SUPPORT OF LONGWALL WORKINGS IN THICK SEAM EXTRACTION

By
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ABSTRACT

The main components of face design are the power loader, face conveyor and powered support system and the interaction of these components determines the effectiveness of strata control. A major influence upon the interrelationship of this equipment is the geological environment, of which seam thickness appears to play an important role.

Recent thick seam experience indicates a significantly different characteristic behaviour pattern from that observed in thin seams. The structural integrity of the face wall is particularly influenced by seam discontinuities such as natural joint planes and mining-induced fractures in the yield zone ahead of the faceline. In addition, the presence of stone bands or dirt partings in the seam offers interfaces for uncontrolled release of blocky material.

Some case study experience at British collieries provides a comparison with performance data at a specific location, that highlights the importance of coal face layout and design.

INTRODUCTION

The complex and interdependent nature of the engineering system comprising the modern longwall face exerts a major influence upon the behaviour of coal seam, roof and floor strata. Hence, face layout and design require careful consideration of geological environment, i.e., structural and proximate geology, in order that the principal components of the engineering system, viz., power loader, face conveyor, powered support installation, and face end support system, generate full output potential. The integration of these components is reflected in current rates of face advance, and it is generally accepted that high rates of face advance lead to optimum strata control.

An examination of mining literature between 1960–1985 clearly shows the technological advances made in British longwall mining in that relatively short period. Commencing with the Remotely Operated Longwall Face (ROLF) in 1965, the British Coal Industry has rapidly moved through an increasingly sophisticated development phase using banners such as Spearhead (1968), Advanced Technology Mining (ATM, 1974), Heavy Duty Programme (1978), and latterly Shield Support Programme (1983) to identify various stages (Longden, 1985). Each stage in this development has moved towards greater equipment strength and reliability which in turn involves greater power requirements. The success of the policy has become self-evident with the output results shown in Table 1 (Price, 1985).

The Shield Support Programme placed emphasis upon the introduction of chock shield support at longwall faces, particularly in thick seam extraction. This introduced a new criterion of 'support density' compared with its more inflexible fencerunner, the 'prop free front' approach in relation to support design and performance assessment. The improved output results at Kellingley Colliery, Yorkshire, since introduction of the first chock shield face in 1977 (Simpson, 1985), encouraged a selectively wider introduction in all.

<table>
<thead>
<tr>
<th>Output (tonnes)</th>
<th>Productivity (Output/ Manshift)</th>
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<tbody>
<tr>
<td>Daily Output per Face</td>
<td>1665</td>
</tr>
<tr>
<td>Output/ Machine Shift</td>
<td>All heavy duty/ shield/ ATM faces</td>
</tr>
<tr>
<td>All other faces above 1.8m extraction and more than 2 shifts/day</td>
<td>1045</td>
</tr>
<tr>
<td>All other faces</td>
<td>726</td>
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Table 1 - U.K. Output Performance (1983) (after Price)

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the U.K. for high volume production at low cost per tonne. Whilst Table 1 results confirm that chock shield support is probably the key element in realisation of output potential, it is clear from examination of the best with average U.K. results that substantial improvement is possible. Comparison of British with South African, Australian, and American results show a marked shortfall between the best British result and those of overseas (Clasby, 1984). Although valid reasons may exist for lower British outputs, observations at a number of thick seam faces indicate the sensitivity of the relationship between geological environment, face layout, and equipment design and performance. The paper examines this relationship with reference to a particular location in the South Wales Coalfield, U.K.

**FACE DESIGN**

In order for a Coalfield to attract the six million pounds capital required for a Shield Support/ATM installation, a strong case has to be made to the Executive Board. Comparative figures for a 200m long shield face and an alternative conventional installation are given in Table 2.

The output figures in Table 2 indicating a higher return from the Shield Face, are due to thicker seam working. Such installations require high output situations to provide an acceptable return on the capital expenditure, which explains the emphasis currently given to thick seam extraction in the U.K. with extracted seam thicknesses of between 2-6m. One of the key elements of face design is that of mechanisation and the successful development and the interrelationship of the main components reflect the levels of cooperation achieved between the Coal Industry and Equipment Manufacturers.

**POWER LOADER**

A review of world coalmining indicates the widespread application of high powered double ended ranging drum shearsers (DERDS) for thick seam extraction. The Anderson Strathclyde AMSO0 DERDS powered by 500 hp or 1,000 hp motors is an example of the type of coal loader capable of producing up to 12,000 tonnes/day from a 4m thick hard coal seam. Such a machine could be equipped with a 1.5m diameter by 0.7m web drum, chainless haulage, lump breaker gear head, radio control, dual electrical controls, health monitoring devices, ventilator ventilation system, all powered from a trailing cable with between 1.0-4.2 kV supply. Most machines still employ a hydraulic power pack but the use of all-electric machines is envisaged to be increasing due to the lower maintenance requirement.

**FACE CONVEYOR**

In the interests of operational efficiency, a study of face conveyors, has been pursued within the U.K. Coal Industry since 1969 and current efficiency levels reflect the development process (Hates, 1984). The heavy duty requirements implicit in high outputs from thick seams demands compatibility between power loader and AFC. It has been found that to service a shearer with a production rate in excess of 1,000 t/hr, the AFC requires:-

- 450-750 kV drive heads;
- 26-30mm twin centre strand chains;
- 800-900mm wide pans with 30mm deckplate;
- side-discharge facilities to in wide stage loaders.

Using conveyors of this design properly interfaced with the coal clearance system, provides continuous running that ensures high face performances.

**POWERED SUPPORT**

Laminate linkage design of powered support structure provides the means of operating safely in thicker seams. Virtually all new longwall faces in the U.K. and probably all thick seam faces worldwide now employ shield or chock shield supports. The development process has been continuous from chock type supports with 4-6 legs having 150-250 tonnes capacity, to 2 or 4 leg shields with capacities up to 900 tonnes. Design features subsequently added for structural strength and operating efficiency (Ronell and Clough, 1985) are referred to in the next section.

**HYDRAULIC POWERED SUPPORT**

The first full installation of laminate linkage type powered supports in the U.K. was at Kellingley Colliery, Yorkshire. 46 District lay at a cover depth of 650m with extraction of 1.8m used conventional chock supports which subsequently experienced severe damage due to periodic weighting by roof beds, lateral roof

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movement and severe waste flushing. 46 Face established a European output record for an advancing panel, of 31,000 tonnes in a week. The introduction of the lemniscate linkage generation of powered supports released the potential of the successful longwall extraction technique. This support design enabled a wide range of extractive heights and strata conditions to be supported in a controlled manner with high levels of production to be achieved.

DESIGN REQUIREMENTS

By 1980, the progress in mining engineering technology was such that support legislation drafted 20 years previously was increasingly restrictive to continued progress in face powered and productivity. In conjunction with the Mines Inspectorate and support manufacturers, the National Coal Board developed a different approach to face support requirements. The Production Instruction PI/1982/6 became operational on 1 January 1983, specifying support setting and yield load densities as the main criteria for coalface support design.

The standards required by the Production Instruction are based on the desirable features of mining systems which have been operating successfully on longwall coalfaces and on the main features of the modern generation of powered supports. These are:

- consistent and adequate setting resistance;
- adequate yield resistance;
- good face support;
- maximum roof cover;
- prevention of spalling coal;
- reasonable distribution of floor loading pressures.

The minimum required setting and yield load density criteria for faceline and buttress supports of 7.5H tonnes/m² and 15H tonnes/m² respectively, are based on the mass of the block of immediate roof strata carried by powered supports, assuming a caving height of 2H.

In the pack and roadhead zones of the face, support is enhanced by the packs, permanent support and the solid coal on the rib side. Pack and roadhead supports must provide support equal to two-thirds of the faceline requirements, i.e. 5H tonnes/m² and 10H tonnes/m² respectively.

Other operational requirements of powered support detailed in PI/1982/6 include:

1. the maximum distance between roof canopy tip and the coalface shall not exceed 0.4m up to 2.5m extraction;
2. powered forepoles shall be provided and used systematically on all powered supports where the extracted height is 2.5m or greater and/or where the designed depth of web exceeds 0.8m;
3. powered face sprays shall be provided and used systematically on all supports where the clearance between the top race of the AFC and the roof exceeds 2.3m;
4. where immediate Forward Support (IFS) systems are employed, supports must be advanced within 10.0m behind the coal getting machine.

To meet these requirements heavy duty lemniscate linkage type powered supports designed for thick seams incorporate such features as:

- powered forepoles;
- powered face sprays;
- hydraulically operated side shields;
- reverse principle rams;
- base lifting rams;
- hydrostone rams.

Control systems now available for these supports include:

- in cheek manual;
- bi-di adjacent control;
- uni-di adjacent control;
- sequential control;
- on-face push button electronic control;
- remote electronic control.

Contact advance, high pressure set and positive set facilities can be built into the support valve system providing roof control benefits which can be applied to all control systems.

PERFORMANCE EVALUATION

A combination of instrumentation systems may be used to evaluate the behaviour of powered supports and surrounding strata on longwall coalfaces. Support performance and design parameters were monitored using purpose designed Data Logging Systems and associated transducers (Bradbury, 1984; Bigby, 1985).

Coal seam fracturing and extrusion were monitored using the Magnetic Reference Point Extensometer System (Aalis, 1978).

THICK SEAM EXTRACTION

A considerable amount of operational experience in thick seams has now been gained with impressive output figures quoted from collieries in the U.K., South Africa, Australia, North America, China and Romania. These results have been achieved in varying conditions with the equipment referred to previously in the paper. The interfacing of AFC, DEDES and powered support forms the basis of controlled strata movement, the pre-requisite of high performance on the face line. Any investigation of coalface operations will...
confirm this assessment and planning has to give due consideration to equipment specifications, geological structure and strata properties. However, not all thick seam installations have been immediately successful and general observations of strata behaviour form a useful basis of assessment of performance.

ROSSINGTON COLLIERY, YORKSHIRE

800 District. 2.8m of the composite Barnsley/Dunslil seam was extracted at 875m cover depth under a 0.3m coal layer and mudstone roof. The floor comprised very soft seatearth to 0.6m depth below which lay mudstone beds. The face dipped at 30° and cleat planes were insignificant. The 1.5m thick Dunslil portion of the seam was separated from the Barnsley section by a thin dirt band.

The face line was equipped with two BERDS cutting uni-directionally and Gulick Dobson 4/300 tonne shield supports set at 1.5m spacing, and fitted with sprays and forepoles. The general arrangement of face equipment produced large quantities of debris under the AFC and supports. This in turn led to loss of cutting horizon control, delays in support advance, top coal spalling, large unsupported roof spans from canopy tip to face, and roof falls up to 2m above the seam throughout the face. An added complication was penetration by the support toe into the debris and weak seatearth floor which exacerbated strata control problems.

Spalling of 0.8m top coal and spans of unsupported roof of up to 2m combined to produce roof falls which affected the roof in advance of the face line. It appeared that although face sprays were available, their use was made difficult, eventually leading to a breakdown in the face wall. In this situation, production levels became progressively and unacceptably lower (Bigby, 1986).

848 District. Set in the same seam and with identical supports, the major differences were in the general arrangement of equipment, the existence of a stronger more competent floor, and the height of extraction. A major fall had occurred on this face stretching 125m along the face line and with a cavity some 30m in height at some points.

At the time of investigation, the face was cut by a single pass of a BERDS with an extraction height of 3.2m. Horizon control was good, and little debris occurred beneath AFC and supports, but roof debris accumulated over support canopies resulting in uneven roof conditions.

Face spalling was again severe and it had been observed (Holmes, 1983) that the mechanism was initiated along the dirt band overlying the Dunslil seam causing movement of the adjacent coal along cleat planes. The upper coal section was undermined, then spalled for up to 1m, usually immediately following machine pass causing restriction to AFC advance. This in turn caused large unsupported roof spans in excess of 1m with potential for roof falls. Production levels were consistent and higher than 80t at 5m/week, which was well below potential.

DEEP NAVIGATION COLLIERY, S. WALES

V105 District. Extracted thickness from V105 District at 7.6m resulted from the coalescence of the Five Feet and Gallideg seams. The seams with a combined thickness of 3.1m were separated by a 0.8m stone band just below midway in the section. Lying at a depth of 650m, the seam possessed a layered mudstone roof and a strong competent mudstone floor. Primary and secondary joint planes in the seam were pronounced throughout the face line with the former occurring at an average interval of 3.5m and orientated perpendicular to the face line.

The face line was equipped with a BERDS cutting the face by single pass, and 3SW 4/450 tonne Hydrostore cheek shield supports set at a spacing of 1.5m. The supports are described more fully in the next section of the paper (Smith, 1986).

General conditions on the face line were good with low levels of debris accumulation, good horizon control, and clear evidence of effective strata control. However, the presence of natural joints and mining-induced fracture planes above and below the stone band, caused large blocks of stone and coal to spall onto the AFC immediately ahead of the shearer. Blocks measuring 3m x 0.6m x 0.7m were not uncommon and caused considerable production delays. Joint plane orientation appeared to be the factor creating more frequent spalling when cutting towards the main gate.

Satisfactory levels of production were being achieved and development of improved face sprays was in progress to give greater stability to the face wall and to prevent spalling of the stone blocks.

LADY WINDSOR/ABERTYON COLLIERY

V0 District. This coal face was also mining the Five Foot Gallideg seam with an extracted thickness of 2.8m and a proximate geology similar to that at Deep Navigation. The primary joint planes in the seam occurred regularly and parallel to the face line, being inclined at about 50° away from the face. The face was equipped with a BERDS and BERDS, both cutting the face in dual pass mode, and Gulick Dobson 4/370 tonne cheek shield supports. A large fall had occurred over 1m of the face line and up to 10m over the roof at its mid point.

At the time of observation, the face exhibited a competent face wall over 60% of its length. Where the overlap of the two shears
occurred, evidence of localised stress concentrations was clear in the loss of face wall in bottom and top coal sections which had adversely influenced strata control, with pronounced roof fracturing well ahead of the face line, and also over the front leg of the support. Loss of horizon control in some sections had produced excess section which the supports were unable to accommodate. Face orientation to primary joint planes created sections of face line where spalling occurred off the joint planes with large unsupported roof spans at these points.

Production levels were not satisfactory on this face and attempts were being made to increase the Shifting Index and rate of machine travel.

SUMMARY OF THICK SEAM PERFORMANCE

It would appear that most thick seam installations are achieving target outputs, particularly in conditions able to accommodate an inherently weaker face wall than those found in faces below 2m thickness.

The influence of natural joint planes and mining-induced fractures in the yield zone ahead of the face line is considerable in destabilising the face wall. Lateral stress acts parallel and perpendicular to the face wall, and in thick seams enhances fracture potential along seam discontinuities.

The rate of face advance appears important in maintaining face wall stability and roof beam competence. Hence, delays to face advance caused by debris accumulation, poor horizon control, seam spalling, and roof falls, should be prevented by attention in the planning stage to machine design and face layout.

Seam partings have a potentially adverse influence upon seam spalling and unsupported roof spans in thick seam extraction.

SOUTH WALES COALFIELD, U.K.
DEEP NAVIGATION COLLIERY, V105 DISTRICT

INVESTIGATION AIMS

The precise aims of the investigation were:

- to establish performance criteria for a new generation of thick seam supports;
- to identify strata deformation behaviour in thick seam extraction.

Specific terms of reference by Colliery Management concerned control of face spalling, because of large blocks of stone falling in advance of the shearer causing delays in the production cycle.

GEOLOGY

The Five Feet and Gellideg Seams have a combined thickness of 3.1m, and are separated by a 0.8m quartz rich stone band. V105 Face lay in a de-stressed zone, 12m below the extracted Seven Feet Seam, at a cover depth of 650m. The immediate roof was composed of 0.25m of poorly bedded pyritic mudstone passing into 0.10m of dark carbonaceous mudstone. The immediate roof was overlain by well bedded mudstone of more competent nature. The floor was composed of competent dark carbonaceous mudstone.

Detailed geological mapping of the faceline established the major discontinuities present and classified the major joint planes shown in Fig. 1.

FACE DETAILS

The face length of 165m was worked by longwall advance, up a 1 in 17 gradient. A BERDS cut bi-directionally extracting a 2.6m section with a 0.8m web. The face was equipped with 94 Fletcher Sutcliffe Ltd., 4/450 tonne Hydrostore chock shield supports. This support was a new design that incorporated two horizontally converging rams connecting the roof beam to the laminar linkage. This feature allowed lateral movement to occur above a predetermined load, thus enabling a reduction to be achieved in support length and weight.

A gate-and arrangement of 2 FSM 6/300 tonne packhole and 2 FSM 6/725 tonne buttrass supports permitted the installation of a 2.7m x 2.7m TDK pack. Both gates were advanced and profiled by the shearer.

![Fig. 1 - Structural And Seam Geology](image_url)
The powered supports were served by an FSW ACS 60 gpm ring main system. The Designed Nominal Unload pump pressure was 13.79 MPa (2000 psi) through a feed and return line of 0.032m and 0.025m diameter respectively. The installation was equipped with Phase V valve gear, positive set, and 'trip and advance' facilities.

Operational experience on V105 Face highlighted two adverse characteristics of the face sprag design, viz., (1) the plate had a tendency to point load the face with its top edge on setting, and (ii) on successful setting was located above the stoneband.

In an attempt to improve sprag plate contact for restraint of the stone band, the plate was modified by extending its length by 0.37m. This modification was assessed during the investigation.

The instrumentation layout is shown in Fig. 2.

**SUPPORT PERFORMANCE**

**Setting Pressure/Setting Load Densities.**
The measured mean setting pressure was 99% of the designed nominal figure of 13.70 MPa (1987 psi) indicating the effectiveness of the positive set facility. The ability of the positive set facility to produce consistent setting pressures combined with good support advance was reflected by excellent achieved Setting Load Densities. Calculated from supported roof areas and measured setting pressures, the measured mean setting load density achieved was 0.269 MPa (27.49 T/m²), this being 118% of the Production Instruction/1982/6 minimum requirement.

The high satisfactory achieved mean setting pressures and mean setting load densities compare well with previously monitored installations.

**Hydraulic Leg Pressures And Convergence.**
The measured mean hydraulic leg pressure and corresponding convergence over the average cycle are presented in Fig. 3. To aid analysis the mining cycle was divided into seven periods of activity:

1. Support Reset
2. Support Reset leaves Zone a
3. Shearer enters Zone
4. Shearer at Site
5. Shearer leaves Zone
6. Support Reset enters Zone
7. Support Lowered

a Zone: i.e. Zone of Influence 5 Supports each Side of Monitored Support

Throughout the average cycle the rear leg pressures were consistently higher than the front leg pressures indicating stable load distribution. The maximum mean rear leg pressure achieved 79% of the Designed Nominal Yield Pressure (D.N.Y.P.) whilst the maximum front leg pressure achieved 65% D.N.Y.P. The overall maximum mean leg pressure achieved over the average cycle was 72% of D.N.Y.P., indicating available potential support capacity to further induced loads.

The predicted minimum convergence rate in terms of mm/m face advance, during production from a 3.0m extractive height, was 80 mm/m ± 12mm/m (Wilson, 1980). For the monitored period the total convergence over the average cycle was 17.7 mm equivalent to 22.1 mm/m face advance. This was 40% of the minimum predicted value.

The low convergence value corresponded to a very acceptable pressure/convergence ratio of 1.25 MPa/mm, which indicated a high sensitivity of support resistance to convergence.

The results indicate that the powered support offers sensitive and controlled resistance to strata convergence, which is a fundamental prerequisite for good strata control.

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Figure 3 - Support Leg Pressure And Strata Convergence For Average Mining Cycle

Figure 4 - Support Base Loading Profile For Average Mining Cycle

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Mean Load Densities. The mean load densities were calculated from log circuit pressures and roof areas measured throughout the monitored period, all values being time-weighted.

The achieved mean load density in the 'Q' (support standing back) position was 0.470 MPa (47.91 T/m²), this being 10% of the Production Instruction/19826 minimum requirement. This value was highly satisfactory considering the achieved mean leg pressure was 72% D.N.Y.F. This feature again indicated the capability of the support rating and its potential capacity to absorb more induced load before yielding.

These values compared well with other installations monitored.

Base Loads. The stress distribution induced by a single support pontoon is presented in Fig. 4.

The analysis highlights that this design of anchor shield exhibited excellent base loading and stability characteristics.

Lateral And Sprag Loads. Roof lateral loading was calculated as lying between 30-39 tonnes, from which a coefficient of friction between canopy and roof strata of 0.16 was derived, but this value requires further investigation.

The sprag loading varied from 3-4.3 tonnes through the periods of use.

STRATA MOVEMENT

Coal seam deformation was monitored using the multi-reference point magnetic extensometer. A horizontal 9.5m borehole drilled 0.57m above the central stoneband was installed containing 37 reference points.

The borehole plot (Fig. 5) revealed a trend of reference point migration away from the face excavation over the 'weekend stand' period. Interpretation of this contraction is that time-dependent closure of existing fractures occurred within the monitored zone.

A trend of general coalface extrusion was produced during the production periods, with an increase in fracture development as the faceline advanced. This was emphasised by Scan 4, where Reference Points 8, 16 and 24 migrated 56mm, 71.5mm and 82mm respectively. All the reference points moved with a similar trend between established fractures, indicating block formation approximately 2m thick ahead of the advancing face.

CHARACTERISTIC DEFORMATION BEHAVIOUR

Strata deformation behaviour at V105 Face appeared primarily influenced by seam thickness, natural and mining induced fracture planes, powered support performance, and coal cutting machine travel. Figs. 6 and 7 illustrate pictorially the inter-relationship of these four factors.

Figure 5 - Coal Seam Fracture Behaviour

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The extracted section of composite Five Foot/Gelligean Seam containing the centre stone parting, appeared to fragment into blocks above and below the parting. Although the geometry of the face situation indicated that the structural integrity of the face edge support may have been impaired as a result of this behaviour, strata control at V105 Face was of a high order.

The natural seam joint sets or 'slip' planes intersected the mining-induced fracture planes in a regular manner. Therefore significant discontinuity existed in the coal seam both parallel and perpendicular to the faceline. Added to this was the effect of the stone parting, which because of its greater strength compared with the coal seam, fragmented into elongated slabs with axes parallel to the faceline, whereas the top and bottom coal separated into large blocks.

The high efficiency of powered support performance at this face resulted in a low convergence between roof and floor. The FSW 4/450 tonnes supports exerted a high resistance to load, which together with the face advance rate, gave the effect of limiting the clamping of the coal seam by roof and floor. In this situation of reduced vertical loading, the lateral stress from the coal seam achieved prominence, the immediate effect being coalface extrusion. Of greater significance was the effect of this stress when combined with the direction of travel of the coal cutting machine.

Machine cutting of the face introduced the agency for coal block and stone slab release. In the best situation, the face wall remained vertical and competent between machine passes, with the DERDS cutting the whole section of face wall. At Deep Navigation Colliery, bi-directional cutting was noted to create large block release in both directions, with the majority of blocks and slabs spalling off the face when cutting from tailgate to maingate.

Considering the forces acting on the coal block shown in Fig. 7, it may be noted that greater block release occurred when approaching a 'slip' plane that inclined away from the machine, compared with the reverse. It is proposed that the resultant force developed from combining machine travel and lateral stress overcame the frictional resistance between blocks when travelling Tail to Main, but was counterbalanced by this restraint in the opposite direction. It may be argued that blocks were pushed off the 'slip' plane in the Tailgate direction, and into the 'slip' plane in the opposite direction. In those situations on V105 Face where the secondary joint planes achieved prominence over the primary joints (Fig. 1) the same mechanism of block release may be proposed.
CONCLUSIONS

Effective strata control achieved with Heavy Duty Shield Supports in thick seams leads to high production levels when the support system is an integral component of an efficient ATM system. The combined contribution made by support, power loader and clearance system influences the overall efficiency of an installation, which emphasises the importance of an integrated approach in face planning.

The application of high powered double ended ranging drum shearsers, wide pan side discharge face conveyors and lemmiscate linkage support designs in thick seams, has resulted in high production figures worldwide. Observations at a number of British faces indicate the sensitivity of relationship between geological environment, face layout and equipment design and performance.

Geological structures achieve greater importance in thick seams by allowing block release off natural fracture planes. This impairs the structural integrity of the face wall as a natural support structure and extends its location deeper into the seam.

Face restraint with positive pre-loading is required for thick seam extraction to limit the effects of natural and mining-induced fracture movements. This may be achieved by uprating the face spray setting load.

Powered support performance at V105 Face, Deep Navigation Colliery, proved to be in excess of both Production Instruction and designed nominal requirements. Good strata control was achieved in what has traditionally been a difficult seam to mine due to the friable nature of the roof. This, combined with a single pass BEKDS cutting sequence and a Heavy Duty clearance system resulted in operating success at V105, with high levels of production being achieved.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge support of this work by the National Coal Board, U.K., the European Coal and Steel Commission, and Gullick Dobson Ltd., Wigan, England. The work was made possible by the total co-operation received at all stages of the research programme.

The facilities and encouragement of staff at University College Cardiff and the contribution of colleagues in the Strata Mechanics Research Group, Institute of materials (Mining, Geological and Minerals Engineering) is fully appreciated.

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