AUSTRALIAN LONGWALL GEOMECHANICS - A RECENT STUDY

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ABSTRACT
This paper presents recent findings concerning longwall caving mechanisms relating to Australian mining conditions and their effect upon longwall support requirements and behaviour. The findings are based on a program of intensive hydraulic support monitoring in a variety of Australian mining conditions coupled with geotechnical observations.

Results from the study illustrate periodic weighting cycles of varying severity and these are related to the overlying geology in terms of the strength of individual strata units, their thickness and proximity to the longwall extraction. Several different caving mechanisms are identified which contribute to periodic weighting cycles. The importance of recognising weighting cycles in relation to the operation of the longwall face will be discussed in detail.

Longwall support design methods are critically examined in relation to the case histories of the monitoring program. The applicability of the said design methods to Australian coal mining conditions is discussed and an outline of design considerations to facilitate productive longwalling is presented.

Overall, the paper only "scratches the surface" of the work currently being undertaken by ACIRL in this area, and the findings of that work.

INTRODUCTION
When discussing geomechanical design techniques for longwall support specification one must firstly consider the question "why do we mine coal using longwall methods?" The foremost answer to this question relates to high productivity and presumably profitability although safety issues can also be strongly argued in support of the use of longwalls. Given that productivity is the driving force behind longwall mining it must also be the major consideration in the geomechanical design and specification of longwall supports.

Recent research by ACIRL (sponsored by NERDDC) has monitored the performance of hydraulic longwall supports on several Australian longwall faces in a variety of mining/geological conditions. This paper presents the initial findings of the research work and outlines the approach, ACIRL believe should be applied to the geomechanical design of longwall faces.

GEOMECHANICAL FACTORS AFFECTING LONGWALL PRODUCTIVITY

Given that the emphasis behind the geomechanical design of longwalls is productivity, one must know which geomechanical factors affect longwall productivity. Two major factors have been identified:

- Face Spall
- Roof Falls

Face spall is not always detrimental to productivity as in some instances it can actually improve productivity by reducing shearer power requirements and allowing the shearer haulage speed to be increased. Essentially, if face spall manifests itself as small to medium size pieces which the A.F.C. can easily transport then productivity will not necessarily be affected. In fact, some mines have noticed that their highest production occurs when the supports are

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in yield and the face spall is at a maximum. Under these conditions the shearer supply acts as a power loader and shearer power is low.

If however, the face spall consists of large very large lumps which continually block the A.F.C. then productivity can be seriously reduced. Note also that large blocks of face spall pose a serious safety threat to face crews. Given that the majority of longwall faces observed suffer some degree of face spall, the next consideration is as to what effect will it have (if any) on the stability of the immediate roof?

Immediate roof stability between the face and canopy top has been observed to be a problem on many longwall faces, reducing productivity for the following reasons:
- large lumps can block A.F.C. or crusher.
- roof cavities make support setting difficult/impossible/time consuming.
- large roof cavities requires cleaning and supporting.

In addition, roof rock being mixed in with the R.O.M. Coal will increase the ash content and require added washing to produce a saleable product.

Roof stability is not only affected by face spall but also more importantly, the amount of roof convergence during the mining cycle. Essentially, high roof convergence results in a heavily stressed area (due to bending action see Figure 1) between the face line and the support. It is this mechanism which (in certain strata conditions) is a major cause of roof falls in front of the longwall supports.

Given then, that face spall and immediate roof stability are the major geomechanical problems associated with longwall mining the question is posed as to “What control do we have over their occurrence in terms of longwall specification and can we improve face productivity as a result?”

GEOMECHANICAL MECHANISMS ASSOCIATED WITH LONGWALL MINING

Stresses and Displacements

Before one can consider the productivity aspect of a particular coal seam it is vital to understand (at least conceptually) the mechanisms that are causing both face spall and roof instability. Traditionally, all the arguments posed to explain face spall etc have been based on abutment stresses (see Figure 2) whereby a stress peak exists a short distance in front of the face line [2]. The distance in front of the face line to the stress peak is determined by the amount of face spall.

However, recent findings by ACIRL suggest that whilst the stress abutment is undoubtedly there in order to arrive at a unique solution to each mining condition, one must consider the amount of roof or roof to floor convergence associated with longwall mining. The real issue in geomechanics is not how stresses redistribute due to mining but how the redistributed stresses manifest themselves as convergences. This brings into question the role of local geology, structure etc and this provides the basis for the design approach that ACIRL are developing.

Convergence measurements in geomechanics are simple, accurate and inexpensive with a short turn-around time, whereas stress measurements are complex, less accurate, expensive and with long turn-around times required to calculate actual stresses from the measurements taken. Strata convergence therefore whilst providing a unique fingerprint for each mining
situation also provides easy measurement and control for the engineer. Stress measurement is not however to be discounted as it provides valuable information in understanding the processes involved in causing strata convergences.

Weighting Mechanisms

The starting point or first consideration in the geomechanical design approach must be the WEIGHTING MECHANISM that low walls face will experience. This will determine the caveability of the overlying strata and the magnitude of roof convergence rate (i.e. loading) that the longwall will experience and variation thereof during mining. Note that convergence rate (mm/hr) will be used in the discussions for the geomechanical aspects, as the weighting mechanism will determine the convergence rate. Only then coupled with the speed of mining can the absolute convergence affecting both face spoil and roof stability be assessed.

ACIRL have identified two conceptual weighting mechanisms from monitoring on Australian longwall faces:

1. VARIABLE WEIGHTING: conditions do not visibly change over protracted periods of monitoring and measured convergence rates remain within narrow bands. Figure 4 illustrates typical support behaviour in variable weighting conditions.

2. PERIODIC WEIGHTING: phases of heavy and light loading conditions both of which last for several consecutive shearings. Vastly different magnitudes of convergence rate exist between the two conditions and visibly different mining conditions. These two loading conditions are attributed to the presence of a massive strata unit in close proximity to the seam and its intermittent failure. The period of light loading depends on length of cutlineover required for massive strata to fail. Heavy loading period determined by where failure occurs is in front of face or at face line (see Figure 3). Figure 5 shows typical support behaviour in two loading conditions described. It should be noted that this effect has been noticed and described by other engineers. In fact Wilson (3) whilst recognising it, dismisses periodic weighting by arguing that over a long period of time the average convergences remain unaltered. Whilst this may be true, one must consider the short-term implications of periodic weighting and the geomechanical problems it causes.

The precise definition in engineering terms of what strata is massive is unclear at present. It would appear though that there is some form of relationship as follows:


massive strata = f (strata thickness, L/distance from seam horizon)

In other words, once must consider not only the strata thickness but also its distance from the seam and as a 3m unit, 2m above the seam for example can be just as destructive as a 30m unit, 30m above the seam.

Recent experience suggests that the possibility of periodic weighting can be indicated by examination of boreholes sections. Indeed, ACIRL have tested this by making predictions of possible weighting conditions prior to monitoring and initial results indicate the success of these predictions.

The overall concept suggested is that variable weighting tends to fit somewhere between the light and heavy loading conditions of periodic weighting and can still conceivably be beset by geomechanical problems.
if local conditions dictate. Figures 4 and 5 illustrate measurements taken for both variable and periodic weighting respectively. The fact of the matter though is that the weighting mechanism is an INEVITABLE CONSEQUENCE of mining as it is determined by the cave ability of the strata, not the support rating. Whist it can be predicted it cannot be prevented, the question therefore is "can it be controlled and if so how?"

**EFFECT OF WEIGHTING MECHANISM ON LOCAL FACE CONDITIONS**

The weighting mechanism due to longwall mining and the caving of overlying strata will manifest itself at seam level as a roof convergence rate which when combined with the speed of mining determined the absolute convergence level of the roof over one mining cycle. For the purposes of this discussion it will be assumed that the speed of mining is reasonably consistent form mine to mine. Hence, convergence rate can be used in the place of absolute convergence.

**Face Spall**

It is believed that the degree of face spall is driven by the convergence rate of the roof, and observations during monitoring bear out this statement. The only situation whereby roof convergence may not cause face spall is in conditions whereby the floor material is significantly weaker than the coal and the coal has little or no structural features eg Great Northern Seam. This however is the exception to the rule.

The major consideration with respect to face spall is its effect upon productivity and/or safety. Essentially, it is necessary to consider the block size of any face spall and this is determinable from examination of the structural features of the coal. A well cleated, fractured coal will spall in small pieces, which pose no threat to safety and the A.F.C. can easily transport. Conversely, a coal seam with widely spaced major cleats and only minor fracturing will tend to spall in large lumps (metres in dimension). This poses not only a threat to safety but also can reduce productivity if the A.F.C. cannot clear the lump. Blasting may be required in extreme conditions.

**Roof Falls**

The immediate roof between the tip of the canopy and the face line is the most sensitive area with respect to the convergence of the roof. Due to cantilever bending action, using the coal face (and not the so-called breaking-off line at the rear of the supports) as a fulcrum, high compressive stresses are generated on the undersides of the roof strata and more seriously, high tensile stresses are generated on the upper surfaces of the individual beds. The magnitudes of these stresses are directly related to the degree of roof convergence. Face spall, increasing the effective tip to faceline distance, compounds this effect. The likelihood of a roof fall will be directly related to the strength and structure of the immediate roof strata. Structure of the immediate roof is of greater importance than actual strength. Cantilever theory indicates that the amount of convergence a beam can sustain before failure is directly related to the tensile strength and the beam thickness. While tensile strengths of rocks may vary by a factor of up to fifty, bedding thicknesses may vary from a few millimetres to tens of metres - a much more significant variation. Roof falls can persist upwards for several metres if the immediate roof contains no competent strata while it abates strata failure.

As with the weighting mechanism it is also evident that the type and magnitude of face spall and possibility and extent of roof falls can be evaluated from examination of borehole sections and/or any exposures of the relevant immediate strata and coal either in the form of existing underground workings or adjacent open cut site. Simple engineering logic and previous experience is more than adequate in making such judgements.

**TRADITIONAL DESIGN APPROACHES**

Before discussing in detail ACIRL’s approach to design it is worth making a few comments concerning traditional design methods. There are several commonly used and referred to design methods ranging from simple analytical models (detached block, Wilson [3]) to complex numerical models (finite elements, Pollington and Isaac [4]). Attempts have also been made to relate measured behaviour to geological conditions by statistical analysis (Peng et al [5]). Smart [6] has combined bulking factor considerations with geological conditions to formulate a "yielding foundation model". This model identifies different caving mechanisms according to the nature of the overlying strata.

It is not intended to describe each of these methods in detail but simply to make general comments concerning their validity and short-comings.
Taking the detached block model in isolation, it is possibly the most used method although its limitations have been recognized as evidenced by attempts to supersede it. The basic assumption is shown in Figure 6. The model balances the mass of the detached block with support rating with any overlying strata load bridging from the solid coal to recompacted goaf. The height of the block is defined by the bulking factor of the goaf and the height of caving required such that the void left by coal extraction is filled up.

(iv) overuse of trial and error and inappropriate use of factors of safety.

Peng referring to the USA states that "the general practice in this country is that if supports of lower capacity do not work out, the next one of higher capacity is used" [7]. Similarly, Factors of Safety between 1.5 and 2.0 are quite common in detached block designs which are high for the design of a structure which may only be required to be stable for several hours in general.

The approach of Smart [6] is partially based on bulking factors but recognizes a need for adjustment to account for non-European conditions. It also defines two forms of caving, namely bulking factor controlled and parting plane controlled and introduces the design concept of a Yielding Foundation Model (see Figure 7). Information as to the specifics of the approach are sparse and it is therefore difficult to scrutinise its application. The major perceived limitation is the fact that although account is taken of massive overlying strata the effect of any bridging beds is ignored (see Figure 7) even though they are shown as converging strata layers. Note also in Figure 7 that there is no concept of strata failure either in the immediate roof or the bridging beds.

The approach detailed by Peng et al [5] is based on empirical guidelines attained from statistical analysis of measured behaviour in the USA. It would appear that some of the factors of importance are recognised in this paper. The major drawback with their analysis is that whilst it is more complex than the detached block model it still simplifies the problem to a level which makes extrapolation to other sites fraught with difficulty. It also ignores the phenomenon of face spall and the question of productivity aspects.

If one accepts that the geomechanics of longwall faces are driven by the failure of overlying strata and that face spall/roof falls are driven by the resultant roof convergence, then fundamental problems in terms of a design model become evident:

(i) numerical models are not totally suitable in the prediction of strata failure and it is very difficult to assign realistic values to rock mass strengths if indeed this is an acceptable practice.

There are several major problems with the detached block model which are now outlined:

(i) no account is taken of the geology and structure of the overlying strata.

(ii) tendency to concentrate on the immediate roof and discount the possibility of higher caving mechanics.

(iii) based on bulking factors (which is not definitive) and variations in conditions (i.e. non-European) are explained by different bulking factors not varying geological conditions. By the term “non-European” it is assumed to refer to conditions associated with massive overburden and periodic weighting which is not always found in the cyclic measures of Europe.
numerical models are not sufficiently well developed to allow the accurate computation of induced displacements from the resultant stresses.

(iii) measurements by ACIRL show that the longwall support problem is dynamic rather than of static equilibrium as usually assumed (see Figure 8). Numerical models whilst being able to incorporate time dependent/creep laws, are not proven as being advanced enough to accurately solve dynamic problems.

Table 1 illustrates the applicability of the NCB Production Instruction (based on a detached block concept) for the yield load of a support to measured behaviour on Australian longwalls. Whilst it is not intended to suggest that the N.C.B. PI is used for the design of Australian longwalls it will serve to illustrate the disparity of the detached block approach and the reality of support behaviour on Australian longwalls. It must be remembered that under the detached block concept a high factor of safety is applied and that accordingly the support should theoretically not go into yield. It is quite clear from Table 1 that the theoretical SLD’s are generally 50% lower than the actual SLD’s, yet the majority of the longwall faces measured are either consistently at yield or periodically at yield. It is concluded that there must be some fundamental error in logic in the detached block approach given the wide disparity between theoretical and actual support behaviour.

<table>
<thead>
<tr>
<th>Site</th>
<th>S.L.D (Model)</th>
<th>S.L.D (Actual)</th>
<th>Measured Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>42.5</td>
<td>93.0</td>
<td>Pecky - yield</td>
</tr>
<tr>
<td>B</td>
<td>41.5</td>
<td>107.5</td>
<td>Pecky - yield</td>
</tr>
<tr>
<td>C</td>
<td>34 - 35.5</td>
<td>95.0</td>
<td>Yield always</td>
</tr>
<tr>
<td>D</td>
<td>38 - 37.5</td>
<td>84.0</td>
<td>Yield always</td>
</tr>
<tr>
<td>E</td>
<td>57.0</td>
<td>83.0</td>
<td>Pecky - yield</td>
</tr>
<tr>
<td>F</td>
<td>42.0</td>
<td>85.0</td>
<td>Yield - comparator delays</td>
</tr>
<tr>
<td>G</td>
<td>30.0</td>
<td>86.0</td>
<td>More yield - low panel width</td>
</tr>
<tr>
<td>H</td>
<td>48.0</td>
<td>114.0</td>
<td>Total - variable weighting</td>
</tr>
</tbody>
</table>

NCB Production Instruction: Yield Load = 15 x mean height in meters (sq.m)

Table 1: Support Ratings for Measured Sites as Suggested by NCB PI compared to Actual Ratings and Behaviour.

One final comment relates to the support specification in terms of SLD for the four of the most recent Australian longwalls supplied by three different manufacturers. All four support specifications are 100 T/m² or very close to that figure. The question posed is then "if three manufacturers can arrive at the same answer to four vastly different problems, why do we even need a design method for longwall support specification?" This question will be answered and put into context in the remainder of this paper.

PROPOSED ACIRL APPROACH TO LONGWALL DESIGN

As a result, ACIRL have re-evaluated support design requirements and are formulating a new approach based on a sound conceptual model of what happens around a longwall face and what the support is required to do to allow mining to proceed unhindered. As a guide several fundamental considerations need to be reiterated:

(i) at present, regardless of the approach taken on SLD of 100 T/m² will be arrived at. This arises out of the currently available technology at a reasonable price. The cost of SLD's above this value may increase disproportionately.

(ii) some of the high convergence rates monitored recently (with high support ratings) suggest that even with unlimited finances, a sufficiently large support could not be manufactured to reduce the...
convergence rate to a insignificant level. In other words, there are inevitable consequences involved with longwall mining in certain conditions over which we have no control. It is believed that such conditions only relate to the heavy loading phase associated with periodic weighting. With regard to variable weighting it is thought that support rating may be more of an issue as due to the lower convergence rates measured, there may be scope for improving face conditions by increasing support ratings.

(iii) when investing tens of millions of dollars on capital equipment alone, there should at least be some guidelines available to establish the likely mining conditions/problems such that the return on that investment can be assessed.

ACIRL's approach is to utilise empiricism based on the data bank of support/face performance data being collected from around Australia at present (under NERDDC sponsorship). Distinct patterns are emerging from this work which relate overlying geology, local geology, coal structure, working methods and other factors to geomechanical problems and resulting productivity. This will allow judgements to be made relating to likely conditions in coal seams which are as yet unmined or undeveloped. The impetus behind a first pass design is not to specify the support rating but to provide meaningful arguments by which the mine planner can assess the risk of investing large amounts of capital in terms of the expected returns.

Figure 9 illustrates the logic flow by which such a design approach would follow. At present it must be stressed that the database of information is based on a limited data set (14 faces) and that future work is intending to expand it by monitoring additional Australian and overseas longwalls.

ADDITIONAL FEATURES OF LONGWALL SUPPORTS CURRENTLY BEING EVALUATED

In addition the arguments presented for the geomechanical assessment of longwalls and their productivity, ACIRL is presently examining other features of longwall supports as part of the same NERDDC project. Many features of longwall mining and support appear to be poorly understood to some degree and warrant examination. Whilst it is not within the scope of this paper to discuss them, they are listed simply for reference:

- contact advance
- power lower
- canopy behaviour during support advance
- speed of lower-advance-reset (LAR) cycle times in relation to the haulage speed of the shearer
- positive set and its control
- gas yield valve operation and canopy damage in severe periodic weighting conditions
- two leg versus four leg supports
- effect of canopy debris
- achievement of design set pressures

CONCLUDING REMARKS

This paper has highlighted the geotechnical issues involved with longwall support rating specification and assessing the potential for high productivity longwalling. Intensive monitoring has identified distinct weighting mechanisms which are predictable from the overlying geology and their effect is assessable from near-seam geology and the seam structure itself. Furthermore, it is concluded that in some instances the available support load densities cannot adequately control the induced roof convergences and that geomechanical problems will occur from time to time. Mines already experience these problems, but under certain conditions, high productivity can still be maintained.
The design approach will be based on empirical methods using a database which is currently being established. The use of numerical methods has been carefully examined, but rejected on the basis that the problem does not lend itself readily to their application. The database itself is at present relatively small, but monitoring in the near future is planned to better establish its validity.

The real emphasis of the design approach is not necessarily to define a support rating (that may be dictated by other non-geomechanical factors) but to assess the geomechanical risks to productivity with that available support technology. This will give the mine planner meaningful arguments by which to assess the capital outlay against the likely returns and make a fundamental decision as to the suitability of the seam in question to longwall techniques. Experience around the world indicates that not all coal seams are suited to longwall mining and that some form of rationale needs to be applied to this question.

REFERENCES


