed was a reasonable approach to provide a basis for prediction

ii) the main factors in order of importance governing the static interaction mechanism were rib edge geometry, initial roadway stability, seam interval, and age of the rib edge

iii) interaction effects should not be arbitrarily discounted on the basis of a large seam interval.

At Ellington Colliery bord and pillar workings were carried out under the seabed at a depth of cover between 105 m and 120 m. An investigation was carried out to study the feasibility of working the lower Yard Seam to within 3 m of the upper Main Seam, in order to increase reserves. Instrumentation monitored roof movement and pillar strain as the pillar was being isolated. The investigation concluded that parting distance had little influence on roadway stability, since there was movement in the immediate roof only. A small increase occurred in the loading of the instrumented pillar as it was isolated.

Although the collieries are deeper than in the USA, and the strata weaker, mechanisms such as pressure arch theory have been applied to US conditions albeit with reservations.

### 3.2.5 Canada

An investigation was carried out by Szwilski (1979) to estimate the influence of undermining two higher seams at a mine in the Rocky Mountains. Seam 3, which is the lowest, was initially developed by bord and pillar mining and followed by pillar extraction. Seam 2 which is 90 m above was partially developed. Pillar extraction in Seam 3 caused roof falls to occur in Seam 2, because to the roof consists of thinly laminated shales. It was concluded from the investigation that the choice of mining for Seam 2 will depend on the stability and expected life of the development entries, and that longwall mining would be the preferred system.

## 3.3 Factors Considered Important in Multiseam Design

From the many investigations carried out considerable effort has been made to identify the factors that affect multiseam mine design. They are usually divided into those that are mainly dependent on the geological environment (fixed) and those that depend on engineering design. The fixed parameters include depth, parting thickness, parting characteristics, seam thickness, coal characteristics and age of workings. The engineering design parameters are seam sequencing and geometry of workings.

i) Fixed variables

a) Depth

Depth is recognised as a critical factor in multiseam interaction. In India finite element modelling of superimposed bord and pillar workings showed a linear relationship between tensile stress in the parting and depth. In total extraction situations relationships have been developed between abutment stress and depth (NCB, 1954).

b) Parting thickness

Research in the Appalachian region concluded that the maximum interactive distance between bord and pillar workings is 33,5 m (Haycocks et al, 1971).

Indian research shows, in the case of superimposed bord and pillar workings parting thickness has little effect on the change in tensile stress in the parting. However, parting thickness was important when the pillars were partially or non-superimposed.

c) Parting characteristics

It has been shown that the distance stress is transferred below a pillar depends on the rock type of the parting (Ehgarter,1982). Low modulus stratified rock tended to increases the distance through which stress is transferred, while stiff isotropic materials had the opposite effect.

d) Seam thickness

Although Lazer (1965) concluded that the lower seam thickness of a mined out seam had little influence on upper seam mining, most other investigators would differ.In multiseam bord and pillar mining the seam height has no influence on whether pillars should be superimposed or not.

e) Coal characteristics

The coal characteristics will have an influence on pillar load transfer, especially in the case of highly stressed pillars undergoing failure.

f) Age of workings

It has been recognised that time will have an important effect on the type of interaction that can occur. In the case of a situation where a seam is lying above a lower seam three types of interaction may occur (Zhou and Haycocks,1986):

- undermining is currently active with upper seam mining - simultaneous mining
- undermining is complete but the ground is still in the process of settling
- undermining is complete and the ground has settled, reaching a new state of equilibrium; a passive condition.

In the second situation design for the upper seam, mining is more difficult than in the third because interaction will change with time as the ground continues to settle. Where the ground has completely settled interaction conditions can be estimated.

From the damage factor concept developed by Webster et al (1984) expected damage in the upper seam lessens considerably if mining commences five years after undermining.

In the case of undermining, goaf compaction in an upper seam can take a long time to reach the point where full cover load is re-established. Dunham and Stace (1979) suggest that as the goaf accepts load, stress levels on adjacent pillars would be reduced with time.

ii) Controllable factors

a) Seam Sequencing

The sequence of mining has long been known to have an effect on subsequent workings in other seams (Hasler, 1951; Stemple, 1956; Lazer, 1965). These effects depended on four basic mining sequences.

- the upper seam mined out before mining of any underlying seam
- mining of the upper and lower seams is carried out simultaneously and is coordinated one with the other
- the lower seam is mined first
- any combination of the above.

Among the mines experiencing interaction problems, simultaneous mining caused the most trouble and accounted for 48 percent of the problems, overmining and undermining accounted for 30 and 22 percent respectively.

The ideal solution for multiseam mining problems would be to mine each seam completely leaving no pillars, starting with the uppermost seam and continuing downwards. This is rarely possible and therefore a range of problems will be encountered depending on the sequence of mining (Haycocks et al,1981).

- Upper Seam mined First

Possible problems in lower seam:

* load concentrations under upper seam pillars and abutments

Typical effects:

* pillar crushing and failure
* sidewall spalling
* roof failure
* floor heave

Criteria:

* thickness of parting
* rocktype and quality of parting
* pillar size and spacing

Possible solutions

* leave no pillars in upper seam
* leave small closely spaced pillars
* superimpose pillars
* avoid high stress zones

- Lower seam mined first

Possible problems in upper seam

* subsidence
* arching Stresses
* block failure between shear planes

Typical effects:

* cracking with possible water and methane movement

- roof falls
- shearing of the seam
- floor Heave
- seam lowering

Criteria

- parting thickness
- percent extraction in the lower seam
- seam thickness
- angle of draw
- lower seam panel width

Possible solutions

- avoid subsidence wave
- restrict subsidence with reduced extraction and lower seam panel width
- backfill lower seam
- predict upper seam damage using Damage Factor,Critical M Index, or Subsidence Factor methods (Zhou and Haycocks, 1986)

- Seams mined simultaneously

Possible problems

- face advancing into other seam abutment zone
- pillar load concentration

Typical effects

- pillar crushing
- rib rolls
- floor heave
- roof failure

Criteria

* parting thickness
* parting quality
* relative face positions

Possible solutions

* superimpose pillars
* synchronise face advance sequences
* distance each face from each other. Peng and Chandra (1980) recommend that the upper seam is kept ahead of the lower seam by the angle of draw.

b) Relative location and orientation

In overmining operations, workings in the direction of maximum principal tensile stress will sustain the most roof damage. Roadways driven perpendicular to the remnant pillar lines will experience bad conditions from the extremely high stress transferred by the remnant pillar. In the situation of trough subsidence a joint set parallel with the trough will produce the worst conditions for the top seam (Haycocks et al,1990).

c) Mining methods

The mining method employed is a controlling factor in interaction. The effects of longwall mining usually far exceed those of bord and pillar mining.

It is generally agreed by most investigators that superimpositioning of pillars should be standard practice in multiseam mine design in areas that may be prone to pillar load transfer. The effect is to lessen the interaction that may occur. It is recognised as being difficult to achieve in practice. Amongst all the investigations reviewed there is not one criteria or guideline to determine whether pillar superimposition should be carried out. Research has shown that when workings are less than two pillar widths apart ground control problems can occur in both seams (Haycocks and Karmis,1983).

## 3.4 Discussion and Conclusions

Considerable research has been carried out into multiseam mining, and the problems have been well documented.

A complete engineering design for all conditions does not exist because of the many complexities and geotechnical unknowns that occur. There is no total analytical approach to multiseam design. All design methods are based on empirical or analytical-empirical procedures.

Interaction mechanisms have been identified. Pillar load transfer mechanisms and parting shearing have been used to explain interaction associated with undermining, while arching and subsidence have been used to assess problems during overmining.

Numerical modelling and field studies can identify trends and possible problem locations, but it is considered that critical variables may be ommitted (Wu and Haycocks,1986). Statistical analysis has been used to overcome some of the disadvantages of not knowing the critical variables ( Dunham and Stace, 1979; Webster et al, 1984 and Chanda, 1989 ). These methods require considerable amounts of data on failed and successful multiseam situations. This approach would be unsuitable for local analysis aiming to the lack of sufficient case histories.

The guidelines that exist (Salamon and Oravecz,1976) have proved successful for bord and pillar mining even though they are thought to be conservative. The guidelines formulated by Hsiung and Peng (1987) can be useful for total extraction situations in identifying possible problems and solutions (Appendix A).

It has long been recognised that the quality of the parting is critical in multiseam design. In India an analytical-empirical approach was considered, using numerical modelling followed by an empirical failure analysis. It was recognised that considerable engineering judgement was necessary if in situ geotechnical information was not available.

It is interesting to observe that there is no direct reference to Salamon and Oravecz's work (1976) on multiseam mining in any of the literature. While Salamon and Oravecz discuss multiseam mining in terms of pillar centre distance most American references use the pillar width only, as a criteria.

# 4 BORD AND PILLAR LAYOUTS

Safety hazards may occur in multiseam bord and pillar layouts if the seams are in close proximity and non-superimposed. Guidelines for multiseam bord and pillar layouts were developed by Salamon and Oravecz (1976). A further analysis was carried out by Bradbury and Lear (1984).

It can be concluded that the guidelines are suitable for initial determination of pillar superimposition. In borderline cases however it is advisable to determine the limiting distance using numerical modelling.

Surface monitoring at Khutala Colliery has been carried out in an area where the guidelines recommended pillar superimposition between the No 2 and No 4 Seam workings. Numerical modelling showed that it would not be necessary. The surface monitoring consists of borehole anchors. Underground observations were carried out using borescope holes in pillars in the No 2 and No 4 Seams. No adverse movement has been recorded nor has any deterioration of the pillars due to non-superimposition. A common problem is for superimposed layouts to become partially superimposed. Figure 4.1 shows a typical situation.

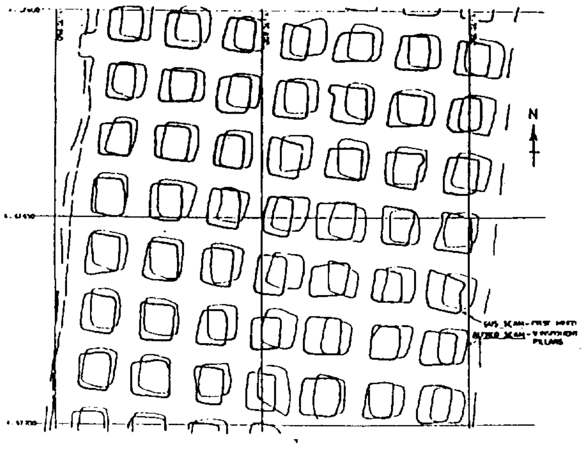


Figure 4.1 Pillars becoming Non-Superimposed

## 4.1 Effect of Barrier Pillars in Multiseam Layouts

Barrier pillars are an integral part of any mine layout. Owing to their superior strength and higher stiffness they carry proportionately more overburden load than the panel pillars. In a multiseam layout other workings are likely to be affected by the presence of barrier pillars.

Using a two dimensional boundary element program the limiting distance of barrier pillars for various panel geometries was calculated and is shown in Table 4.1.

Table 4.1 LIMITING DISTANCE BELOW BARRIER PILLARS FOR DIFFERENT PILLAR GEOMETRIES

| W/H | Wb | Wp | Wb/Wp | LD | LD/C | LD/Wb |
|---|---|---|---|---|---|---|
| 0,4 | 12 | 12 | 1,0 | 14 | 0,77 | 1,16 |
| 0,8 | 12 | 12 | 1,0 | 15 | 0,83 | 1,25 |
| 1,0 | 12 | 12 | 1,0 | 16 | 0,88 | 1,33 |
| 2,0 | 12 | 12 | 1,0 | 13 | 0,72 | 1,08 |
| 0,5 | 24 | 12 | 2,0 | 28 | 1,55 | 1,16 |
| 0,8 | 24 | 12 | 2,0 | 24 | 1,33 | 1,0 |
| 1,0 | 24 | 12 | 2,0 | 26 | 1,44 | 1,08 |
| 1,4 | 24 | 12 | 2,0 | 27 | 1,55 | 1,12 |
| 0,5 | 48 | 12 | 4,0 | 38 | 2,11 | 0,79 |
| 1,0 | 48 | 12 | 4,0 | 39 | 2,43 | 0,81 |
| 1,4 | 48 | 12 | 4,0 | 32 | 1,77 | 0,67 |
| 2,0 | 48 | 12 | 4,0 | 33 | 1,83 | 0,68 |

Where: W/H = Ratio of width of panel to depth of panel
Wb = width of barrier pillar
Wp = width of panel pillars
Wb/Wp = Ratio of barrier pillar width to panel pillar width
LD = limiting distance below barrier pillar where stress returns to within 5% of the virgin stress
LD/C = ratio of limiting distance below barrier pillar to panel pillar centre distance
LD/Wb = ratio of limiting distance below barrier pillar to barrier pillar width.

From Table 4.1 the limiting distance of the barrier pillar as a ratio of the pillar centre distance varies from 0,77 to 2,43 depending on the ratio of the barrier to panel pillar width.

For barrier pillars of the same width as the panel pillars (Wb/Wp = 1) the limiting distance is between 0,72 C and 0,88 C for the examples shown. If the parting is greater than 0,9 or 1,0 C it will therefore, not be necessary to superimpose barrier pillars.

From a rock mechanics point of view the purpose of barrier pillars is to contain a pillar run should one occur. If the panel pillars have been designed correctly the chances of a pillar run occurring are negligible and therefore large barrier pillars are not necessary. Superimposition of barrier pillars can thus be avoided if the barrier pillar width is reduced, therefore allowing independent design in both seams.

## 4.2 Parting Stability

Where partings become thin in bord and pillar workings there exists the possibility of a parting collapse. For partings where the thickness is less than 1/5 of the bord width, failure is usually in tension. The thickness of a self supporting beam ($\sigma_t$) can be determined from the following equation:

$$t = \rho g b^2 / 2\sigma_t \quad (\mathrm{m})$$

Where p = density of rock strata (kg/m$^3$)
g = gravitational accelaration (m/s$^2$)
b = bord width (m)
$\sigma_t$ = laboratory tensile strength of the parting (Pa)

The minimum thickness required for a self supporting span derived from the above equation is based on laboratory results and assumes no discontinuities in the parting. It is usual to apply a safety factor to derive a safe self supporting span.

The above analysis is a two dimensional one and does not examine the more likely collapse of an intersection. It has been found in the Witbank area that parting thicknesses of 1,0 m are self supporting between the No 1 and No 2 Seams. The tramming of heavy machinery imposes increased risk of parting collapse where the parting is thin.

An underground investigation was carried out at a colliery in the Witbank coalfield. Mining was taking place in the No 1 and No 2 Seams and the parting was approximately 2,0 m. Using precise levelling techniques the roof of the No 1 Seam was monitored while a continuous miner was trammed over the monitoring positions. The deflection measured was less than the accuracy of the levelling system (0,5 mm). It was concluded that the tramming of an 85 ton continuous miner had no effect on the stability of the parting in this case.

Parting stability is also dependent on the degree of superimposition of the pillars. If the pillars are offset , additional loading is imposed on the parting and this can generate shear failure.

## 5 PILLAR EXTRACTION OVER BORD AND PILLAR WORKINGS

The mining sequence examined is as follows:

i) upper and lower seam mined by bord and pillar methods
ii) upper seam pillars extracted.

Figure 5.1 shows pillar stress profiles in the lower seam due to upper seam pillar extraction. Considerable changes in loading conditions occur on the pillars as the abutment passes over. As the abutment passes over, the pillars will experience a temporary increase in load followed by considerable destressing. As goafing continues in the top seam the lower seam

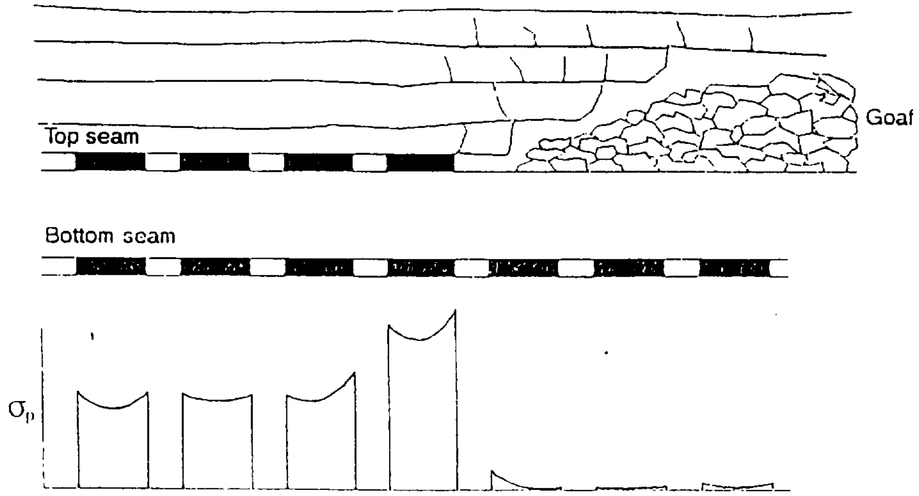
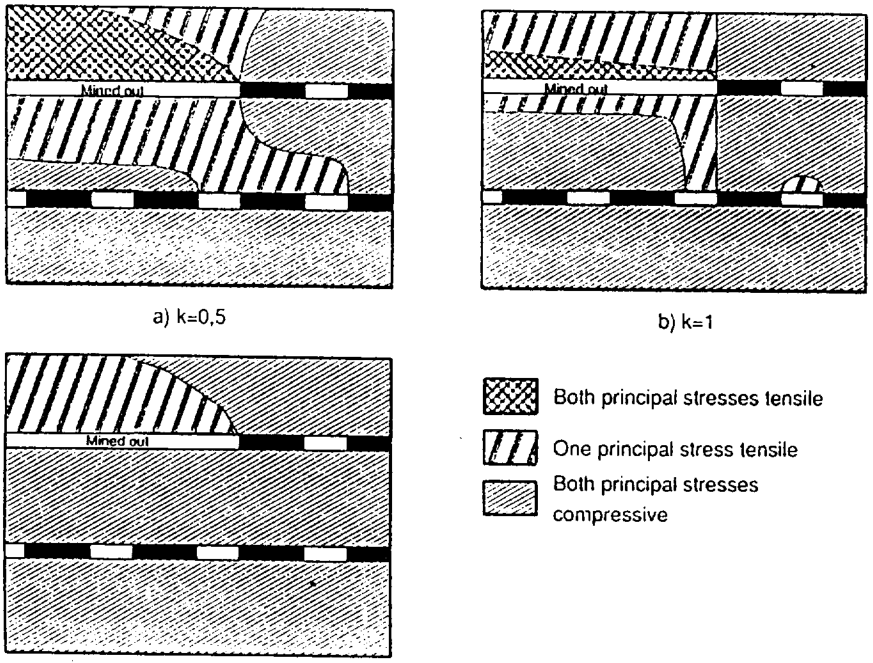


Figure 5.1 Pillar stress profile in lower seam due to upper seam pillar extraction.

pillars will be reloaded. The surrounding strata undergoes stress changes, Figure 5.2 shows the distribution of the major principal stresses due to overmining for three different values of K (ratio of horizontal to vertical stress) for a superimposed bord and pillar layout. It can be seen that where K is one or less a zone exists where one principal stress is tensile.



a) k=0,5

b) k=1

c) k=2

Figure 5.2 Distribution of major principal stresses due to overmining

The effects of total extraction usually far exceed those of bord and pillar mining. In the particular sequence examined the increase in load on the lower seam pillars will depend on

i) parting distance

ii) caving mechanism taking place in the extraction area.

Increased parting distance will dissipate the effect of the abutment stress being transferred to lower seam pillars, although it is known that this can be a considerable distance.

As the parting distance increases the change in pillar load on the lower seam pillars will be less pronounced since the abutment load will be spread over more pillars.

Pillar design in South Africa is based on the safety factor formula where

$$\text{safety factor} = \frac{\text{pillar strength}}{\text{stress}}$$

The pillar strength is calculated using the strength formula proposed by Salamon, or its extension the squat pillar formula where the width to height ratio of the pillar is five or more. Stable pillar geometries have been successfully designed for the past 27 years.

In a bord and pillar layout the load on the pillar is calculated from tributory area theory. The theory assumes that each pillar supports the overlying strata up to the surface. It has generally been accepted that pillars designed to a safety factor of 2 or more, are suitable for pillar extraction. During stooping however, the loading of the pillars varies and therefore, adopting a nominal safety factor of 2 may not always be applicable. The situation is more complex if a bord and pillar layout with smaller pillars exists in the seam below. It will be necessary to calculate the safety factors of the pillars in each seam from the abutment stress. This must be carried out using a numerical modelling program. A suitable method has been described in detail by van der Merwe.

It is important to note that although the safety factor of a pillar in a stooping layout can be calculated the probability of stability cannot.

## 5.1 Case Studies

### Colliery A

Colliery A is located in the Eastern Transvaal Coalfield and mines coal from the B and C Seams. Between October 1989 and January 1990 pillar extraction took place in the B Seam over bord and pillar workings in the underlying C Seam workings.

During the time that pillar extraction took place in the top seam monitoring took place in the bottom seam. Three roof falls and one parting collapse occured in the C Seam while overmining.

A generalised geological section is shown below. The parting between the two seams varied from 6,7 m to 3,6 m, and consisted mainly of a 4,3 m thick sandstone with a 0,7 m thick shaly sandstone layer at the top. The sandstone roof of the lower seam was competent enough not to require roof bolting.

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | | |
| B Seam | 1,4 | 106 |
| Sandstone shale | 0,7 | |
| Sandstone | 4,3 | |
| C Seam | 1,8 | 113 |
| Standstone | | |

Pillar superimposition was carried out and from the plans appears to be good. The safety factor of the pillars in the C Seam was 2,88.

The results of the monitoring are shown in Figure 5.3. Two patterns emerge. The first pattern is of convergence as the stooping line passes over, followed by divergence under the goafed area. The second pattern is one where no divergence takes place after the stooping line has passed over. This is due to fractures having formed in the roof which continue to enlarge after the stooping line has passed over. A photographic record was kept of six pillars while stooping took place in the upper seam. Prior to overmining the bottom seam pillars were freshly stonedusted. The amount of spalling that took place from overmining was minimal. The situation was simulated using the boundary element program BESOL P5004. The purpose of the modelling was to determine the amount of convergence that could be expected as pillar extraction took place.

The modelling showed that in the initial formation of the pillars in the C Seam 8,8 mm of convergence occurred in the centre of the bords. Mining above and superimposing the pillars in the B Seam causes 1 mm divergence in the C Seam bords. The situation where two rows of pillars had been extracted and no caving had taken place was then simulated. The model showed that there would be a large divergence of 9,6 mm in the C Seam under the centre of the B Seam goaf. Under the abutment area in the C Seam, convergence of 3 mm was shown to occur at one side of the bord while divergence of 2 mm occurred at the other side.

The divergence shown by the numerical model is larger than that measured at the convergence stations. This is to be expected since the model assumes the strata behaviour is perfectly elastic.

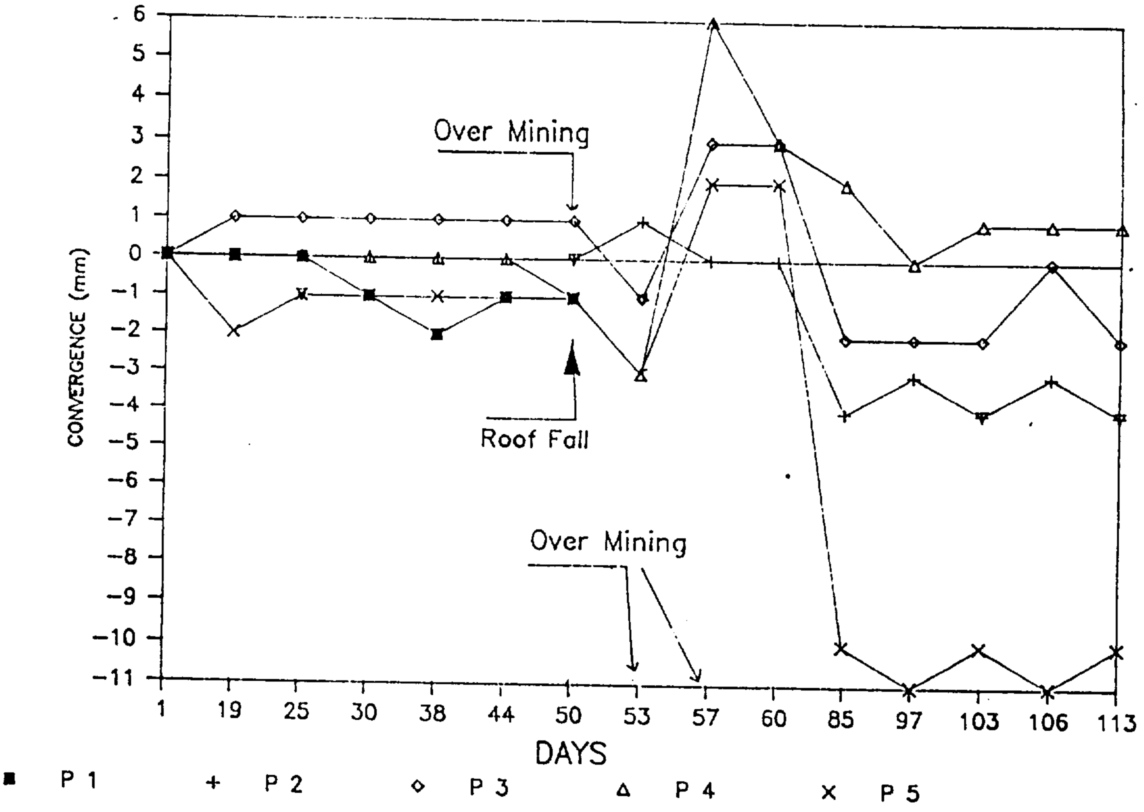


Figure 5.3 Results of monitoring

The roof falls that occurred varied in height from 0,5 m to 1,5 m, and all were located in intersections. The position of the stooping line to each fall varied from two pillars ahead, immediately overhead, to ten pillars past. One of the falls was probably caused by the pillars not being totally superimposed at that point. The parting collapse was located at the end of the section where the parting was at its thinnest at about 3,6 m. The stooping line was between one pillar away and overhead when the collapse occurred.

The roof falls that occurred in the bottom seam, although low in number could not have been tolerated if there was activity simultaneously taking place in the C Seam. Roof bolting would probably have eliminated three of the falls, but not the parting collapse. Cable anchors or roof trusses would have to have been installed to have prevented the parting collapse.

In situations where stooping takes place over bord and pillar workings separated by thin variable partings it is therefore important to know the exact parting thickness and the degree of pillar superimposition.

**Colliery B**

Colliery B is located in the Vryheid area Coalfield in Natal. A general geological section is shown below. Stooping in the Gus Seam caused severe deterioration in the Dundas Seam workings below. Since the bottom seam workings had to remain open for future developments, mining had to stop in the top seam. The Dundas Seam section was a bord and pillar layout on 30 m centres. The planned bord width was 6 m, the extraction height 1,3 m and the depth of workings approximately 195 m. The section in the Gus Seam was laid out for scraper mining. Stooping had previously taken place over a large area. Excessive stress on a number of pillars had caused floor heave making it impossible to extract certain pillars, therefore many remnant pillars remained in the Gus Seam.

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | | |
| Gus Seam | 0,98 | |
| Sandstone | 9,00 | |
| Upper Dundas Seam | 0,4 | |
| Sandstone | 5,6 | |
| Dundas | 1,5 | 195 |

In the Dundas Seam many roof falls had occurred in the intersections. The condition of the pillars was observed to be satisfactory with only a small amount of spalling having occurred. Severe deterioration of some of the roadways had taken place under the goaf/pillar line of the Gus Seam. The primary support installed was 1,2 m mechanically anchored roof bolts. Additional support in the form of RSJ girders had been installed but due to point loading on the girders many of these had buckled. It was evident that the current support installed was insufficient to keep the roof in a stable condition under dynamic stress conditions. It was then recommended that cable anchors be installed.

**Colliery C**

Colliery C is located in the Vryheid Coalfield. Two seams were mined namely the Gus and the Dundas Seams. A general geological section is shown below.

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Dolerite | 4,2 | |
| Sandstone | 20,8 | |
| Gus Seam | 1,1 | |
| Sandstone | 14,4 | |
| Dundas Seam | 1,2 | 167 |
| Standstone | | |

The Dundas Seam workings at a depth of 167 m were initially developed with 15 m square pillars and 6 m roadways. The mining height was 1,2 m. The Gus Seam 14,4 m above the Dundas, was developed on the same dimensions and the pillars superimposed. The mining height was 1,1 m. Stooping in the Gus Seam was being carried out at the same time as development in the Dundas Seam below. This resulted in deterioration of conditions in the bottom seam. Pillar spalling occurred followed by roof falls and also floor creep. The roof support installed was 1,2 m mechanical anchor bolts spaced 1 m apart. The section in the lower seam was stopped as conditions were too dangerous to work. The lower seam development was moved to another section which could be completed before stooping commenced in the top seam. Four pointer wooden packs were installed in the travel road, scoop road and return airway to ensure re-entry after stooping had finished in the Gus Seam. Stooping in the Gus Seam again resulted in severe spalling, total collapse except for the pack areas and creep between the packs. Crushing of the packs took place.

The roof above the Gus Seam consisted of a 20 m thick, competent, medium grained sandstone. Above the sandstone a 4 m thick dolerite sill was located. Caving of the immediate roof did not occur immediately and it was able to hang up after pillar extraction for a distance of over 30 m into the goaf area(Figure 12 ). This resulted in a large abutment being transferred to the pillars below. The support installed was insufficient and the section was later abandoned.

**Colliery D**

Colliery D is located in the Utrecht Coalfield of Northern Natal. The colliery mines coal from the Alfred and Gus Seams.

A section of the strata is shown as follows:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone Bods | | |
| Alfred Seam | 3 | |
| Sandstone | 4 | |
| Gus Seam | 2 | 55 |

Three months after stooping commenced large falls were observed in the Gus Seam. The system of stooping was such that large snooks were left in each pillar.

**Colliery E**

Colliery E is located in the Witbank area and has extensive bord and pillar workings in the No 2 Seam. A geological section is shown below. Pillar extraction has been carried out in the No 5 seam over the No 2 Seam workings. The parting distance between the two seams is 38 m and no effect has been observed on the No 2 seam workings because of stooping taking place above.

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Shale | | |
| No. 5 Seam | 1,9 | |
| Sandstone/shale | 4,0 | |
| Sandstone | 6,0 | |
| No. 4A | 0,90 | |
| Sandstone | 5,50 | |
| No. 4 Seam | 6,5 | 41,8 |
| Sandstone/shale | 7,6 | |
| Shale | 6,15 | |
| No. 2 Seam | 4,43 | 60 |

**Colliery F**

Colliery F is located in the Witbank Coalfield and has extensive workings in the No 2 Seam. The colliery proposed to carry out mining in the No 4 Seam. A general geological section is shown below. A feasibility study was carried out to assess the stability of the workings in the No 2 Seam while total extraction was carried out in the upper seam.

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Siltstone/Shale | 17,6 | |
| No. 4 Seam | 3,4 | 39,03 |
| Sandstone/Siltstone | 9,0 | |
| Carbonaceous Shale | 5,0 | |
| No. 2 Seam | 7,04 | 60,07 |
| Sandstone | | |

Primary mining in the No 2 Seam consisted of extracting to a height of 3,3 m followed by top coaling to a final height of 5,5 to 6,0 m. The pillar widths were 9 and 12 m and the average depth to the base of the No 2 Seam was 57 m. For the 9 m pillars the safety factor ranged from 2,27 to 1,53 after top coaling. For the 12 m pillars the safety factor ranged from 3,2 to 2,15 after top coaling.

The parting between the two seams consisted of an upper 9 m of interlaminated sandstone/siltstone bands and a lower 5 m of carbonaceous shale.

Applying the Salamon and Oravecz guidelines for the design of the workings in the No 4 Seam workings showed that the upper seam could be designed independently although the barrier pillars should be superimposed. A pillar width of 7 m was considered for the top seam which gave a safety factor of 2,38.

Although it appeared from the geology that caving would occur readily there would still be a distance into the goaf area where full caving had not yet occurred. The situation was modelled to assess the effect of the abutment on the No 2 Seam pillars. Four scenarios were simulated with the strata hanging up for distances of 0, 32, 58, 84 m. This is the situation when 0, 2, 4, and 6 pillar rows are extracted and the strata does not cave. From the modelling, safety factors were calculated for the lower seam pillars at varying extraction heights (e) (Tables 5.1 and 5.2).

Table 5.1 Safety Factors in No 2 Seam pillars (w=12 m)

| | HANG-UP IN NO. 4 SEAM (m) | | | |
|---|---|---|---|---|
| e | 0 | 32 | 58 | 84 |
| 3,3 | 3,2 | 2,82 | 2,45 | 2,21 |
| 4,0 | 2,82 | 2,48 | 2,16 | 1,95 |
| 5,0 | 2,43 | 2,14 | 1,86 | 1,68 |
| 6,0 | 2,15 | 1,90 | 1,65 | 1,49 |

Table 5.2 Safety Factors in No 2 Seam pillars (w=9 m)

| | HANG-UP IN NO. 4 SEAM (m) | | | |
|---|---|---|---|---|
| e | 0 | 32 | 58 | 84 |
| 3,3 | 2,27 | 2,05 | 1,70 | 1,45 |
| 4,0 | 2,00 | 1,81 | 1,50 | 1,28 |
| 5,0 | 1,72 | 1,56 | 1,29 | 1,10 |
| 6,0 | 1,53 | 1,38 | 1,15 | 0,98 |

It was concluded from the modelling that pillar extraction could be carried out over the 12 m pillars even if top coaling had preceded it. In the case of pillar extraction over 9 m pillars, the safety factors were low should top coaling have been carried out. It was therefore recommended that where the pillar width was 9 m, no top coaling be carried out until after pillar extraction had taken place above these areas.

The ratio of the parting thickness to the No 2 Seam pillar centre distance is around 0,8, which from the guidelines would suggest that the barrier pillars be superimposed. Modelling showed that where 7 m wide pillars in the No 4 Seam overlay a 16 m barrier pillar in the lower seam only a small increase in stress on the top seam pillars was expected, and this was not considered important. A simulation of pillar extraction in the No 4 Seam showed that should the barrier pillar be above a No 2 Seam bord then a tensile zone could develop. Since the lower 5,5 to 8,0 m of the parting consists of carbonaceous shale, the presence of a tensile zone creates the potential for an intersection failure. The modelling therefore confirmed the recommendations of the guidelines.

A good indication of the likely mechanism of caving is to estimate the modulus of rigidity of the strata.

The modulus of rigidity (MOR) is given by

$$MOR = E \times I$$

where, $E$ = Young's Modulus
$I$ = Second Moment of Area of Beam

The value of I is calculated from

$$I = \frac{t^3}{12}$$

where, $t$ = thickness of beam

The estimated values of the modulus of rigidity (MOR) for the strata from one of the boreholes is shown in Table 5.3.

The values calculated are low, a 5 m thick competent sandstone layer would give a MOR value of around 200. A 10 m thick competent sandstone layer would give a MOR value of around 1660.

Table 5.3 Modulus of rigidity for strata above the no. 4 seam

| STRATA | DEPTH (m) | t (m) | E (GPa) | E*I (GPa*m) |
|---|---|---|---|---|
| Depth of weathering | 18,03 | 18,03 | * | * |
| Siltstone/shale | 23,06 | 5,03 | 10 | 106,05 |
| Grit | 26,28 | 3,22 | 20 | 55,64 |
| Siltstone/sandstone | 26,64 | 0,36 | 15 | 0,058 |
| Coal | 27,43 | 0,79 | 3 | 0,123 |
| Grit | 29,76 | 2,33 | 20 | 21,08 |
| Shale | 31,47 | 1,71 | 18 | 7,50 |
| Sandstone/siltstone | 33,83 | 2,36 | 15 | 16,42 |
| Coal | 33,89 | 0,06 | 3 | 0,00005 |
| Shale | 34,19 | 0,3 | 18 | 0,04 |
| Grit | 34,31 | 0,12 | 20 | 0,002 |
| Shale | 34,37 | 0,06 | 18 | 0,0003 |
| Grit | 36,32 | 1,95 | 20 | 12,35 |
| Sandstone | 36,69 | 0,37 | 17 | 0,07 |
| Siltstone/shale | 37,09 | 0,40 | 15 | 0,079 |
| Grit | 38,43 | 1,34 | 20 | 4,01 |
| Sandstone/Siltstone | 38,74 | 0,31 | 15 | 0,036 |
| Sandstone | 39,28 | 0,54 | 17 | 0,22 |
| Siltstone/shale | 39,65 | 0,37 | 15 | 0,063 |
| No. 4 seam | 42,33 | 2,68 | * | * |

Composite strata such as sandstone/siltstone have been assumed to behave as a single beam. This is unlikely to be the case since there will probably be a number of parting planes present which would increase the number of layers and considerably lower the modulus of rigidity. The Young's Modulus E is an estimated value.

Table 5.4 Summary of Conditions in Lower Seam Bord and Pillar Workings where Total Extraction has taken place in the Upper Seam

| MINE | U.SEAM | | P | L SEAM | | | COMMENTS |
|---|---|---|---|---|---|---|---|
| | Name | h(m) | (m) | Name | h(m) | H(m) | |
| A | B | 1,4 | 3,6 - 6,7 | C | 1,8 | 113 | 4 roof falls<br>1 parting collapse<br>(when P < 4,0 m) |
| B | Gus | 0,98 | 15,0 | Dundas | 1,3 | 195 | Remnants left in Gus. Roof falls in Dundas severe under Gus goaf/pillar line |
| C | Gus | 1,1 | 15,4 | Dundas | 1,2 | 167 | Spalling, roof falls and floor creep in Dundas |
| D | Alfred | 3,0 | 4,0 | Gus | 2,0 | 55 | Large roof falls in Gus |
| E | No. 5 | 1,9 | 38 | No. 2 | 3,0 | 60 | No effect on No. 2 Seam workings |
| F | No. 4 | 2,7 to 3,5 | 14 to 17 | No. 2 | 3,3 to 6,0 | 57 | Feasibility study |

## 5.2 Conclusions

Pillar extraction over bord and pillar workings can create considerable problems in the lower seam. This will be greatly influenced by the caving characteristics in the upper seam and the parting distance between the two seams.

Where the parting is thin the degree of pillar superimposition is of prime importance. It was shown in the first case that even where a competent roof exists and no support has been installed failure may occur when over mined.

In areas where caving does not occur readily high abutment loads are created which affect roadway stability in the seam below. An assessment of possible caving characteristics should be carried out. The safety factor of affected pillars should be calculated using the abutment load determined from numerical modelling.

It was shown in Colliery D that top coaling of the lower seam where the pillars were only 9 m wide should only be carried out after overmining in order to maintain sufficient safety factors.

Dynamic changes take place during pillar extraction. The support installed in the lower seam must be capable of operating under these large stress changes.

## 6 MINING OVER GOAFS

### 6.1 Introduction

Many collieries have unmined seams overlying lower seams which have been extracted using high extraction mining methods. Many of these seams have been written off as potential reserves by owners assuming the coal to be unminable because of the danger of subsidence. Several collieries have recently however, successfully recovered coal from seams which have been previously undermined.

In South Africa mining over goafs has only occurred, to date, in the collieries of Natal while in the USA mining over goafs has taken place in the eastern US coalfields.

### 6.2 Factors Affecting Upper Seam Mining Conditions

High extraction methods, such as pillar extraction, result in the immediate roof caving, causing subsidence and fracturing of the upper strata. Where seams exist in the upper strata, the feasibility of mining these seams will depend on the amount of fracturing and subsidence that has taken place due to lower seam mining. Figure 6.1 shows a typical situation where mining has taken place below two upper seams. There are four characteristics of this type of mining:

i) caving of the upper strata creates fracturing due to subsidence

ii) remnant pillars in the lower seam causes differential subsidence to occur. This creates areas of instability due to tensile zones over the pillar/goaf boundary.

iii) remnant pillars causing stress concentrations which will be transferred to the upper seam workings. This may be observed as pillar spalling and floor heave.

iv) areas over incomplete goafing may be destressed.

Mining conditions in the upper seam will therefore depend on a number of factors.

i) Type of strata

The presence of a massive rigid layer in the overlying strata has the effect of dampening stress transfer and immediate subsidence from lower seam mining. Upper seam conditions can be expected to be poorer if the parting consists of shales compared with stronger sandstones. Disturbance of an upper seam has been showed to be less in the USA (Stemple,1956), where the lower mined out seam was overlain by a fairly thick shale bed which was, in turn, overlain by a strong sandstone bed.

ii) Parting thickness

The wider the parting the less damage will occur. Stress from lower seam remnants can however be transferred over large vertical distances. Experience in the UK has shown that the maximum seam interval beyond which interactive effects are no longer felt can be as much as 228 m (Scurfield,1976).

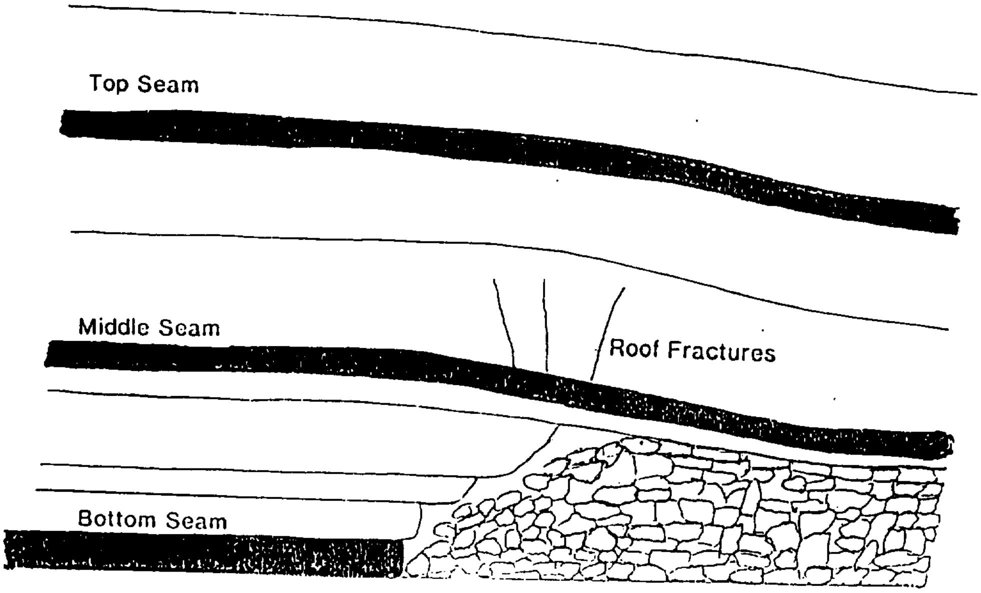


Figure 6.1 Effect of Caving and Settlement of Strata around Two Upper Seams after Mining the Lower Seam

iii) Seam Thickness

A difference of opinion exists concerning the effect of extracted seam height. Lazer (1965) concluded from a study in West Virginia, USA that within normal limits the thickness of the lower mined out seam has little appreciable effect on upper seam mining, even if the parting is only 15 m. It is generally recognised, however, that the vertical extent of any disturbance will depend on the extraction height of the lower seam.

iv) Time interval

Three situations may arise:

a) mining is currently active in the lower seam
b) mining in the lower seam is complete but the ground is still in the process of settling
c) mining in the lower seam is complete and the ground has settled

It is generally recognised that the longer the time span between lower seam mining and upper seam mining, the better will be the conditions in the upper seam since equilibrium will have been achieved. Roof conditions will usually be better on a stable floor than on one which is subsiding.

Experience in the USA shows conditions to be better in the upper seam after eight years since mining of the lower seam has taken place.

v) System of mining

Where the mining of the lower seam has been complete, conditions are usually better than when incomplete mining has taken place since remnant pillars are minimal and subsidence profiles more even.

If the bottom seam has been worked by hand-got longwall methods, packs will usually be present in the goaf, as well as around the gate roads.

### vi) Caving Mechanism

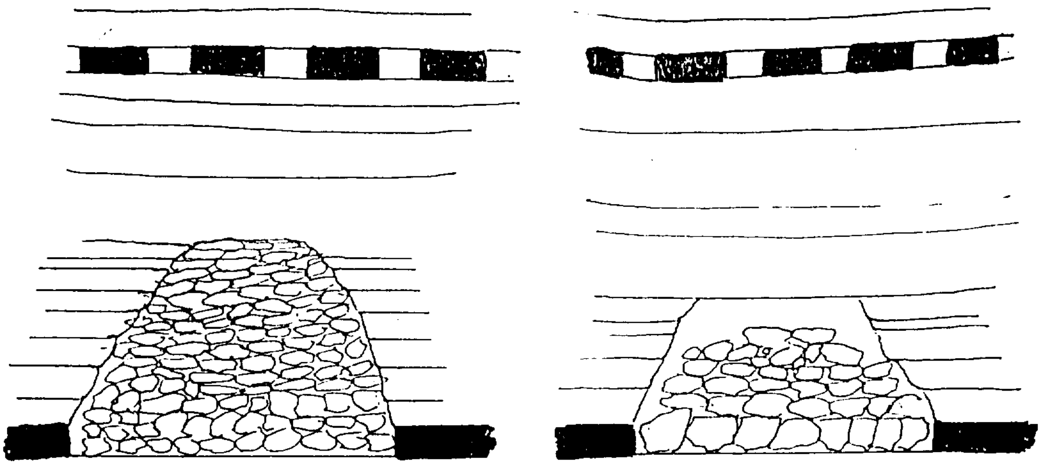
The expected conditions in the upper seam will be influenced by the caving mechanism of the lower seam and the subsequent subsidence. The caving mechanism can be completely or partially controlled by the bulking factor of the caved rock.

The bulking factor is the ratio of the volume of broken rock strata to the original volume of the same strata before displacement occurred. Bulking factors vary with rock type, shape and size of the caved rock fragments, the caving mechanism and the eventual overburden load.

The caved fragments immediately around the pillar extraction line will have a higher bulking factor (initial bulking factor, $bf_i$) than those fragments further into the goaf. The bulking factor is reducd into the goaf owing to the weight of the overlying strata acting on it. When the goaf reaches its maximum compaction, the residual bulking factor ($bf_r$) will have been achieved.

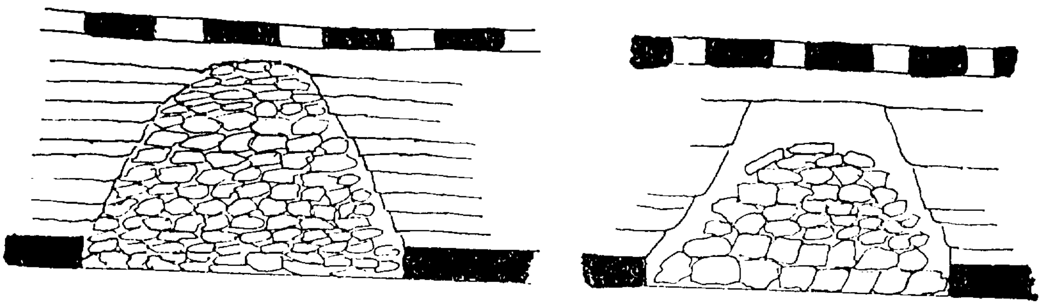
The significance of the caving mechanism in multiseam mining situations is shown in Figure 6.2 where four different situations can occur, especially in the vicinity of remnant pillars.

Where the ratio of the parting thickness/lower seam height is high and bulking factor controlled caving has taken place, anticipated problems will be minimal (Figure 6.2a). If the parting thickness to lower seam height ratio is low and parting plane controlled caving has occurred, then there is the possibility of mining over incomplete goafing or voids (Figure 6.2d).



a) Complete Caving
Thick Parting

b) Incomplete Caving
Thick Parting



c) Complete Caving
Thin Parting

d) Incomplete Caving
Thin Parting

Figure 6.2 Effect of Caving Mechanism From Lower Seam Mining On Upper Seam Stability

The possibility of a parting collapse will depend on the thickness of strata, the length of unsupported bridging strata and the dimensions and stress on the upper seam pillars.

## 6.3 Mining Over Multiple Goafs

When mining over more than one goaf, the maximum height of caving from each individual seam should be determined. If the height of caving from the lowest seam is greater than that of the parting to the next highest seam, then the goafs will combine. The height of caving (H) above the top seam will be:

$$H = \frac{(h_1 + h_2)}{(bf - 1)} - P$$

where $h_1 + h_2$ = combined seam height of the two seams
and $P$ = parting distance between the two seams

If bulking factor controlled caving has taken place then caving will be incomplete and a void will exist, especially if adjacent to a solid ribside or a remnant pillar. The magnitude of the void (v) can be determined from

$$v = (h_1 + h_2) - P(bf-1) - H(bf-1)$$

The suggested procedure for examining situations where mining is to take place over two goafs is to start from the lowest seam that has been extracted and determine the effect on the seam immediately above. The geological section should be examined to determine whether caving will be controlled by the bulking factor or the presence of parting planes.

If the lower seam is thin and the parting thickness large, it is unlikely that caving will reach the upper seam. In Natal, this has usually been the case on the Coking and the Dundas Seams. In this case it is only neccessary to examine the effect of the Dundas Seam caving on the Gus Seam. Multiple goafs may occur however, if the Dundas and the Gus Seams have been mined out.

## 6.4 Case Histories

### 6.4.1 Colliery G Alpha Anthracite

The colliery is located in the Vryheid Coalfield in the Ngwibi Mountain. A typical section is as follows:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | | |
| Upper Alfred Seam | 0,3 | |
| Shaley Sandstone | 0,7 | |
| Lower Alfred Seam | 0,99 | 160 |
| Course shaley sandstone | 15,0 - 17,0 | |
| Gus Seam | 1,0 | |
| Sandstone | | |

The Gus Seam was stooped in the early 1970s and development and stooping of the Lower Alfred Seam took place during the 1980s. The stooping method is described in detail by Beukes (1989).

Minor roof cracks were observed in the roof of the Lower Alfred Seam, but no problems were experienced during stooping operations.

Roof support in the haulage roads consisted of four 1,8 m mechanical anchor roof bolts per row spaced 1,5 m apart. In all other roads, support was with two wooden props per row spaced 1,5 m apart. The ratio of the parting thickness (P) to lower seam mining height (h) is between 15 and 17.

### 6.4.2 Colliery H Hlobane Section 15

In 1990/91 development and stooping took place in the Gus Seam close to the seam outcrop.

A typical section of the coal bearing strata is as follows:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | | |
| Gus Seam | 0,9 | 0 - 62 |
| Sandstone | 17,0 | |
| Dundas Seam | 1,4 | 0 - 80 |

The Dundas was stooped out by 1989, leaving about a year before mining commenced in the Gus Seam. No problems were experienced during stooping and only one fracture in the floor could be observed. The P/h ratio was 12,4.

### 6.4.3 Colliery I Hlobane - Section 91

In 1991 a bord and pillar development took place in the Gus Seam on 20 m centres and 6,0 m bords over the Dundas Seam goaf. Pillar extraction has subsequently been carried out successfully.

The seam and parting thicknesses are as follows:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Alfred Seam | 1,67 | |
| Sandstone | 15,0 | |
| Gus Seam | 0,97 | 40 |
| Sandstone | 17,0 | |
| Dundas Seam | 1,4 | |

The Dundas seam was developed initially on 30 m pillar centres and subsequently stooped during the 1950s. Ribs of between 3 and 5 m were left on each pillar.

The sandstone roof of the Gus Seam showed occasional cross bedding and was supported by mechanical roof bolts.

The Gus Seam was undulated due to undermining and the roof conditions deteriorated as a result. A few small roof falls had occurred. In one heading, a 'chimney' collapse from the

Dundas Seam was mined into, resulting in loss of the Gus Seam.

Using a Firefly drill, 22 mm diameter holes were drilled into the floor of the Gus Seam in order to locate fractures from the Dundas Seam goaf. The criterion was that when full water loss occurred, it was assumed a fracture from the lower goaf had been intersected. The results are shown in Table 6.1.

Table 6.1 Depth of drill holes when water loss occurred

| HOLE | DEPTH OF WATER LOSS (m) |
|---|---|
| 1 | 0,9 |
| 2 | 2,5 |
| 3 | Abandoned |
| 4 | 1,8 |
| 5 | 0,25 |
| 6 | Abandoned |
| 7 | 1,8 3,1 |
| 8 | 2,25 |
| 9 | 2,3 |

Holes No 3 and 6 were abandoned due to difficulties in clearing the fines from the hole. Hole No 7 showed some water loss at 1,8 m, however drilling was continued until full water loss occurred at 3,1 m. The drilling showed that random fractures exist in the parting despite not being visible in the Gus Seam floor. The P/h ratio was 11,0.

### 6.4.4 Colliery J Vryheid Coronation Colliery - Vrede Section

A bord and pillar layout on 21 m centres was developed in the Alfred Seam over Gus Seam workings.

A section of the coal bearing strata is as follows:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | | 180 - 200 |
| Alfred Seam | 1,7 | |
| Sandstone | 14,0 | |
| Gus Seam | 1,5 - 1,8 | |
| Sandstone | 17,2 | |
| Dundas Seam | 1,7 | |

The Gus Seam was developed and stooped during the 1970s, and development took place in the Alfred Seam in 1991. Roof fractures were observed in places. Roof support is by full column resin bolts. The parting consists mainly of fine grained sandstone. In 1979 boreholes were drilled from surface into the area. One borehole records cavities of 0,5 m; 0,25 m and 0,42 m located 4,72 m; 1,47 m and 0,73 m respectively above the mined out Gus Seam.

In 1991 drilling was carried out by COMRO into the floor of the Alfred Seam in order to locate fracturing from the lower goaf. The results of the drilling are shown in Table 6.2.

Table 6.2 Depth of Drill Holes when Water Loss Occurred

| HOLE | DEPTH OF WATER LOSS (m) |
|---|---|
| 1 | 0,55 |
| 2 | 1,24 |
| 3 | 0,36 |
| 4 | 0,67 |
| 5 | 3,68 |
| 6 | 1,0 |
| 7 | 1,7 |
| 8 | 0,6 |
| 9 | Abandoned after 11,0 |

It was suspected that hole No 9 was drilled over a remnant pillar since there was no water loss after 11 m. The holes drilled lineally away from hole 9, namely Nos 5, 2, and 3 show progressive reductions in depths before water loss, indicating a return to goafing conditions.

No fracturing could be observed in the floor of the Alfred Seam.

The P/h ratio varied from 9,3 to 7,7.

### 6.4.5 Colliery K Makateeskop

The colliery is located in the Utrecht Coalfield of Northern Natal near Paulpietersburg (Spurr et al, 1986).

Mining of the Coking, Dundas and Gus Seams took place between 1934 and 1945. Mining in the Alfred Seam commenced in 1991, initially over the Dundas goaf, and later over both the

Dundas and Gus Seam goafs. A general section of the coal bearing strata is as follows:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | 2,43 | 0 - 100 |
| Alfred Seam | 5,0 | |
| Sandstone shale | 0,76 | |
| Gus Seam | 9,0 | |
| Sandstone shale | 2,6 | |
| Dundas Seam | 19,0 | |
| Sandstone shale | 1,0 | |
| Coking Seam | | |

It can be seen that the influence of the Coking Seam goaf on the mining of the Alfred Seam will be negligible due to the large ratio of the parting thickness to Coking Seam height.

The bord and pillar layout was developed on 25 m centres with 5,0 m bords.

Where the Alfred Seam was mined over the Dundas Seam goaf, vertical fractures were present along several sections of the roadways. The fractures were parallel with two haulage roads located in the Dundas Seam below. Barrier pillars had probably been left to protect the lower roadways from stooping, producing differential subsidence.

The pillar conditions were generally satisfactory although sidewall spalling was evident in places. Since spalling normally occurs when the depth of workings exceeds 250 m and the workings were only around 100 m in depth, it can be concluded that the increase in stress was due to stress transfer from lower seam remnants. Bending of wooden props had also occurred.

The P/h ratio between the Alfred and Dundas Seams was 5,6.

At one location it was suspected that the Alfred was being mined over Dundas and Gus goafs, even though the plans showed the Gus Seam had been worked nearby but not directly below. However, because the available plans only show the position of faces at six month intervals, it is possible for undermining to have occurred and not to have been shown on the plans. Development out from the last six month line could have taken place followed by pillar extraction on the retreat to inside the old development line all within a six month period. All mining outside the face line would not be recorded on the plan. A large increase in subsidence underground supports this theory, with conditions deteriorating and large roof falls occurring.

The P/h ratio taking a combined seam height of 3,36 m was 4,16.

### 6.4.6 Colliery L Dumbe

The colliery is located in the Utrecht Coalfield of Northern Natal at Paulpietersburg (Spurr et al, 1986).

The seam and parting thicknesses are as follows:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | 1,82 | 90 - 100 |
| Alfred Seam | 8,28 | |
| Sandstone shale | 0,91 | |
| Gus Seam | 6,97 | |
| Sandstone shale | 2,13 | |
| Dundas Seam | 17,60 | |
| Sandstone | 0,76 | |
| Coking Seam | | |

The Gus and the Dundas Seams were mined during the early 1930s. In both seams pillar extraction was carried out simultaneously, with mining in the Gus Seam being half a pillar in advance of the Dundas. During the 1960's development took place in the Alfred Seam. The pillar widths were between 14 m and 16 m, and the bord widths were approximately 5,0 m. Roof support was with timber props and bars. Around 1967 a floor collapse occurred resulting in three fatalities. The strata collapsed causing an unmined block of coal to be displaced downwards approximately 1,0 m (Smith, 1991). The depth of workings was between 90 m and 100 m which gives a safety factor of 4,0 to 5,5 depending on the pillar width.

A possible explanation for the collapse is that the parting sheared in an area between a solid remnant and the caved goaf. This would have been initiated by the stress concentration on the bridging strata during the formation of the pillar.

In order for the floor to collapse, two criteria must be satisfied:

i) a void must exist below the Alfred Seam
ii) the uncaved strata must be thin.

For a void to exist below the Alfred Seam, could be due to any of the following four situations:

i) incomplete caving in Dundas, complete caving in Gus
ii) complete caving in Dundas, incomplete caving in Gus
iii) incomplete caving in both seams
iv) complete caving in Dundas to Gus Seam, incomplete caving in Gus.

i) Incomplete caving in Dundas, complete caving in Gus

Taking bulking factors of 1,1 to 1,5, the voids remaining through incomplete caving are shown in Table 6.3.

Dundas h = 2,13 m parting to Gus 7 m

Table 6.3 Voids remaining above goaf from incomplete caving

| HEIGHT CAVING STOPING (m) | UNCAVED STRATA (m) | VOID (m) | | | | |
|---|---|---|---|---|---|---|
| | | bf=1,1 | bf=1,2 | bf=1,3 | bf=1,4 | bf=1,5 |
| 1 | 6 | 2,03 | 1,93 | 1,83 | 1,73 | 1,63 |
| 2 | 5 | 1,93 | 1,73 | 1,53 | 1,33 | 1,13 |
| 3 | 4 | 1,83 | 1,53 | 1,23 | 0,93 | 0,73 |
| 4 | 3 | 1,73 | 1,33 | 0,93 | 0,53 | 0,2 |
| 5 | 2 | 1,63 | 1,13 | 0,63 | 0,13 | NA |
| 6 | 1 | 1,53 | 0,93 | 0,33 | NA | NA |

It can be seen that voids and thin uncaved sections can exist for all bulking factors up to 1,5.

ii) Complete caving in Dundas, incomplete caving in Gus

Gus Seam h = 0,91 m parting to Alfred Seam 8,28 m

The voids remaining after caving heights of 1 to 8 m are shown in Table 6.4.

Table 6.4 Voids remaining above goaf from incomplete caving

| HEIGHT CAVING STOPING (m) | UNCAVED STRATA (m) | VOID (m) | | |
|---|---|---|---|---|
| | | bf=1,1 | bf=1,2 | bf=1,3 |
| 1 | 7,28 | 0,81 | 0,71 | 0,61 |
| 2 | 6,28 | 0,71 | 0,51 | 0,31 |
| 3 | 5,28 | 0,61 | 0,31 | 0,01 |
| 4 | 4,28 | 0,51 | 0,01 | * |
| 5 | 3,28 | 0,41 | * | * |
| 6 | 2,28 | 0,31 | * | * |
| 7 | 1,28 | 0,21 | * | * |
| 8 | 0,28 | 0,01 | * | * |

* indicates full caving has occurred, i.e. no void

From Table 6.4 it can be seen that small voids and thin partings are only possible for a bulking factor of 1,1.

iii) Incomplete caving in both seams.

This is a combination of situations (i) and (ii), and is only possible for low bulking factors.

iv) Caving from Dundas into Gus Seam goaf with incomplete caving below Alfred Seam

For caving to propagate from the Dundas into the Gus goaf, the bulking factor must be less than 1,3. Using a combined seam height of the Gus and Dundas as 3,04 the voids remainig for caving heights of 2 to 8 m above the top of the Gus Seam are shown in Table 6.5.

Table 6.5 Voids remaining above goaf from incomplete caving

| HEIGHT CAVING STOPING (m) | UNCAVED STRATA (m) | VOID (m) | | |
|---|---|---|---|---|
| | | bf=1,1 | bf=1,2 | bf=1,3 |
| 2 | 6,28 | 2,14 | 1,44 | 0,34 |
| 4 | 4,28 | 1,94 | 1,24 | * |
| 6 | 2,28 | 1,74 | 1,04 | * |
| 8 | 0,28 | 1,54 | 0,84 | * |

In this situation large voids and thin partings are possible if the bulking factor is low. It is concluded for this case study that the two lower seam goafs combined, creating the conditions for a floor collapse when the Alfred Seam was mined.

### 6.4.7 Case History M Vryheid Coronation - Coronation Section

A considerable portion of Middle Seam reserves were considered sterilised in an area where both the Top and Bottom Seams had been totally extracted. It was considered that goafing from the two seams had caused irreparable damage to the roof and floor of the Middle Seam. The seams lie in very close proximity to one another as shown in the following section:

| STRATA | THICKNESS (m) | DEPTH (m) |
|---|---|---|
| Sandstone | | |
| Gus Seam (Top seam) | 1,4 | |
| Sandstone | 1,5 - 2,0 | |
| Upper Dundas (Middle seam) | 1,3 | > 80 |
| Sandstone shale | 2,0 - 3,0 | |
| Lower Dundas (Bottom seam) | 1,3 - 1,5 | |

In order to extend the life of the mine, mining was attempted in the Middle Seam. Initially coal was mined using bord and pillar methods followed by pillar extraction, but problems arose when the pillars punched through into the Bottom Seam goaf. The method of mining was then changed to handgot longwalls. The mining method has been described in detail by Rutherford (1981), Vissekerker (1990), and Weldon and Johnson (1987).

The main features of mining in such close proximity to the lower seam goaf are:

i) the prominent subsidence troughs on the face which can give rise to poor roof conditions

ii) additional subsidence occurring while mining, causing the hydraulic props and the floor to dip towards the face.

Since the Middle Seam is still continuous, caving from the bottom seam has not extended into it and therefore it can be assumed that the caving has been arrested due to the complete or partial bulking of the strata. Subsidence of the Middle Seam takes place in two stages: firstly, due to the mining of the Bottom Seam, and secondly due to recompaction of the goaf from abutment pressure caused by Middle Seam mining.

If the height of caving has been determined by the bulking factor only, the caving heights for bulking factors from 1,1 to 1,8 can be calculated as shown in Tables 6.6 and 6.7. The initial and final subsidence are also shown assuming an initial and final residual bulking factor of 1,3 and 1,1 for Bottom Seam thicknesses of 1,3 (Table 6.6) and 1,5 m (Table 6.7).

Table 6.6 Heights of caving and initial and final subsidence (h=1,3 m)

| bf | H (m) h=1,3 m | S (m) bfi=1,3 | S (m) bfr=1,1 |
|---|---|---|---|
| 1,1 | 13,0 | NA | NA |
| 1,2 | 6,5 | NA | NA |
| 1,3 | 4,3 | NA | NA |
| 1,4 | 3,25 | NA | NA |
| 1,5 | 2,6 | 0,52 | 1,04 |
| 1,6 | 2,16 | 0,65 | 1,08 |
| 1,7 | 1,85 | 0,74 | 1,11 |
| 1,8 | 1,62 | 0,81 | 1,13 |

Table 6.7 Heights of caving and initial and final subsidence (h=1,5 m)

| bf | H (m) h=1,5 m | S (m) bfi=1,3 | S (m) bfr=1,1 |
|---|---|---|---|
| 1,1 | 15,0 | NA | NA |
| 1,2 | 7,5 | NA | NA |
| 1,3 | 5,0 | NA | NA |
| 1,4 | 3,75 | NA | NA |
| 1,5 | 3,0 | 0,60 | 1,2 |
| 1,6 | 2,5 | 0,75 | 1,25 |
| 1,7 | 2,14 | 0,99 | 1,28 |
| 1,8 | 1,87 | 0,93 | 1,31 |

NA = not applicable since the caving height is more than seam interval

Since the parting between the Middle and Bottom Seams is 2 to 3 m thick it is evident that high bulking factors (>1,5) are required to prevent caving from reaching the Middle Seam.

If the caving is only partial and voids are formed initially, the subsidence produced for caving heights of between 0,5 to 2,5 m is shown in Tables 6.8 and 6.9. An initial bulking factor of 1,3 due to Bottom Seam mining and a residual bulking factor of 1,1 due to Top Seam mining have been assumed.

Table 6.8 Initial and final subsidence produced from incomplete caving (Bottom Seam thickness = 1,3 m)

| Height of Caving (m) | S (m) bfi=1,3 | S (m) bfr=1,1 |
|---|---|---|
| 0,5 | 1,15 | 1,25 |
| 1,0 | 1,00 | 1,20 |
| 1,5 | 0,85 | 1,15 |
| 2,0 | 0,70 | 1,10 |
| 2,5 | 0,55 | 1,05 |

Table 6.9 Initial and final subsidence produced from incomplete caving (Bottom Seam Thickness = 1,5 m)

| Height of Caving (m) | S (m) bfi = 1,3 | S (m) bfr = 1,1 |
|---|---|---|
| 0,5 | 1,35 | 1,45 |
| 1,0 | 1,20 | 1,40 |
| 1,5 | 0,05 | 1,35 |
| 2,0 | 0,90 | 1,30 |
| 2,5 | 0,75 | 1,25 |

With the caving controlled by the bulking factor, between 50 and 60 per cent of the maximum subsidence has occurred after Bottom Seam mining. With parting plane controlled caving, the amount of subsidence that has occurred after Bottom Seam mining varies from 52 to 92 per cent of the maximum expected subsidence. The remaining subsidence takes place during Middle Seam mining. The maximum subsidence is the same in both cases as it is dependent only on the residual bulking factor. Thus, in the case where caving controlled by the bulking factor has occurred the additional subsidence experienced while mining will generally be greater than if the caving was controlled by parting planes and will be more detrimental to roof conditions.

Since subsidence is active as the Middle Seam is being mined, it would appear that the goaf from the Bottom Seam is loosely compacted. There have been no incidents of the parting failing violently.

A high initial bulking factor would result in a loosely compacted goaf. This is evident from compaction being obtained at the face line, and also from pillars punching through in the original bord and pillar mining method.

The P/h ratio ranges from 1,33 to 2,33.

It can be concluded that mining in this situation where the seams are so close is only feasible using longwall methods due to the better roof control achieved, the accommodation of subsidence troughs and the elimination of the problem of pillars punching through into the goaf when using bord and pillar methods.

## 6.5 Comparison of Conditions

Table 6.10 summarises the main parameters in each of the case histories.

Table 6.10 Summary of mining parameters in the case histories

| COLLIERY | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|
| Top Seam | Alfred | Gus | Gus | Alfred | Alfred | Alfred | Middle |
| Thickness (m) | 0,8 | 0,9 | 0,97 | 1,7 | 2,43 | 1,82 | 1,,3 |
| Depth (m) | 160 | 0-80 | 30-40 | 180-200 | 100 | 90-100 | 80 |
| Mining | BP+PE | BP+PE | BP+PE | BP | BP | BP | HGLW |
| Lower Seam | Gus | Dundas | Dundas | Gus | Dundas | Gus & Dundas | Bottom |
| Thickness (m) | 0,99 | 1,4 | 1,3-1,6 | 1,5 | 2,6 | 0,91 + 2,13 | 1,3-1,5 |
| Mining | BP+PE | BP+PE | BP+PE | BP+PE | BP+PE | BP+PE | BP+PE |
| Parting (m) | 15-17 | 17,4 | 17,0 | 14,0 | 14,7 | 8,3+7,0 | 2,0-3,0 |
| Time interval (yrs) | 18 | 2 | 30-40 | 20 | 50 | 30 | 22 |
| P/h | 15,1 - 17,1 | 12,4 | 11,0 | 9,33 | 5,65 | 5,0 | 1,33-2,33 |

Key

BP = Bord and pillar mining only
BP+PE = Bord and pillar mining followed by pillar extraction
HGLW = Handgot longwalls
P/h = Parting thickness/ Lower seam mining height

The case studies can be broadly divided into two groups.

Group 1 consists of collieries G,H,I,and J. The P/h ratio is high (>9) and only minor roof control problems were experienced. The partings are all sandstones of thickness 14 to 17 m. Pillar extraction in the upper seam was carried out safely at collieries G, H and I.

Group 2 consists of collieries K,L and M where the P/h ratio is less than 6 and where roof and floor stability problems exist. The low P/h ratio for colliery M has necessitated a change to a more accommodating and safer mining method for the conditions, namely longwall.

Numerous roof falls at colliery K were associated with remnant pillars left in the lower seam. Conditions deteriorated further when two goafs were mined over. A floor collapse at colliery L can be attributed to mining over two goafs where a void existed.

With the exception of colliery H, the time interval between top seam and lower seam mining is in excess of 18 years. The short time interval with colliery H however, did not have any major effect on top seam extraction although some floor instability was reported. Subsidence due to lower seam mining may not have been complete.

## 6.6 Application to other areas

Many collieries in the area have extensive reserves of No. 4 Seam. Mining to date has mainly been in the No. 2 Seam by bord and pillar methods in order to protect the No. 4 Seam.

Pillar extraction was carried out at New Clydesdale Colliery in the No. 2 Seam. The No. 4 Seam existed 17,2 m above the No. 2 Seam. In order to examine the caving characteristics of the goaf two surface boreholes (89/92, 90/92) were drilled over the proposed pillar extraction area in the No. 2 Seam. Five anchors were located in each borehole. The general geological section is shown in Figure 6.10 and the anchor locations are shown in Table 6.11.

Table 6.11 New Clydesdale Colliery - Geological Section

| DEPTH | THICKNESS | STRATA |
|---|---|---|
| 21,5 | 1,25 | No. 5 seam |
| | 4,8 | mudstone |
| | 0,35 | sandstone |
| | 2,55 | shale |
| | 2,82 | sandstone |
| | 13,32 | shale |
| | 0,43 | sandstone |
| | 1,47 | shale |
| | 0,48 | 4A Seam |
| | 1,61 | sandstone |
| | 2,85 | 4U Seam |
| | 3,0 | shale |
| 57,6 | 2,35 | 4 Seam |
| | 2,85 | sandstone |
| | 1,14 | No. 3 seam |
| | 2,26 | sandstone |
| | 1,95 | shale |
| | 7,17 | sandstone |
| | 1,90 | shale |
| 77,2 | 2,38 | No. 2 seam |

Table 6.12 Location of borehole anchors

| ANCHOR NO. | DEPTH BELOW SURFACE OF BOREHOLE ANCHORS (m) | |
|---|---|---|
| | B/H 1 | B/H 2 |
| 5 | 25,5 | 25,5 |
| 4 | 34,5 | 34,5 |
| 3 | 51,0 | 51,0 |
| 2 | 61,0 | 61,0 |
| 1 | 71,5 | 72,0 |

Table 6.13 Displacement of borehole anchors

| ANCHOR NO. | DISPLACEMENT (m) | |
|---|---|---|
| | B/H 1 | B/H 2 |
| 5 | 0,985 | 0,902 |
| 4 | 0,999 | 0,916 |
| 3 | 1,040 | 0,928 |
| 2 | 1,074 | 0,937 |
| 1 | 1,164 | 1,151 |

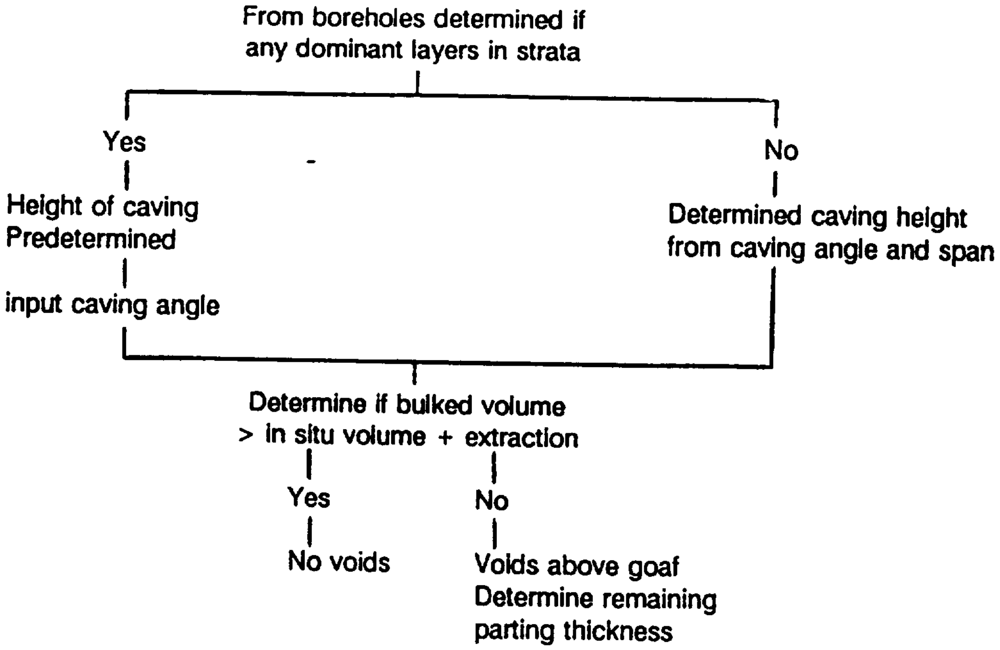
Table 6.13 shows the vertical displacement of the borehole anchors. Surface subsidence readings were taken on a regular basis. The maximum surface subsidences measured were 0,946 m and 0,868 m. This gives S/h ratios of 0,39 and 0.36.

Most of the caving and bulking occurred 5 to 6 m above the No. 2 Seam. the bulking factor was determined to be 1,3. Above the caving and bulking zone displacement only occurred. The No. 4 Seam was displaced by 1,04 m.

The ratio of the parting thickness to seam extraction height was 7,22. This would indicate that roof control might be a problem if mining was to take place in the No. 4 Seam.

Proposals to protect the No. 4 Seam by partial extraction in the No. 2 Seam usually result in limited spans being created. The height of caving will be determined by the caving angle and the ability to form self supporting spans. Insufficient rock may cave to completely fill the void. Future mining in the No. 4 Seam may take place over thin partings and voids.

A methodology was devised for determining whether upper seams can be protected through partial extraction of the lower seam. The criteria is determined if thin partings and voids will occur above the goaf.



## 6.7 Conclusions

Upper seam reserves can be recovered where high extraction mining methods have taken place in the seams below.

The feasibility of mining these seams will depend on the amount of fracturing and differential subsidence that has taken place. Remnant pillars, and boundaries between unmined coal and goaf in the lower seam produce differential subsidence and fractures. Mining over goafs mainly affects roof stability in the upper seam rather than pillar stability.

Upper seam mining conditions will depend on the type of strata, parting thickness, and the lower seam extraction height. The presence of a massive rigid layer has the effect of dampening stress transfer and immediate subsidence from lower seam mining. Upper seam conditions can be expected to be poorer if the parting consists of shales rather than stronger sandstones.

The type of strata in the parting will determine the caving mechanisms that occur after lower seam extraction. Two caving mechanisms are identified, namely bulking factor controlled caving and parting plane controlled caving. Where the ratio of the parting thickness/lower seam height is high and bulking factor controlled caving has taken place, anticipated problems in the upper seam will be minimal. If the parting thickness to lower seam height ratio is low and parting plane controlled caving has occurred, then there is the possibility of mining over incomplete goafing or voids. The possibility of a parting collapse will depend on the thickness and length of the bridging strata, and also the dimensions and stress on the upper seam pillars.

The case studies show that where the P/h ratio is high (>9) minor roof control problems exist. At three collieries pillar extraction was successfully carried out, in these cases however, the P/h ratio was greater than eleven.

Where the P/h ratio is low (<6) roof and floor stability problems can exist. At one colliery where the P/h ratio was less than three bord and pillar mining methods were unsuccessful and a change to longwall methods was more suitable.

It is concluded that by determining the P/h ratio, and examining the possible caving mechanisms, upper seam mining conditions can be determined when mining over lower seam goafs.

A methodololgy was devised for determining whether upper seams can be protected through partial extraction of the lower seam. (The criteria is determine if thin partings and voids will occur above the goaf.)

## 7 MINING UNDER GOAFS

Mining in a descending order such that each seam worked is under the top seam goaf is normally the prefered method of multiseam mining. It usually works well where good caving and consolidation has taken place. Problems may occur if the parting is thin and the upper seam workings are flooded. Time is allowed for goaf to settle before the bottom seam is mined. Mining under goafs with thin partings is common in the Natal collieries. Where the method of mining has been longwall few problems can be expected. When pillar extraction is carried out small remnants or snooks can be left. If a lower seam bord and pillar development becomes partially non-superimposed roadways may be located under remnants. Where remnants are known to have been left in the upper seam, lower seam mining should be superimposed below the original upper seam layout.

Where remnant pillars occur over lower seam bords fracturing may be observed, this can develop into a collapse.

Remnant and barrier pillars left in upper seams can cause severe damage when mining in a seam below, owing to the high stresses which are transferred even where the parting is thick (>15 m). Developments under remnant pillars can result in major intersection collapses. The mechanism is similar to the case of pillar extraction over bord and pillar workings where large tensile zones can be created. Methods of reducing the risk of roof collapse include reducing the road width, staggering the junctions as well as changing the roof support.

## 8 SIMULTANEOUS PILLAR EXTRACTION IN TWO SEAMS

Simultaneous mining is the mining of two (or more) seams in the same area at the same areal extraction rate. The horizontal distance between the two face lines in each seam is kept constant.

This type of mining has been carried out in Natal in the past especially where it has been difficult to keep lower seam roadways open for complete development under a goaf. It is normal for the coal to be transported out through one seam only.

Two methods have been employed (Rutherford, 1981)

(i) Simultaneous stooping in both seams (I)

Superimposed pillars are developed in both seams (Figure 8.1). Stooping takes place simultaneously in both seams with the top seam extraction line being about half a pillar ahead of the bottom seam extraction line. Problems can be experienced if goafing is not consistent. Some collieries spent many years experimenting with different top seam leads over the lower seam extraction line to find the optimum distance ( Heslop, 1921).

(ii) Simultaneous stooping in both seams (II)

The bottom seam is first developed on a bord and pillar layout. The pillars are extracted on a splitting system. As splits are developed the parting is dropped by drilling and firing. The top seam is recovered by top coaling from top of parting.

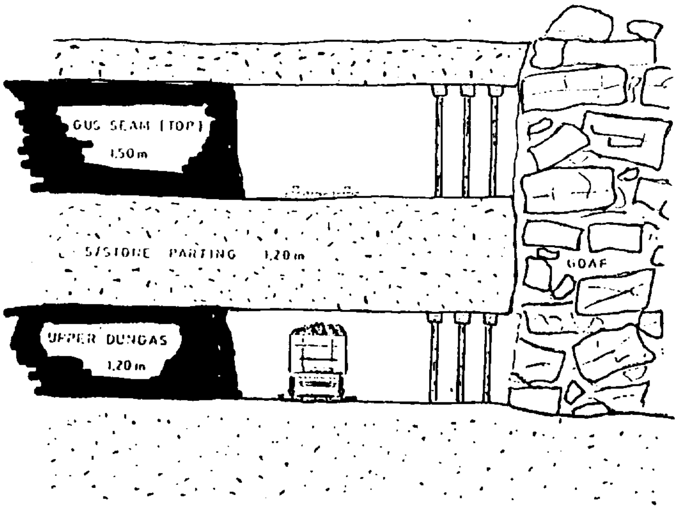


Figure 8.1 Simultaneous Pillar Extraction of Two Seams (after Rutherford, 1981)

Simultaneous mining has had mixed success probably because of reliance on good caving of the parting between the two seams.

## 9 EFFECT OF WORKINGS BEING UNDERMINED

High percentage extraction can be obtained from bord and pillar workings at shallow depth. This is particularly true for the No 4 seam in the Witbank area. If pillar extraction is subsequently carried out in a lower seam the question arises as to how the upper seam workings will be affected. If the workings collapse then eventual surface stability can be assured. If the workings partially collapse then the assessment of long term surface stability is difficult to determine. The factors affecting the stability of the upper seam will be the parting thickness, lower seam extraction height and the caving characteristics. Very few cases like this are known in South Africa.

Pillar extraction was carried out in the Gus Seam under Alfred Seam bord and pillar workings at one colliery in Natal. Access was eventually gained into an area in the Alfred Seam which would be undermined. The parting between the two seams was 18 m and the extraction height of the Gus Seam was 1,1 m. Photograghic monitoring showed no significent change in the upper seam conditions while undermining took place.

At another colliery in Natal access was gained to abandoned bord and pillar workings in the Gus Seam where pillar extraction later took place in the Dundas Seam. The parting was about 15 m and the lower seam height 1,2 m. The upper seam bords had collapsed as a result of the stooping in the Dundas Seam.

Numerical modelling shows conditions should be related to the ratio of the depth of cover to parting thickness.

Due to the lack of case histories the stability of the upper seam workings cannot always be determined. It is recommended that where possible pillar extraction be carried out in the upper seam in order that long term stability can be assured and mine closure certificates can be issued. This situation is most likely to arise in the Witbank No 2 and No 4 Seams.

It should be noted that this situation is different to the assessment of mining over goafs where the upper seam is virgin and therefore confined. In the case of undermining bord and pillar layouts the workings are unconfined and therefore more damage can be expected.

## 10 CAVING MECHANISMS

In multiseam mining layouts the caving mechanism is important.

Two types of caving mechanisms have been identified (Smart and Redfern, 1986; Smart and Aziz, 1989). These caving mechanisms were originally developed for powered support rating analysis on longwalls; however, the theory is extended here to examine multiseam situations.

For small spans the height of caving will be determined by the caving angle of the overlying strata.

i) Bulking factor controlled caving in which the height of caving will be determined mainly by the bulking factor of the caved material (Figure 10.1). The height of caving (H) may be estimated using:

$$H = h / (bf_i - 1)$$

where $h$ = extraction height and $bf_i$ = initial bulking factor

Caving continues upwards until the goafed material is in contact with the upper strata. As the pillar extraction line moves away, compaction of the goaf will take place.

Bulking factor controlled caving is typical of conditions where the strata consist of shales and mudstones and are therefore relatively weak.

ii) Parting plane controlled caving in which the caving height is determined by the location of dominant parting planes within the roof strata (Figure 10.2). A waste void will initially occur between the caved waste and the overlying strata. The magnitude of the void (v) can be calculated ( Smart and Redfern, 1986) from:

$$v = h - p(bf - 1)$$

where $p$ = height of parting plane above top of extraction section

From the pillar extraction line into the goaf area, the strata will converge until they make contact with the caved rock. The length of unsupported bridging beds (L) is the distance between the unmined area and the point of contact with the goaf. The length of this unsupported span (L) can be calculated by:

$$L = v / \sin \varnothing$$

where $\varnothing$ = the convergence angle

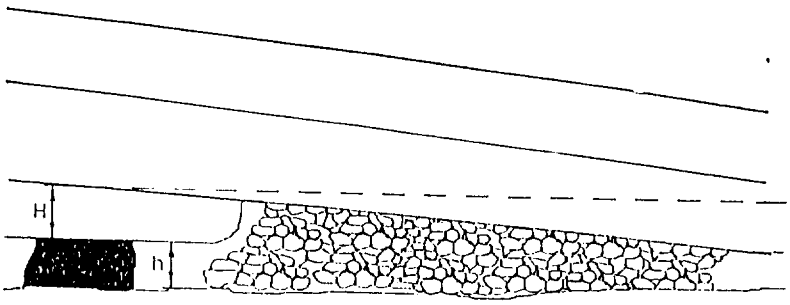


Figure 10.1 Complete Caving - Controlled by Bulking Factor

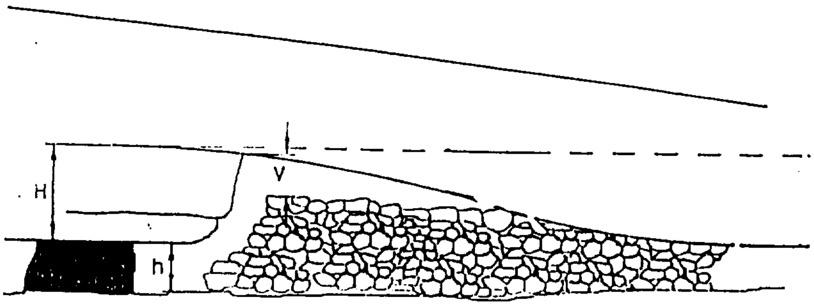


Figure 10.2 Incomplete Caving - Controlled by Parting Planes producing Voids

Measurements taken in British coal mines ( NCB, 1972) indicate a convergence angle of 2,5°. Assuming a convergence angle of 2,5°, L can be calculated for various values of v as shown in Table 10.1.

Table 10.1 Length of unsupported span created by a void

| v (m) | L (m) |
|---|---|
| 2,5 | 57,3 |
| 2,0 | 45,8 |
| 1,5 | 34,4 |
| 1,0 | 22,9 |
| 0,5 | 11,5 |
| 0,25 | 5,7 |
| 0,1 | 2,3 |

It can be seen that large unsupported spans can exist where full caving has not occurred, depending on the immediate strength of the strata.

Parting plane controlled caving is typical in conditions of alternating layers of different strength, where layers are identified by well defined parting planes. Where thick sandstone layers exist incomplete caving and therefore voids can be expected, and as the pillar extraction line advances, consolidation will take place in the goaf.

Whether the caving is totally controlled by the initial bulking factor or by the location of dominant parting planes, the final subsidence (S) of the immediate superincumbent strata can be calculated by:

$$S = h - H (b_r - 1)$$

Since the height of caving will by definition be less with parting plane controlled caving, it can be seen that the expected subsidence will be greater.

It can be expected also, that at shallow depths reconsolidation of the caved goaf will be less than at greater depths,and will impose less damage on an upper seam.

## 11 CONCLUSIONS

The safety hazards associated with multiseam mining have been recognised and will depend on the mining sequence and method. Multiseam mining will continue in South Africa for the foreseeable future in order to maximize reserves at collieries. Brownfield developments are preferred to greenfield developments since capital costs are usually less.

Considerable research has been conducted into multiseam mining in other countries especially the USA. Several methods have been used to identify the factors affecting the success or failure of multiseam mining. Numerical modelling and field studies have been used to identify trends and problem areas, but critical factors may be omitted. Statistical analysis has been used to overcome some of the disadvantages of not knowing the critical variables. These methods require considerable amounts of data of failed and successful multiseam situations. This latter approach is not suitable for South African analysis aiming to the limited data available.

The Salamon and Oravecz guidelines have proved successful for bord and pillar mining although they can be conservative. They are suitable for average South African colliery conditions. The limiting distance concept is dependant on stress as well as pillar size.

It is recommended that for borderline cases i.e. where the parting approximates 0,75 the pillar centre distance, numerical modelling be carried out to determine if pillar superimposition is necessessary. For layouts beyond average conditions (> 100 m) numerical modelling should always be used.

The degree of superimposition is important, since partial superimposition may cause high stress concentrations. Nominal safety factors in each seam are acceptable only if pillar superimposition is carried out with a high degree of accuracy.

Surface and underground monitoring of non-superimposed bord and pillar layouts has shown no adverse effects at a site where the guidelines suggested superimposition but numerical modelling showed otherwise.

The original guidelines did not make recommendations regarding barrier pillars. A guideline that has been in use is to superimpose barrier pillars if the parting is less than 1,5 times the panel pillar centre distance (C). Subsequent research has shown that the limiting distance of stress normalization varies with the ratio of the barrier to panel pillar width. For barrier pillars of the same width as the panel pillars it will not be necessary to superimpose the barriers if the parting is greater than 0,9 or 1,0 C. Where barriers are considerably larger than the panel pillars the limiting distance will be greater than the 1,5 C rule. It is again recommended that numerical modelling be carried out where barrier pillars exist since the relative loading between panel and barrier pillar is complex and depends on panel geometry and depth.

Numerical modelling has shown that if pillar superimposition is properly carried out stable thin partings may exist between workings. Considerably thicker partings are required if pillar extraction is carried out in the upper seam.

Pillar extraction over bord and pillar workings can create considerable problems in the lower seam; the main influencing factors being the parting distance and the caving mechanism. Where caving readily occurs anticipated problems are minimal. The degree of pillar superimposition is of prime importance. Even where a competent roof exists and no support installed roof failure may occur when over mined. Since dynamic changes take place any support is installed, should be compatible with the expected change in stress.

When mining over goafs a good assessment of the expected conditions can be obtained from the parting (P) to lower seam height (h) ratio. When the ratio is greater than 9 few problems can be expected. If the P/h ratio is less than 6 roof control problems can be expected. At very low ratios (<3) bord and pillar mining may be unsuitable and a different method such as longwall may be necessary. Conditions can rapidly deteriorate when mining over two goafs. It was shown that the worst scenario is one where a thin parting exists over incomplete goafs.

Investigations have shown that partial extraction in a lower seam may not always ensure safe upper seam extraction at a later date. The caving angle is a critical factor in this situation.

There have been limited case histories on the situation where pillar extraction has been carried out under upper seam bord and pillar workings. Numerical modelling has been carried out to determine influencing parameters.

For optimum extraction of two seams, total extraction in a descending or ascending order (depending on the parting to lower seam height ratio) is preferable for high recovery and safe mining.

The sequence of bord and pillar in the top seam followed by pillar extraction in the lower seam with eventual pillar extraction in the top seam is not recommended.

The success of simultaneous mining in two seams is very dependent on the caving mode of the parting. On some mines it was successful while others were forced to abandon it when conditions became too dangerous. It is not recommended as a first choice of mining method.

## 12 REFERENCES

Bandopadhyay, C., Sheorey,P.R., Singh, B. and Ghose, A.K.(1988). Stability of Parting Rock Between Level Contiguous Coal Pillar Workings, Int J Rock Mech Min Sci & Geomech Abstr. Vol 25, No 5, pp 307-320.

Beckett,L.A.,and Madrid,R.S., (1986) Practical Application of MULSIM/BM for Improved Mine Design, 3rd Conf.Use of Computers in the Coal Industry, Morgantown 28-30 July 1986.

Bradbury,T.J. and Lear, C.D.(1984) Pillar Design Considerations for Multiseam Bord and Pillar Mining at Khutala Colliery, Rand Mines Discussion Document.

Chanda,E.C.K., (1989) Evaluation of Success Probability in Multiple Seam Room and Pillar Mining, Min Sci & Tech,9 57-73

Checkan,G.J.,and Matetic,R.J., (1988) Loading Characteristics of Pillars in Multiple Seam Mining Operations. U.S. Bureau Mines RI 9173,

Dhar,B.B., Shrivastava,B.K., and Gupta,S.K, (1988) Effect of Staggering of Longwall Panels in Contiguous Seams - A FEM Approach, Underground Engineering

Dunham,R.K.,and Stace,R.L., (1978) Interaction Problems in Multiseam Mining, Proc 19th Symp Rock Mech., Stateline, Navada, May 1978, Vol.1 pp 174-179.

Ehgartner, B.L., (1982) Pillar Load Transfer Mechanisms in Multi-seam Mining, M.S. Thesis, Virginia Polytechnic Inst. and State Univ. Blacksburg.

Galvin, J.M.,and Anderson K.G., (1986) The Design of Multiseam Workings at Shallow Depth Under Tidal Waters, Proc Symp Ground Movement and Control Related to Coal Mining, AusIMM,Illawara Branch,Aug 1986

Grenoble, A., and C. Haycocks,(1985) Design Factors in Near Seam Interaction. 4th Conference on Ground Control in Mining. WV Univ., Morgantown, WV,1985, pp.166-177.

Hasler, H.H. Simultaneous vs Consecutive Working of Coal Beds (1951), Trans.AIME, Min.Eng., May 1951

Haycocks,C., Ehgartner,B.L., Karmis,M., and Topus,E., (1982) Pillar Load Transfer Mechanisms in Multi-Seam Mining. Soc.Min.Eng. AIME preprint 82-69, 1982

Haycocks,C., Holland,C.T.,and Zhou,Y., (1990) Multiple-Seam Mining - A State of the Art Review, 9th Int. Conf. on Ground Control in Mining, Morgantown, W.Virg.

Haycocks,C., and Karmis,M., (1993) Ground Control Mechanisms in Multiseam Mining, BuMines OFR 7-84.

Haycocks,C.,Karmis,M.,and Topus,E.,(1991) Optimising Productive Potential in Multiseam Underground Coal Mining, Symp on Underground Mining, Proc.Coal Conf. and Expo VI Oct 27-29,1981

Haycocks, C., Wu, W. and Zhou, Y. (1987) Integrated Design for Stability in Multiple seam Mining. Bureau of Mines Information Circular/1987 IC 9137.

Heslop, W.T., (1921) Coal Pillar Extraction from Two Seams and Surface Effects, Journ.Chem. Metall.and Mining Soc. S.Afr.,Oct.

Hodkin, D.L., (1982) Interaction Between Pillar Workings at Ellington Colliery, Symp on Strata Mechanics, Univ.Newcastle Upon Tyne, April 5th - 7th, 1982.

Holland,C.T., (1951) Multiple-Seam Mining, Coal Age, Aug.1951

Hsuing,S.M and Peng,S.S. (1987) Design Guidelines for Multiple Seam Mining, Part 1 Coal Mining, September 1987 pp 42-46

Hsuing,S.M and Peng,S.S.(1987) Design Guidelines for Multiple Seam Mining, Part 2 Coal Mining October 1987 pp 48-50

King,H.J.,Whittaker B.N.,and Bachelor A.S., (1972) The Effects of Interaction in Mine Layouts, Fifth International Strata Control Conference,London England.

Lazer,B.J., (1965) Mining Seams above Mined-Out Lower Seams, Mining Engineering,Sept 1965.

Matetic,R.J. and Chekkan,G.J. (1988) Comparative Study of Pillar load transfer Associated With Multiseam Mining Bureau of Mines Report RI 9176, 1988

Matetic,R.J., Checkan,G.J.,and Galek, J.A., (1987) Pillar Load Transfer Associated With Multiple-Seam Mining Bureau of Mines RI 9066.

Monger,N.R., (1986) Multi Seam Working, Australasian Coal Mining Practice, Aust.Inst.Min and Metall. Monograph No 12, Chapter 22.

National Coal Board, (1954) Report on the Effects of Working in Adjacent Seams Upon New developments. Trans. Inst. Min. and Metall.,v. 113.

Oravecz, K.I. (1968) Mining of neighbouring seams at Coalbrook Collieries, Research Report No 51/68, Chamber of Mines of South Africa

Oravecz, K.I. (1972) Long term effects of double seam extraction at Coalbrook Colliery, Research Report No 39/72, Chamber of Mines of South Africa.

Peng, S.S. (1986) Coal Mine Ground Control. 2nd Ed.John Wiley, Peng,S.S.,and Chandra,U., (1980) Getting the Most from Multiple-Seam Reserves, Coal Mining and Processing, Nov 1980

Rutherford, M., (1981) Multiseam Mining at Vryheid Coronation Colliery. Paper presented at SAIMM Summer School: Increased Underground Extraction of Coal.

Salamon,M.D.G. and Oravecz,K.I.,(1976) Rock Mechanics in Coal Mining, Chamber of Mines of South Africa.

Smart, B.G.D. and Redfern, A, (1987) The evaluation of powered support specification from geological and mining practice information, Proc. 27th US Symposium on Rock Mechanics.

Stemple, D.T. (1956) A Study of Problems Encountered in Multiple-Seam Coal Mining in the Eastern U.S. Bull. VA Polytech.Inst., v.49, No 5, Mar. 1956.

Szwilski,A.B., (1979) Stability of Coal Seam Strata Undermined by Room and Pillar Operations, 20th U.S. Symp.on Rock Mech, Austin, Texas, June 4-6.

Van der Merwe, J.N. (1980) The extraction safety factor concept in high extraction coal mining, J.S.Afr.Inst.Min.Metall., Nov.

Wagner, H., and Schumann, E.H.R., (1991) Surface effects of total coal-seam extraction by underground methods, J.S. Afr. Inst. Min. Metall., vol 91, no7. Jul. 1991.pp 221-231

Webster,S.,Haycocks,C.,and Karmis,M., (1984) Subsidence Interaction Effects in Multiseam Mining, 2nd International Conference on Stability in Underground Mining, Lexington.

Wilson, A.H., and Ashwin, D.P.,(1972) Research into the Determination of Pillar Size. Min.Eng. (London), v.131, No 141.

Wu,W, and Haycocks,C., (1986) A Statistical Analysis of Interaction Problems in Close-Proximity Multi-Seam Mines, Proc 27 US Symp on Rock Mechanics.

Zhou,Y. and Haycocks,C., (1986) Designing For Upper Seam Stability In Multiple Seam Mining, Proc 5th Conf. Ground Control in Mining. WV. Univ., Morgantown, WV.

## APPENDIX 1 ENABLING OUTPUTS

The safety hazards associated with multiseam mining have been recognized and will depend on the mining sequence and method.

The Salamon and Oravecz guidelines have proved successful for bord and pillar mining although they can be conservative. It has been shown that the limiting distance concept is dependent on other factors as well as pillar size. It is recommended that for layouts beyond average conditions numerical modelling should always be used. A simple elastic model can be used which is usually quick and efficient to run.

Research has shown that for barrier pillars the limiting distance of stress normalization varies with the ratio of the barrier to panel pillar width. For barrier pillars of the same width as the panel pillars it will not be necessary to superimpose the barriers if the parting is greater than 0,9 or 1,0C. Where barriers are considerably larger than the panel pillars the limiting distance will be greater than the 1,5C rule, which has sometimes been applied. It is recommended that numerical modelling be carried out where barrier pillars exist since the relative loading between panel and barrier pillar is complex and depends on panel geometry and depth.

Numerical modelling has shown that if pillar superimposition is properly carried out stable thin partings may exist between workings. Considerably thicker partings are required if pillar extraction is carried out in the upper seam.

It has been shown that pillar extraction over bord and pillar workings can create considerable problems in the lower seam; the main influencing factors being the parting distance and the caving mechanism.

The caving mechanism can be determined by examining the strata above the upper seam. The modulus of rigidity can be calculated or estimated. Since dynamic changes take place any support installed should be compatible with the expected changes in stress. Lower seam travelways should be well supported prior to stooping taking place in the upper seam.

When mining over goafs a good assessment of the expected conditions can be obtained from the parting (P) to lower seam extraction height ratio. When the ratio is greater than 9 few problems can be expected. If the P/h ratio is less than 6 roof control problems can be expected. At very low ratios (<3) bord and pillar may be unsuitable and a different method such as longwall may be necessary. Caution must be exercised where thin partings exist over incomplete goafs.

A methodology is devised for examining partial extraction of a lower seam in order to protect an unmined upper seam.

For optimum extraction of two seams total extraction in a descending or ascending order (depending on the P/h ratio) is preferable for high recovery and safe mining.

The sequence of bord and pillar in the top seam followed by pillar extraction in the lower seam with eventual extraction in the top seam is not recommended.

## APPENDIX 2

R.W.Hill (1990) Review of Underground Multiseam Mining outside South Africa, COMRO Internal Note C12/90

R.W.Hill (1993) Mining Upper Seams over Lower Seam Goafs - Case Histories in the Natal Coalfields 1993, COMRO Reference Report 23/92.

R.W.Hill (1993) Mining Upper Seams Over Lower Seam Goafs, Paper presented to South African Colliery Managers' Association, August 1993 to be published in 1993 SACMA proceedings.

R.W.Hill (1993) Underground Multiseam Coal Mining in South Africa, 25th Int.Conf.of Safety in Mines Research Institutes, Pretoria, September 1993.

# APPENDIX 3 SUMMARY OF DESIGN GUIDELINES FOR MULTISEAM MINING IN THE USA (AFTER HSIUNG AND PENG, 1987)

## 1 UPPER SEAM MINED BY LONGWALL, LOWER SEAM TO BE MINED

Situation 1- Parting more than 2 times the width of remnant pillars left in upper seam.

Lower seam is outside influence zone therefore little damage.

Situation 2- Parting less than 2-3 times width of remnant pillars left in upper seams but larger than 10 times the mining height of the upper seam.

The following precautions should be taken:

(a) Superimposition of longwall chain pillars not advisable.
(b) Positioning panel entries under goaf may bring about improvements.
(c) Main entries better positioned in virgin ground.
(d) If lower seam to be longwall mined, panels should be positioned under goafs. If the longwall must cross the solid/goaf boundary in the upper seam, then mining from the goaf to the solid side of the boundary is recommended. Even better if the face approaches the solid/goaf boundary with an angle between 30 and 45 degrees.
(e) If the lower seam is to be mined by bord and pillar, coal pillars of about three times the width of the remnant pillar should be left.

Situation 3- Parting less than 10 times the mining height of the upper seam.

Coal in lower seam highly fractured or extremely stressed.

Mining will be extremely difficult. The alternative is to mine the upper seam by bord and pillar with partial extraction. Then mine the lower seam by either longwall or bord and pillar.

If an aquifer lies in the roof within a distance less than thirty times the mining height, longwall mining will fracture the aquifer.

To prevent water problems the parting should be larger than forty times the mining height or two to three times the width of the remnant pillars, whichever is the larger. The alternative is bord and pillar mining with partial extraction for the lower seam.

## 2 MINING IN ASCENDING ORDER - LOWER SEAM MINED FIRST

Situation 1- Parting less than thirty times the mining height of the lower seam.

Highly unstable entries and extensive roof falls can occur.

Better conditions will occur in the upper seam if bord and pillar mining with partial extraction is used in the lower seam.

Situation 2- Parting is greater than thirty times the mining height.

Ground control problems most likely caused by subsurface subsidence.

The following should be considered if the lower seam has first been longwalled.

(a) If the upper seam is to be longwalled then the panels should be positioned over the mined out areas. Positioning panels across solid goaf boundaries should be avoided.

(b) Main entry systems and longwall panel entries in the upper seam should not be positioned within the angle of draw.

(c) Caution to be taken when mining over remnant pillars. Superimposition of longwall chain pillars is not recommended.

## 3 PRECEDING SEAM MINED BY BORD AND PILLAR WITH PARTIAL EXTRACTION

Few problems will result and will depend on the extraction ratio. Superimposition of pillars is recommended especially when two seams are close or the extraction ratio in the preceding seam is relatively high.