THE INFLUENCE OF CAVING IN THE HIRST AND BULLI SEAMS ON POWERED SUPPORT RATING

By
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ABSTRACT

The objective of the paper is to develop an understanding of the influence of caving on powered support rating by examining the geology and support performance at two sites which represent the current extremes in support rating, ie 6/240 Ton supports operating in the Hirst Seam at Solsgirth Colliery, Scotland, and 4/900 Tonne supports operating in the Bulli Seam, West Cliff Colliery, Australia.

A conceptual model is introduced which considers the coal ahead of the face, the powered support, and the caved waste to be three yielding foundations which interact to control the subsidence of the roof strata.

Different caving mechanisms are identified for the strata of the Hirst and Bulli Seams, these mechanisms being related to rock properties, ie to the palaeogeography and depositional conditions at each site, producing caved wastes with different yield characteristics.

The results obtained for convergence and support reaction during production cycles at both sites are analysed to show the manner in which support reaction is developed, indicating the importance of high setting load densities in the Bulli Seam.

Evaluation of the work done on the subsiding roof strata during typical production cycles by two of the yielding foundations, ie the powered support and the caved waste immediately behind the powered support, is used to further demonstrate the influence of caving mechanisms on support rating.

INTRODUCTION

The favourable economics of longwall coal mining compared to pillaring methods has led to its application throughout the world in a wide range of geological conditions.

The rating and configuration of the powered support are probably the most important parameters within the total longwall system specification, as they directly affect mining feasibility.

The optimum powered support specification for a given face may be defined, from a strata control point of view, as that specification which permits the longwall face to advance at a rate which is independent of the need to provide on-face roof support, apart from that provided by the unhindered (and automatic if required) advancing of the powered supports.

The object of this paper is to examine the geological factors which influence support specification by comparing two installations at the extremes of the rating range, viz.

(i) A 6/240 Ton Chock operating in the Hirst Seam at Solsgirth Colliery, Kinross-shire, Scotland.

(ii) A 4/900 Tonne Chock-Shield operating in the Bulli Seam at West Cliff Colliery, New South Wales, Australia.

Details of the two installations are given in Table 1.

The comparison is made with the aid of conceptual model of support and strata interaction which makes due allowance for the influence of caving conditions on support rating.

CONCEPTUAL MODEL TO EXPLAIN EFFECT OF GEOLOGICAL CONDITIONS ON THE SUPPORT RATING

The rating of the powered support in the UK is based largely on 30 years of operating experience which has been related in an NCB Production Instruction to the extracted height, as follows:

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(i) The required Setting Load Density = 
7.5 T/m² x Extracted Height in m

(ii) The required Yield Load Density = 
15 T/m² x Extracted Height in m

The conceptual model used to explain these ratings is that of the detached block, as shown in Figure 1(a). The height of the detached block is determined by the caving height.

![Diagram of detached block model and yielding foundations]

(a) DETACHED BLOCK MODEL
(b) YIELDING FOUNDATION MODEL

**Fig. 1 - Detached block and yielding foundation Models.**

<table>
<thead>
<tr>
<th>Face Details</th>
<th>Newn Shoot, Shearwall Gallery</th>
<th>Multi Shoot, West Cliff Gallery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of over</td>
<td>4m</td>
<td>4m</td>
</tr>
<tr>
<td>Seam thickness</td>
<td>80m</td>
<td>50m</td>
</tr>
<tr>
<td>Extracted Height</td>
<td>114m</td>
<td>114m</td>
</tr>
<tr>
<td>Net Depth</td>
<td>84m</td>
<td>84m</td>
</tr>
<tr>
<td>Plane Length</td>
<td>272 m</td>
<td>272 m</td>
</tr>
<tr>
<td>Panel Length</td>
<td>700 m</td>
<td>700 m</td>
</tr>
<tr>
<td>Grade Along Face</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>Intersection from above or below</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

**Support Specifications**

- Type:
  - 6/240 70" Galvanised Steel Tracks with extended capacity, set at 7.2 m centres.
  - Front and rear legs connected hydraulically to permit to a return valve and yield valve.
  - Upper legs added.

- Setting Pressure (NM): 19.5
- Support Density at setting (T/m²): 21
- Yield Pressure (N/mm²): 65.5
- Support Density at yield (T/m²): 57

Table 1 Summary of face specifications

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immediately behind the supports, which in turn is determined by the bulking factor of the caved rock:

\[ h = \frac{e}{b_f - 1} \]  

where \( h \) = caving height above top of extracted section (m)
\( b_f \) = bulking factor of caved rock (m)
\( e \) = extracted height (m)

The recently introduced NRCA Production Instruction (PI) assumed a bulking factor of 1.0 and applies a safety factor of 2 to provide ratings which are capable of supporting the weight of any detached block liable to form during support advance.

In order to explain the “heavier” conditions abroad where operating experience has shown that ratings above are not required by the PI, a lower bulking factor is often applied in equation (1), generating a greater height and therefore greater weight of detached block. This approach highlights the deficiency of the model when applied to non-European geologies, as in the strong, stratified conditions in which these higher ratings are required, the caving height behind the supports can be observed and is frequently not high enough to account for the support rating predicted by the detached block model. This has lead to the suggestion (Smart and Redfern, 1986) of an alternative conceptual model which allows for variation in both caving height and type.

With reference to Figure 1(b) it has been suggested that the powered support is one of three yielding foundations which react to the convergence of roof and floor strata around the longwall coalface, the other two being the coal seam ahead of the face and the waste behind the support. The function of the powered support is to interact with these other yielding foundations, developing enough reaction to modify the convergence over the face area sufficiently to allow unhindered extraction to proceed.

The yielding characteristics of the coal will depend on its physical properties and the orientation of any structural features, e.g. cleat and slip planes, all in relation to the abutment stresses being generated ahead of the face line.

The reaction to convergence developed by powered support will depend upon its stiffness and setting and yield rating, the stiffness being largely governed by the hydraulic extension of the legs.

The yielding characteristics of the waste will depend on the caving type, of which two, are proposed, as shown in Figure 1(b) viz.

(i) Bulking factor controlled caving, in which the caving height is determined mainly by the bulking factor of the caved material, although caving may actually stop on a parting plane. Caving height in this case will be determined by an equation similar to (1) but modified to allow for convergence due mainly to roof deflection before caving is initiated:

\[ h = \frac{e - c}{b_f - 1} \]  

where \( h \) = caving height above top of extracted section (m)
\( b_f \) = bulking factor of caved rock
\( e \) = extracted height (m)
\( c \) = convergence that has occurred prior to caving (m)

(ii) Parting plane controlled caving, in which the caving height is determined by the location of a dominant parting plane within the roof strata. In this case, while the caving height is fixed, the magnitude of the void between the caved waste and the overlying strata can be calculated using the formula:

\[ v = \frac{p}{b_f} - (b_f - 1) - c \]  

where \( v \) = waste void immediately behind the cave line (m)
\( e \) = extracted section (m)
\( c \) = convergence that has occurred prior to caving (m)
\( b_f \) = bulking factor for caved rock
\( p \) = height of parting plane above top of extracted section (m)

Bulking factor controlled caving is typical of European conditions and produces a choked waste which offers immediate reaction to the convergence of the bridging beds, minimising the reaction required from the powered support.

Parting plane controlled caving, however, produces a waste which offers no reaction to convergence of the bridging beds until they have subsided through the waste void. This type of caving therefore demands maximum reaction from the powered supports and accounts for the higher support ratings required in some non-European geologies.

This “yielding foundation” model will be used to examine the significance of the differing geologies of the Hirst and Bulli Beams
in a qualitative manner.

**CONTRASTING GEOLOGICAL CONDITIONS**

**SOLESGIRTH COLLIERY: HIRST SEAM**

Solesgirth Colliery lies toward the north east edge of the Central Coalfield within the Midland Valley of Scotland, and exploits the Hirst seam. The Hirst seam occurs in the Upper Limestone Group which is overlain by the Passage Group (formerly called the Millstone Grit). A typical vertical section is shown in Figure 2, (Francis, 1983) along with a comparison of the immediate roof and floor with those of the Bulli Seam. The depth of the Hirst where observations were made was 210 m.

The coalfields of the Midland Valley were formed in subsiding basins between land blocks to the north and south as shown in Figure 3. In the Upper Limestone Group (as in the Lower Limestone Group and the Limestone Coal Group) synclines similar to those of the classic Yoredale sequence occur, which is in succeeding order of deposition (Norton 1968, Anderson et al, 1970):-

- 3.4 Seathearth and peat, and hence coal
- 3.3 Sandstone
- 3.2 Mudstone
- 3.1 Limestone
- 3.4 Seathearth and peat, and hence coal
- 3.3 Sandstone
- 3.2 Mudstone
- 3.1 Limestone

This sequence is however, subject to considerable local variation, and in the case of the Hirst seam, the Limestone (2.1) is displaced from its position immediately above the seam by some 16m of fissile mudstone. The Yoredale sequence indicates a progression from the relatively deep and still marine conditions required to create Limestone, through the depths where incoming fine clastics derived from the bordering land blocks were deposited as shales and flaggy-bedded fine grained sandstones, to very shallow high water energy conditions where the combination of coarser clastics and greater turbulence created cross-bedded sandstone, eventually reaching near or marginally above water level as shown by ripple marking and worn borings and casts. These beds indicate the initiation of delta formation, with subsequent deposits being coarser deltaic materials, often filling in earlier stream channels. These finally formed the foundation on which sufficient fine soil-forming sediments were deposited to support a peat-forming swamp. After peat formation inundation by the sea recommenced, leading in the Yoredale sequence to the formation of limestone. In the case of the Hirst seam, the process of inundation must have been relatively slower, allowing finer clastics to be deposited as marine mudstone in lagoonal conditions prior to limestone formation in truly marine conditions. This mudstone developed stratifications which may be due to compaction while still in a reasonably plastic state.

An important result of the Yoredale sequence in the version applicable to the Hirst seam is that the coal seam has an immediate roof which consists of mudstone which, due to its depositional conditions, tends to be fissile with a limited single unit thickness, caving and bulking readily to protect the longwall face from the potentially more massive sandstones in the upper roof, and creating a waste foundation which offers immediate support to the overlying beds, ie allowing “bulking factor controlled caving” to operate, transferring minimum reaction on to the powered supports.

Examination of the strata of the Upper Limestone Group suggests that marine inundations occurred more frequently than periods of land emergence which formed peat and hence coal. Fluctuations in the nature of the marine environment were such, however, to preclude the development of large thicknesses of homogeneous and uninterrupted sedimentation which would create strong roof beds within the immediate caving distance of the Hirst seam. This result is probably typical of the majority of British coal seams.

The overlying passage Group sediments reflect a change to less frequent marine inundation with few impure limestones being formed. The strata comprise mainly sandstone which may be coarse or pebbly, suggesting deposition in deltaic conditions, although some mudstones, seatheaths and thin coal seams occur.

The in-situ properties and hence the “caveability” of the upper Limestone Group, and other Groups in the Carboniferous have been influenced by tectonic forces. Disturbances began towards the end of the Carboniferous and continued throughout the Permian, causing the folding and faulting of the Carboniferous and thus creating the synclinal structures typical of the Midland Valley coalfields which protected these deposits from subsequent erosion.

Three sets of major faults occur in the Midland Valley, distinguished according to their direction of strike:

(i) a NE - SW set
(ii) an E - W set
(iii) a NW - SE set

Most of the third set of faults are believed to be of Tertiary age. The second and third sets are thought to have occurred during or after the Permian - Carboniferous folding.

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Fig. 2 - Geological sections, Solagirth and West Cliff Collieries.

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although some of the main faults of the first set may have originated in Lower Old Red Sandstone times.

One of the most noteworthy of this set, the Ochil Fault, passes to the North of Solsgirth Colliery and has an estimated throw of 3000 m. It remains one of the most significant British centres of seismic events. Of the other major faults in the locality of the colliery, the Gibele fault which has a throw of 100m runs parallel to the direction of advance of the instrumented faceline, some 100m from the colliette.

In addition several smaller faults with throws of a few metres traverse the workings.

WEST CLIFF COLLIERY: BULLI SEAM

West Cliff Colliery lies in the Sydney Basin NW of Wollongong and exploits the Bulli Seam. The Bulli Seam is the top coal in that area in the Illawarra Coal Measures and is overlain by the Narrabeen Group and Hawkesbury Formation. A typical vertical section is shown in Figure 2 along with the comparison of the immediate roof and floor of the Wollong Seam.

The Illawarra Coal Measures and the overlying sediments were formed in a basin or basins with tectonic movements influencing both the geometry of these basins and the source of the sediments (Herbert and Helby, 1980). The basins were thought to be formed during the Hunter Orogeny of mid-Pennian times, which caused the over thrusting of the New England Fold Belt to the NE of the basin area over the older stable Lachlan Fold belt to the SW, creating a NW – SE trending foredeep which became the Sydney Basin, as shown in Figure 4. Throughout the late Pennian and Early Triassic the high relief New England Fold Belt contributed large volumes of debris which were deposited in the rapidly subsiding foredeep of the Sydney Basin, creating both the Illawarra Coal Measures and the basal Narrabeen Group in a series of filling upwards cycles, ie lithic sandstone, laminitie, siltstone, mudstone and coal, which suggests a lower deltaic distributive plain. The already denuded Lachlan Ford Belt contributed relatively minor amounts of debris.

The Illawarra Coal measures were transgressed initially by estuarine conditions creating either a mudstone (shale) or sandstone immediate roof for the Bulli Seam.

Subsequent deposition in Lower and Middle Narrabeen above the Illawarra Coal measures has been attributed to a combination of braided streams and huge alluvial fans flowing from across the Hunter-Mooki Thrust System in the north and prograding southwestwards, creating thick deposits of sandstone. Finer-grained
deposits were deposited by meandering streams ahead of the advancing alluvial fans, being
buried by the coarser deposits from the alluvial fans and braided streams, creating the
alternating succession of claystones and sands lying in the roof of the Bulli Seam. Thus local
roof variations of slate or mudstone and sandstone occur in the West Cliff area.

There appears to be less evidence of roots underneath the Illawarra coals, suggesting that
they are either alluvial, i.e. have accumulated as a floating marsh environment, or have been redistributed within the general area of growth, in contrast to the coals of the
United Kingdom which are usually autochthonous.

What ever type of immediate roof is present above the Bulli Seam, there tends to be a strong
3-5m thick sandstone stratum with bridging capabilities within immediate caving range. Thus immediate caving height is governed by the parting plane located on the underside of this
stratum, creating a waste void whose magnitude depends on both the height of the parting plane
and the bulking characteristics of the roof between the top of the seam and the parting plane. This can be demonstrated using equation (3).

Inserting for a mudstone roof, \( p = 4 \),
\[ e = 2.7a, c = 0.93m \text{ and } bf = 1.5 \text{ gives } v = 0.67. \]
Inserting the same values for \( p, e \) and \( c \) but \( bf = 1.1 \) to represent a sandstone roof, gives
\[ v = 2.27 \] and this latter condition with a large value of waste void volume, according to the
yielding foundation model, transfer maximum reaction on to the powered supports.

During Upper Narrabeen, less sediment reached south of Sydney Basin, the Bodd Hill
Claystone of this period being derived from the Permian Gerringang Volcanics to the east.
During the succeeding Bawdsey depositional episode uplift of the Lachlan Fold Belt to the
South West of the Sydney Basin initiated erosion of late Permian and early to middle Triassic
sediments in the Southern Sydney Basin, producing the transport to the North East of coarse quartzose sand by energetic braided streams to form the Hawkesbury sandstone with
thickness up to 25m.

A pervasive jointing, system striking 370° and 29° has been reported for the Sydney Basin,
and the longwalls instrumented advanced at an angle of 30° to a main set of joints which have
been reported to influence caving especially at the face ends (Lama et al., 1984). Tension
faults are also known to occur oriented with the
main set of joints.

**SUMMARY OF THE CONTRASTING GEOLOGICAL CONDITIONS**

The significance of the geological conditions can be summarised from the point of
view of the yielding foundation model and hence

with regard to support rating as follows:

The Hirst Seam was laid down in a depositional cycle involving marine inundations
with rapid fluctuations in the type of sediment, producing a fissile immediate roof with numerous
parting planes. The thickest structural unit is probably 1.5m of limestone 16m above the roof of
the seam, i.e. outside immediate caving range.

Bulking factor controlled caving therefore occurs, producing a choked waste which offers
early reaction to bridging bed subsidence and therefore comparatively little reaction is
required from the powered support in assisting with the control of subsidence over the face.

The Bulli Seam is overlain by sediments deposited in Deltaic conditions, prograding
alluvial fans and streams producing numerous units of massive sandstones with structural unit
thicknesses of up to 5m within the immediate caving range. Due to the bridging capabilities
of these units, parting plane controlled caving with a waste void occurs, creating a waste which
offers no early reaction to bridging bed subsidence and therefore to compensate a relatively high support reaction is required from the powered support in assisting with the
control of subsidence over the face.

**6/740 TON SUPPORT PERFORMANCE IN THE HIRST SEAM**

**MONITORING OF SUPPORTS**

The instrumentation system used to monitor support performance was assembled around a
commercially available intrinsically safe 16 channel data logger with scan rate step-wise
adjustable between 4, 20, 90 and 180 seconds. This device uses a 12 bit A to D conveter and
therefore had a theoretical resolution of 1 in 4096, although the actual resolution of any
given parameter was found to be less precise due to a combination of inaccuracies in the
transducers, signal conditioning cards and conversion of the analogue signals.

Log circuit pressures were monitored using transducers with a 0 - 70 MPa range, the
accuracy achieved being 0.3 MPa.

Convergence was monitored with telescopic struts incorporating a rectilinear potentiometers
with an electrical stroke of 250mm. A final accuracy of 0.5mm was achieved.

Mining activity was recorded using a manually switched "event marker" capable of generating 36 codes. Thus the passage of the shearer and support advance were encoded on the
tape.

In an external modification to the logger, a rotary potentiometer was ganged with the scan

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Seam at West Cliff, with greater or lesser demands being made of the support system depending on the magnitude of the prevailing waste void.

Support load densities are normally quoted in defining mining conditions, and the differences shown for the Hirst and Bulli seams amply show the influence of caving conditions on support specification. An enhanced understanding can be developed by examining the manner in which the support density is generated. Using an argument developed previously by Smart and Isaac, 1982, the powered support is only an active device for the brief period taken to advance and set it between roof and floor. Thereafter the support becomes a passive device, developing increased reaction to convergence between the roof and floor by absorbing that convergence as leg closure and hence developing increased pressures within the leg circuits. The relationship between leg closure and pressure development can be established from a mixture of theory and test data as follows.

Calculation of the relationship between Pressure development and Leg Closure for the Bulli Seam Support Leg (West Cliff):-

(1) Extracted Height
2700mm

(2) Allowing for base and canopy thickness, leg extended height
2300mm

(3) Solid leg in this height
300mm

(4) Height of fluid column for one leg (hollow inner)
2000mm

(5) Height of fluid column for two interconnected legs
4000mm

(6) Taking the bulk modulus of water to be 1.96 GPa gives a 0.345% change in fluid column length due to fluid compression, per 6.7 MPa (1000psi) pressure increase ie 0.00345 x 4000mm for two legs, 13.80mm

(7) Allowing for the expansion of the leg tubes
2 x 0.30mm per 6.7MPa for upper tubes
0.60mm
2 x 0.44mm per 6.7MPa for lower tubes
0.88mm

(8) Allowing for expansion of hoses
2 x 0.10mm per 6.7MPa
0.20mm

(9) The total leg closure (ie sum of closure of both interconnected legs required for development of 6.7MPa pressure increase = (6) + (7) + (8) 15.48mm

...the pressure/ closure characteristics for the Bulli Seam 4/900 Tonne support leg circuit is 0.43MPa/mm, when operating at 2.7m extraction. A similar approach gives a pressure/closure characteristic of 1.44MPa/mm for the Hirst Seam 6/240 Ton support leg circuit (Note that when using these characteristics the sum of the closure of both legs must be used) when operating at 2.7m extraction. Thus due to the greater height of fluid column, the 4,000 Tonne support leg circuits develop less pressure per mm of leg closure than the 240 Tonne support leg circuits. Converting the pressure developed by each circuit into force or reaction developed by each support by multiplying pressure by total leg cross-sectional area shows that the 4/900 Tonne support develops an additional 17.2 Tonne when 1mm of closure occurs on all four legs, while the 6/240 Tonne support develops an additional 18.6 Tonne under similar conditions for all six legs. As an alternative manner of expressing this result, the 4/900 Tonne support requires 10.5mm of all round leg closure to take it from setting to yield, while the 6/240 Tonne support requires 8.8mm to take it from setting to yield.

In practice however, all convergence between roof and floor is not absorbed as leg closure, some being dissipated due to the compaction of debris above the support canopy and below the support base.

Dissipation was significant in the Hirst Seam, altering the pressure/closure characteristic to a pressure/convergence characteristic and reducing its value to 0.24MPa/mm, while the value for the same characteristic in the Bulli Seam remained very close to the calculated leg characteristic, the average measured value being 0.45 MPa/mm, reflecting "clean" operating conditions and influence of higher setting pressure on debris compaction.

While the above results indicate the reaction of the support to convergence, it must be remembered that the 4/900 Tonne support pressure increases during the cycle are superimposed on top of a higher (35 MPa) setting pressure than the 6/240 (13.8 MPa).

Accordingly it is suggested that the best assessment of the contribution that a support makes to strata control, allowing for both...
setting pressure and the actual reactivity of the support to convergence (effects of debris included), in order to determine the work done by the support on the roof and floor during a typical production cycle, ie with reference to Figure 8, the area under a support reaction/convergence curve is evaluated, support reaction being determined by multiplying leg circuit pressure by leg cross-sectional area. The area under a graph produced from recorded data can be determined, or, if average values of in-situ pressure/convergence characteristics and convergence per cycle are known, the work done by the support per pair of legs can be evaluated for that cycle as follows:-

No Yield During Cycle:-

\[
WD = 2 \times A \times C \cdot \frac{(SP + ZC \times PCC)}{2}
\]

Yield During Cycle:-

\[
WD = 2A \times \left( \frac{(C \times TF) - (YP - SP) \times (YP - SP)}{PCC} \right)
\]

where

- \( WD \) = work done by the support per pair of legs
- \( C \) = convergence during cycle
- \( SP \) = setting pressure
- \( TF \) = yield pressure
- \( PCC \) = in-situ pressure/convergence ratio for a pair of legs
- \( A \) = cross-sectional area of each leg

Using this approach to examine the support performance in the Hirst and Bulli Seams shows that the 6/240 Ton support did an average of 19.3kJ work per cycle, while the 4/900 Tonne support did an average of 40.8kJ work per cycle. Adjusting these results to work done by each support per metre run of face gives the following results:-

Hirst Seam, 6/240 Ton Support - 16.1kJ
Bulli Seam, 4/900 Tonne Support - 27.2kJ

The concept of evaluating the work done by the support can be extended to examine the contribution that the caved waste made to controlling roof deflection. This requires the adaptation of the roof-strata-tilt calculation devised for permanent support system design. (Smart, paper to be published) This calculation allows the result that subsidence of the roof strata across the gate road and pack area can be described mathematically by a straight line tilting about a pivot point located in the ribside. Representation of the pack as an elastic foundation of known modulus which is compressed by this tilting action enables the reaction generated by the pack and the work done by the pack in resisting the subsidence to be evaluated, viz

\[
K = \frac{1}{b}
\]

\[
R = \frac{K(1 - \frac{z}{b})^2}{2h}
\]

where

- \( R \) = reaction developed per metre run of pack (N)
- \( K \) = modulus of pack (MPa)
- \( b \) = original height of pack (m)
- \( r \) = radius from pivot point to waste side edge of pack (m)
- \( r \) = radius from pivot point to roadside edge of pack (m)
- \( \gamma \) = roof-strata-tilt angle (radius)

\[
WD = \frac{K}{6b} \left( \frac{z}{b}^2 - (\frac{z}{b}^3 - \frac{z}{b}) \right)
\]

where

- \( WD \) = work done per metre run of pack (N)

Moduli have been evaluated for several types of pack, including stone built packs. Assuming that this modulus of 17MPa can be taken to represent the Hirst Seam caved waste, and that during a cycle the tilt of the bridging beds changed by 0.5, then equation (5) suggests that the 2m of waste immediately behind the powered supports did 22.7kJ of work per metre run of face in resisting the convergence of the bridging beds. The work done on the bridging beds by the equivalent region of waste in the case of Bulli Seam with its parting plane controlled caving was zero, as the bridging beds would still be subsiding through the waste void, thus demanding more of the powered support. The estimated contribution of 22.7kJ by the Hirst Seam waste is more than enough to account for the 11.1kJ additional work input by the 4/900 Tonne support in the Bulli Seam.

**CONCLUSIONS**

Due primarily to depositional conditions, (type and frequency of change of sediment), the Hirst Seam roof strata have limited bridging capabilities, the waste caving to height determined by the bulking factor of the caved rock, so producing a yielding foundation which offers immediate resistance to the subsidence of the overlying strata, assisting the face supports in the control of roof-to-floor convergence over the faceline.

Again due to depositional controls, the Bulli Seam roof strata can have considerable bridging capabilities, the waste caving behind the supports to a height governed by the location of dominant parting planes with a void being left above the caved rock, so producing a yielding foundation which offers no immediate resistance to the subsidence of the overlying strata, requiring in compensation a greater contribution from the face supports in...
Fig. 5 - Typical processed output from the data logger, Hirst seam.

Fig. 6 - Typical results recorded manually, Bulli seam.

Fig. 7 - Comparison of support performance during typical production cycles for the Hirst seam and "median" cycles for the Bulli seam.

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controlling the roof-to-floor convergence over the faceline.

Comparison of roof-to-floor convergence measurements during a typical production cycle for the Hirst Seam and a "median" cycle for the Bulli Seam suggests that the Hirst Seam roof strata were more pliable than the Bulli Seam roof strata. There was therefore more convergence available in the Hirst Seam to be absorbed as leg closure, and so increase the support density during the production cycle.

Evaluating the work done by the support during each of the above cycles made due allowance for the reactivity of the supports in situ and demonstrated the increased contribution that the higher rated Bulli Seam supports made to strata control, that increase being effectively due to the higher settings densities of the Bulli Seam supports. Applying the same concept of "work done" to the bulking-factor controlled waste shows that it input a significant amount of energy to the control of bridging bed subsidence, supporting the argument that the difference in caving characteristics of the roof strata was the major reason for the difference in support rating required in the Hirst and Bulli Seams.

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REFERENCES


