Key success elements of coal pillar extraction in New South Wales

by G.H. Lind*

Synopsis

Seven full and partial pillar extraction operations were visited in New South Wales, Australia, in the early parts of 2001. Certain factors unique to these operations have led to the general success of the safe and economic extraction of these coal pillars. Some of these factors attributable to the overall success of these operations are discussed in this paper. In particular, geotechnical mapping, specific legislation pertaining to pillar extraction, mining methods, the role of temporary supports and training are described. It is found that some of these factors have useful attributes which could be used to design a methodology for extraction of underground coal pillars in the Witbank and Highveld coalfields of South Africa.

Introduction

This paper is a follow-up paper to a previous paper entitled, 'Coal pillar extraction experiences in New South Wales'. Whereas that paper described the types of underground pillar extraction conducted in New South Wales, this paper looks specifically at the factors that influence this type of mining method that have ensured its general successes there. Again, the aspects described in this paper are from the author's experiences stemming from a research visit of seven underground pillar extraction operations in New South Wales in the early parts of 2001 as part of the Coaltech 2020 collaborative research initiative.

The number of pillar extraction operations in the State of New South Wales in Australia has declined in recent years to contribute only 7 per cent of the State's coal production in 2000. Conversely longwall operations contributed approximately 33 per cent in the same period. This paper will discuss some of the important design and operational factors of the four full pillar extraction and three partial pillar extraction sites visited in New South Wales. These will be discussed under the broad headings of Section 138, geotechnical mapping, caving of the immediate roof, mining method, temporary support, mining equipment and training.

Section 138 of the New South Wales Coal Mines Regulations Act of 1982

Section 138 of the New South Wales Coal Mines Regulations Act of 1982 was introduced in September 1994, to ensure proper consideration of three significant issues associated with the extraction of coal by means of underground methods (those methods other than the bord-and-pillar system such as longwalling and pillar extraction). These three factors are:

- ➤ The safety of persons working in mines
- ➤ The responsible exploitation of the State's coal resources
- ➤ The impact of mining operations on other land users and groups within society.

In terms of safety, the first and most important of these issues, any operation applying under Section 138 is required to detail the following information before an application is considered for approval

- ➤ The proposed mining method
- ➤ The ventilation system
- ➤ The possible presence of methane and noxious gasses and proposals on how to limit their effects
- ➤ The possible danger of spontaneous combustion, ingress of water and windblasts and proposals on how to limit their effects;
- ➤ An assessment of the likely impact that the roof and floor may have on mining safety
- ➤ Where the depth of cover is below 30 m, a geotechnical study into the likelihood of an uncontrolled collapse must be undertaken and details of control and other amelioration measures required to ensure workplace safety, must be provided.

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The second issue of resource recovery requires that the operation making an application must demonstrate that the proposed mining method is efficient as regards to recovery of the coal and must demonstrate that any economic resources contained within seams above or below the proposed seam to be mined are not sterilized. Although the law is not prescriptive as to how this is done, it is generally accepted that some numerical modelling be conducted to estimate the overall impact of the extraction method in terms of likely stresses and surface subsidence.

The third objective of the impact of mining operations on other land users and groups within society requires the identification of significant man-made and natural features within the surface lease area affected by the operation and to assess the impact of the proposed mining activity upon these features. This usually requires identifying existing or proposed surface features (such as rivers, public utilities, public amenities, residential structures, etc.) and assessing the impact that the underground extraction will have on these; in particular the estimation and measurement of surface subsidence.

The approval granted under Section 138 is for a maximum period of 5 years, although extensions can be granted provided an updated application considering all the above factors accompany the application. The introduction of Section 138 has ensured that operators are holistic in their approach in terms of developing this risk management plan to ensure the successful conduct of the underground extraction in terms of the safety of the operation and the economic benefit derived from it.

Geotechnical mapping

Geotechnical mapping is an all-encompassing visual evaluation of underground panels to observe and fully document roof, pillar and floor conditions so as to assess whether pillar extraction can be conducted safely. This technique assesses changes that may have occurred since primary development and ensures that the potential risks associated with geotechnical features are identified and minimized prior to secondary extraction. The following are the major components of a geotechnical mapping study

- Measurement of pillar dimensions, roadway widths and heights in comparison to those reported on the survey plan. In addition to the assessment of accuracy of the plans, any excessively wide intersections should be marked on the plan
- Measure any seam gradient changes indicating dip direction to compare these with the surveyed measurements. In particular note and mark any ridges or cracks on the floor, as these generally indicate an increase in joint spacing frequency which are usually accompanied by higher stresses
- Measure, mark and indicate on the section plan recognisable joints, the extent of any feather-edging (usually an indication of roof bedding separation) in terms of whether or not they have been affected by water, and whether or not they are minor faults
- Measure and mark on the section plan the nature of the primary roof support as this generally indicates the condition of the roof. Further, any scaling or roof-induced shear should also be noted
- Measure and mark on the plan the extent of any rib spall that has occurred
- Measure and mark on the section plan the nature and extent of any floor heave.

A geotechnical mapping study minimizes any geotechnical risk prior to a pillar extraction operation as potential areas of weakness are clearly identified and marked both in the section and on the section plans prior to extraction commencing. In this way, any additional roof support can be installed prior to the extraction operation to minimize these higher risks. Further, as all section miners have a copy of the resultant geotechnical mapping inputted onto their section plans, they are able to act as a first line of control for risk management at the working face in terms of being proactive by raising awareness when operating in a hazardous area. In New South Wales, a geotechnical mapping assessment is required under Section 138 of the Coal Mines Regulations Act to accompany the application for pillar extraction.

Understanding the caving mechanism of the immediate roof

Anderson[1] reported that the nature of the immediate roof strata, ranging from the seam roof to 20 m above the seam, plays a critical role when the goaf is formed and this explains how cantilevering of the goaf strata leads to collapses. In caving practices there are two types of identifiable strata that have the greatest influence on goaf behaviour:

- Massive strata (such as conglomerate and sandstone) and
- Laminated rock (such as coal, mudstones, laminated shales and laminated sandstones) overlain by massive strata.

Massive strata is able to span large distances (60–70 m in New South Wales) before the first major goafing occurs. Abutment stresses prior to the first goaf are substantially higher than with weaker roof strata and result in rib crush on pillars prior to the goaf. Sudden, massive energy releases causing windblasts and feather-edging are common occurrences after the first major goaf of the massive strata. Consequently, under massive strata in New South Wales, no full caving practices are conducted to avoid these potential roof fall risks. Rather, partial extraction of pillars is considered.

Under laminated rock strata, the laminated beds cave readily and regularly, while the overlying massive strata behaves in a manner as described previously. However, the initial fall of the laminated rock provides a buffer for when the massive strata collapses. Anderson[1] adds that as load increases in the seam roof with the upper massive strata cantilevering, the roof deflects with the variable stiffness of the strata resulting in the immediate laminated roof failing while the upper beds remain stable. Ultimately these upper beds will also fail. Figure 1 shows the dynamics of goaf creation.

Anderson[1] also describes how the immediate strata also accounts for the sudden collapse of a hanging goaf in instances of shallow depths of cover, citing two cases in New South Wales where falls of ground leading to a fatal accident and burial of a continuous miner were attributed to the shallow depth below surface (below 35 m cover).

The nature of the overlying strata as described here influences the type of mining method that is employed which is discussed next.

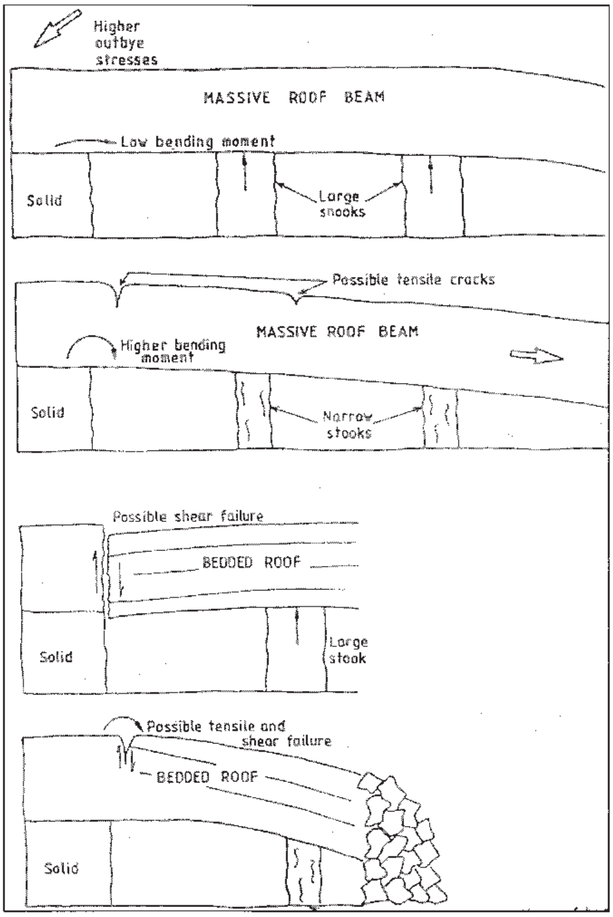

Figure 1—Dynamics of goaf creation

Mining method

The economics of an operation are readily understood in terms of the profitability of the operation which ultimately form the basis of a decision by the operator whether to mine or not. The more important considerations to the operators are the effects the operations will have on the community and the effects the operation will have on the personnel of the operation. Generally, partial extraction is conducted under sensitive areas (such as housing and public utilities) and under massive roof conditions, while full pillar extraction is conducted as far as possible in other suitable areas which are not limited by roof conditions or surface restrictions to maximize extraction.

The trend in New South Wales is to move away from pillar extraction techniques in favour of longwalling, but where pillar extraction is considered, the trend is to move away from the specialist techniques such as the Wongawilli and Munmorah systems. Rather, pillar extraction depends on ensuring that operational expenditure is focused during the development of a panel, so that the extraction process is focused primarily on the speed of the extraction (i.e. fully developing a panel before extracting it). This further ensures that the development and extraction activities are independent of one another, unlike the specialist techniques (such as the Wongawilli system) which have interchangeable periods of development and extraction throughout the panel's life. Thus, training and retraining of personnel is fixed for known periods of panel development and panel extraction.

Irrespective of whether the mining method is a full or partial pillar extraction operation, the resultant method of extraction is very similar in that fenders are lifted on retreat (called pillar stripping), generally at a 60° angle. Geotechnically, extracting as close to 90° as possible is ideal, but this however would make it very difficult for a continuous miner to manoeuvre itself into this difficult angle. Thus, a trade-off between good geotechnical practise and machine capability resulted in the 60° angle being used as an industry standard for pillar extraction. Remote controlled continuous miners and remote controlled Mobile Breaker Line Supports (MBLS) are used in most instances. Where the fender width-to-height ratios are greater than 2.5, double-sided lifting can be conducted (with the fenders extracted in New South Wales being a maximum width of 11 m).

Overlying workings

In deciding upon a mining method, cognisance of overlying workings must also be taken. Where an active panel is overlain by workings which contain full pillars or goaf areas where substantially sized snooks remain, their influence on the lower workings need to be investigated. Anderson[1] found that, in areas where the interseam parting to the upper workings is less than 40 m thick and consists of mainly shales and mudstones, load is concentrated almost vertically below the upper seam pillars which could cause the premature collapse of the pillar being extracted. He also found that where the interseam parting is massive, the load concentrations are more evenly distributed on the lower workings and would not negatively affect the extraction operation there.

Combating windblasts

In some underground coal mines where the roof comprises strong and massive rock, the roof strata does not collapse regularly as extraction progresses. When these areas collapse, they compress air underneath, forcing it into roadways and other openings in a phenomenon known as windblast. Windblasts are characterized by the main airflow outbye usually being followed by an immediate flow of air in the opposite direction towards the goaf and into the newly created void above the fallen roof[2]. The force of the wind may cause injury to personnel, damage to equipment, and disruption to the ventilation system and can increase the hazard of explosion by expelling methane from the goaf and mixing it with raised coal dust to form an explosive mixture. If this stirring of coal dust contains a quartz content exceeding 20 per cent the potential for frictional ignition, which could result in an explosion if an explosive mixture is present, exists[3].

Torabi[4] highlighted a number of historical cases in New South Wales of full extraction operations (which included pillar extraction and longwall operations) that resulted in fatalities and/or injuries associated with windblasts. These mainly occurred in areas overlain by massive roof strata. The most severe consequences of windblasts resulted under massive roof strata, with the effects from the collapse of weaker, laminated roof strata being less severe. In some areas in New South Wales, the practice of hydrofracture has been applied. Hydrofracture is the application of high pressure water injection or blasting in boreholes preceding the line of mining to induce breaking of the massive strata to encourage early caving. This technique has been applied successfully in longwall operations under massive roof strata. It could also be applied to pillar extraction operations under massive roof strata although, as mentioned previously, the general practice is not to induce full caving under these massive roof conditions by keeping the panels sub-critical (i.e. the ratio of the depth below surface to the width of the panel below 1.4 for New South Wales conditions). Also, if caving of massive strata is planned, a full risk analysis together with mitigating control measures is required in terms of Section 138.

The role of temporary supports

Both full and partial extraction techniques rely specifically on the role of a small coal pillar (or snook) for their safe operation which is left to control roof activity at intersections. Anderson[1] recognised that the probability of strata collapse increases at or near intersections, having identified six incidences of strata collapse associated with the beginning of the fender and fourteen cases at the end of the fender leading to a fall of ground event in pillar extraction operations in New South Wales between 1980-1992. The increase in span of intersections (as opposed to normal roadways), the influence of time and elevated goaf edge loads are key factors in intersection behaviour in extraction panels. Snooks are specifically designed to provide adequate temporary support at intersections, and the overall importance of snooks, as well as the other forms of temporary supports used in New South Wales are now discussed.

Snooks

Snooks are legally required to be left during pillar extraction, particularly at intersections, to provide a temporary support of the workings by limiting the resultant span created at the intersections. The size of the snook is dependent mainly on the nature of roof (see Figure 1). In weak roof conditions the roof has low stiffness that causes the snook to load quickly and to fail and snook sizes may be small under such conditions. In strong roof conditions the roof has a high stiffness and can span or cantilever over great distances and cause cyclic loading conditions. Snooks under these conditions would need to be very large to induce the competent roof to break off and prevent failure from occurring immediately outbye of the working face. However, these large snooks could further impede the development of caving and thus create higher abutment stresses as a result of them not failing.

As the action of pillar extraction retreats toward an intersection, the resultant snook is subject to immense and dynamic load as the load supported by the fender is shifted and concentrated onto the smaller area of the snook. The design of the resultant snook is thus very important and is the current focus of research in the USA[5]. It is further believed that when the width-to-height ratio of these snooks (which are slender pillars) is equal to or less than 2, the uniaxial compressive strength (UCS) of the coal may be an important consideration in their design[6].

Snooks offer one of the most effective means of controlling pillar extraction hazards in the vicinity of intersections because:

- They have a high load carrying potential
- They are formed *in situ* and therefore provide continuous resistance to the roof and floor displacements
- They are a much stiffer support system than either timber or MBLS and therefore provide a greater resistance against displacement
- They can be designed to be located in a more effective position for restricting roof span than with either timber or MBLS.

The type of extraction method also impacts on the increase in size of the intersection. Double-sided lifting (lifting left and right from a split) creates a significantly larger intersection area than when only single-sided lifting is employed. The overall snook design has to cater for adequate roof control across these large intersections. An over-design of these, however, will result in negative caving effects (in preventing caving) while an under-design would result in snook softening and the possibility of their premature failure.

Mobile Breaker Line Supports (MBLS)

Mobile Breaker Line Supports (MBLS) were introduced into pillar extraction operations in New South Wales during the 1980s, after their successful trials with the rib pillar mining methods in South Africa[7], with the aim of achieving three goals.

- Improving safety by providing greater support at the goaf edge to reduce the risk to workmen and also to reduce the incidences of buried continuous miners. Less timber would thus be used and as a result there would be less injury to labour associated with transport and installation of this timber
- Increased production as a result of the mechanized goaf edge allowing fluency of mining through greater cutting time
- Reduction in costs as a result of less timber being used, as well as lower costs resulting from fewer continuous miners being buried.

They consist of a roof canopy, four hydraulic cylinders, a caving shield canopy, and associated electro-magnetic and hydraulic systems mounted on crawler tracks (see Figure 2).

They are controlled by radio from a remote location and operate on self-contained power units. They typically have a capacity of 5340 kN (540 tonnes)[8]. The efficient and safe use of MBLS depends on the interaction between them and the immediate overlying strata. They carry relatively low loads when compared to stable coal fenders and can only be expected to control a small portion of the goaf (see Figure 3) and are not designed to carry the full load of the roof. Rather, they are designed to aid in the controlled collapse of the roof strata, maintaining a straight goaf line and providing a safer working environment for the continuous miner driver.

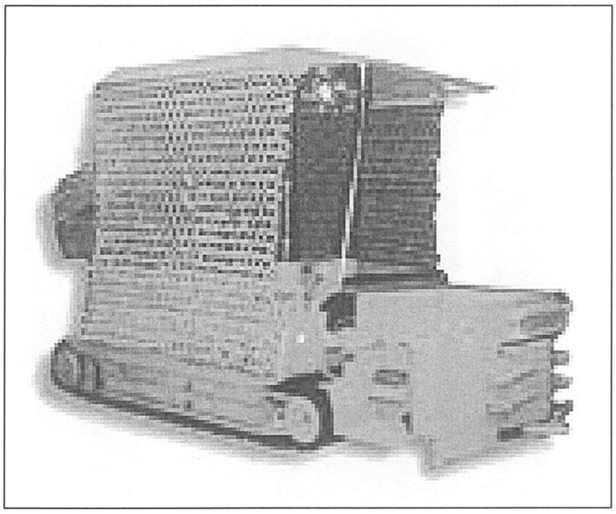

Figure 2—Mobile breaker line support

They provide unique ground control advantages over other types of secondary support by significantly reducing the time between mining and installation of secondary support. As a result of their mobility, they are safer and can increase the overall production cycle. As opposed to timber, they are more effective under static loads because they can maintain loads at near peak capacity; whereas once timber props fail they lose their ability to limit roof deformation.

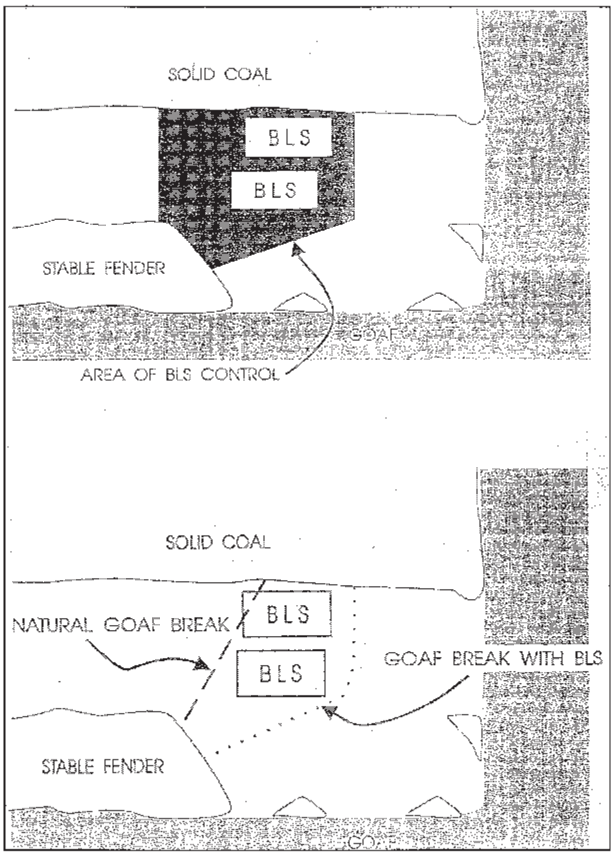

Figure 3—Area of support of mobile breaker line support

MBLS will not prevent the goaf flushing into the working face and associated extraction roadway in the event of fender failure. They are not intended to replace the high load carrying capacity of a snook or fender. The following example highlights the load carrying potential of a 6 m long by 4 m wide snook that is 2 m high (under New South Wales conditions), compared to the use of MBLS or timber props[9]:

$$\textit{Strength} = 7.4 \times \frac{w_e^{0.46}}{h^{0.66}}$$

$$\textit{where} \quad w_e = \frac{4(w_1 w_2)}{2(w_1 + w_2)}$$

Strength = *8.66 MPa*
= *886 tonnes per m²*

Snook area = *6 m 3 4 m*
= *24 m²*

Thus, snook load carrying capacity = 886 tonnes per m²
3 *24 m²*
= 21267 tonnes.

This value is significantly higher than placing three 600 ton load carrying potential MBLS at their maximum, which equates to a combined total load carrying capacity of 1800 tonnes if three MBLS are used. Placing 30 by 150 mm diameter timber props (on the assumption that they are uniformly loaded) will equate to 900 tonnes. This demonstrates that MBLS are a more effective temporary roof support than timber props, but not as effective as a snook. MBLS are a rigid mechanical support type and they will consistently offer the load to which they are set. Snooks on the other hand may (through lack of adequate mining control) not be created as planned and as a result may be either under- or over-designed.

The MBLS in New South Wales are generally set to one-third of their maximum loading capacity, although these differ under varying conditions from operation to operation. They are set as close as possible to the point of extraction and always in as straight a line as possible (such as that shown in Figure 4).

The law specifies that they be moved individually, and that they be moved no more than 50 percent ahead of the adjacent MBLS. It is a further requirement that they are reset to the roof every time that they are moved.

Maleki and Owens[7] indicated that MBLS influence the overlying strata up to 18 m. Remembering that Anderson[1] reports that the nature of the immediate 20 m roof strata plays a critical role when the goaf is formed indicates that MBLS are a successful means of controlling the immediate overlying strata during full pillar extraction.

The use of MBLS has also resulted in an increase in production output. Williams and Brown[10] predicted an increase of up to 19.7 per cent when MBLS are used during pillar extraction. They also indicated that there was a reduction in accident statistics associated with the introduction of the MBLS into the New South Wales pillar extraction operations.

The main disadvantage of the use of MBLS is that they

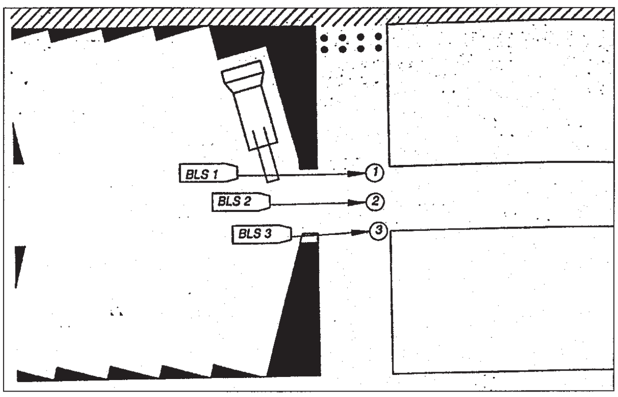

Figure 4—Use of mobile breaker line supports in a straight line

break the permanent roof supports (usually roofbolts) everytime they are set to the roof which can cause bedding separation in areas of weak roof which can create a roof fall.

Roofbolt breaker line supports

Shepherd and Singh[11] conducted tests using roofbolts as breaker lines in pillar extraction collieries in New South Wales that were affected by feather-edging (mostly under massive roof conditions). This was trialled after the successes of the use of roofbolt breaker line supports were reported in South African collieries[12]. Although the use of roofbolt breaker line supports was successful and consistent with the results achieved in South Africa, Shepherd and Singh[11] concluded that their use in New South Wales is minimal as MBLS are the preferred method of temporary breaker line supports.

Mining equipment

The choice of the type of mining equipment for use during pillar extraction is a decision based on the needs of each operation. A continuous miner, two or three shuttle cars, a roofbolter (either a stand alone machine or a rig as part of the continuous miner), MBLS (dependent on the roof conditions) and a feeder breaker, together constitute the equipment needs of a typical pillar extraction section.

The introduction of remote controlled continuous miners enabled fundamental changes in the pillar extraction mining methods in New South Wales. Before the introduction of these, the maximum depth of cut was limited to the position of the on board continuous miner driver not passing the last line of permanent roof support, which was approximately 6 m. With the remote controlled system, the depth of a lift could be increased so that the shuttle car driver does not pass the last line of permanent roof support, which is approximately 12 m. This also encouraged the use of double-sided lifting extraction (which significantly increased the speed of the extraction operation) which is now a common practice in the New South Wales pillar extraction operations. Further, all cutter heads are limited to a width of 3.6 m in order to manoeuvre the continuous miner to extract at a required lifting angle of 60°.

The choice of shuttle cars, roofbolters and feeder breakers is made on the basis of physical dimensions and a matter of preference of the individual operations. There are numerous manufacturers of these types of equipment, the choice of which again varies between operations. An important note is that the equipment used during development was in all cases the equipment that was used for extraction.

Overall, the introduction of the MBLS together with remote controlled continuous miners ensured that pillar extraction operations in New South Wales were safer and more productive. Informal discussions with the various operators indicated that without the introduction of these two systems, the pillar extraction mining method would in all likelihood have been discontinued.

Training

Pillar extraction can be considered a specialist mining technique and the training of personnel should also be considered a specialist function. In terms of this, all the factors discussed in this paper form the basis of the specialist training that all mining personnel are subject to in New South Wales, with a bias placed on risk management. Prior to any pillar extraction activity, the personnel are required to attend a State-approved training programme that will create awareness and understanding of the potential hazards associated with this mining practice. Follow up training is conducted usually at six-monthly intervals.

The move away from specialist extraction techniques also helps to focus training into definite phases of panel development and panel extraction, unlike the specialist techniques in which these phases are interchangeable. Training scheduling can thus also be structured according to these production phases to ensure worker focus and minimize the potential for error.

Conclusions

Based on detailed underground geotechnical investigations, Shepherd and Chaturvedula[13] observed that strata caveability, roof cantilever behaviour, fender width-to-height ratio and remnant snook size are all critical parameters for successful and safe pillar extraction. In addition to these factors, numerous other aspects ranging from the risk management oriented legislation in New South Wales in terms of Section 138 of the Coal Mines Regulations Act of 1982 to the introduction of remote controlled continuous miners and remote controlled Mobile Breaker Line Supports (MBLS), have all contributed to a better understanding of the nature of a pillar extraction operation and ensured its overall success.

The topics discussed in this paper will aid the operations in the Witbank and Highveld coalfields of South Africa to enhance the overall framework (or design methodology) and assist in developing a standardized tool for the safe and economic extraction of coal pillars. This is part of the objective of Task 2.5.2 of the Coaltech 2020 collaborative research initiative.

Acknowledgements

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Engineering professors at Tuks elected Fellows of the SAAE*

Prof. R.F. Sandenbergh, Dean of the Faculty of Engineering, Built Environment and Information Technology, and Prof. F.W. Leuschner, Chairman of the School of Engineering at the University of Pretoria (UP), were recently elected Fellows of the South African Academy of Engineering (SAAE).

The objectives of the SAAE are to promote excellence in the science and application of engineering for the benefit of all members of the public in South Africa. The Academy comprises South Africa's most eminent engineers of all disciplines and related professionals with proven ability and achievement.

Prof. Roelf Sandenbergh obtained degrees in Chemical Engineering and Metallurgical Engineering from the University of Pretoria and in 1974, he joined the University of Pretoria as a lecturer in the Department of Material Science and Metallurgical Engineering.

In 1996, he was appointed Head of the Department, in 2001, he was nominated Chairman of the School of Engineering and in October 2001 he was appointed as Dean of the Faculty of Engineering, Built Environment and Information Technology. He teaches, conducts research and consults in the fields of Extractive Metallurgy, Corrosion and Failure Analysis.

In 1989, Prof. Sandenbergh received a silver medal for excellent publications from the Corrosion Institute of Southern Africa and also from the South African Institute of Mining and Metallurgy in 1991 and 1997. He also received special recognition as an excellent achiever from the University of Pretoria in 1998 and 2001.

Prof. Wilhelm Leuschner obtained his degree in Electrical Engineering from the University of Pretoria. In 1976, he joined the Department of Electrical Engineering at UP and moved to the Department of Electronic Engineering in 1985 to develop the Photonics Group in the Department. In 1994, he was appointed professor and head of the Department of Electrical and Electronic Engineering and in 2001, he was nominated Chairman of the School of Engineering.

Prof. Leuschner has presented more than 15 papers at local and international conferences. He is also the author of five articles in technical journals and the inventor/co-inventor of five patents. He acts as external examiner for master's and doctoral students at other universities, is a member of the ECSA Professional Advisory Committee and serves on the accreditation panel of ECSA for accreditation visits to other Electrical and Electronic Engineering departments in South Africa.

Prof. Leuschner has developed and introduced the first Computer Engineering degree in South Africa. He also facilitated the establishment of the first Cisco Regional Network Academy in Africa, in the Department in 1998.

The Academy provides Professors Sandenbergh and Leuschner with a forum to share their abilities and eminence in the profession by promoting the aims and objectives of the Academy for the benefit of all members of the public in South Africa. ◆

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