IN-SITU PERFORMANCE ANALYSIS OF IMMEDIATE FORWARD SUPPORT (IFS) SYSTEMS IN THIN-MEDIUM SEAM SECTIONS IN THE UNITED KINGDOM

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ABSTRACT

This paper describes the in-situ performance of two IFS powered support installations at Betws and Penallta Collieries in the South Wales Coalfield, United Kingdom.

Intensive monitoring of all powered support functions, strata movement, support/support interaction and coal seam disturbance permitted an extensive evaluation of powered support performance for all periods of the mining cycle. The influence of support design, support rating, face design, immediate strata and seam section upon support and operating performance are discussed.

In-situ performance is compared to design specification and to the requirements of Production Instruction 1982/6. Aspects which show significant variation are highlighted.

Particular attention is drawn to the precise analysis of support/support interaction in the form of canopy and base loading profiles. This illustrates the influence of support rating and configuration in determining the interaction of the canopy and base with the immediate strata. Extensive monitoring of the coalface highlights the potential zones of disturbance within the seam which allowed the support position monitoring provides an accurate basis for theoretical considerations of support loading.

Conclusions are drawn, the application of which may enhance the performance and operation of IFS supports in thin to medium sections.

INTRODUCTION

This paper describes the in-situ performance of two contrasting IFS Heavy Duty Powered Support systems introduced into the South Wales coalfield in the United Kingdom (Freeman 1988, O'Grady 1990). The work was carried out as part of a research contract sponsored by

1 Moos International Marketing Limited, UK (formerly, Duty Mining Ltd)
2 Berrett, Puller & Partners (Sydney)
Both authors undertook this work as members of the Strata Mechanics Research Group, University College Cardiff, Wales.

British Coal and the European Coal and Steel Community (ECSC) which aimed to determine the in-situ performance characteristics of various support types and configurations and to identify any factors which caused them to differ from the theoretical. The installations monitored were the N5 face at Betws Colliery west of Llanelli and the M24 face at Penallta Colliery, north of Cardiff. These faces were amongst the first in the coalfield to be equipped with Heavy Duty IFS Supports.

FACE LAYOUTS AND CONDITIONS

BETWS COLLIERY, SOUTH WALES, NS DISTRICT

The location of the panel within the lease is shown in Figure 1.

![Figure 1. Location of NS District, Betws Colliery](image)

The panel extracted the Red Vein seam, a high quality anthracite coal, at a depth of cover of 530 m. The seam thickness was 0.8 m with the extracted height being 1.0 m (100 mm of roof and 100 mm of floor were extracted). The face length was 225 m with the panel length being some 450 m. The face worked to the rise at
a gradient of 1 in 16 with the seam inclination being 1 in 5.5 from chocks C1 to C100 and 1 in 4 from chocks C100 to C153. To help counter the steep inclination the maingate normally led the tailgate by 30 m. The shearer was an AM420 In-Seam Shearer which featured extended gobside control arms. Steering control of the shearer was very limited and this resulted in steps being cut in the floor. These caused delays in powered support advance and hence restricted face retreat. The immediate roof proved to be extremely friable and the supports commonly had in excess of 300 mm of debris above them.

PENALLTA COLLIERY, SOUTH WALES, M24 DISTRICT

The M24 District extracted the Seven Feet seam with a working section of 1.7 m at a depth of 770 m. The panel had been previously overworked by extraction in the Four Feet seam some 31.5 m above, the Six Feet seam some 26.3 m above and by the lower Nine Feet seam 14.0 m above although there did not appear to be any resulting interaction. The M24 worked on advance (Fig 2) with a previously worked out panel, the M21 District, on the tailgate side and virgin coal on the maingate side.

The design of the pillar between the panels created severe problems in the tailgate and hence restricted face advance rates. The pillar width, average 50 m, had been arrived at based upon the regulations relating to working in proximity to old workings known to be flooded rather than having been designed with a view to optimising stope conditions in the tailgate. Hence the pillar design proved to be too narrow to prevent interaction of the stress fields created by the two adjacent longwall panels and too wide to relieve stress build up by acting as a crush pillar. The result was extreme arch distortion and floor heave in the tailgate with the effective clearance being less than 1.0 m in places. The subsequent continuous repair work and supply difficulties severely restricted face advance.

GEOLOGICAL/GEOTECHNICAL CONDITIONS

BETWS COLLIERY, NE DISTRICT

The face mined the lower half of the Red Vein seam and was unaffected by major faulting although roof rolls had been recorded in the adjacent panel. The immediate roof was formed from the thickened coalband which divided the middle and lower leaves of the Red Vein. This laminated mudstone had UCS, Tensile Strength and Young's Modulus, determined from bulk samples, of 61 MPa, 7.6 MPa and 7.7 GPa respectively. The proximate roof strata were determined from the adjacent surface borehole, No. 11. Correlation of two boreholes (Nos. 1 and 11) (Fig. 3) showed the consistency of the sequence over almost a kilometre. The immediate floor of the seam consisted of a 2 to 3 m sequence of hard, competent sandstones. The upper 0.3 m showed no bedding and was of a dark, carbonaceous nature with numerous coal fragments. The materials property tests performed upon this material gave a UCS of 9.8 MPa, 2.2 MPa Tensile Strength and a Young's Modulus of 0.75 GPa. The lower sandstone contained numerous polished surfaces and was found to be of a highly competent nature. The material's property tests indicated that it was stronger than the upper layer with a UCS of 11.3 MPa, 3.8 MPa of Tensile Strength and Modulus of 1.8 GPa. The face cleat trended 150 to 240 degrees the spacing of the cleat being 1 to 2 cm. No nodules were found in the proximity of the seam although a 0.15 m thick iron rich band was irregularly developed along the top of the seam. The dominant joint set displayed an average dip/dip direction of 52/236. Seam stability in the face was good.

PENALLTA COLLIERY, M24 DISTRICT

The immediate seam roof was composed of slightly silty mudstones with a UCS of 42 MPa and a Young's Modulus of 12.4 GPa. An underground borehole to prove seams below the lower Nine Feet seam indicated that the roof above the Seven Feet seam was composed of a sequence of mudstones. The soft floor problems were caused by the immediate basal layer of the seam. This
consisted of two portions: a 0.1 m layer of dark, carbonaceous mudstone which contained numerous cycly parings and which lay upon a 0.3 m layer of inferior coal. These incombustable bands were underlain by a 1.5 m layer of slate which yielded material properties of 14 MPa UCS and Young's Modulus of 6.4 GPa. The slate was underlain by a 0.3 m layer of shale which was almost 1.5 m thick. The seam section was 1.6 m thick with a 0.15 m thick band located 0.5 m from the bottom of the seam. Four sets of discontinuities could be identified with the major two being:

- The dominant set was a set which cut the face at 25$. This was well developed in both the seam and the immediate roof, and
- The butt cleat trended in the same direction as the nearby Bellinger Fault, cutting the face at approximately 80° with a dip/dip direction of 55° 216.

Correlation of data from other local collieries showed that the dominant discontinuity set in the region had a strike of 300°. In the context of the South Wales Coalfield, a synclinal basin elongated in the W–E direction, it would appear that this strike direction is a reaction to the principal horizontal stress direction of 0–30–210°.

**SUPPORT SPECIFICATIONS**

**BETWS COLLIERY, NS DISTRICT, GD 4240**

The face layout and the support configuration are shown in (Fig 4). The 4 leg clock shield support featured splayed legs and an unrestricted forward travel travelling way. A full yield flipper bar formed an extension to the canopy and allowed 125 mm (9 degrees) of vertical articulation at the tip of the canopy. The supports were spaced at 1.5 m centres and had an operating range of 740 – 1445 mm. The long, rigid canopy presented problems in the removal of debris from above the support. The weight of the extended canopy and flipper tended to cause the canopy tip to lower more rapidly than the rear allowing debris to fall into the travelling way and increasing cycle time. After the investigation, restrictions were placed in the front leg circuit which allowed the canopy to lower horizontally.

The support feature positive set and hydraulically operated side shields ensured skin to skin contact of the canopies. The 4340 face supports had two configurations; conventional standback and IFS. The supports which operated in IFS mode had longer flipper bars and relay bars. Owing to the previous lack of experience with IFS supports it was a requirement of the installation that banks of conventional supports were positioned between the gate-end supports and the central bank of IFS supports.

*Figure 3. Geological Sequence, Betws Colliery*
The face support was the Dewty four leg 500 tonne shield support which although it had been in use for several years in conventional form had not previously been assessed when configured for HFS working. The face was equipped with 141 face supports with two batteaux and two packhole supports being used at either end. The support canopy was equipped with a wedge set flipper bar 0.9 m long. The base postons were linked by the hing pin of the single upper link with the lower semicircate members linking the base postons to the flashing shield (Fig 5). The front legs of 500 tonne capacity were angled at between 45° and 75° and had a designed yield pressure of 33.37 MPa (4,840 p.s.i.) whilst the rear legs had a designed capacity of 50 tonnes at a yield pressure of 26.89 MPa (3,900 p.s.i.). The designed setting pressure for all legs was 13.79 MPa (2,000 p.s.i.). Although, the supports were equipped with a positive set system it was not used owing to problems encountered with the base postons penetrating the soft floor. However, the contact-advance system was used and condition of the immediate roof was normally good.

IN-SITU POWERED SUPPORT PERFORMANCE MONITORING

The aim of the underground monitoring programme was to determine the in-situ behaviour and performance characteristics of each of the powered supports in order to compare this with the designed performance, the regulatory requirements (National Coal Board 1982) and surface testing. In addition to monitoring pure support performance, support operation procedures and face conditions which were dictated by the support were noted. Also any particular routine 'housekeeping' practices and operator reactions to any particular facet of a support's operation, characteristics and ergonomics were recorded.

Each investigation was carried out along the following lines: one or more underground reconnaissance visits were carried out primarily to take a pressure survey throughout the face but also to assess general face conditions and to familiarise personnel with support design in order to ensure instrumentation compatibility. This visit and the installation shift were normally accompanied by representatives of the support manufacturer and the colliery engineering staff.

The reconnaissance visit also allowed colliery management to be briefed as to the instrumentation and the monitoring procedures as well as allowing appropriate...
introductions to be made along with arrangements for the provision of the necessary underground and surface facilities. The aim of the face pressure survey was to ascertain a rough guide to the general hydraulic condition throughout the face and to ascertain whether there was any marked variation in load distribution across the face. The monitoring programme aimed to record the specific behaviour of one or two chocks within a bank of ten correctly functioning chocks in a zone of 'typical' face conditions: The emphasis being to examine the performance of the support under 'normal' conditions rather than to examine any problems which a particular face might suffer from. Hence monitoring zones were chosen so as to avoid geological anomalies such as areas of particularly poor roof or floor, faults in the face or major roof falls.

MONITORING EQUIPMENT AND TECHNIQUES

Intensive powered support monitoring took place for 5 to 7 days which normally included a weekend stand period. All support loading and displacement functions were monitored using a series of intrinsically safe (I.S.) transducer which were able to measure pressure, linear displacement and inclination. All transducers readings were logged against real time in order that monitored results could be related to face activity which was logged and recorded manually. Two data logging systems were used; the Cardiff Microdata logger and the Rapco data logger. Both these systems were intrinsically safe and featured independent power supplies and magnetic tape data recording. The Microdata logger featured twelve channels, one of which was dedicated to the real time clock with the remaining eleven being available for transducer use. The Rapco logger featured 16 channels all of which were available for data input with the recording unit featuring an independent clock system. The Microdata system permits variable frequency monitoring in order to maximise data collection during periods of intense activity in the monitored zone and to allow economical use of data storage and battery power during low activity or stand periods. The Rapco data logger offered a range of monitoring frequencies which remained fixed for a logging run. However, the system was more advanced that the Microdata in that it featured digital tape as the data recording source and Ni-Cad batteries. This gave an equivalent 'intensive' data recording capacity to the Microdata system whilst also offering the capability (owing to battery performance) for long term monitoring with minimal attention to the logging equipment. During an investigation monitoring took place on a twenty four hour basis with minimal interruption to allow tapes and batteries to be replaced. A zone of influence was defined as being ten chocks either side of the instrumented chocks. When face activity (chock and shearer interaction) took place within this zone the Microdata logger was set to scan and record the transducer outputs every two seconds, for the remainder of the production shift a logging frequency of two minutes was community selected. During production shifts the Rapco logger recorded constantly at ten second intervals. During known stand periods (typically weekends, industrial disputes and major breakdowns) both systems were set to log at ten minute intervals. By identifying seven specific activities in the mining cycle it could be broken up into its critical phases in order to identify the characteristic behaviour of each combination of activities. The seven activities identified were:

1. Monitored support reset.
2. The reset leaves the zone of influence.
3. The shearer enters the zone of influence.
4. Shearer cuts past the site.
5. The shearer leaves the zone of influence.
6. The reset enters the zone of influence, and
7. The monitored support is lowered.

Depending upon the equipment selected and the mining system employed the sequence was not necessarily in this order. By identifying the specific events in the set order the impact on the support loading/unloading phases imposed by different mining methods and cutting patterns could be ascertained.

PARAMETERS MONITORED BY TRANSDUCERS

Powered support performance was determined by considering the load development of the support and by considering the sensitivity of the load development to strata convergence i.e. the effective support stiffness. The behaviour of the support, in terms of its stability and orientation within the face was also measured.

In order to measure load development pressure transducers were fitted to the individual leg circuits of the supports under investigation. By referencing the support design diagrams the pressure history of the support could be expressed as leg load by multiplying the leg pressures by the hydraulic areas; compressibility and position load densities may be determined by dividing the total leg load by the bearing areas of the roof and floor members. In the instance of splayed leg supports the support geometry and the leg loads can be used to calculate the effective lateral force generated by the support.

In order to calculate the effective stiffness of the support the roof to floor convergence was measured between the first uninterrupted layer of both the roof and floor. This allows any penetration of a soft floor or compaction of layers of debris above and below the support to be measured independently. The measurement of the debris compaction and floor penetration also provided an indication as to the stability of the support under load. The hydraulic stiffness of the support was determined from measurements of hydraulic leg closure. Along with measurements of the hydraulic supply feed and return, monitoring of the hydraulic stiffness of the support provided a means of assessing the condition of the hydraulic circuits and prevented hydraulic/mechanical malfunction being mistaken for poor support performance.
The inclinations of the canopy and positions were monitored in both the gate-to-gate and face-to-waste directions in order to record the variation in attitude of the support under load. This allowed the characteristic movement of the base and the canopy to be assessed in order to determine whether their relative displacements were conducive or otherwise to both support advance and stable roof and floor conditions.

**Manually Recorded Events and Parameters**

In addition to the electronically monitored parameters the following events and parameters are monitored manually:

- Face activity events and sequence.
- Detrits thickness before and after the reset.
- Canopy tip to face distance before and after the reset.
- Extracted height at the face.
- Roof to floor separation.
- Roof and floor condition.
- Coal face condition.

**In-Seam Displacements**

**Monitoring Equipment and Techniques**

An understanding of the relationship between the powered support and the proximate strata around the coalface requires a detailed knowledge of the extent and magnitude of fracture in the surrounding strata.

The boundary of the fracture or yield zone is taken to be where the strata exceeds its elastic limit. Monitoring of the fracture development in the coal in front of the face was carried out using borehole extensometers on each underground investigation. The system involved the drilling of a 10m borehole in front of the coal face. A series of small magnets were fixed along the axis of the borehole. Magnets were positioned by the use of spring loaded clips inserted into the hole around a plastic access tube. Once in position a draw wire was pulled releasing the clips and allowing them to spring against the strata. Any movement of the magnets was thus interpreted as movement of the strata. Two methods of monitoring magnet displacements were used.

**The Rod Extensometer**

The previously established monitoring system involved the use of a series of flexible nylon rods which were clipped together and inserted up the hole. The rods incorporated a groove into which was seated a sealed tube filled with iron filings in a glue medium. When fully in the hole, the rods were rotated, allowing the iron filings to become sensitised while in close proximity to the magnets.

Scanning of the rods was carried out in a surface laboratory. Distances between the sensitised points along the rods were detected by a scanner incorporating a Hall effect transducer mounted on a moving carriage.

The system had a number of disadvantages, including the fact that the rods had to be removed to the surface for processing. Despite four sets of available rods, scanning and travelling time did not generally allow more than two sets of rods to be available per shift. Transportation to the surface often resulted in vibrations and shock impact to the rods resulting in loss of signal strength. There was also a high level of manual involvement in the results processing.

These disadvantages prompted the development of high technology extensometer, the prototype of which was trialed during these investigations.

**The Digital Magnetic Extensometer**

This system involved passing a magnetic sensing probe along the borehole and recording the presence of magnetic peaks on a solid state data logger. The unit was mounted on the drum plate and the probe withdrawn from the borehole by a manually driven system. The magnetic peaks were recorded by the data logger and analysed after the borehole was measured. The system proved accurate and the large volume of data that could be obtained brought a new dimension to the investigation conclusions.

**Results Interpretation**

The difficult point of any extensometer investigation is the location of a stable datum point from which to relate measurements. The coalface itself is continually advancing and the coal immediately in front of the face has failed and is unstable. For each borehole, the innermost magnet, 10m from the face was taken to be stationary and all measurements points were taken from it.

As the face advances, the shearer cuts away one web of coal and plastic access tube. By reopening the hole, readings could be taken before and after each shear and at intervals between.

For each extensometer run, recordings were made of the distance between each magnetic peak. When two magnets moved apart it was assumed that a vertical fracture had opened up between them. When the distance between magnets decreased it was interpreted as a closing of fractures.

Close observation allowed a clear picture of strata behaviour to be drawn and attempts were made to try and relate this to powered support performance.
RESULTS

BETWS COLLIERY, NS DISTRICT

Betws Powered Support Results

The mean setting pressure for the monitored supports as measured over the four cycles is compared to the Designed Nominal Setting Pressure (DNSP) in Table 1. Average check setting pressure was 12.73 MPa (1846 psi), 92.7% of the DNSP. However, the leg pressures climb to 13.60 MPa (1981 psi) by the end of resuming operations.

<table>
<thead>
<tr>
<th>COLLIERY</th>
<th>SUPPORTS (x10)</th>
<th>POST-SETTING PRESSURE (MPa)</th>
<th>DESIGN</th>
<th>MEASURED</th>
<th>COEFFICIENT</th>
<th>EXCEEDS DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>BETWS</td>
<td>50</td>
<td>12.73</td>
<td>13.1</td>
<td>12.6</td>
<td>105.2%</td>
<td>No</td>
</tr>
<tr>
<td>PUNNALLY</td>
<td>50</td>
<td>12.73</td>
<td>13.1</td>
<td>12.6</td>
<td>105.2%</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 1 Setting Pressures And Setting Load Densities.

The positive set system may have been hampered in its operation by the thick layer of debris (in excess of 300 mm) above the support. The measured mean setting load density (msld) (Table 1) is 0.15 MPa (15.29 kN/m²). This was achieved with a mean unsupported distance (sud) of 0.516 m. During the course of the investigation the mean front right leg pressure was consistently higher than the mean front left leg pressure. This was attributed to the fact that the right legs were lower than the left legs due to face inclination. Typical leg pressure build up during the mining cycle is illustrated in Figure 6. The front and rear leg yield pressures had nominal values of 43.20 MPa (6265 psi) and 55.94 MPa (8112 psi) respectively to give an overall yield of 49.57 MPa (7190 psi). The highest mean leg pressure was 24.77 MPa (3593 psi). The mean load density (MLD), Table 2, in the Q-position was 0.22 MPa (22.96 kN/m²).

<table>
<thead>
<tr>
<th>COLLIERY</th>
<th>M.SLD (KPa)</th>
<th>M.RSLD (KPa)</th>
<th>M.LoD (KPa)</th>
<th>M.PSD (KPa)</th>
<th>M.PSD (KPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BETWS</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUNNALLY</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Mean Load Densities (MLD).

The leg closures analyses are shown in Tables 3 and 4. These show that in all but one cycle leg extension occurred after the support had apparently been set to the roof. Overall a total leg closure of 3 mm is seen after a 2 mm initial extension Fig. 1. The overall mean pressure closure ratio is shown in Table 4. During the investigation average leg travel remaining was 312 mm.

Owing to the steep inclination of the seam and the lack of any lateral movement control on the supports it proved impossible to install roof-to-floor convergence transducers. Compilation of debris below the support was

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11th International Conference on Ground Control in Mining. The University of Wollongong, N.S.W., July 1992.
Table 3 Lay Closure Analysis, N5 Face, Boves Colliery

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>DURATION (hr)</th>
<th>CLOSURE (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PERIOD</td>
</tr>
<tr>
<td>1</td>
<td>10.67</td>
<td>1.0</td>
</tr>
<tr>
<td>2-5</td>
<td>10.00</td>
<td>-1.0</td>
</tr>
<tr>
<td>6</td>
<td>3.00</td>
<td>-1.0</td>
</tr>
<tr>
<td>7-8</td>
<td>4.61</td>
<td>-0.3</td>
</tr>
<tr>
<td>9-10</td>
<td>0.47</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

Table 4 Hydraulic Lay Pressure - Closure Ratio, N3 Face, Boves Colliery

<table>
<thead>
<tr>
<th>CYCLE NO.</th>
<th>DURATION (min)</th>
<th>REAR AER. CLOSURE (mm)</th>
<th>FRONT AER. CLOSURE (mm)</th>
<th>PRESSURE CLOSURE RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>445</td>
<td>4.20</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>620</td>
<td>3.00</td>
<td>2.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>720</td>
<td>3.71</td>
<td>3.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>490</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Overall Mean PCR = 0.124 (mm/kPa/mm)

Table 5 Support Component Instability, N3 Face, Boves Colliery

<table>
<thead>
<tr>
<th>Cycle No.</th>
<th>Point in Cycle</th>
<th>Direction</th>
<th>Support Cavity Left</th>
<th>Support Cavity Right</th>
<th>Support Linkage Extension</th>
<th>Base Support Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Set</td>
<td>Left</td>
<td>5.92</td>
<td>-</td>
<td>0.45</td>
<td>2.32</td>
</tr>
<tr>
<td>2</td>
<td>Lower</td>
<td>Left</td>
<td>3.08</td>
<td>-</td>
<td>0.99</td>
<td>2.00</td>
</tr>
<tr>
<td>3</td>
<td>Lower</td>
<td>Right</td>
<td>8.00</td>
<td>-</td>
<td>0.99</td>
<td>2.00</td>
</tr>
<tr>
<td>4</td>
<td>Lower</td>
<td>Left</td>
<td>0.00</td>
<td>-</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 6 Gillenbeck 6/40 Base Leading Profiles

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>Ground Control</th>
<th>Theoretical Reduction</th>
<th>Closure Leading Profiles</th>
<th>NS Benches, Boves Colliery</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td>11-20</td>
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<td>5.00</td>
<td>5.00</td>
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<tr>
<td>21-30</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
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<tr>
<td>31-40</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>41-50</td>
<td>2.00</td>
<td>2.00</td>
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<tr>
<td>51-60</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 7 Gillenbeck 6/40 Canopy Leading Profiles, N5 Benches, Boves Colliery

The base loading profiles (Fig. 7, Table 6) exhibited trapezoidal distributions with the heel load always higher than the toe load. In the most exaggerated case before the support was lowered off the heel load was 3.031 MPa (440 psid) whilst the toe load was only 0.278 MPa (40 psid). Although this heel load is high, it is approximately 30% of the intact UCS of the underlying strata. Canopy loading exhibited a triangular distribution (Fig. 8, Table 7) with the loading being taken up almost entirely in the rear third of the canopy. The maximum canopy load achieved was 2.594 MPa (391 psid).
Betws Local Seam Fracture Behaviour

A 8.2 m extensometer hole was drilled 0.4 m below roof level opposite support 88. Monitoring extended over the weekend wind period and four complete production cycles. Figure 9 illustrates movement of the individual reference point movements within the borehole, while (Table 8) shows extriation rates for each scan.

<table>
<thead>
<tr>
<th>Scan No</th>
<th>Article</th>
<th>Time (min)</th>
<th>Extent (mm)</th>
<th>Rate (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 1</td>
<td>No activity</td>
<td>120</td>
<td>2.4</td>
<td>0.02</td>
</tr>
<tr>
<td>2 - 1</td>
<td>C L + P1</td>
<td>120</td>
<td>3.5</td>
<td>0.03</td>
</tr>
<tr>
<td>3 - 1</td>
<td>No activity</td>
<td>120</td>
<td>3.4</td>
<td>0.03</td>
</tr>
<tr>
<td>4 - 1</td>
<td>C L + P1</td>
<td>120</td>
<td>3.4</td>
<td>0.03</td>
</tr>
<tr>
<td>5 - 1</td>
<td>No activity</td>
<td>120</td>
<td>3.4</td>
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<tr>
<td>6 - 1</td>
<td>C L + P1</td>
<td>120</td>
<td>3.4</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Borehole: 1m long horizontal, adjacent to Support 88
No. reference points in borehole: 23
No. extensometer runs to date: 8

Table 8  Borehole Displacement, NS Face, Betws Colliery

For the weekend non production period, an extraction rate of 0.007 mm/min was recorded, compared to a value at 0.009 mm/min for previous investigation in thin seams (Freeman 1988). During the four monitored cycles, three major areas of reference point movement were observed at marked on Figure 9. All three fractures exhibit considerable cyclic opening and closing during the monitored period. The maximum opening recorded was 52 mm in the case of fracture 2, 3.1m into the coalface, while the greatest closure was 54 mm at the same point one cycle later.

The deformation process is further illustrated in Figure 10 which shows three region of seam activity.

- **Region 1**

  Throughout the four cycles a general trend of contraction was observed in the innermost 1 m of the borehole. Movement is very slight, being limited to 1 or 2 mm and it is considered that although under stress from abutment pressures, this area resists failure and maintains stability assisted by the high confining pressures generated within the seam.

- **Region 2**

  This area displayed a considerable amount of movement with large displacements of up to 50 mm and associated contractions to accommodate them. This action creates individual blocks of coal which due to the decrease in the confining pressure as the face advances towards them, become more mobile as the hole length decreases.

- **Region 3**

  The last 1 to 2 m of the hole becomes free of the confining pressure of roof and floor and is allowed to move out towards the excavation. The coal has failed at this stage except where face weighting still maintains large confining pressures.

Figure 9. Coal Seam Fracture Development, NS District, Betws Colliery

11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.
Table 9  Reset Occurrence, M24 Face, Penallta Colliery

The leg pressures over the average cycle (Table 9) demonstrate a fairly rapid pressure increase to 90% of the nominal yield pressure (31.55 MPa). Yield pressure was reached in some instances. The Mean Load Density (MLD) (Table 2) value of 95% of Designed Yield Load Density (DYLD) confirmed that the support was operating at near full capacity.

Table 10  Hydraulic Leg Pressure, M24 Face, Penallta Colliery

The principal components of roof-floor closure were monitored in: roof-floor convergence, hydraulic leg closure and debris compaction. The roof-floor convergence (Table 11) was found to be 14.8 mm/min which is significantly lower than the predicted value (1.7 mm/min). The Pressure Convergence Ratio (PCR) was 1.85 MPa/mm, a higher value than those recorded in other localities. The proximity of the canopies prevented the monitoring of debris composition above the supports although this was hardly necessary as the Contact-Advance system prevented debris accumulation.

Canopy and base loading pressures are shown in Table 12 with the profiles being shown in Figures 12 and 13. The base loading profile exhibited a triangular form.
acting over the full length of the pentocon, the heel load was consistently higher than the toe load. The minimum heel load was 0.859 MPa (125 psi) which rose to an operating maximum of 1.953 MPa (283 psi) with a potential yield value of 2.134 MPa (309 psi) whilst the minimum toe load was 0.625 MPa (91 psi) rising to an operating maximum of 1.449 MPa (210 psi) with a yield maximum of 1.542 MPa (226 psi). Of the total increase in toe load 78% was between period 1–2 and 2–3.

Penalta Coal Seam Fracture Behaviour

A 10 m extensometer hole was drilled into the coalface 0.6 m below the roof, 0.2 m above the floor in the broken floor. The third monitored production cycle, two extensometer rods became lodged in the rear of the borehole. This resulted in the loss of observations for six cuts, after which the rods were freed by coal spalling from the face. This exposed a large vertical slip which had trapped the rods 4 m from the back of the hole. Monitoring then continued for a further two cuts until the hole was abandoned due to its reduced length.

Results from two cuts taken before the weekend stand revealed two major zones of movement; an opening of 9 mm, 7.1 m into the seam and a contraction of 115 mm, 2 m from the outbye end of the hole. General reference point expansion was observed throughout the outer 2 m of the hole. It is considered that this major contraction was due to the closure of previously existing fractures.

The reopening of this fracture zone after the weekend stand by a value of 167 mm indicated block detachment and resulted in an expansion rate of 0.051 mm/min, far in excess of anything recorded or previous investigations. Without this block migration, no expansion or contraction would have been observed. Figure 19 shows reference point movement over the monitored period while Table 13 displays extensation rates.
Although six production cycles were lost due to trapped extensometer rods blocking the hole, their release allowed certain observations to be made. The plastic access tube displayed severe deformation and striations on the outer surface indicating a vertical slip, parallel to the face line. It is estimated that a vertical displacement greater than 50 cm occurred at this point. After release of the rods, further runs revealed that little or no movement had occurred in the hole past that point despite six cuts having taken place, the maximum displacement measured being 6 mm. It is considered that the occurrence of this fracture acted as a mechanism of stress relief for the coal inbye that point, allowing it to remain intact and reducing movement to a minimum.

<table>
<thead>
<tr>
<th>Runs</th>
<th>Activity</th>
<th>Time (min)</th>
<th>Distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Cut + Rest</td>
<td>38</td>
<td>15.9</td>
</tr>
<tr>
<td>1-2</td>
<td>Worked Stand</td>
<td>27</td>
<td>13.0</td>
</tr>
<tr>
<td>2-4</td>
<td>Cut + Rest</td>
<td>27</td>
<td>22.6</td>
</tr>
<tr>
<td>4-5</td>
<td>Cut + Rest</td>
<td>30</td>
<td>20.1</td>
</tr>
<tr>
<td>4-5</td>
<td>Cut + Rest</td>
<td>30</td>
<td>10.4</td>
</tr>
<tr>
<td>4-7</td>
<td>Cut + Rest</td>
<td>30</td>
<td>10.5</td>
</tr>
<tr>
<td>5-7</td>
<td>Cut + Rest</td>
<td>45</td>
<td>30.0</td>
</tr>
<tr>
<td>5-7</td>
<td>Cut + Rest</td>
<td>45</td>
<td>30.0</td>
</tr>
</tbody>
</table>

Tab 15: Run Extensometer Data, M26 Bean, Penalla Colliery

**Overall Assessment of Support Performance**

The runout achieved by the OD 4340 was 168% of the Production Instruction (PI) minimum requirement (PIMR) but only 91% of the designed nominal value. This disparity of achievement was brought about by the support having a very high rating (in comparison to conventional supports) for this height of extraction and thus being able to easily exceed the regulatory requirements whilst the failure to achieve designed performance is attributed to two factors:

- the mean unsupported distance after rest was 51.6 mm, 129% of the PI and design maximum, and
- the failure to achieve designed setting pressures in the legs owing to thickness of debris which accumulated above the support.

The highest mean leg pressure recorded was 24.77 MPa (3592 ps) some 50% of the overall nominal value. The support only achieved 44% of the PI minimum requirement for mean load density in the Q-position. This is 48% of the DYLD and indicates the supports potential to absorb more load. However, this is restricted by the short remaining leg travel of 212 mm although, in this instance, it is accepted that this was principally brought about by the thick layer of debris above the support.

![Figure 14: Reference Point Expansion, M26 District, Penalla Colliery](image-url)
The failure of the G 134/40 to achieve designed performance is in marked contrast to the performance of the Dowty 4/300. In the M24 district yield pressures were recorded on a number of occasions as the shearer passed the monitored supports. However, similarly to the N5 situation, although the 4/300 easily exceeded the FIMR for setting load density it failed to achieve designed performance levels owing to the supports not being advanced sufficiently near to the face upon reset. The measured mean unsupported distance upon reset was 0.51 m, some 127.5% of the designed maximum of 0.40 m. The overall mean load density recorded was 95% of the designed nominal yield load density with the MLD in the advanced, P, position being 135% of the FIMR and the pre-reset, Q, position be 184% of the FIMR.

The characteristic support loading (Fig 15) on the N5 face proved to be a function of two main problems:

- the severe fracturing of the immediate roof, and
- the difficulties in cutting an even floor horizon.

The high canopy stresses generated, even by setting pressure, were believed to be instrumental in causing the roof to shatter and rest upon the support. The accumulations of this thickness of debris above the support prevented the supports from being set to solid roof and restricted the clearance of the shearer under the supports.

The lack of clearance compounded the difficulties in cutting an even floor created by the machine steering system and the physical similarities between the coal and the roof. The uneven floor created problems in support control as the pontoons tended to ride over the steps and this resulted in a high incidence of damage to the clevis pins and the relay bars. Despite the poor transmission of the support loads to the strata the immediate roof caved readily thus easing the requirement for optimum support performance. It is considered that the gradual compaction of the debris layer as it made its way along the canopy during a number of resets was probably helpful in allowing sufficient support force to be generated to promote a regular cave immediately behind the supports. Overall the performance of the supports in the N5 face was considered to have been adequate to promote caving and thus maintain reasonably good strata control: the low seam height contributed to the negligible levels of deformation in either roadway. The small amount of bed separation in the tailgate end is considered to be indicative of a low vent abutment pressure.

The good support performance observed in the M24 is reflected in the overall strata conditions and the general support/strata interaction. Caving (Fig 16) was strongly influenced by the discontinuities in the immediate roof and was believed to have occurred up to the hard siltstone band 3.6 m above the Seven Feet seam. Caving was observed to occur immediately behind the support with debris collecting on the flashing shield and around the linkage. Some minor fracturing of the immediate roof and face spalling did occur although strata control was effective. Vertical (fractures) were observed in the immediate roof towards the rear of the supports but these did not extend towards the face. The supports were generally set against a solid roof with very little debris accumulating above the supports. Despite earlier difficulties there was no evidence of soft floor conditions during the investigation and there was no penetration of the floor by the pontoons.

**CONCLUSIONS**

- The IPS configured supports permitted good strata control to be attained in both faces. The regulatory requirements (PI 1982/6) were satisfied but neither support achieved designed setting load densities.
- In friable roof conditions high setting loads are critical to achieving good roof conditions and in controlling the extent of fracture development in front of the face.

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Figure 15. Characteristic Deformation Mechanism, NS District, Betsy Colliery
In their IPS configurations both supports afforded a clear travelling way and good access to the shearer. However, in 'stand back' configuration, the OD 4/340 only offered a very restricted travelling way even before advance and no travelling way at all when advanced near to face communication equipment mounted on the pan side.

Contact-advance systems are advantageous to maintaining good roof conditions and to preventing debris accumulation above supports. Following the performance investigation a contact-advance system was trialled on a number of supports in the NS face. The canopies of those supports remained clean whilst those of the adjacent supports continued to suffer with accumulated debris. As a result of this investigation all supports were fitted with contact-advance.

The supports generated the canopy and base loading profiles typical of their types. However, these were not necessarily appropriate to the face conditions in which they operated. The OD 4/340 failed to achieve sufficiently high toe loads to allow the pontoon to maintain an even horizon and the canopy load distributions and magnitudes were of a destructive rather than constructive nature. The Dowry 4/300 displayed a favourable base loading profile with low toe load, high heel load characteristics although the soft floor caused difficulties with base penetration.

Trends of displacements in front of the coalface have been identified. It is considered that the initial one to two metres of coalface is highly fractured and unstable, and prone to relatively large displacements of both expansion and contraction. The remainder of the zone, defined as accommodating displacements of 5 mm or more displays smaller degrees of movement are assumed to be the interfaces between discrete blocks of intact coal, and acted upon by the confining pressure of roof and floor. Beyond the plastic/elastic boundary of the fracture zone lies a more stable area of coal, although, still under the influence of the front abutment pressures.

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REFERENCES


11th International Conference on Ground Control in Mining. The University of Wollongong, N.S.W., July 1992.