

## **Real Time Analysis and Forecasting of Strata Caving Behaviour during Longwall Operations**

By

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### **Summary**

Discontinuous manual observations and irregular caving characteristics of roof rocks often lead to improper decisions resulting in accidents and production loss. Hence, systematic monitoring of the hanging roof behind the chock shields is necessary for safe and productive mining operations. A real-time application was successfully implemented in an Indian mine for forecasting of hanging roof behaviour to enhance safety and productivity. This paper reports the functioning of real-time TWAP (time weighted average pressure) analysis in the forecasting of hanging roof behaviour in real time.

*Keywords:* Real-time system, strata caving, continuous monitoring, time-weighted average pressure analysis, wireless transmissions, tunneling.

### **1. Introduction**

Difficult caving characteristics of overlying strata have been experienced in most of the longwall faces in India. Uncaved span of the roof in the goaf causes excess strata loading on the face supports. This also leads to increase of front abutment pressure. Further increase in the hanging roof behind the supports on a few occasions will lead to dynamic loading on face supports. This situation leads to strata control problems and disturbs the safety and productivity of face operations. Caving of the hanging roof becomes essential to reduce load on supports for safe mining operations (Haramy et al., 1987). The decision to fracturing the hanging roof depends mainly on field data analysis. However, conventional data analysis is not reliable due to the discontinuous nature of manual observations and irregular caving characteristics of the rock mass. Real-time data analysis with time weighted average pressure (TWAP) is shown to be an efficient method. This paper discusses the role of real-time analysis in forecasting adverse strata behaviour.

Hydraulic leg pressures are the result of a continually changing interaction between the supports and the roof strata (Barczak et al., 2002). As such the data can be used to analyse the past and current roof conditions and predict the roof conditions prior to mining. A high-performance real-time system was successfully employed to analyse the performance of the supports on real time for effective and efficient operations (Hanna et al., 2001).

## 2. Detection of Supports Leg Closure and Pressure

Thin-film strain gauge pressure sensors were interfaced to the chock shields test port (Fig. 1) of rear leg circuit. The maximum pressure was 1000 bar with an accuracy of 1% FSD (Full Scale Division). The burst pressure was 2000 bar. The excitation power requirement to pressure sensors was 100 mW. Potentiometric leg closure sensors were interfaced to the chock shields. They were interfaced between the top leg cylinder and canopy of front leg circuit (Fig. 2). The maximum range was 1000 mm at an accuracy of 0.01 mm. The excitation power requirement to closure sensor was 400 mW. The sensors were intrinsically safe and compatible to underground environment.

## 3. Wireless Data Transmissions

The wireless transmitter was installed on the surface. The multipair data cable of the underground sensor was routed through the borehole and interfaced to the wireless transmitter (Fig. 3). This method of implementation avoids the requirement of extra wireless modules. The wireless transmitter is capable of transmitting data at 32 km in license-free frequency bands of 902 to 928 MHz. The rate of data transmission is 114 kbps. One of the wireless data transmission techniques employed was frequency-hopping algorithm. It guarantees reliable transmission irrespective of underground

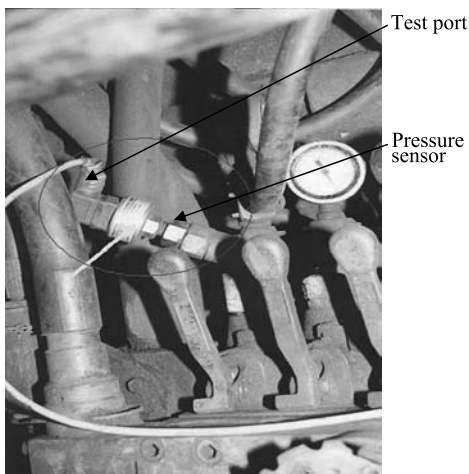


Fig. 1. Pressure sensor



Fig. 2. Leg closure sensor

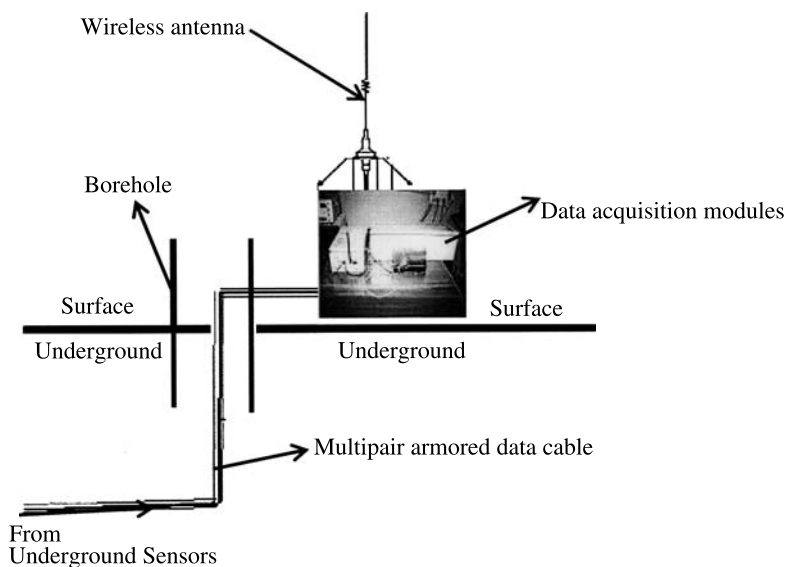


Fig. 3. Wireless data transmitter

noises and also maintains data quality and continuity. As a result, many limitations and disadvantages of the conventional cable transmission can be overcome.

#### 4. Real-Time (RT) System

The RT system was developed on advanced virtual instrumentation environment (Tadisetty et al., 2002), and software plays a significant role in this system. The system is reliable and is economically viable. Its virtual environment enables to accommodate additional geomechanical parameters monitoring as and when required. It was commissioned at GDK (Godavarikhani) 10A longwall mine of the Singareni Collieries Company Limited, Ramagundam, India.

The RT system was interfaced to the wireless receiver and the intelligent dump terminal (Fig. 4) and was commissioned on the surface around 15 km away from the wireless transmitter. Line of sight was maintained for effective data transmission. The system acquired the data from the underground sensors via wireless receiver and displayed on real-time monitor after analysis (Fig. 4).

All the underground sensors were configured on the configuration menu. The data acquisition time selected was one minute. The warning limit selected was 400 bar. The system initiates the in-built warning module whenever hydraulic pressure crosses the threshold limit. The real-time display updates automatically every minute with the latest data on strata and supports. The information helps to take effective decisions during adverse strata behaviour.

The real-time display shows information of underground sensors, and the behaviour of supports (Fig. 4). The sensor information includes type, location, units, calibration and date of installation. The information on chock shields includes setting,

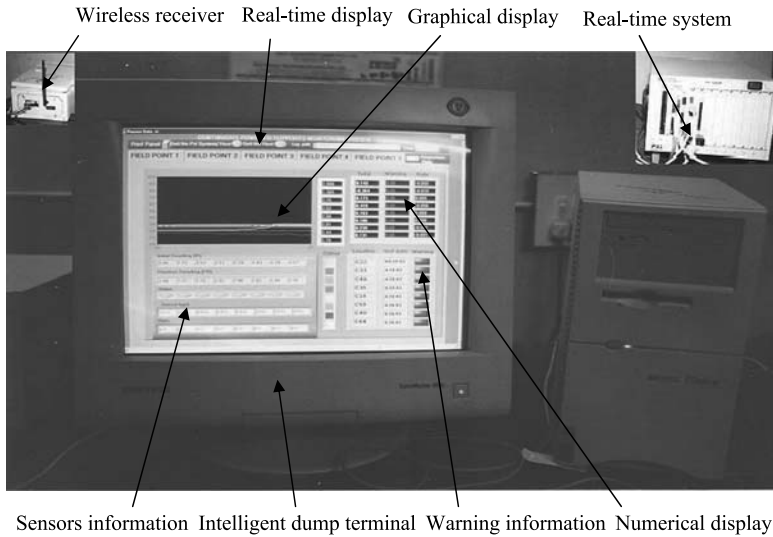


Fig. 4. Real-time system interfaced to wireless receiver and intelligent dump terminal

yield, and supply pressures, hydraulic circuit failures, influence of shearer cutting, influence of adjacent chock shield advancement and dynamic loading (Fig. 4). All the data is displayed in graphical and numerical form for quick observation. Further, the numerical display also indicates the rate of change in parameters. The strata behaviour includes the data on caving of the immediate and main roof.

All the information is updated every minute after detailed analysis. The system promptly initiates in-built warning modules during adverse behaviour of strata and supports to implement necessary precautionary measures for safety and to minimize production loss. The system records the behaviour of chock shields in standard format for easy and quick access.

### 5. Experimental Longwall Panel

Longwall panel No. 4 was prepared in No. 1 seam bottom section leaving the 3 m clay/shale coal in the roof. The depth of the panel was in the range of 120–126 m. The uniaxial compressive strength of the main roof (sandstone) was 13.6 MPa. The overlying strata were water bearing. Longwall retreat was 4–5 m per day. The face retreat was not uniform most of the time due to supports and strata problems. On average, daily production was 2500 t. The panel and face lengths were 950 m and 116 m, respectively. The working height was 3 m. The total seam thickness was 6.40 m with a 0.30 m clay band and an average gradient of 1 in 6 towards N73° E. The strata overlying the coal seam was composed of coarse-to-medium-grained ferruginous sandstone, coarse-grained kaolinised felspathic massive sandstone with clay and gray shale. Figure 5 shows the experimental panel on mine plan.

As per the geological cross-section of borehole No. 637, two (1A and 3B) of the seven seams (1A, 1, 2, 3, 3A, 3B and 4) present within the mine boundaries were

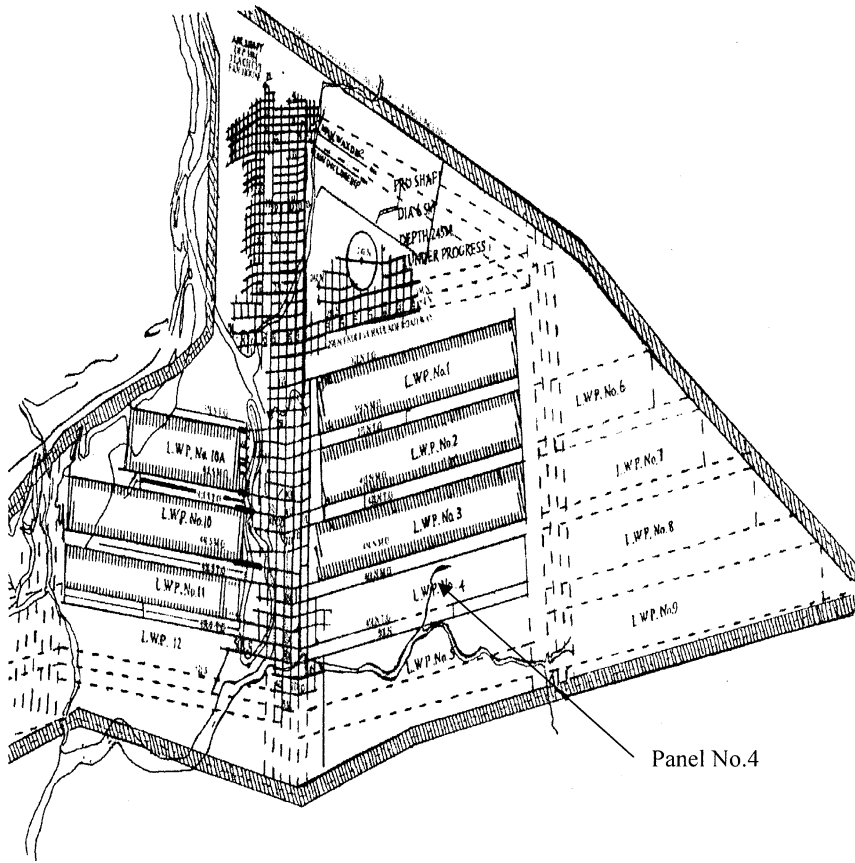
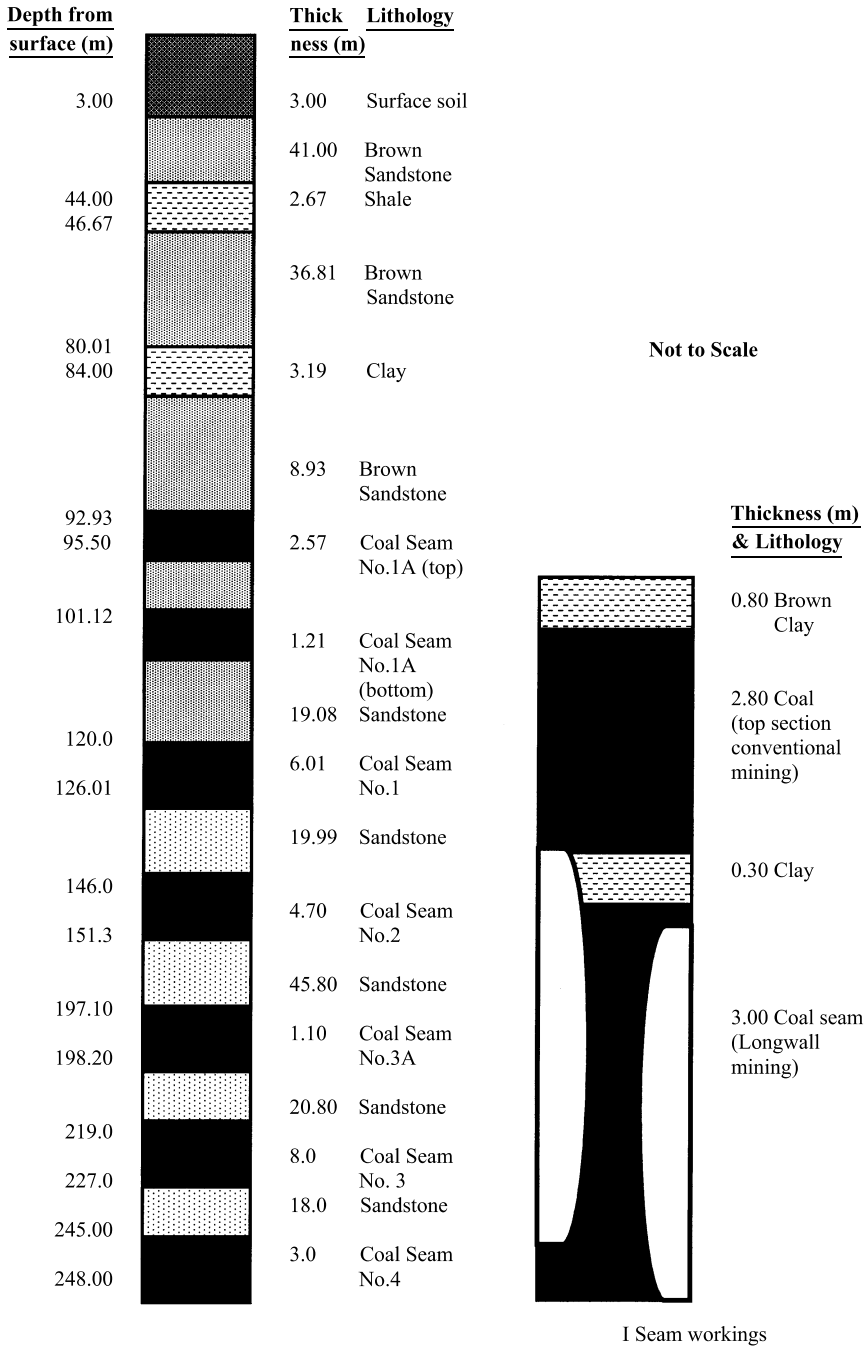


Fig. 5. Experimental mine plan of I seam workings

inconsistent (Fig. 6). Seams 1 and 2 only are considered for extraction at GDK 10A Incline mine. However, No. 1 seam is presently under extraction with longwall technology. Seam Nos 3, 3A and 4 are being worked by GDK 10 Incline mine. The GDK 10A incline mine has two main entries, one of which is a belt road and the other a haulage roadway. Both these tunnels are main intake airways and an air shaft of 6.0 m diameter with an exhaust fan of 300 000 cft/min capacity serves as the main return.

Seam No. 1 is 6–6.5 m thick and is free from major geological disturbances. It has two distinct clay bands (Fig. 6). One is 0.60–0.80 m thick at the top section along sandstone roof. The other, 0.15 to 0.30 m thick, is about 2.8 m below the roof level. Trunk roads were developed along the top section and longwall panels at the bottom section at a working height of 3.3 m. All the gate roads were driven at 1 in 20 with a rising gradient to suit the drainage of water. The grade of the coal was improved by changing the cutting horizon and leaving the clay band in the roof along with 30 cm of coal and extracting the 60 cm coal left on the floor. The working height got reduced from 3.3 m to 3.0 m. Table 1 shows the physico-mechanical properties of roof rocks. The RQD of I seam workings is 84 per cent and tensile strength is 2.35 MPa.



**Fig. 6.** Geological cross-section with rock materials (Borehole lithology of BH.No. 637)

**Table 1.** Rock mass properties. (Physico-mechanical properties of roof rock BH.No. 637-I Seam working)

Depth from surface (m)	Bore hole no.637	Lithology	Thickness (m)	Density (kn/m <sup>3</sup> )	Tensile strength (kpa)	Young's modulus * 10 <sup>5</sup> (kn/m <sup>2</sup> )	Rock quality designation (% RQD)
03.00		Surface soil	03.00	-----	----	-----	-----
		Brown sandstone	41.00	333.03	1561.27	22.56	96
44.00 46.67		Shale	02.67	245.06	3601.13	23.54	79.1
		Brown sandstone	34.14	333.03	1674.05	34.32	42
80.81 84.00		Clay	03.19	347.16	2482.15	40.21	88
		Brown sandstone	8.93	333.03	1561.27	22.56	96
92.93 95.50		Coal	2.57	219.92	2346.81	20.60	84
		Brown sandstone	19.08	333.03	1561.27	22.56	96
120.00 126.01		Coal I Seam	6.01	219.92	2346.81	20.60	84
		Brown sandstone	19.99	333.03	1561.27	22.56	96
146.00 151.30		Coal II Seam	4.60	219.92	2346.81	20.60	84
		Brown sandstone	45.80	333.03	1561.27	22.56	96

## 6. Instrumentation Layout

Longwall panel No. 4 is equipped with 80 chock shields. The capacity of each chock shield is  $4 \times 800$  t IFS (Immediate Forward Support) and each weighs about 20.5 t. The supply pressure is 276 bar and the setting pressure 345 bar. However, the yield pressure is 434 bar. Monitoring of the behaviour of all the chock shields is not required since it is costly and tedious. Therefore, problematic areas of longwall panel were selected based on preliminary investigations. The behaviour of the selected chock shields was continuously monitored and performance evaluated to forecast the status of strata caving behaviour.

Pressure and leg closure sensors were interfaced to the chock shields C18, C22, C30, C35, C40, C45, C48 and C64. Chock shields C30, C35, C40 and C45 were at the centre of the longwall panel, and C18 and C22 were located on the left side and C48 and C64 on the right side of the panel (Fig. 7). All the sensors were interfaced to the wireless data transmitting system through multipair armored data cable (Fig. 7). The wireless transmissions avoided expensive conventional cable which needs regular maintenance.

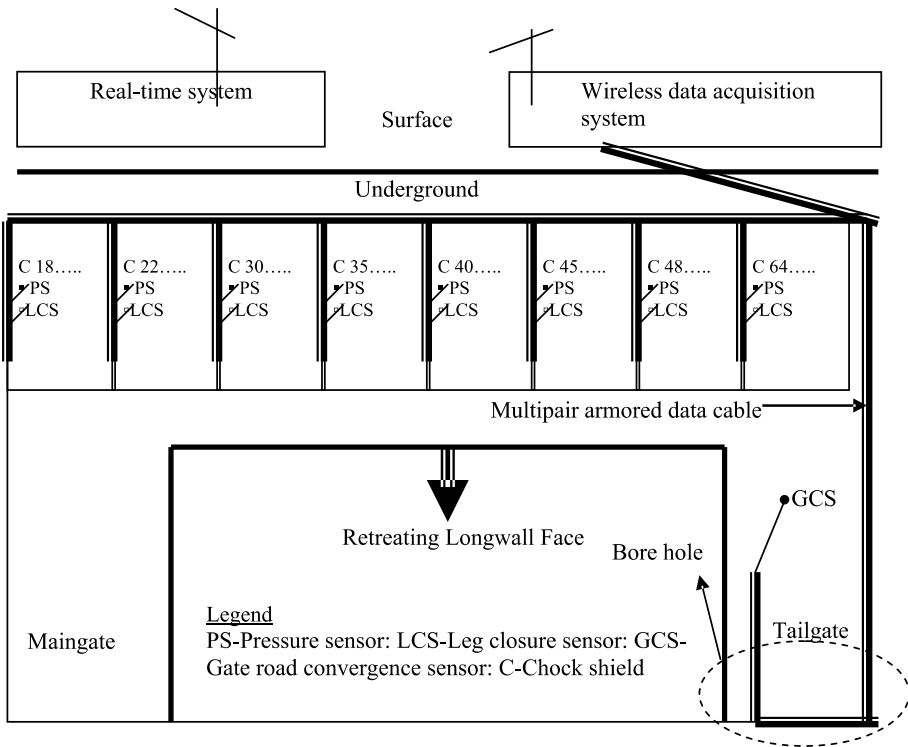


Fig. 7. Instrumentation layout in Experimental Longwall Panel

## 7. Time-weighted Average Pressure Analysis of Field Data

TWAP analysis is one of the significant data analysis for forecasting strata caving behaviour. It indicates the status of the strata caving in real time. The TWAP of each chock shield leg is the area under the pressure-versus-time curve recorded for each working cycle divided by the total cycle time (Fig. 8). The variation in hydraulic pressure results from the force applied to the chock shield through the roof and floor. Initially, the chock shield is set against the roof. As the neighboring chock shields are lowered, advanced, and set, the pressure on the chock shield increases from point 's' to 'a'. The increase in the pressure from point 'a' to 'b' is caused by excess chock shield loading due to mining.

When the shearer is cutting in the immediate vicinity of the chock shield, an increase in pressure from points 'b' to 'c' is noticed. As the adjacent supports are lowered, advanced, and set, there is a significant pressure increase in the cycle from point 'c' to 'd'. Finally, the chock shield is lowered so it can be advanced, dropping of the pressure from point 'd' to 'e'. Every chock shield cycle varies owing to the interaction among the roof, floor, and chock shield, the location of the chock shield with respect to face location, setting pressure and changes in hydraulic pump pressure (Haramy et al., 1987).

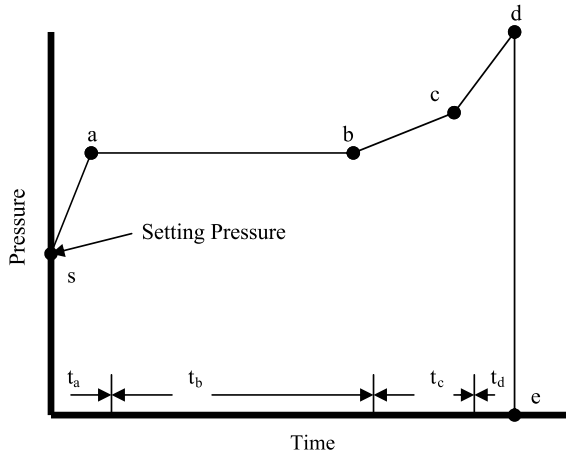


Fig. 8. A typical pressure time curve

The TWAP is calculated for each chock shield leg using the following equation

$$\text{TWAP} = \left\{ \left[ \frac{1}{2}(P_a + P_s)t_a + \frac{1}{2}(P_b + P_a)t_b + \frac{1}{2}(P_c + P_b)t_c + \frac{1}{2}(P_d + P_c)t_d \right] \right\} / [t_a + t_b + t_c + t_d].$$

$P_a$ ,  $P_b$ ,  $P_c$ , and  $P_d$  in Fig. 8 are the pressures at points a, b, c, and d, respectively;  $P_s$  is the chock shield setting pressure; and  $t_a$ ,  $t_b$ ,  $t_c$ , and  $t_d$ , respectively, are the times at points a, b, c, and d.

The analysis of the field data shows that when the roof readily caves, the face is not overstressed and no major face spalling occurs. On the other hand, as the roof hangs as a cantilever beam behind the chock shields, the weight of the beam is transferred on to the coal face and face spalling conditions are noticed. The exact cantilever length that causes the high stress conditions is not easy to determine. However, TWAP analysis forecasts the behaviour of cantilevered roof.

The TWAP analysis reveals a pattern of periodic loading, with pressure peaks of different intensities occurring at different intervals. The pattern is indicative of the caving behaviour of the roof layers. The TWAP analysis was automatically executed in real time, and hence, it is called the real-time TWAP or TWAP analysis. The stratum caving was evaluated based on TWAP analysis during 100–325 m and 400–625 m (middle of the panel) of face retreat (Figs. 9–10). The strata movements are more in the centre of the panel. Hence, the chock shields C35, C40, C45 and C48 were located at the centre of the face (Fig. 7). The strata caving behaviour was forecast as per the TWAP analysis. The pressure peaks of different magnitude are attributes of immediate and main roof caving.

The small and big pressure peaks indicate the caving of immediate (periodic falls) and main roof (strata caving), respectively (Figs. 9a,b). The behaviour of two chock shields is almost the same because of similar nature geomechanical conditions. Periodic falls occurred at 115, 130, 140, 165, 180, 215, 230, 240, 260, and 280 m, and the

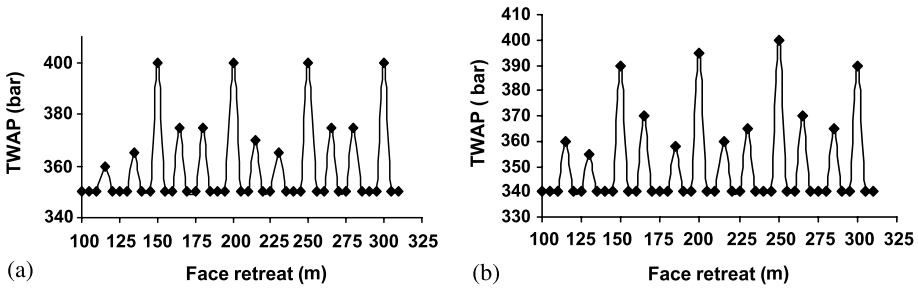


Fig. 9. TWAP analysis of (a) C45 and (b) of C48 during face retreat of 100–325 m

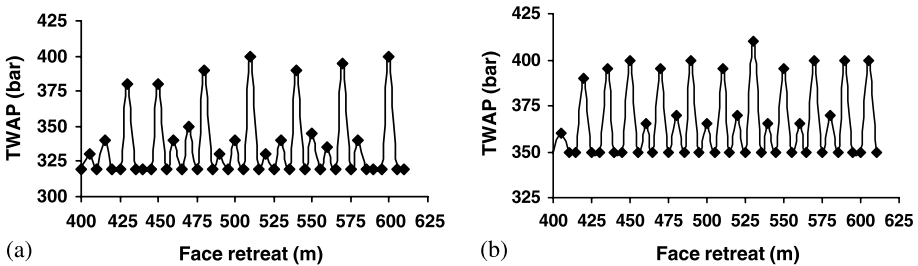


Fig. 10. TWAP analysis of (a) C35 and (b) of C45 during face retreat of 400–625 m

main roof caved at 150, 200, 250 and 300 m of face retreat (Fig. 9a). The main roof caved in after every three periodic falls and at an interval of 50 m. In the second case, the caving of immediate and main roof was at 115, 130, 165, 180, 215, 230, 265, 280 and 150, 200, 250, 300 m, respectively (Fig. 9b) as per the C48 behaviour. The main stratum caved in after every two periodic falls (Fig. 9b), and at a regular interval of 50 m. The interval of the main strata caving was the same in both the cases. However, the difference in the interval of periodic falls is because of non-uniform face operations.

The immediate and main roof caved in at 405, 415, 460, 470, 490, 500, 520, 530, 550, 560, 580 and 430, 450, 480, 510, 540, 570, 600 m respectively as per C35 behaviour (Fig. 10a). The main roof caved in almost after every two periodic falls. The stratum caving was regular at an interval of 30 m. In the second case, the immediate and the main roof caved in at 405, 460, 480, 500, 520, 535, 560, 580 and 410, 430, 450, 470, 490, 510, 530, 550, 570, 590, 610 m, respectively, as per the C45 behaviour (Fig. 10b). The main stratum caving was regular at an interval of 20 m. The main and immediate roof strata caving intervals were not the same in the two cases because the face operations were in the centre of the panel (400–625 m) and were non-uniform.

As per the TWAP analysis the caving of main and immediate roof was irregular, particularly during the centre of the panel extraction i.e. 400–625 m. Therefore, the strata movements were more active. Subsequently, the TWAP analysis played a dominant role in forecasting of strata caving behaviour. As a result, the RT system successfully forecast the caving behaviour of the roof strata in real time. Furthermore, the stratum caving was confirmed by manual methods and the implementation of an expensive induced blasting for fracturing of hanging roof strata beyond the chock

shields was stopped. The longwall operations were continuous, and the productivity and safety of operations improved.

## 8. Conclusions

Wireless real-time operations helped in achieving data quality and continuity. The strata caving behaviour was successfully forecast as per the TWAP analysis in real time. The operation of the expensive induced fracturing of hanging roof strata currently in place which also interrupts production was discontinued. Subsequently, with the implementation of the real-time TWAP analysis the longwall operations were continued, enhancing productivity and safety.

Further, real-time TWAP analysis of strata caving is necessary for working under difficult (hard) roof caving characteristics. The strata caving characteristics play a dominant role in determining the support capacity. As a result, effective roof control will be achieved. In addition, the RT system instills confidence in the underground worker improving efficiency, productivity and safety.

Wireless real-time technology can be effectively utilized in developing underground mine robots (robomining) to improve safety of mining operations. The system can also find application in civil and military operations like tunneling with suitable modification in sensors. Disasters like the recent French tunnel tragedy can probably be avoided with systems like this in place.

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The views expressed in this paper are those of the authors and not necessarily of the organization they represent.

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