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A HOLISTIC EXAMINATION OF THE GEOTECHNICAL DESIGN OF LONGWALL SHIELDS AND ASSOCIATED MINING RISKS

Russell Frith

ABSTRACT: This paper examines the design of longwall shields, focusing on those geotechnical aspects that are critical to either their success or failure during longwall extraction. The driver for the paper is the recognition that in many instances, longwall shields are assessed and designed along similar lines to that of roadway ground support systems, namely according to typical or normal geotechnical conditions. However the paper will contend that for longwall shields, this is inappropriate as unlike roadway ground support systems, longwall shields cannot be supplemented with additional or secondary support in localised areas of adverse geotechnical conditions. In other words, the longwall shield needs to be designed according to what are judged to be worst case or adverse geotechnical conditions, the outcome being that a well-designed shield will be significantly over-rated for the majority of its working life. However it will be argued that the additional capital cost of such shield design can be readily justified as a prudent risk-based outcome that is essential to minimising future business risks due to strata instability on the longwall face. Shield geometry is discussed including such relevant factors as leg angle, inclination of the top caving shield, canopy ratio, operating height range and tip to face distance, these all being well established longwall shield design considerations and most importantly, areas whereby inadequate design can render a longwall shield highly ineffective. The issue of tip to face distance is considered in detail, in particular the extent by which it is an important geotechnical design consideration. The critical importance of maximising set to yield ratio within practical operating limits is discussed. Overall the aim of the paper is to provide industry with a set of suggested guidelines for future use when designing longwall shields and hopefully to initiate discussion on a subject that unlike roadway ground support design is not well covered in its entirety in the published technical literature.

INTRODUCTION

Few in industry would argue that most longwall faces work well for the majority of the time. It is the exception rather than the rule that the longwall is unstable with large cavities hindering production and requiring both remediation and recovery. That is not to say that some longwall faces are not more prone to strata instability than others and certainly, when major roof cavities do form the operational difficulties and costs involved in the recovery are substantial.

This paper does not address in detail the various geotechnical drivers for strata instability on the longwall face, for example:

- depth of cover, panel width and general face loading conditions;
- extraction height and the propensity for face spall;
- the contribution of the chain pillar to face stability for sub-critical panels;
- periodic weighting of the near-seam overburden;
- the influence of chain pillar cut-throughs in causing surges in face loading;
- the competence of the immediate roof strata;
- traversing major geological structures such as faults and dykes;
- the alignment of joints with respect to the longwall face.

These have all been covered in detail in other publications (e.g. Frith and McKavanagh, 2000; Frith, 2005) and are well established based on both research studies by various groups and the investigation of numerous longwall roof falls.

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On the assumption that all of these geotechnical parameters are used and considered as part of a longwall feasibility process and a longwall panel layout is established, once mining commences the mine operator has only two controls available to prevent instability on the longwall face – the longwall shields and face operations. Good longwall operational practice (e.g. keeping the face straight, setting of shields and maintenance) has been the subject of significant industry interest via the regular column "*Wills on Walls*" in the "Australian Longwalls" journal, whereby one of the industries authorities on the subject, Nick Wills, provides an informative and at times, amusing commentary on the subject.

Unless longwall shields are well-designed in the first place, best-practice operational controls may not be sufficient to prevent face instability. For example, if the shield legs are leaking significantly or a minor roof cavity (which can always occur) has resulted in the excavation height being greater than the operating range of the shields, the potential for instability on the face may be far greater than what can be achieved by operational controls such as "keeping going".

Therefore, the focus of this paper is to consider the design of the longwall shields in a more holistic manner in order to assist mining companies make informed choices when procuring face equipment, thus maximising the likelihood that operational controls will be effective during mining.

CURRENT STATE OF THE ART

Establishing the current state of the art is actually difficult, as the amount of published literature or industry guidelines on the complete subject of longwall shield design is essentially nil. Many papers discuss longwall instability case histories or report research studies on their *in situ* performance, but none (that could be found) actually address the issue of how to go about designing a longwall shield in a known set of geological and geotechnical circumstances. Given the critical importance of the longwall shields to the economic performance of a longwall face, this is a surprising state of affairs and one that perhaps the industry might wish to address.

What appears to occur with the shield design process is that:

(a) the mining company undertakes a feasibility study and decides that it will invest upwards of A$1 billion in a longwall mine;

(b) the longwall OEM's are provided with a series of design parameters (e.g. shield width, yield load rating, set:yield ratio, operating height range.);

(c) the individual OEM's then each prepare a face/shield design to allow the mining company to make an informed decision as to which OEM will be contracted to provide the equipment.

From experience of having been involved in these processes in the past, common focus areas are (i) fatigue design and testing of the shields, (ii) building the shields to the design specification and (iii) commercial terms. Certainly there would be many examples of highly rated, structurally well-designed longwall shields in the industry that have performed far below expectation in terms of longwall face stability. Accepting that the geotechnical environment is a significant driver of face instability, the question that has to be asked is whether there are other elements of shield design that are critical to its supporting effectiveness that therefore should also be evaluated as part of the procurement process?

GENERAL CONCEPTS

As a starting point, it is suggested that longwall shields offer the highest level of roof control when they meet the following six design requirements:

(i) they are able to be set to the roof along all or most of their canopy length.

(ii) the leg loads are applied to the roof as close to the face as possible, albeit within practical mining considerations.

(iii) the tip to face distance is as small as possible, noting that the tip to face distance is defined by the closest position to the face that the canopy is first in contact with the roof not simply by the canopy tip itself.

(iv) the yield rating of the shield is as high as possible, the higher the better in terms of roof control on the longwall face.

(v) the set:yield ratio is as high as possible, this leading to improved levels of direct or active reinforcement to the immediate roof of the longwall face.

(vi) the leg hydraulics are not impaired by fluid leaks that would allow leg loads and stiffness to drop during the mining cycle.

However it is immediately obvious that some of these shield design requirements lead to compromises with other longwall design aspects. For example:

- the location of the shield legs with respect to the longwall face is limited by the presence of the AFC and a forward walkway, both having width requirements if they are to meet other longwall design outcomes (e.g. AFC conveying capacity and front walkway ergonomics).
- even if the canopy tip could be set against the roof at the face, risks associated with the shearer drums colliding with the canopy preclude that as a practical proposition.
- yield loads are limited by such issues as capital cost and shield weight in terms of transporting them underground using rubber-tyred vehicles.

Recognising that such compromises exist, the design of longwall shields should seek to reach the best overall balance such that none of the required design outcomes are unduly poor, the final question then being how they are likely to perform within the geotechnical environment of the longwall face under consideration.

The shield design aspects considered as part of this paper are:

(i) shield width

(ii) tip to face distance

(iii) canopy ratio

(iv) planned working height range in relation to the maximum operating height

(v) inclination of the top caving shield within the planned operating height range

(vi) floor bearing pressures

(vii) yield load rating

(viii) set:yield ratio

(ix) flipper arrangement

(x) inclination of legs towards the face

Each will now be considered individually by reference to the conceptual mechanistic model of the longwall face and shield that was first published by Frith (2005) and is reproduced herein as Figure 1.

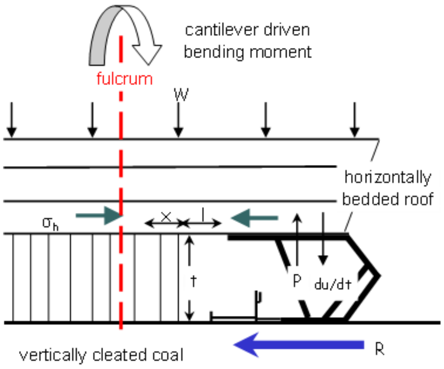
Shield width

Shield widths have increased during the past 20 years from 1.5 m, to 1.75 m and currently 2 m wide shields are becoming more common. This evolution has been driven largely by operational efficiency considerations such as reducing the face production constraint due to shield Lower-Advance-Reset (LAR) cycle times, reducing the number of shields and AFC pans to be moved during face relocations (the move to wider longwall faces has simply exacerbated this requirement), less components on the longwall face requiring maintenance or that can fail.

It is also true to say that as individual shields get wider, higher load capacities can be achieved (without increasing leg pressures markedly) as increased leg diameters that are directly proportional to the increased shield width, act to increase the shield load rating by the leg diameter squared. The load rating of the current 2 m wide Moranbah North longwall shields (875 t/m) could not have been achieved within a 1.75 m wide shield without significantly increasing leg pressures.

The major downside of increasing shield width (and shield loading as a direct consequence), is that the shields become very heavy and potentially difficult to move around the mine. The 2 m wide, 1750 t rated Moranbah North shields weigh in the order of 60 t each, such that purpose built LHD's. needed to be designed and developed to allow their transport within the mine.

Therefore, shield width is clearly a compromise decision between having the option of increasing the effective load rating of the shield in terms of t/m of face (as has proven to be very effective at Moranbah North - Martin, *et al.*, 2012), against the practicalities of moving them within the mine.



W - abutment loading
t - extraction height
l - tip to face distance prior to spall
x - increase in tip to face distance due to spall
σ_h - horizontal stress due to strata bending
du/dt - rate of powered support/roof convergence
P - powered support loading
R - rate of face retreat

Figure 1 - Simplified mechanistic model of a longwall face

Tip to face distance

Tip to face distance is undoubtedly the simplest concept in relation to roof stability on the longwall face, it being directly analogous to roadway width. It represents the unsupported span between the face and the tip of the shields from where roof instability emanates. Few longwall operators would disagree that maintaining the tip to face distance as low as possible has a positive impact on roof stability on the longwall face.

The actual tip to face distance in place at any point within the mining process will be governed by a number of independent factors:

(i) the minimum tip to face distance as determined by the face equipment and method of working (see "l" in Figure 1) which is commonly found to be in the order of 500 mm;

(ii) an increased tip to face distance due to face spall effects (see "x" in Figure 1);

(iii) an increased tip to face distance caused by the tip of the shields not being set to the roof – this can have a number of different causes such as the cutting of steps in the roof (Figure 2) and whether two or four leg shields are being used (Figure 3).

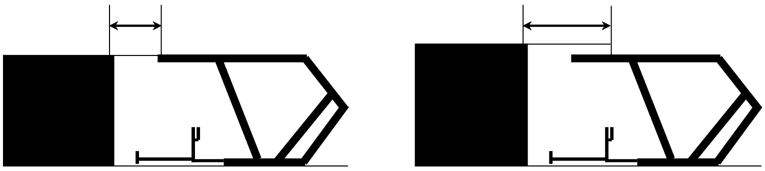
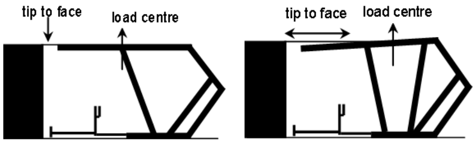


Figure 2 - Illustration of the impact of "steps" in the roof on effective tip to face distance



Two Leg Supports Four Leg Supports

Figure 3 - Illustration of different setting characteristics of two and four leg shields on tip to face distance and load centre

It is usual for the tip to face distance to be analysed and optimised by reference to the position of the shields and face before the cut is taken. The tip location in relation to the face relates to the shields being back from the AFC and the cut yet to be taken. A theoretical tip to face of approximately 500 mm is consistent with current well-designed longwall shields operating in the Australian coal industry and cannot be reduced further, primarily due to shearer collision concerns. In other words, operational rather than geotechnical considerations are the limiting factors in this regard.

In reality the tip to face distance during longwall extraction will only fleetingly if ever be as low as 500 mm. The influence of face spall can be very significant at times (e.g. under peak face loading conditions or in proximity to a major geological structure) and the author has observed face spall of several metres in conjunction with major instability on the face has been observed rendering any arguments about whether the tip to face distance should be 450 mm or 500 mm for roof control reasons as essentially meaningless.

Even though the method of face working can be changed to reduce the tip to face figure under extreme face loading conditions by an amount determined by the web depth (e.g. double chocking when working Uni Di IFS which can only be used when significant face spall is occurring anyway), tip to face distances of 1 m to 2 m with the shields behind the AFC waiting for the AFC to be advanced (so that double-chocking can again take place) are an inevitable outcome during mining under high face loading conditions, particularly in thick seam environments.

The designed tip to face distance as is shown on OEM face cross-sections is no more than a practical minimum value rather than what is likely to be the case during mining. Accepting that the tip to face distance prior to the cut should be minimised, it should not be done at the expense of front walkway utility, AFC width or canopy ratio (see next section) due to the potentially overriding influence of face spall. It is assessed to be of little overall value to compromise the overall face geometry to minimise tip to face before the cut, only to eventually realise that it makes little or no difference to the maximum values that inevitably occur during mining when the potential for roof instability is logically also at a maximum.

Canopy ratio

Canopy ratio is basically the ratio between the canopy length ahead of the legs divided by the canopy length behind the legs (A/B in Figure 4). The importance of the canopy ratio is to provide a balanced canopy whereby its centre of mass is reasonably close to the location of the legs. This ensures that the canopy tip doesn't have a significant tendency to drop away from the roof, which will either tend to reduce tip loading of the shield if it stays in contact with the roof or increase the tip to face distance if it doesn't, neither of these outcomes are beneficial in terms of roof control.

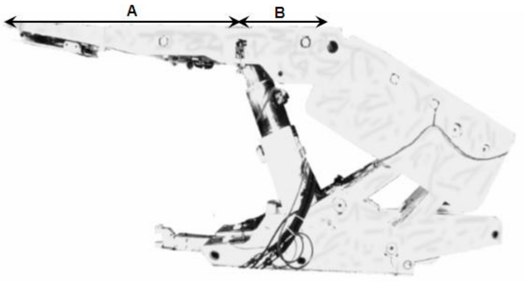


Figure 4 - Shield side profile showing the definition of canopy ratio (A/B)

There does not appear to be any design values for canopy ratio that are backed by fundamental shield design research, optimum values commonly used are between two and three, with values closer to two being preferred. Obviously, a better canopy balance could be achieved by making the length of the canopy behind the legs (B) longer, although this simply adds weight and hence cost to the shields. It also tends to reduce the shield Support Load Density (SLD) (in t/m^2), which whilst being a commonly used parameter is not a particularly useful means of assessing shield design. This is because maximising SLD (by reducing the distance B behind the legs) will almost certainly lead to the canopy becoming less balanced via an increased canopy ratio, which is counter-productive in terms of roof control.

The other obvious outcome when considering canopy ratio is that lengthening the canopy to reduce tip to face distance for strata control reasons is also potentially counter-productive, as it will tend to increase the canopy ratio thus making the canopy less balanced.

Certainly a combination of reducing tip to face distance by making the canopy longer ahead of the legs (A) and also increasing the shield SLD by reducing the canopy length behind the legs (B) is a recipe for disaster in terms of canopy ratio and shield effectiveness. It is noted at least one set of relatively recently procured shields in the Australian coal industry that have been designed with exactly this concept in mind and significant consequences in terms of roof control on the longwall face have seemingly eventuated.

Planned operating height range in relation to the maximum operating height

It is important that when a shield is working at the upper end of its designated operating height range, there is still an amount of leg travel to allow the shield to be correctly set to the roof should either the cut inadvertently be taken too high or a small roof cavity forms ahead of the shields. Having the ability to set the shield to the roof for a distance above the designated planned maximum working height is a prudent shield design consideration, as once the shield cannot be correctly set to the roof, the threat of major roof instability occurring increases significantly.

Again there are no industry accepted design guidelines in this regard, the amount of extra operating height above the planned maximum working height being a risk mitigation measure to be decided upon by the mine itself. However as a general rule, it is considered that two criteria should be applied:

(i) the higher the general likelihood of roof instability occurring on the longwall face for geotechnical reasons, the greater the additional operating height, over and above the planned maximum working height, should be; and

(ii) the higher the maximum planned working height, the greater the additional operating height should be - this relates to the argument that the severity of major roof falls on the face increases in line with the face operating height.

Building-in increased operating height into the shields results in additional capital cost and will also make the shields slightly heavier. However when this is compared against the consequences of production or reserve losses associated with (a) unplanned roof falls on the face or (b) having to reduce the face working height to ensure that a sufficient amount of leg travel is available to accommodate small cavities and/or cut roof horizon variations, such additional costs and shield weight are surely prudent compromises to make.

Inclination of the top caving shield within the planned operating height range

It is a fundamental requirement of shield design that the inclination of the top caving shield is never less than about 30 degrees to the horizontal. The reason is that broken goaf material should always slide off the top caving shield so that when the shield is being reset to the roof, the available leg load is applied to the roof above the canopy (where it assists roof stability) rather than through the top caving shield where it has no useful purpose other than to raise broken goaf material during the shield setting process. These two scenarios are illustrated schematically in Figures 5(a) and 5(b).

Frith and Stewart (1994) undertook shear tests between steel and rock and found that the limiting angle of friction was in the order of 26° to 27°. Therefore a top caving shield inclination of no less than 30° would logically have a very high likelihood of the resulting broken goaf material sliding off and not directly loading the shield.

(a) goaf load slides off the top caving shield - leg load applied to roof

(b) goaf load direct loads top caving shield - leg load applied to goaf

Figure 5 - Schematic illustrations of how the Inclination of the top caving shield influences leg load distribution

Whilst not published, several examples are known in Australia and overseas of longwall shields being worked very close to the bottom of their operating range with top caving shield inclination angles of substantially less than 20°. Face roof control difficulties have commonly occurred under this scenario.

Maintaining the inclination of the top caving shield at > 30° throughout the operating height range increases in difficulty as the operating height range is increased. The higher the operating range, the longer the top caving shield needs to be in order to provide enough shield reach, therefore the lower its inclination at the bottom of the operating height range will be (all other factors being equal).

The conclusion reached is that whilst providing for a large operating height range may have theoretical benefits, particularly when the seam thickness in a given mine varies significantly, there are potential major roof control downsides when operating such longwall shields at the bottom of their operating range due to the top caving shield having a very shallow inclination angle. This has been observed on several occasions as being a major controlling factor in on-going strata control difficulties on the longwall face.

Floor bearing pressures

Whilst there are no publications discussing this issue in detail with respect to longwall shields, there are known examples (albeit not published) of major longwall collapses occurring either fully or partly due to the presence of very soft floor beneath the shields causing a dramatic reduction in shield loading to the roof. It is a fundamental design requirement that any form of standing support (including longwall shields) should be able to be set against both the roof and floor without either undergoing compressive failure.

Whether a longwall shield will fail the floor beneath and so effectively "sink" into it, is essentially a bearing failure type mechanism. Therefore it is appropriate to consider it in this manner. Based on available information, the peak vertical stress acting through the shield pontoons and into the floor is typically around 8 MPa, this being applied at or very close to the toe of the base.

The bearing capacity of any strata unit beneath the shields is a function of (a) the load being applied, (b) the width of the footing (in this case the shield base) and (c) the strength and thickness of the floor material. There are many different methods of analysis that could be used in this regard. Seedsman (2012) provides the following equation for use when considering the stability of the floor beneath a coal pillar:

$\text{Bearing Capacity} = \text{UCS} / 2\,(4.14 + W / 2 / h)$

where:
W = pillar width;
h = unit thickness with an Unconfined Compressive Strength (UCS).

Using this equation with a peak applied stress of say 8 MPa, a UCS can be determined that would represent the limiting equilibrium condition for the first 1 m of floor beneath the shields in terms of whether a bearing failure would occur or not. On the assumption that a pontoon is in the order of 700 mm wide (this representing the minimum footing dimension expected for a 1.75 m shield), it is found that for the first 1 m of floor beneath the base, the limiting equilibrium UCS is 3.6 MPa. For values lower than this floor failure is likely, for values above this, floor failure becomes less likely. The above equation can be used to consider floor stability for different sections of strata beneath the shields, different maximum floor pressures and different pontoon widths. However the analysis presented indicates that the typical UCS of the first 1 m of floor needs to be below 4 MPa before the issue of floor failure compromising shield effectiveness becomes a significant possibility.

It is noted that this analysis has not considered the extent by which the shields may tend to "plough" the floor material ahead of the pontoons as they are advanced. This relates to such considerations as the effectiveness of base lifting rams to lift the toe of the base clear of the floor and also whether the shields are being advanced up-dip or down-dip, the specifics of which are outside the scope of this report.

Yield load rating

The yield load rating of longwall shields in terms of their supporting effectiveness is simply covered by the statement "*the bigger the better*". The justification for this statement is that the load rating design of a longwall shield cannot and should not be likened to that of roadway ground support whereby support levels can be modified during mining according to the actual conditions encountered. With a longwall face the only available roof support is that contained within the shield, therefore it should be specified based on worst-case face loading and strata conditions. The problem from a design perspective is that those worst case loading and strata conditions are almost certainly undefined; hence it is not possible to then design the shields on that basis.

As a result the shield needs to carry the highest "practical" level of available load so that on those infrequent occasions when it is required, it is available for use. If longwall shields are designed according to background or typical face loading conditions and so potentially down-rated for either cost or weight savings, the impact upon face stability and hence, production levels could be many times more significant than any capital or shield weight benefits.

Does this then mean that all mines should simply default to the 2 m wide, 1750 t Moranbah North shields described by Martin *et al.* (2012)? The answer is "of course not" as these shields were clearly designed and procured based on both a history of major roof control difficulties at the mine and concern over the increasing cover depths. In other words there were a number of geotechnical reasons as to why these shields were necessary in the first place.

The point being made is that the design of the yield load rating of longwall shields should not be based on a detailed technical assessment of typical or normal geotechnical conditions (by whatever means), but a risk-based assessment of both the general background conditions (to provide overall context as to the stability of the longwall face in general terms) in combination with the potential for locally adverse strata conditions where the roof fall potential is significantly elevated. How this may be done is not considered further in this particular technical paper.

Set:Yield ratio

The history of shield development over the past 50 to 60 years, all points to the concept that as well as the yield load rating being "*the bigger the* better", the set:yield ratio should be "*the higher the better*". The justification for this is that the longwall shield is essentially a reinforcing device for the immediate roof of the longwall face and in the same way that roof bolts and tendons reinforce the roof of a mine roadway, it acts to "*clamp together*" what is typically a stratified strata sequence immediately above the shield.

It is argued that the initial driver for guttering type failure of the immediate roof ahead of the shields is bending of the immediate roof strata around the face (see Figure 1). Whilst the shield is rarely ever able to prevent such bending, it can act to minimise it. Therefore it makes no sense to allow such bending of the roof to compress the shield and so develop load in the legs. It is far better to apply such load actively back to the roof and so limit the overall level of shield closure and hence roof bending about the face, this then contributing positively to roof stability ahead of the shields. It may also be the case that by setting the shields to the highest possible or practical level and so reducing roof to floor closure, this acts to reduce face spall, which is again a positive aspect in terms of roof stability ahead of the shields.

Trueman *et al.* (2008) made the suggestion that under certain face loading conditions, it may be preferable to set the shields to only 60% rather than say 90% of their yield loading. The following quote is taken from that paper:

"*Where periodic weighting is high enough to result in periodic shield overload, it may be better for set pressures to be nearer 60% of yield than 90% (with shields of support density of 100 t per square meter or* *greater before the cut). This relates to the effect of time. If the support is set to 60% of yield then it will take much longer to the first yield event and for the same cycle time, there will be fewer yields. Fewer yields will result in less convergence and subsequent roof degradation and it will be easier to mine through the periods of support overload. If a shield periodically has an inadequate capacity for the conditions, the authors have seen no evidence that very high setting loads will stabilise the roof. The belief that very high set pressures are beneficial may have arisen when support capacities were less and set pressures close to the yield value were necessary for the set pressure to be adequate*".

The underlying logic behind this statement seems to be that leg yield events allow increased rates of roof convergence, in which case the statement potentially makes sense. However in all of the shield convergence monitoring studies across the coal industry reported by Frith and Stewart (1994), not once was the rate of shield closure seen to increase due to the legs going into yield. The rate may have remained constant after going into yield (which makes sense) but certainly it never accelerated. Therefore the idea that reducing the set pressures (assuming it could be done on an as-needs basis), thus allowing greater shield convergence to simply reduce the number of subsequent yield cycles, may not be well- founded and certainly goes against the entire history of the development of longwall shields.

Fortunately, Trueman *et al.* (2011) make the following statement:

"*Operational controls can nevertheless be effective in minimising roof control issues in the presence of high level periodic weighting leading to support overload. Specific attention to achieving the highest set pressure practicable without compromising the attitude of the support canopy can reduce the extent of cavities and associated delays in many instances*".

It is possible to agree with this later statement because it appears that there is no obvious dissention to the universal concept of maximising the set:yield ratio of shields in order to increase their supporting effectiveness.

Flipper arrangement

The flipper at the tip of a shield serves two distinct purposes:

(i) it allows some measure of direct support to the upper coal face which has both roof stability and also safety benefits, and

(ii) in the event that significant amounts of face spall occur, it can be used to offer confinement to the exposed roof ahead of the tips.

Both are legitimate functions although as discussed by Payne 2008, in order to function as a roof support ahead of the tips, the flipper needs to be double-articulated. Otherwise the situation shown in Figure 6 will eventuate whereby the flipper can only act to control the face and not the roof when the face has spalled.

Figure 6 - Inability of single articulated flippers to secure the face or roof due to previous face Spall (Payne, 2008)

The available load capacity of a flipper arrangement is generally small, however in terms of acting to control a buckling/guttering type failure mechanism in the tip to face area, roadway roof support knowledge shows that relatively small vertical loads can prevent buckling under much higher levels of horizontal stress (Colwell and Frith, 2010). Therefore despite a low load rating, a flipper that can be positively set to the roof offers potential roof control advantages.

However the limitations of a flipper are two-fold, namely:

(i) that like a shield, at some point it needs to be retracted from the roof during which time if it were preventing roof buckling, such failure could then occur resulting in a small roof cavity which immediately then acts to reduce over shield supporting effectiveness.

(ii) its reach is limited ahead of the tip, therefore as the amount of face spall increases, its overall effectiveness in terms of roof control decreases.

Overall, a double-articulated flipper is a useful addition to a longwall shield, particularly in high seams with friable roof. However it only assists roof control and will not usually prevent large scale roof collapses that are driven by excessive face loading and associated face spall. It is certainly not a substitute for a well-designed and proportioned longwall panel layout and highly rated and well-designed longwall shield.

Inclination of legs towards the face

The inclination of the shield legs has been a general shield design consideration since Peng (1990) first published the concept of an "active horizontal force" assisting roof stability ahead of the shield tips (see Figure 7).

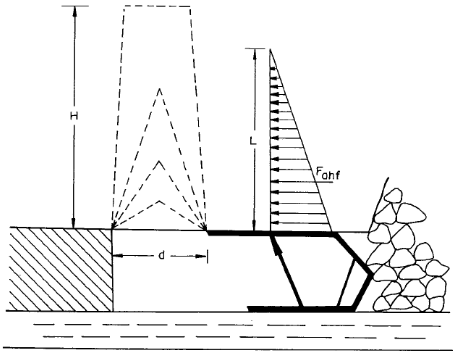


Figure 7 - Active horizontal force concept (Peng, 1990)

It is considered that the active horizontal force concept has little or no practical impact on shield effectiveness because:

(i) the active horizontal force is limited by friction between the canopy and roof (which is why Frith and Stewart (1994) undertook shear tests between steel and rock;

(ii) accepting that roof stability on a longwall face decreases as the face height increases, an increasing face height results in the legs becoming more vertical, therefore any active horizontal force decreases as a direct consequence. In other words, when it would be most required it is least able to be generated; and

(iii) the model shown in Figure 1 has the immediate roof ahead of the shields initially failing due to horizontal stress driven buckling, the horizontal stress being generated due to bending of the roof strata. Therefore adding active horizontal force into this area due to the design of the shields can hardly be beneficial to roof stability in the tip to face distance.

As shown in Figure 3, the primary reason why two leg shields result in far better roof control than four leg shields (which was the context behind the development of the active horizontal force concept) is that they are more effective at (a) setting the canopy tip to the roof and (b) keeping the total leg load as close to the face as possible.

The primary concern with leg inclination is assessed to be to ensure that it does not result in a significant reduction in vertical force being applied to the roof. On the basis that the vertical force applied is equivalent to the leg load multiplied by the cosine of the leg inclination angle (to the vertical), a leg inclination of 20° only results in a 6% reduction in the vertical component as compared to the absolute leg loading. When it is remembered that the maximum leg inclination occurs with the shield at the lower end of its operating range, such a reduction is judged to be insignificant in terms of the overall roof instability threat.

As a general shield design concept, leg inclination should be maintained at no more than 20° to the vertical throughout the defined operating height range.

CONCLUSIONS

The objective of the paper has been to demonstrate that over and above geotechnical and panel layout design considerations, the effectiveness of a longwall shield is subject to a series of compromises that need to be well thought through as part of a shield design process.

It is hoped that following the publication of this paper, tip to face distance as illustrated on an OEM cross-section of the shield and face will never again be considered as a strata control concern. It solely relates to shearer collision concerns which change as a function of extraction height. This is not to say that tip to face distance is not a relevant strata control consideration simply that it should be evaluated based on face loading and face stability issues as well as how the shield sets to the roof. These subject areas are far more informative and relevant than simply an OEM cross-section of the shield and face.

The two most important aspects of this paper relate to canopy ratio and the inclination of the top caving shield during mining. Both are judged to be fundamental aspects of shield design that should never be compromised as part of improving the SLD of the shield or extending its upper operating height. Having a balanced canopy with all or most of the available leg loading acting through it is fundamental to the effectiveness of a longwall shield.

On a positive note, with all of the relevant shield design considerations to-hand and a good appreciation of the various geotechnical drivers of face line instability, there is no reason why a well proportioned longwall shield cannot be developed that provides the maximum possible reinforcing effectiveness within the known geometrical face constraints. This then gives the longwall operators the best possible chance of managing the mining conditions during operations through good operational practices. Given the critical role of operational controls, in the context of longwall shield design, this is the best possible outcome that can be achieved.

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