STRATA SUPPORT INTERACTION ON A POWERED SUPPORT LONGWALL FACE UNDER A MASSIVE DOLERITE SILL - A STUDY

By

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ABSTRACT

Design and selection of support systems for longwall faces call for in-depth knowledge of strata mechanics and in particular of strata-support interactions. The paper presents the results of field investigations and analysis of a difficult-to-extract roof using powered supports under a massive dolerite sill in Central India using a state-of-the-art datalogger system. The mechanised longwall face was equipped with 4/680 tonne chock shields operated on the IPS mode using a 300 kW DERO shearer. The datalogger system was capable of storing data simultaneously in 32 channels. The paper describes the monitoring system and the monitoring programme. The system provided useful information on support behaviour, build-up of leg pressures and face convergence during an intense dynamic periodic weighting phenomenon which destroyed the integrity of almost half of the face supports. At this point, the face had advanced by about 197 metres from the barrier. The paper outlines a post-mortem analysis of this dynamic event and provides a critical evaluation of the data collected for understanding strata support interaction and the behaviour of the massive sill in the overburden.

INTRODUCTION

Mechanised longwall mining is still in its infancy in India. During 1985-90 production from 12 powered supported longwall faces was estimated at 3.4 million tonnes, which was approximately 3.0 per cent of underground coal production. An analysis of performance of powered support faces indicate that inadequate appreciation of support-strata interaction and understanding of strata behaviour in and around longwall faces have largely contributed to the slow growth of longwall technology and failure of some of the mechanised faces in India.

In March 1990 a 150 m long fully mechanised longwall face was commissioned at Churacha West Colliery to extract a 3.0-3.4 m thick seam at a depth of 223 m. The coal seam is overlain by a massive 125 m thick dolerite sill. The rock in between the coal seam and the dolerite sill is a 65 m thick massive medium to coarse-grained sandstone of low competence with distinct parting planes at some horizons. Despite reservations on the success of longwalling below the sill it was finally decided to extract the seam using chock shield supports of 4/680 tonne capacity operated on IPS mode. With a view to investigate the mechanics of strata-support interaction of this difficult-to-extract roof under massive dolerite sill and that supports work consistently at their designed support capacities, a major instrumentation programme was instigated using solid state state-of-the-art 32 channel datalogger system. The system was designed to provide information on support behaviour, build-up of leg pressure and face convergence. During an intense dynamic periodic weighting phenomenon, which occurred after a face advance of 197 m from the barrier, the integrity of almost half of the chock shields was destroyed in less than 4 seconds.

The paper seeks to provide post-mortem analysis of this dynamic event leading to the collapse and a critical evaluation of the instrumented data, an insight into strata-support interaction and the behaviour of the massive sill in the overburden.

THE FACE

At Churacha West Colliery the thickness of seam V varies from 2.2-3.4 m; the seam inclination varies from 1 in 30 to 1 in 15. A massive dolerite sill 112-127 m thick overlies the coal measures of the area. Between the sill and the coal seam, some 80-133 m of intervening strata consists mainly of medium to coarse-grained sandstones.

A panel of 155 m width and 750 m long was planned to start a 150 m wide longwall face B-1. The extraction height in the panel run varied from 3-3.4 m and the depth variation was from 218-223 m. Over the panel the strata comprise 80-90 m of weak, medium to coarse-grained sandstones which are overlain by a massive dolerite sill.
sandstones and 125-132 m thick dolerite sill. The initial face design used geotechnical data of rock cores of two boreholes MPSC-20 and MFSC-23 situated at 600 and 200 m respectively from the face. The geotechnical parameters of the immediate roof rocks are detailed in Fig. 1. It may be noted that in general the roof rock was weak and not too massive. The first parting plane was at 8 m from the seam roof. In general, the RQD was less than 40 per cent. After the collapse of the face at 197 m advance from the barrier, three boreholes were drilled from the surface over the gouged area along the centre line of the panel. These holes were located at 15, 40 and 90 m on the goaf side. Lithologs and geotechnical properties of cores obtained from borehole RD-1 are plotted in Fig. 2. Two boreholes at 15 and 40 m on the goaf side of the face, were also geophysically logged using resistivity survey and collar logging. A borehole TV camera was used to view the location of cracks, fractures and cavities in the dolerite sill and sandstones up to a depth of 150 m.

Figs. 1 and 2 show the significant variation in geotechnical properties of roof rocks logged before starting the face and after the collapse, which can be attributed to variations in geology. Based on the geotechnical properties of rock cores of MPSC-20 borehole (see Fig. 1), nine planners had selected double telescopically 4/600 tonne choice shield supports operated on the IPS mode to provide a support density of 103 tonne/m² before shear and 94 tonne/m² after shear. The minimum and the maximum extended height of supports was 1.9 and 3.6 m respectively. The face was equipped with a 300 kW DEKD Eickhoff shearer with a 0.6 m width of web. There were 101 number of check shields along the face. Supports were fitted with dump valves to permit leg closures at a rate of 30 mm/s to deal with heavy roof weights besides guaranteed setting valves to setting pressure of 80 per cent of yield pressure (45 MPa).

**INSTRUMENTATION**

To assess the effectiveness of the supports in use called for a major programme of instrumentation using a 32 channel solid
state data logger system (HPACO). The entire package consisted of pressure transducers, convergence transducers, junction boxes, data logger, battery pack, data collection unit, interface unit, computer, plotter and printer. The data logger had 2 Mbyte memory and data were stored in seven files. The required scan rate could be selected from a range of one every 1/100th of a second to one every 2 minutes. A scan rate of 30 seconds was selected in the instant case. Recorded information from the data logger were transferred to the surface daily using a data collection unit (DCU). Data from DCU were transferred to a computer through an interface unit using a software program (RTS). Another software programme (ROD) was used to process the data and to plot them in graphical form or to print out in lists form. Details of the monitoring system have been described by Smart, Gupta and Lindsay (1991). Fig. 3 shows the data logging system set-up.

![Data logging system set-up](image)

**Fig. 3 - Data logging system set-up**

Additionally, leg pressure and convergence were recorded manually by a cycle at three locations along the face with leg pressures recorded for three sets of supports at each location. Frequency of observation was 13 minutes during idle time and 1-3 minutes as the supports were set and also as the shearer approached the support under monitoring till it was reset. Weekend pressure surveys of all the face supports were also conducted to examine the health of non-return valves (NRV), hoses and connections in the leg circuits. Face convergence was measured in each cycle using a graduated telescopic convergence meter between pegs in the roof and the floor. Use was also made of remote indicating convergence indicators in the goaf during the first 60m of face advance to predict onset of falls in the goaf.

**PRESSURE SURVEYS AND CAVING SEQUENCE**

In the first 50 m of face advance from the barrier supports setting pressure varied from 261 to 317 bars. Lid pressure was 461 bars. Unloader valve scan was 35 bars. Increase in leg pressure during shearing cycles was below 21 bars. Face convergence varied from 1.7 to 3.3 mm/m face advance i.e. one to two mm per shear. No roof fall in the goaf was observed during the first 50 m face advance. The rate of convergence in the goaf around the centre of the face varied from 2.8 to 3.1 mm/m face advance.

At 52 m of advance from the barrier, a sudden increase in face and goaf convergence rates three hours before the first roof fall in the goaf was noted. Face and goaf convergence rates increased from 1.7 to 5 mm/m and 2.6 to 6.7 mm/m face advance respectively. Cumulative convergence in the goaf three hours before fall, which covered 2/3rd of face length from the main gate, was 71.3 mm for a face advance of 22.7 m. At this juncture face workers were withdrawn to safety and a medium intensity air blast was experienced. Data logger recorded a rapid increase in rear leg pressures of 74 bars and leg closures of 4 mm during the caving sequence. When the front advanced to 62 m, caving extended all along the full face and a minor intensity air blast was also reported. The third roof fall occurred in the goaf after a face advance of 82 m. A major roof cave extending over the entire face occurred after an increase of 94.5 m and was accompanied by an air blast of high intensity. Face convergence rate increased from 1.7 to 6.30 mm/m advance and leg pressures of several supports increased to bleed level of 422-461 bars. Caving was regular thereafter and overhang in goaf ranged between 4-6 m. The sequence of caving is shown in Fig.4.

**THE MAIN AND PERIODIC WEIGHTS**

After the face had advanced to 116 m the setting pressure had to be reduced to 246-282 bars. As a result face convergence increased and there was increase in leg pressures by 35-134 bars and occasionally pressure in several support legs increased to bleed level. After a face advance of 130.8 m it was noticed that leg pressures in all supports along the face increased by 112 bars during a shearing cycle and reached almost to bleed level. Convergence rate increased from 3.33 to 11.7 mm/m advance. This lasted for about 36 hours. Leg closures recorded were 5-11 mm. When the face advanced to 139.7 m on 18/06/80 there was a sudden loading on the chocks with leg pressures increasing by more.
The face advanced 155 m from the barrier at a suddenly dynamic loading of checkers numbering 27-67 occurred. The leg pressure rose to bleed level of 481 bars from the set pressure of 253 bars. A maximum leg closure of 500 mm was recorded in about 30 S and 106.2 mm in 30 S. There was no increase however, in leg pressures in checkers 1-26 and 68-101. Cavities in the roof were formed and these were up to 2 m in height. Tip to face distance increased from 0.3-0.5 m to 1-1.5 m. A shear crack, about 150 mm wide, appeared in the roof at the face and extended well over 12-15 m in height heading at 75-90 degrees towards goaf. Roof stones rolled down over the AFC and the areas over the shearer and some 15m behind the shearer lowered to such an extent that a gap of only 150-200 mm was left in between. Leg pressures, before, during and after the periodic (dynamic) loading are shown in Fig.6. Face advanced by 15 m during the main and the first periodic weight.

When the face advanced to 198 m, a dynamic weighting occurred which was recorded by the data logger between 00.41 50 h and 00.42 20 h on 02.06.80 when the recording went off scale. The weighting was extremely severe destroying completely the integrity of checkers numbering 46 to 86 in less than 30 S. The maximum leg pressure recorded was 810 bars just before bursting of the main hydraulic seal and blowing of outer cylinder caps. The damage included bending...
of leg minor stages, shearing of leg attachment bolts and hewing of the front bridge. Canopies of supports 49-55 opposite the shearer were trapped against the top of shearer body. Forces generated due to weighting were transmitted through the shearer body to damage the under frame and AFC pons. The data logger recorded a leg closure exceeding 467 mm in less than 30 s (support 69). The event, as analysis showed, occurred towards the end of the scan interval and a total leg closure of 1000 mm was recorded in less than one hour. After the collapse, dislodged coal and sandstone from the face side filled the AFC unto canopy level, almost simulating a 'coal burst'. The top coal adjacent to the roof was almost crushed to the powdery stage between chocks 52-50. Typical leg pressure and leg closure records before and during the loading are shown in Fig. 7. Note was made that for a few days prior to the weighting the supports setting pressure was around 211 bar (setting/yield ratio of 0.45) and a day earlier increase in leg pressures was 49-91 bars and rate of convergence was 3.33-6-8.87 mm/s advance. Variation in setting and final pressures of supports and roof to floor convergences at various face locations are shown in Fig. 8.

POST COLLAPSE INVESTIGATION AND ANALYSIS

DATA LOGGER RECORDS

Soon after collapse on 02.06.90, the recorded data from data logger were transferred to surface and analysed on lap top computer. The scan rate of data recording was 30 s. The weighting was recorded towards the end of scan interval from 1 to 12th channel (i.e. chock nos 70,69,68,50 and 49) was only available. The maximum leg pressure recorded was 811 bars in the rear leg of chock 50. The increase in leg pressure was 348 bars in less than 30 s. Leg closure in chock 49 front legs was 467 mm in less than 30 s. A total leg closure of 1500 mm was recorded in less than one hour. Maximum leg closure rates as recorded by data logger during weightings were listed in Table 1.

The chock's bleed and dump valves were capable of allowing leg closures at a rate of 30 mm/s. As a result supports could withstand severe but controlled loading on the first two occasions (16.05.90 and 22.05.90). However, on 2.06.80 supports bleed valves failed to discharge full fluid at the rates legs were closed by the ultra rapid and excessive loading by the superincumbent strata. A back analysis indicated that the weighting lasted only for about 3.6 seconds. During salvaging of face equipment a part of the collapsed face was further advanced by removing the fallen and crushed coal. It was noticed that roof up to 2 m ahead of last face line was completely fractured. The length of poorly supported roof beam in front of front legs was at least 4.5 m which caused excessive damage and bending of front leg cylinders as compared to rear legs. Support canopies also tilted more towards face. A prominent sheer fracture in the roof at a distance of one metre from the face line was developed all along the face.

SUPPORT PERFORMANCE

Setting Pressure: Consequent upon problems with poor pack and poor quality emulsion
Fig. 7 - Typical leg pressure and closure records of data logger prior and during dynamic loading of 02.06.90

Table 1: Leg closure rates during major weighting periods

<table>
<thead>
<tr>
<th>Time before weighting (min)</th>
<th>60</th>
<th>30</th>
<th>10</th>
<th>5</th>
<th>3</th>
<th>1</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) On 16.05.90—First/Main weighting</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.006</td>
<td>0.000</td>
<td>0.15</td>
<td>0.627</td>
</tr>
<tr>
<td>(b) On 22.06.90—Frist periodic weighting</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
<td>0.010</td>
<td>0.104</td>
<td>0.130</td>
<td>3.56</td>
</tr>
<tr>
<td>(c) On 02.06.90—Second periodic weighting</td>
<td>0.002</td>
<td>0.007</td>
<td>0.003</td>
<td>0.133</td>
<td>0.133</td>
<td>0.633</td>
<td>15.57</td>
</tr>
</tbody>
</table>

11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.
Fig. 8 - Variation of setting and final leg pressures and convergence at various face positions

cell the setting pressure of supports was below 217 bars (69% of yield pressure) for most of the time. For a week before collapse the setting pressures varied from 45 to 64% of yield pressures. On some occasions the setting pressure was as low as 142 bars (31% of yield pressure and 0.31 MN/m² support density).

Based on data for difficult caving roof to easy caving roof following empirical relationship between convergence and setting load densities (before cut) can be suggested:

\[ C = K \times \exp(-4.59 \times \text{MSLD}) \]

where,

\[ C = \text{convergence rates between roof and floor at the face (excluding 15-25 m of gate end zones) in mm/m face advance.} \]

\[ \text{MSLD = mean setting load density of supports (of about 5 supports on either side of convergence station) in MN/m}^2 \]

\[ K = \text{a constant which varies from 40 to 150 (40 for difficult caving roof with overhangs and 150 for easy caving roof with no overhangs).} \]

Using equation 1 it was estimated that for church caving roof face convergence rates at different setting load densities would be as per Table 2.

It was observed that whenever face convergence rates exceeded 6-8 mm/m face advance the roof over canopies was invariably fractured and caving extended to rear of supports. It was, therefore, concluded that to maintain the integrity of roof over canopies it is essential that face convergence is not allowed to exceed 3 mm/m face advance. This was possible only when supports were set at setting/yield ratio of more than 0.85 (setting pressure and setting load density of 300 bars and 0.65 MN/m² respectively). Unfortunately, prior to collapse support setting load density was around 0.45 MN/m² for more than a week due to shutdown of high pressure pump circuit for maintenance. Advantages which could be accrued by setting supports at high pressure in some of British longwall faces is reported by Gupta (1982).

Leakages: Week end leg pressure surveys indicated that deficient checks varied from 10 to 20% depending on the availability of spares. This resulted in a reduction of 10-15% of support resistance along the face. Leaking supports also reduced the availability of fluid to other checks by bypassing the fluid to return hose. It was because of this reason that at several occasions positive set valves took up to 30 min to boost leg pressures to desired levels.

Yield and Bleed Valves: It was noticed that several yield valves were bleewing at a pressure of 400-437 bars instead of
Table 2: Estimated and observed face convergence rates at Churra West longwall face.

<table>
<thead>
<tr>
<th>Setting load density (MN/m²)</th>
<th>0.75</th>
<th>0.65</th>
<th>0.55</th>
<th>0.45</th>
<th>0.35</th>
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<tbody>
<tr>
<td>Estimated convergence rate</td>
<td>1.0</td>
<td>1.8</td>
<td>3.0</td>
<td>4.8</td>
<td>7.8</td>
</tr>
<tr>
<td>(mm/m advance) (assuming K=40)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed convergence rate</td>
<td>1.7</td>
<td>3.3</td>
<td>3.3-5.7</td>
<td>5.0-11.7</td>
<td>23.00</td>
</tr>
<tr>
<td>(mm/m advance)</td>
<td></td>
<td></td>
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<td>(Averages 5.1)</td>
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their designed bleed pressure of 461 bars, especially during periods of weighting. Thus, support yield valves had load shedding of the order of 5-7.

Support Type and Characteristics: The face at Churra was equipped with 4/680 tonne double telescopic type shock shields operated on the immediate forward support (IPS) mode. These supports were provided with rigid canopies 4.145 m long. The distance between the tip of canopy and front legs was 2.545 m, between front and rear legs 1.2 m and between rear legs and goaf edge 0.4 m. The average distance between tip of canopies and coal face was 0.4-0.6 m before cut and 1.1-1.2 m after cut. It was concluded that for Churra roof IPS shock shield was not a suitable type of support from kinematic and crosscutting point of view. The design did not allow uniform loading to the roof from the face to the goaf edge. The resistance offered by the canopy at the face edge after cut was only 2% of the yield load whereas at the goaf edge it was 79%. In addition, IPS supports had approximately 25% greater canopy area as compared to conventional supports.

Strata Borehole Logging over caved Goaf:

After the face collapse three boreholes were drilled by the mine management and CMRDIL(1990) over the caved goaf to determine if the dolerite sill had fractured and also to estimate the location of fractures/cavities, if any, in the interbedded strata. The three boreholes RD1 to RD3 were cored near the mid face perpendicular to the face line at a distance of 35.40 and 90 m respectively over the caved goaf. The depths to which holes could be drilled were 217, 206 and 135 m respectively, Boreholes RD1 and RD2 were logged using the methods of Natural Gamma, Neutron and Density. Borehole RD-3 could not be logged as the drill rods jammed after drilling upto 156.2m and these could not be recovered. Subsequently, boreholes RD-1 and RD-2 were logged using a borehole TV Camera. Result and interpretation of logging are tabulated in Table 3 and also illustrated in Fig.9.

No surface subsidence was observed after the face collapse. However, drilling, geophysical and borehole TV camera logging of boreholes RD-1 and RD-2 established that the lower 10-30 m of sill had broken

<table>
<thead>
<tr>
<th>Deformation Zone</th>
<th>Dolerite Sill</th>
<th>Depth (m)</th>
<th>Water loss</th>
<th>Water loss and</th>
<th>Water loss and</th>
<th>Water loss and</th>
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Table 3 - Post collapse borehole logging results and interpretation of data

<table>
<thead>
<tr>
<th>Deformation Zone</th>
<th>Dolerite Sill</th>
<th>Depth (m)</th>
<th>Water loss</th>
<th>Water loss and</th>
<th>Water loss and</th>
<th>Water loss and</th>
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11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.
or the coal seams had opened. No cavity at the parting plane of sandstone and silt was observed. Thin bands of shale were deteced at 51-57 m above the seam. Fig. 9 shows the horizons where low RQD was observed in particular at 20 and 39-45 m over the seam. Horizons with complete loss of water (50m above seam in RD 1 and 100.5m in RD 2) indicated the extent to which interburden strata had broken and moved. In RD 2 boreholes a cavity of 0.75 m in sandstone was recorded on the TV cassette at 80 m above the seam. Cores of RD 1 borehole were tested by CMDBHL (1991) for their physicomechanical properties which are summarised in Table 4.

CONCLUSIONS

The following are the main conclusions based on the analysis of data from face monitoring programme and post-collapse investigations:

(i) Post-collapse borehole logging details showing possible caving line and water loss

(ii) Face supports should be set at a setting/yield pressure ratio of 0.6. AFC starter should be interlocked with the feedline pressure so that in the event of pressure drop below set value the AFC will not start.

(iii) Face supports 94 m from the main gate and 20 m from the tailgate in the 150m long face experienced a load which was approximately three times their designed yield capacity and therefore they collapsed.

(iv) The velocity of lowering of the immediate roof on 2.06.90 was in excess of 120-150 mm/s whereas the designed yield rate of legs was 30 mm/s. The yield valves could not discharge sufficient volume of fluid to ensure hydraulic locking. In consequence, leg pressures rose to around 1338 bars resulting in bursting of oil seals, blowing off sockets and bending of legs.

(v) The damaging effects of dynamic loading on supports could probably have been minimised by fitting rapid yield valves in all legs of more than 500 mm/s yield capacity.

(vi) The parting between the seam roof and dolomite silt was less than 4-5 times the caving height of immediate roof and longwalling at Churchs West was not advisable as per Salamon et al (1972).

(vii) Some 19-20 m of dolomite silt from the bottom appeared to have cracked fractured.

(viii) Significant strata movement took place up to 61 m above seam at a distance 15 m in the goaf from the face line indicating a bulking factor of caved goaf of around 1.05-1.10.
ACKNOWLEDGEMENTS

The study described herein was made possible materially by the British DDA. The authors wish to express their thanks to Prof. E.G.D. Smart of Heriot-Watt University, Edinburgh for initiating the project, installing the data logger and helpful discussions.

Assistance of Mr. K. G. G. B. and Mr. D. B. G. B. and Mr. P. K. Mandal, Research Assistants, DSM is also gratefully acknowledged.

Sincere thanks are due to the management of Churcha West Colliery and CMPDIL for help and cooperation.

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