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Strata behaviour of a wide and deep longwall panel under massive sandstone bed – a case study

Longwall technology is one of the principal underground coal mining methods widely used around the globe which is not fully emerged in India. However, since the introduction of first self-advancing powered roof supports, there has been mixed experience of longwall technology. History of failure of some longwall panels desponded the success stories of others. Majority of longwall downtimes and/or failure had been attributed due to poor cavability of roof, inadequate capacity of supports, lack of knowledge on longwall caving mechanisms, less than adequate strata monitoring systems, etc.

Strata around coal seams in India are dominated by competent beds, which do not normally cave in immediately after face advance, rather it remains in hanging condition for certain length and break into large discrete blocks. This type of caving mechanics is irregular and complex. Fracturing of competent bed in the immediate roof zone is certain to manifest itself on face as heavy load on supports, bleeding of hydraulic legs of supports, aggressive face spall and guttering in gate roads and in worst conditions longwall face stoppage and sometimes even structural failure of supports as the severity may be.

This paper presents a case study of strata behavioural experiences gained while extracting a deep and wide longwall panel overlain by 3.0 to 3.5m coal roof as immediate roof and 20 to 28m thick competent sandstone bed as main roof with high capacity longwall equipment. While extracting the panel the precise strata monitoring and trigger action response plans are prepared and implemented successfully for negotiating all the strata control hindrances.

Keywords: *Longwall, strata control, main roof, weighting.*

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1.0. Introduction

Historically, longwall mining in India started in 1874 [Sarkar, 1998]. But development of longwall technology in Indian coal industry has been slow with lack of continuity. Until 1960, longwall panels were extracted in connection with sand stowing and thereafter longwall with caving was started. During 80s of the last century, about 35 to 40 longwall faces were in operation in combination with hydraulic and friction props. The first fully mechanised longwall face was introduced in India in 1978 in Moonidih colliery, BCCL, Coal India limited (CIL) [Sarkar, 1998]. Subsequently 33 longwall faces, which include 10 longwall packages in Singareni Collieries Company Limited (SCCL) and 22 longwall packages in CIL mines were introduced with overseas collaboration, but unfortunately at present only three longwall faces are operating in India. One of the main contributory factors for this down trend is, insufficiency of scientific research for the selection of rated powered supports for the strata, which can resist the severity of main and periodic weightings preventing strata failure in and around longwall panels.

Weightings occur due to delayed periodic caving of certain length of overhang or the periodic weighting interval of the cantilever competent or strong bed, occurring behind the longwall face supports [Sarkar and Singh, 1985; Trueman et al., 2011]. For thin units, the length of overhang of cantilever roof is short and for thick units, this length is long [Verma and Deb, 2006]. Intensity of periodic weightings is influenced by the face width and thickness of the competent beds [Firth, 1996; 2005; Manoj et al., 2011]. One of the serious potential consequences of periodic weighting is formation of cavities ahead of supports, iron bound event or solidification of powered roof supports and face bursts [Sarkar and Singh, 1985; Frith and Stewart, 1994; Verma and Deb, 2006].

In longwall panels of wider face width, many periodic weightings are observed with shorter length of overhang of increased severity, number of supports in yield pressure and roof degradation [Truman et al., 2010]. Periodic weighting interval under sandstone bed can be equal to thickness of the bed and can be up to half of its thickness [Medhurst,

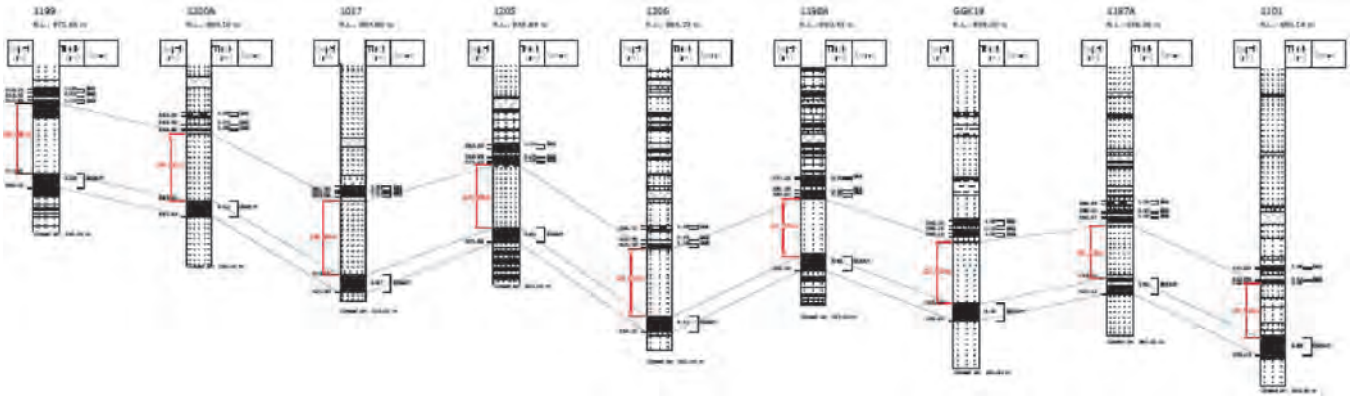


Fig.1 Borehole log traces showing sandstone thickness variation over LWP1 (right to left showing face start to face stop line)

2006]. During periodic weightings, the rate of change in pressure, the number of supports in yield pressure in a load cycle and load on supports increase with the increase in the thickness of the main roof. When the thickness of main roof is more than 20m under a certain geological and geotechnical conditions, the change from low to high intensity of weightings is observed [Truman et al., 2011].

Among the three operating longwall faces in India, the wider and longer operating longwall is Adriyala longwall project (ALP) by SCCL in the Ramagundam coal belt of Godavari Valley Coalfields (GVCF), Telangana state. There are four workable seams in the mine with little geological disturbance. Extractable reserves in the project area are 78.597 Mte. The rated production from the project is 2.817Mte per annum and has a planned life of 35 years. The mine is accessed by four punch entries from the adjacent opencast highwall and one return air shaft of 7.5m diameter sunk up to 484m depth from the surface. The longwall equipment consists of EL3000 shearer with 2245kW installed capacity, armoured face conveyor (AFC) with installed capacity of 2565kW, beam stage loader (BSL) of 400kW, 146 shields of capacity 2×1150t and 1.75m width, two 4.5MVA, 11kV/3.3kV transformers and 1600mm wide three kilometres long gate belt with 3×315 kW drives. The width and length of the longwall panel 1(LWP1) are 250m and 2.31km respectively at a depth ranging from 362m to 450m. The first panel is successfully completed and second panel is under extraction.

This paper highlights the strata behaviour of the longwall panel, while extracting the first panel. Efforts have been made to analyse the caving behaviour of the main roof and behaviour of face supports during main and periodic weightings.

2.0. Geological and geotechnical details of Adriyala longwall project

Geological observations from 95 exploratory boreholes were studied. A significant number of boreholes were cored, providing detailed description on rock types and geotechnical parameters. Additionally, six boreholes were drilled over LWP1 to generate digital wireline log data. The wireline logging data allowed detailed geophysical analysis of the coal seam, overburden and was also used to improve the detailed interpretation and its characterization.

Longwall extraction is done in the bottom section of 6.5 to 7.0m thick Seam I, leaving 3.0 to 3.5m coal in roof. The coal roof is weak and friable with the bands of shaly coal and two distinct clay bands with an overall rock mass rating of 41.4. After a thorough examination of the boreholes data, it is noticed that the seam I is overlain by a massive unit of sandstone of varying thickness remarkably varied from 18 to 28m thickness. The borehole log traces showing sandstone thickness variation over LWP1 are shown in Fig.1.

The caving behaviour of different beds of overlying roof depends on the thickness, strength and massiveness of the bed. The following empirical relationship expresses the relation between caving index no. 'I' with different factors [Sarkar and Singh, 1985]. Later this was followed across India and approved by Central Institute of Mining & Fuel Research, India (CIMFR) as reliable in Indian geo-mining conditions.

$$I = \frac{\sigma_c L^n t^{0.5}}{5}$$

Where σ_c = Compressive Strength, kg/cm^2

L = Average length of core, cm

t = Thickness of bed, m

n = Constant depending upon the RQD of the bed.

The roof classification based on the caving index number is given in the Table 1. The caving index numbers of the overlying strata is shown in histogram (Fig.2).

In addition to above factors, the caving mechanism in sedimentary deposits is also controlled by the dominant planes of weak parting layers in the strata, separated by major planes of parting [Singh et al., 2004]. In between beds, there are laminated layers consisting of shale/clay/coal/ carbonaceous clay and having caving index number less than half the caving index number of strong unit within ten times the extraction height is identified as parting planes [Banerjee

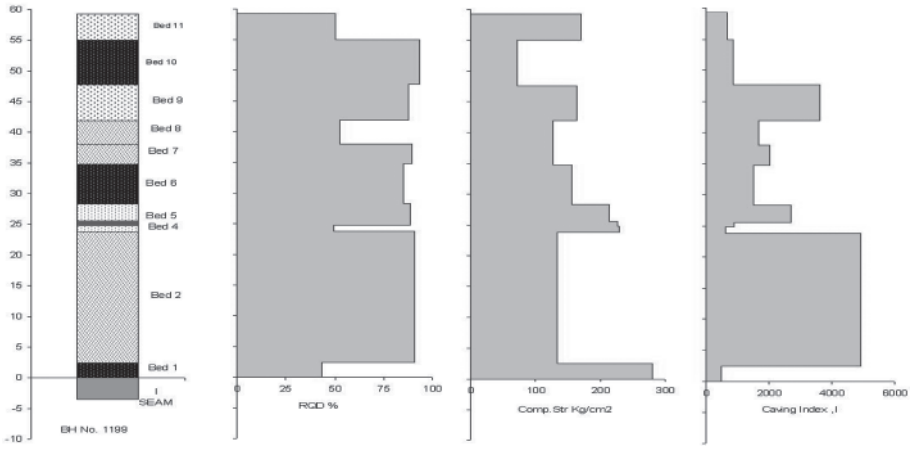


Fig.2. Histogram of PMP and CI for different beds overlying Seam I as per borehole 1199

TABLE 1

Category	Nature of caving	Rage of cavability index	Main fall span, S_m, m
Category-I	Easily cavable	I < 2000	S_m < 35
Category-II	Moderately cavable	2000<I<5000	35<S_m<55
Category-III	Cavable with difficulty	5000<I<10000	55<S_m<80
Category-IV	Cavable with substantial difficulty	10000<I<14000	80<S_m<95
Category-V	Cavable with extreme difficulty	>14000	S_m > 95

et al., 2016]. After comprehensive examination of number of boreholes, the prominent layers of roof separation are identified as shown in Table 2. These parting planes in roof liable to slip and separate from each other in overlying strata. The first parting plane is identified just above the seam and the second is identified above the sandstone bed, i.e., 21 to 32m above the first parting plane depending on the thickness of the sandstone bed. Second parting plane is due to the presence of Seam IA overlying the sandstone bed as shown in Fig.1.

The maximum caving index (CI) number observed for the overlying sandstone of Seam I is 6326. The caving index for this sandstone unit is high among the other overlying beds in the caving zone of Adriyala block. Based on caving index of the overlying sandstone unit, the roof above Seam No.1 is classified as "Cavable with difficulty" as per the classification of CIMFR, India (Table 1). The rock quality designation (RQD) [Deere at al., 1967] of this sandstone bed is high i.e., more than 90 and comprising mostly medium to coarse grained sand stone with an average uniaxial compressive strength (UCS) and tensile strength of the sandstone is 13MPa and 1.25MPa respectively. Histogram of physico-mechanical properties (PMP) and caving index (CI) for different beds overlying Seam I as per borehole No.1199 is as shown in Fig.2.

After reviewing and evaluating PMP and the parting planes of overlying beds of Seam I, the immediate roof in the existing geological and geotechnical conditions is defined as the top section of coal Seam I of 3.0 to 3.5m thick and the sandstone bed overlying Seam I is defined as main roof. The immediate coal roof caves behind the face supports and the sandstone unit hangs as a cantilever beam. Accordingly, it is judged that the overlying sandstone has major influence in caving mechanism and predicted to be the main cause for periodic weightings on supports.

The thickness contours of main roof are generated, by interpolating and extrapolating about 30 boreholes data around LWP1 of ALP, using wire line log data and geological modeling and is as shown in Fig.3.

The thickness of the main roof varied from 18 to 28m over the LWP1. The thickness of the main roof up to 215m from face start line is 25m; from there it is gradually increased and peaked to 28m from 422 to 520m. Between 550 to 1136m, the thickness of main roof, varied from 20 to 26m and from 1160m to the face stop line, it is 18 to 20m.

3.0. Strata behaviour observations of longwall panel

The longwall shield supports are electro-hydraulically operated with CAT PMC-R controls. The hydraulic legs are equipped with pressure sensors, and every second, the signal

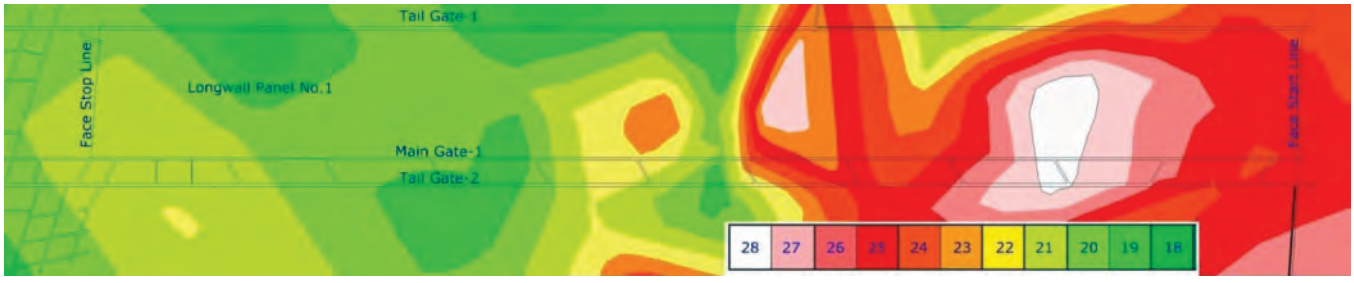


Fig.3 The thickness contours of main roof over LWP1

TABLE 2: VARIATION IN DEPTH OF COVER, SEAM THICKNESS AND LOCATION OF COAL BAND (MAJOR WEAKNESS PLANE) ABOVE SEAM I

Bore hole No.	Location (from face start line, in m)	Depth, in m	Thickness, in m			Parting planes (PP) above extraction horizon, in m	
			Seam	Immediate roof	Sand stone	First	Second (distance of 2nd PP from 1st PP)
1199	87.55	491.3	5.56	2.06	26.5	2.06	28.56
1200A	415 4	77.76	6.12	2.62	25.32	2.62	27.94
1017	444	444	6.86	3.36	28.45	3.36	31.81
1205	730	464	5.82	2.32	24.04	2.32	26.36
1206	758	428	6.1	2.6	26.03	2.6	28.63
1198A	1087	448.53	5.68	2.18	21.75	2.18	23.93
GGK19	1191	429.33	6.4	2.9	23.92	2.9	26.82
1197A	1459	435.24	5.92	2.42	20.13	2.42	22.55
1101	2011	404.94	6.89	3.39	20.92	3.39	24.31

from the pressure sensor is transmitted to the underground computer as well as surface control centre. This leg pressure data is stored in log files and extracted with the help of the software supplied with CAT.

3.1. WEIGHTING DETAILS

Local fall of immediate roof up to 3m height occurred after a retreat of 31.1m. Thereafter immediate roof caves behind the shield supports with little overhang. From thorough shield support monitoring data, weighting was noticed in the longwall face at a retreat of 55m. However, a coupled review of strata monitoring data and physical observations; suggested that 20 shields attained yield pressure in the middle of the face, without any symptoms that can be observed during main weighting. All these observations indicate that there was no collapse of the competent sandstone, i.e., main roof at this point of time.

3.1.1 Main weighting

An extensive and aggressive weighting event was observed at a retreat distance of 83m, followed by observation of breaker line along the face, heavy face spalling, increased loading and yielding of 15 th to 130 th shields, guttering on rise side of main gate 15m ahead of the face and increased goaf water out flow to 946LPM with the breakage of overlying strata. The weighting was released after six loading cycles. From these observations it can be deduced that main weighting is experienced in the longwall face at this location.

3.1.2 Periodic weightings

Two parameters are used in identifying periodic weightings from the raw pressure data (Peng and Chiang, 2006). One is the time weighted average pressure (TWAP), which provides the average pressure in a leg between set and subsequent reset. The other is the 'rate of leg pressure rise' immediately after set, in bar per minute, which is taken to be a surrogate for the amount of strata load being imparted onto the shield support. The higher the rate of leg pressure rise is, the higher is the strata load on the shield support. This is known as dp/dt. The orange trace in the Fig.4 indicates TWAP and Blue Trace represents dp/dt. TWAP of Shield # 76 is shown as brown trace and dp/dt is shown as blue trace in Fig.4.

During the high-loading phase of periodic weighting, the increase in leg pressure after set (dp/dt) is typically 4 to 8 bar/min in a load cycle. During the main and severe periodic weightings, the increase in leg pressure after set (dp/dt) is 8 to14 bar/min in a load cycle. There are high and low of TWAP as face advances. Most of the observed TWAP values are greater than 400bar up to 630m from face start due to weightings imposed by main roof having thickness more than 28m in this zone. The high peaks denote roof weightings that appeared periodically.

Majority of the observed periodic weighting intervals are between 8m and 16m in length as shown in Fig.5. The resultant roof conditions along the face were largely controlled with the use of high-rated and hydraulically robust shield supports pooled with good operational practices. Typical weighting cycle lengths at the in-bye end of the panel were 10 to 15m

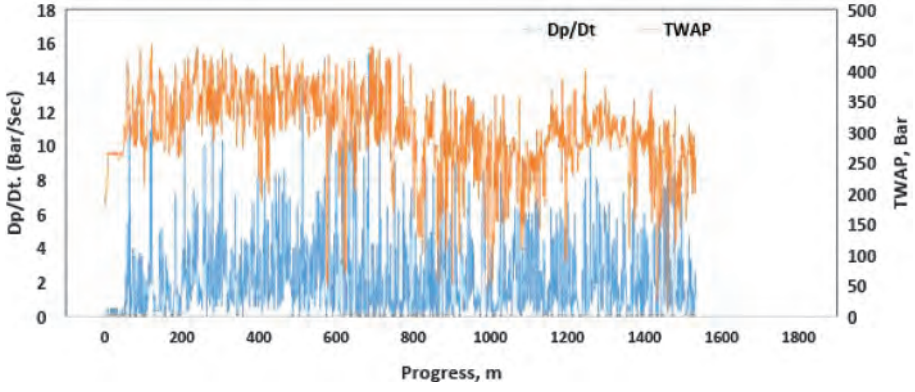


Fig.4 TWAP and yield events (dp/dt) for shield #76

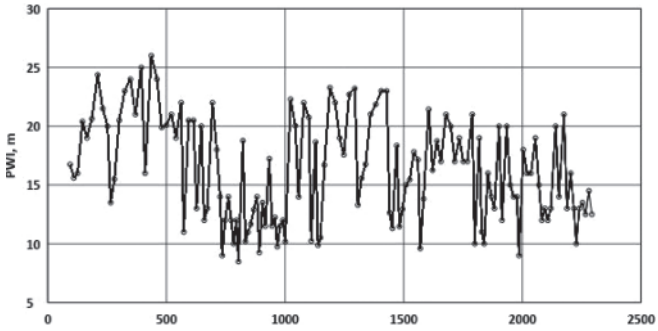


Fig.5 Periodic weighting intervals in LWP1

with localised peaks of 20 to 25m up to 1000m retreat, whereas, at the outby end of the panel the periodic weighting cycle lengths are more consistently between 10 and 20m.

A total of 138 periodic weightings were observed during 2308m retreat of LWP1. All weightings were successfully dealt without the development of any significant strata control problems on the face. The weighting zone was typically from the 30th to 130th shields, covering approximately 70% of the face width. During the high-loading phase of periodic weighting, yielding of about 40% of the shield supports in the weighting zone is observed. Weightings were released after 4 to 6 load cycles. During the failure of main roof, face spalling, bleeding of supports, audible sounds from goaf associated with tensile crack, i.e., breaker line in face/ weighting zone 1.0 to 1.5m ahead of the canopy tip were observed [Sreenivasa Rao et al., 2016].

PWI vs main roof thickness

A graph is plotted between PWI and thickness of main roof along the panel length (centre-line) as shown in Fig.6. The red trace indicates the thickness of main roof, the black markers indicate the PWIs along the panel and the black trace indicates 8 point moving average of the PWIs.

From Fig.6, it is inferred that, PWI varied with the change in the thickness of main roof. Weighting interval increased with the increasing thickness of the main roof because of the increased span of the cantilever beam. PWI ranges from 8 to 29 m. More face spalling and roof disturbances are observed during weightings, where thickness of main roof is more than 23m and however these were dealt effectively.

After back analysis of the data with overlying geology, relation is established between the thickness of main roof and PWI conceptually suitable for the existing geo mining conditions. Based on the unit thickness of main roof and their corresponding PWIs average, a graph is plotted and trend line is fitted using MATLAB is as shown in Fig.7.

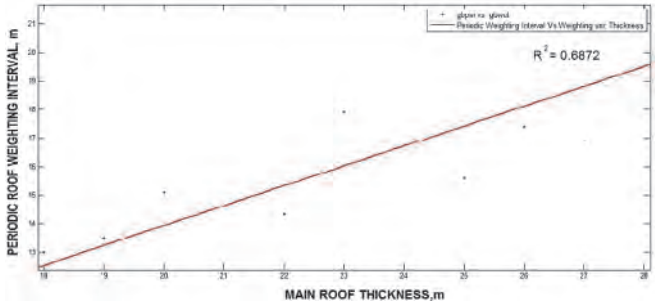


Fig.7 Average of PWIs corresponding to unit thickness of main roof

A relation is established between PWI and thickness of main roof and is as given below

$$PWI = 0.6969 \times tm \quad \text{... (1)}$$

Where,

t_m = Thickness of main roof

From the above Equation (1), it is clear that PWI is approximately 70% of the thickness of main roof. From the Fig.6, the PWIs observed are 17 to 21m for 24 to 28m thick main roof and 13 to 15m for 18 to 23m thick main roof. From this it is obvious that observed PWIs are compatible to results obtained from the above established relation as given Equation (1).

3.2 Mean Load Density

Mean load density (MLD) is the ratio of the total load on supports to area of the supported roof up to rear edge of the canopy. The yield load density of the face supports before and after cut are 120 t/m^2 and 104 t/m^2 respectively. For the purpose of this study, supports along the longwall face are divided into three zones viz; bottom zone on main gate side from shield supports # 1 to 36, middle zone from shield supports # 37 to 110 and top zone on tail gate side from shield supports # 111 to 146. It is observed that the middle zone is associated with more number of weightings. Variation of MLDs in the middle zone with changing thickness of main roof is shown graphically in Fig.8.

In Fig.8, red trace indicates the thickness of main roof (centre line

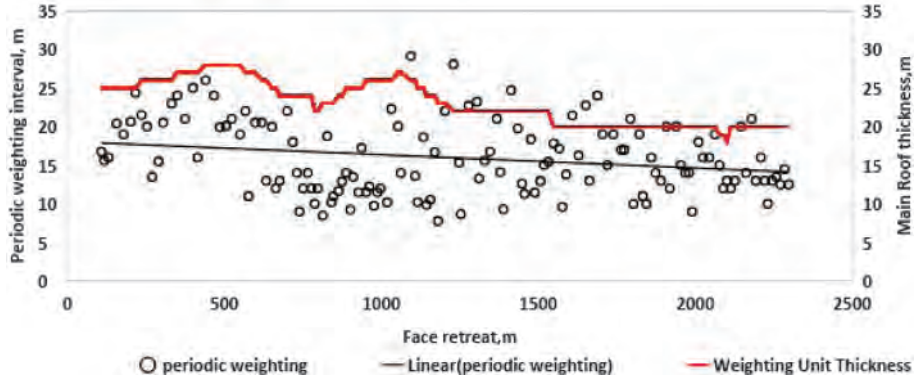


Fig.6 Thickness of main roof Vs PWIs along the panel

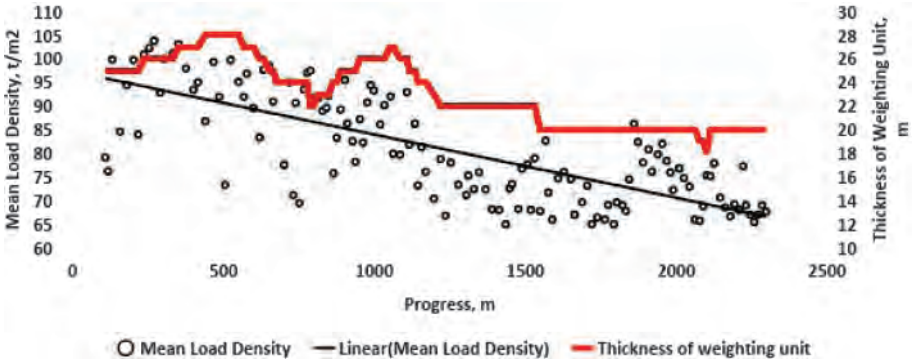


Fig.8 Thickness of main roof vs mean load density along the panel

the face) and the black trace indicates 8 point moving average of the mean load densities of the middle zone during periodic weightings along the panel. MLD of the shield supports range from 65 t/m^2 to 104 t/m^2 in middle zone. The maximum mean load density observed is 97 t/m^2 when the thickness of main roof varied from 18 to 23m and 104 t/m^2 when the thickness of main roof varied from 24 to 28m, which is considerably high. It is apparent that, when the thickness of main roof is greater than 23m, more load is transferred onto the supports resulting in high amount of mean load density. It can also be stated that shield supports are fairly rated for the existing geo mining conditions. The graph between average values of MLDs and respective unit thickness of main roof is plotted in Fig.9, and it is observed that the MLD increased with increase in thickness of main roof.

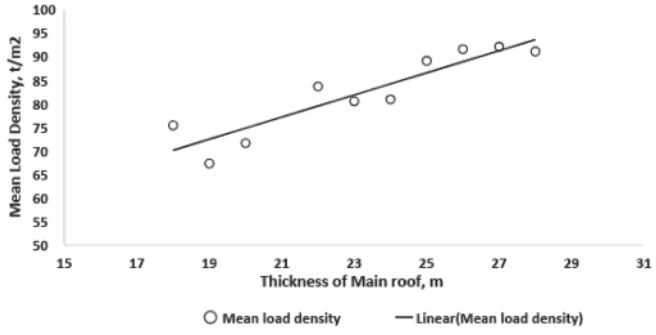


Fig.9 Thickness of main roof vs mean load density along the panel

3.3 Cavities in Longwall Face

Some quantifiable and significant cavities were observed during the extraction of LWP1. Cavities are represented in rectangular boxes, w.r.t., thickness contours of main roof over longwall panel is as shown in Fig.10. The first four cavities occurred up to 1100m retreat, where the thickness of main roof is varied from 24 to 28m. At 520m face retreat, a major cavity prevailing 113m along the face and 7 to 8m above the coal seam is observed, where the thickness of main roof is maximum i.e., 28m. Two minor cavities occurred where the thickness of main roof is 18 to 22m due to face stoppage with longwall equipment breakdowns. These cavities were negotiated within five to six load cycles.

Occurrence of cavities was observed to be more for a 24 to 28m thick main roof. During the failure of thick cantilever block, the sub vertical fractures are developed in the breaking unit and propagated down towards the extraction horizon as the function of the ongoing cantilever block breaking. At that time there is an aggressive face spall, heavy load on supports and significant roof guttering along the face as early warnings of cavity formation. Hence, faster rate of retreat is required at these places to avoid cavities.

4.0 Learnings from strata behavioural observations of LWP1

First longwall panel at Adriyala was successfully completed without major strata control problems; even though there were some problems experienced while adopting the high capacity automated longwall for the first time in India. LWP1 enriched the knowledge and understanding levels of the longwall team regarding strata behaviour of a wide and deep longwall panel; chiefly the safety and operational concerns at the time of intensified weightings due to failure of thick main roof. The learnings include:

- Inclusion of many physico-mechanical properties as well as geotechnical data of the overlying roof rocks, and in particular the thickness of main roof is ought to be investigated in detail during the exploration stage itself

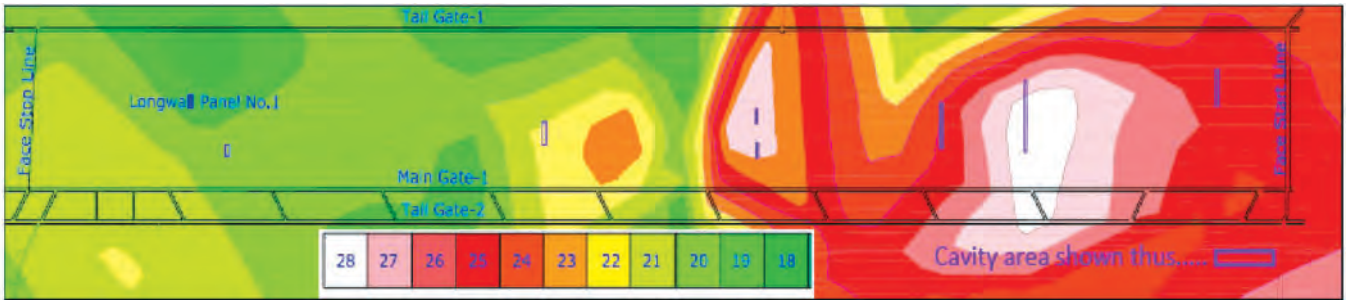


Fig.10 Thickness contours of main roof and roof cavities in LWP1

and mapped in particular.

- During periodic weightings, time weighted average pressure, rate of leg pressure rise, the number of supports in yield pressure in a load cycle and load on supports observed to be increased with the increase in the thickness of the main roof.
- Transition from low level periodic weighting to high level periodic weighting and more load on supports is observed when the thickness of main roof is more than 23m.
- Periodic weighting interval is approximately 70% of the main roof thickness.
- Approximate value of periodic weighting interval and load coming on to supports can also be predicted after mapping of main roof thickness.
- Occurrence of cavities in the longwall face can be minimised, by faster rate of retreat after mapping with main roof.

5.0 Conclusions

Thickness of main roof plays a vital role in strata behaviour of the longwall face. It is very essential to investigate the variation of thickness and strength of main roof above the panel to predict the intensity of weightings and load imparting onto the powered roof supports during the geological studies. The periodic weighting interval is approximately 70% of the thickness of main roof for 250m wide longwall face. That percentage may get increased with decrease in the face width and the influence of the main roof thickness on the gate roads comes under the further scope of study. When thickness of main roof is more than 23m, more strata problems, face spalling, load on supports and occurrence of cavities in the face were observed.

The results from this study provide a basic insight in understanding the main roof based strata behaviour for predicting the periodic weighting intervals, mean load density and occurrence of cavity. This type of monitoring and analysis is not only required for ensuring safety and stability at longwall workings but also provide essential inputs for proper planning and design of safe longwall panel layouts, assessing support requirements and its verification.

Valuable data for geotechnical interpretation and integration is available after exploration, but not often utilized during mine operations to the fullest extent. The identification of parting planes and correlation with physicomechanical properties are to be analysed to find the main roof during the planning stage for selection of adequate supports. The variation in the thickness of main roof need to be mapped with the detailed geotechnical data to avoid mining downtime due to unexpected strata problems in longwall face.

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