Optimizing Fibre Optics for Coal Mine Automation

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Abstract

Powered support systems are considered to be backbone of the longwall mining system. A significant development in underground longwall coal mining automation has been achieved with the successful implementation of fiber optics cable for leg pressure monitoring and performance analysis of shield supports. This paper illustrates the development of a continuous monitoring system of roof pressure and support closure with progressive face advance in longwall workings. A case study of a longwall working is illustrated to assess the effectiveness of the monitoring system in assessing the support performance for safer and smooth operation of roof supports in these workings under different geo-mining conditions.

Keywords: *Longwall, Fiber optical cable, Powered Support, Mine Automation.*

1. Introduction

The design and planning of underground mine is aimed at creating an integrated mine system whereby minerals are extracted and processed for a dedicated market at minimum operable cost. Mining system requires an inter-disciplinary engineering structure and coordination for its operation [1]. This complex array of subsystem includes mining safety as well. It is beyond doubt that the underground mines present one of the most difficult, tough and challenging environment to work for human beings. Although safety is considered as one of the key issues, limitations in feasible technological solution, cost, and the very nature of underground mine has restricted the genesis of a unified mechanism to ensure full-proof safety for the miners in any field is very important for proper and fast completion of the project.

With the above view, a thorough investigation is required for better understanding of the geo-mechanical behavior of strata and support performance during operation of a longwall face, so as to minimise face stoppages and production delays to ensure better productivity and safe work environment for men and machineries. This requires a proper strata monitoring exercise to be conducted in such workings using state-of-the-art instrumentation adopting a suitable scheme to address all the issues related to strata and support behavior.

Support pressure and face convergence are the two crucial parameters for quantifying the strata behavior and the support performance in a given geo-mining condition. The compilation of the field data shows that observations are taken manually usually once in a day or a shift [2]. Moreover, these are neither systematic not regular. Manual observation at a moving face is not possible at higher frequency for a meaningful utilization and reference of such field data. The period of critical face loading or strata convergence is static in most of the cases, but it is very small to be recorded in any manual observation.

Under such condition, it is desirable to have an intensive support pressure monitoring program using electronic gadget based modern continuous monitoring systems to enable more meaningful monitoring and storage of data at requisite time intervals. Implementation of miniaturized integrated circuits, suitable design of safe power supply systems and microelectronics for data storage and transfer may be helpful in development of cost effective continuous monitoring systems.

Present Communication system for underground mines can be hard wired or wireless. Both types of system can fail when faced with fires, roof fall, explosion and power failure. The previous system was based on the Wi-Fi system, which used to fail at the time of disaster due to unavailability of the suitable frequency range. Another communication system is made of radio signals which require a clear line of sight or open air which fails by making pillars in the underground mine workings.

Optical fibre is considered intrinsically safe, provided the light energy transmitted down the fibre is at or below a certain power level. They are unaffected by noise, lightning, interference from RF, EMF, EMI and Harmonics from the VFD drives common in mining. The use of fiber optics for reliable communications to monitor, analyze and control the equipment and facilities during the mining process will increase safety and production efficiency. Fiber optic communication are uniquely suited to connect real time data from environmental and equipment sensors to ensure peak production while maintaining the highest safety standards. The optical fibre cables will need to be suitably armored so they remain operational under the following conditions: routine underground vehicular traffic; underground roof collapse; underground water inundation; and pressure waves resulting from underground explosions. Burying the cable together with crusher dust at a depth of 0.6 m should afford adequate protection against fire, crushing during machine operations & roof failure [3].

The geotechnical literature has included several applications of fibre optics in underground coal mines viz. fiber optic surveillance of the mined-out area of non-coal mines, fibre optic sensors for mine hazard detection, Industrial Ethernet for control and information interconnectivity in automated Longwall mining, VOIP phone system underground and above ground, emergency communication systems, computer network for other coal mining applications etc. [4-11]. However, practically negligible studies were performed to monitor the powered support system on real-time at remote station using fibre optics Ethernet integrated with the data loggers and industrial pc.

The present system, as described in this paper utilizes the fibre optical cable, which are free such difficulties, for continuous monitoring of support pressure and closure characteristics during progressive face advance in a gassy longwall mine.

2. The Monitoring System

A block diagram of the battery operated logging system is shown in figure 1. It consists of 8-channel data logger housed in a rugged Flame Proof – Weathered Proof (FLP-WP) enclosure. The intrinsically safe (IS) circuit is also housed in this enclosure. The power to the data logger and sensor are given by lithium battery in FLP-WP enclosure. The system can continuously log the shield pressure and leg closures for more than one year. No external power supply is required to the logging system. This data logger can also be connected to the DS 100 Ethernet Adapter through IC209 Cable and FO media (use to convert digital signal to optical and optical to digital ones or vice -versa) converter to transmit the data upto 20Km without any loss. The data can be monitored online and/or downloaded to a PC connected to the network. There are two output cables from the data logger to the boxes respectively. Six pressure transmitters (PTx1, PTx2, PTx3, PTx5, PTx6 & PTX7) and convergence sensors (CONVx1 & CONVx2) are connected to these boxes. The cables carry excitation power to these sensors .The loggers can be individually programmed for logging the data from the sensors at different logging intervals ranging from 16 hour to 1 milli second duration. One has to judicially select the logging interval so that it continuously record variation in hydraulic pressure in legs and convergence of the shield support during progressive face advance. For recording dynamic loads, the data logger can be programmed to start fast logging, say at 10 ms intervals, when the pressure in a leg reaches a pre-specified threshold value, and continue fast logging until the pressure drops below this threshold value. This fast logging automatically stops when the pressure drops below this threshold value.

The intrinsically safe logging system has been designed and developed at the Department of Mining Engineering, Indian School of Mines, Dhanbad. Flame proof and water proof (FLP-WP) and intrinsically safety (IS) tests for these loggers have been done by Central Institute of Mining and Fuel Research (CIMFR) Dhanbad. The FLP-WP enclosure, IS power supply and enclosures have been fabricated locally. The compatible IS pressure transmitters and convergence sensors have been procured for the developed logger.

3. The technology

The current developed system has been used for a longwall automation project. In this system, the real time data comes at the rate of 19.2 Kb/sec from one system which is changed into optical signal by a media converter and vice –versa. A DS100 Ethernet adapter is used to programme the system for logging of the data at time interval of 10 milli second. The system is plugged by the IC209 interface cable. After the conversion of the data into optical signal, it travels by the Single mode Fiber optical cable. Single mode using only 2 Fibre with relatively narrow diameter can propagate wavelength of 1300 to 1320 nm. Each system is provided with unique IP address, which can be called to retrieve the load and convergence of different face supports installed at the face in a longwall panel (Fig. 2).

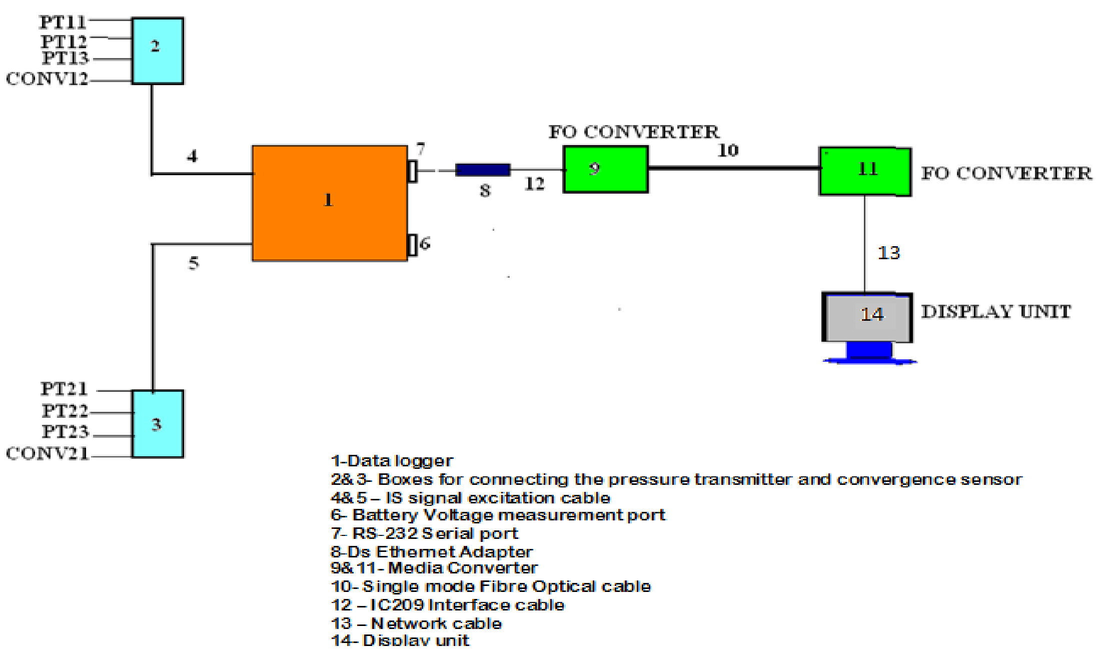

Figure 1. Inrinsically Safe System for real-time monitoring of laod and converegence of powered roof suppors installed at longwall faces.

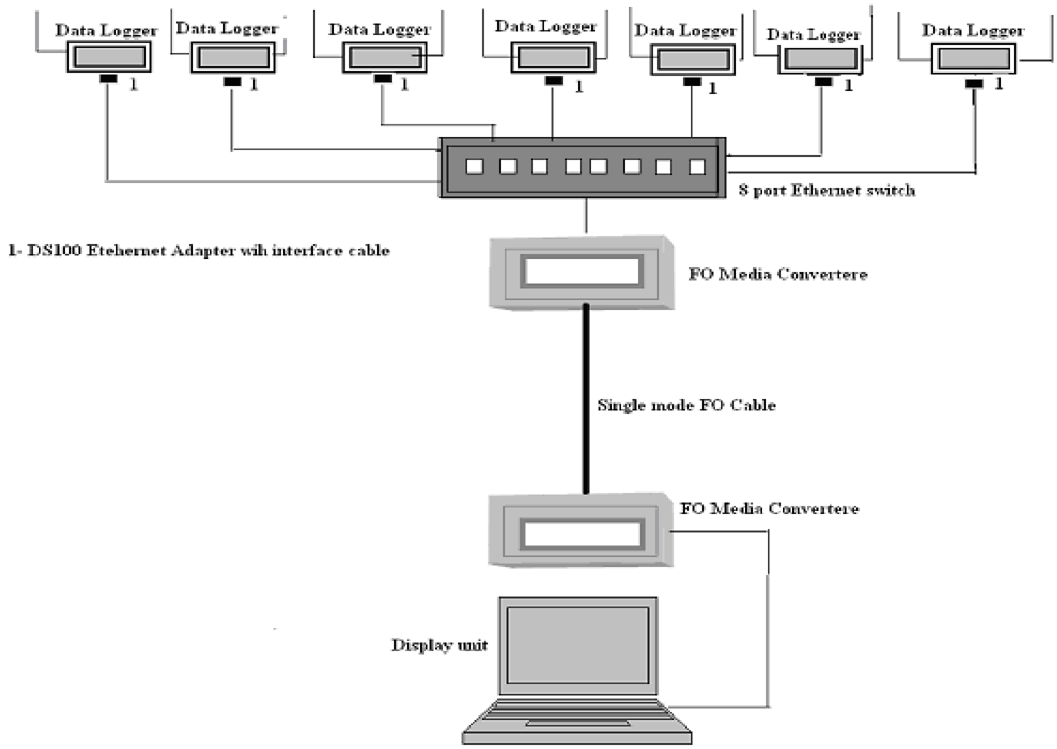

Figure 2. Display System for real-time monitoring of load and convergence of powered roof suppors installed at longwall faces.

4. Case Study: Moonidih Mine

The performance of the monitoring system has been tried in field in a longwall mine of Bharat Coking Coal Limited, a subsidiary of Coal India Limited. It is one of the deepest mechanized coal mines and also the first mine to introduce powered support longwall in India. It is about 20 Km from Dhanbad Railway Station on the Dhanbad - Ranchi road under Jharkhand state. The mine is having six mineable coal seams which have been accessed at different horizons by a pair of vertical shafts located in center of the property. The upcast shaft is equipped with a skip and the down cast shaft with multideck man and material winding cages. The data compiled for different panels under the work reported in this paper shows that depth of such worked out panels varied from 40 to 475 m, whereas the extraction height varied from 1.8-4.5 m.

The support monitoring trial was done in panel D14A (Fig. 3) using data logger system for continuous pressure and leg closure monitoring. The geo-mining details of the longwall panel are given in Table 1. An eight channel data logger (Fig. 4a) was installed on base of the hydraulic powered support S29. Two pressure transmitters, PT11 and PT12 were connected in front legs of support S29 and two pressure transmitters (Fig. 4b) PT13 and PT14 were connected to the front legs of support S30 and one convergence transducer (Fig. 4c) was installed between base and canopy of the support S30. The cables inside the canopy are passed through the armed housed pipe in order to predict the damage from roof fall and explosion. These pressure transmitters and convergence transducer were connected to the two distribution boxes of the data logger. The data logger was programmed to record pressure in legs and convergence of the canopy at an interval of 10 seconds and to store in its memory. The memory in the logger was sufficient to store the data for 6 days. The data was downloaded from the logger at regular intervals on a note book computer.

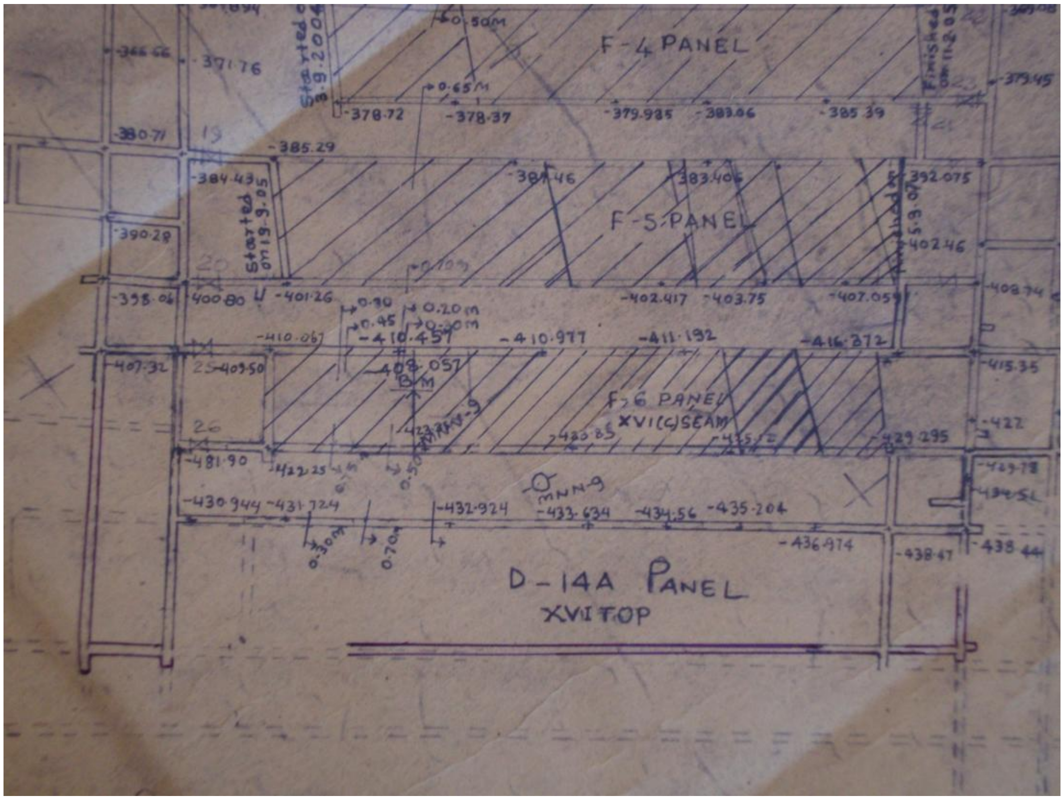

Figure 3. Part Plan of Moonidih Project showing the location of D-14A Panel in XVI T seam

Table 1. Geo-mining Details of the Experimental Panel

Name of the Seam	16 seam
Name of the Panel	D14A
Date of start of the panel	22.12.08
Length of the face	82m
Length of the Panel	316m
Depth of the Seam	432.92 - 453.76m
Seam Thickness	18.6m
Height of extraction	2.5to 3.5m
Gradient of the Seam	1:8
Nature of the immediate roof	Intercalation of sandstone & shale
Nature of immediate floor	Medium grained sandstone
Barrier against Tail Gate	50m between F6 & D14A
Barrier against Main Gate	50m between D14A & D15

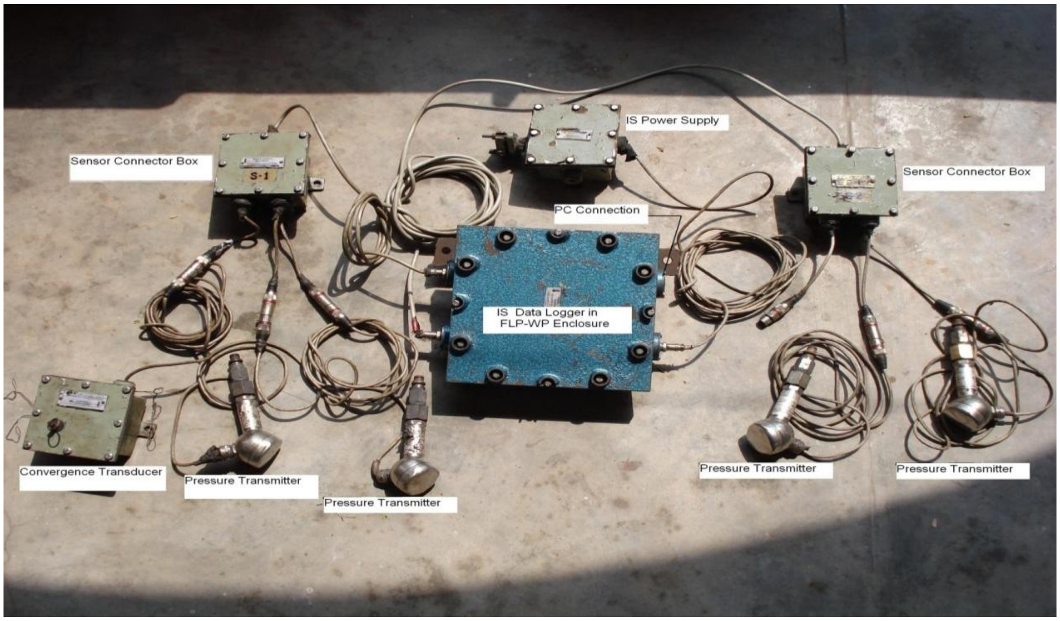

Figure 4a. Pictorial view of Data logger and sensors

Figure 4b. Pressure Transducers fitted in the legs

Figure 4c. Leg closure recorder fitted in the legs

5. Field observation

Plot of a typical set of data down loaded from the data logger is shown in figure 5. The pressure record shows variation of pressure in hydraulic legs between setting of the support and its release for advancement of the support i.e. during one coal cutting cycle of the shearer. From the pressure records, maximum pressure in the individual leg was noted in each cutting cycle. The plot of maximum pressure with advance of the face is shown in figures 6 and 7. The face advance is cumulative length of cuts.

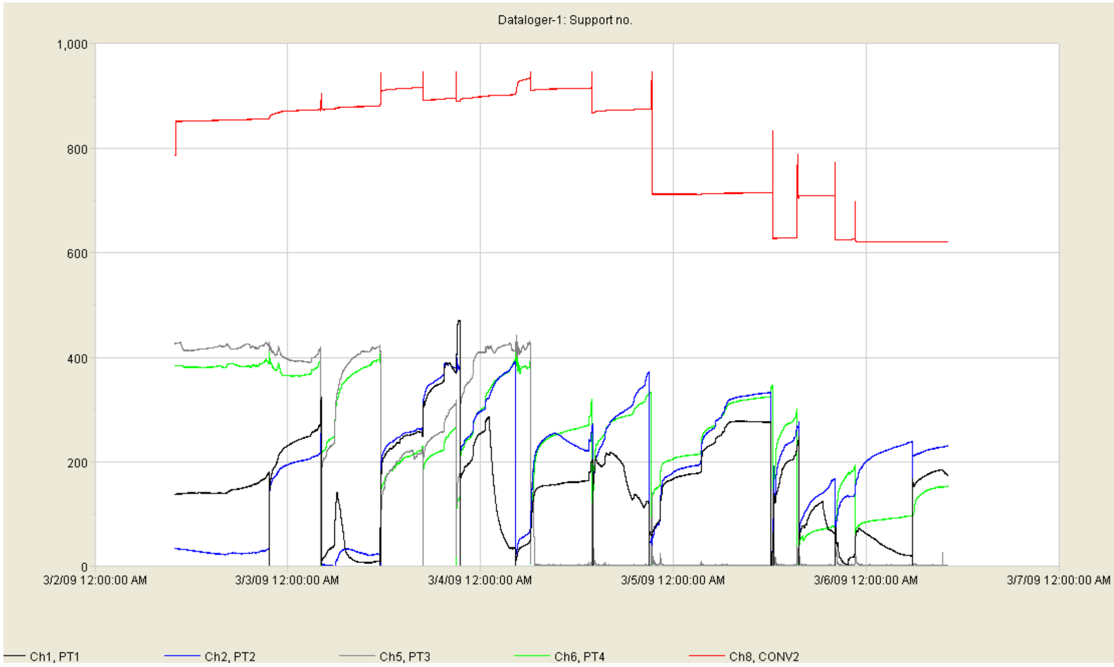

Figure 5. Record of pressure in hydraulic legs in support S29 and S30 and convergence of canoy of support S30 in longwall panel D14 A

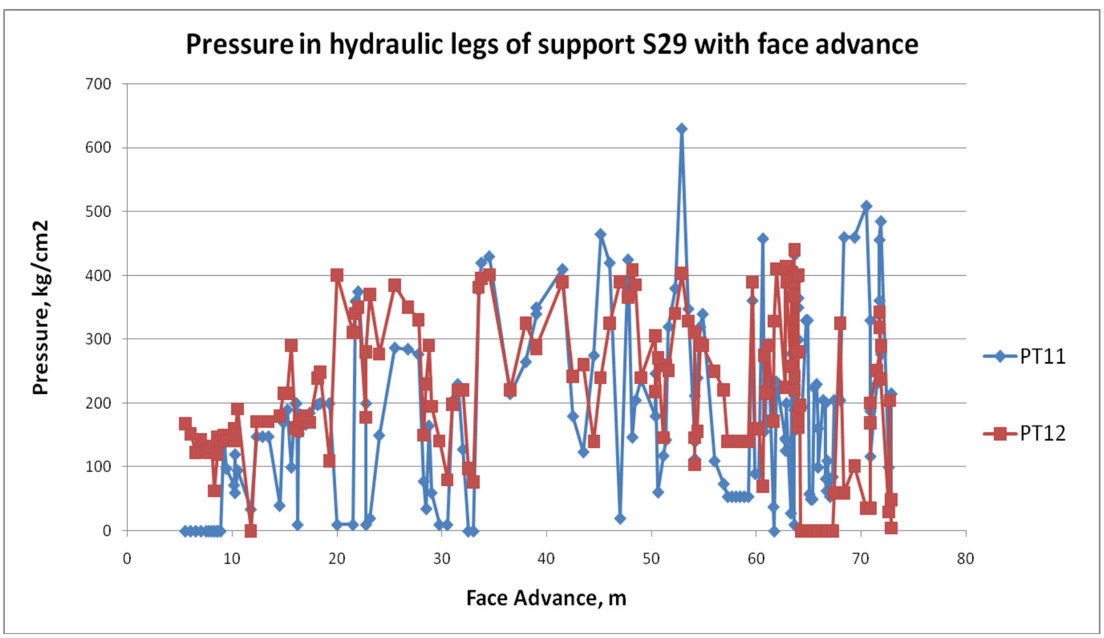

Figure 6. Variation of hydraulic pressure in supports S29 with face advance

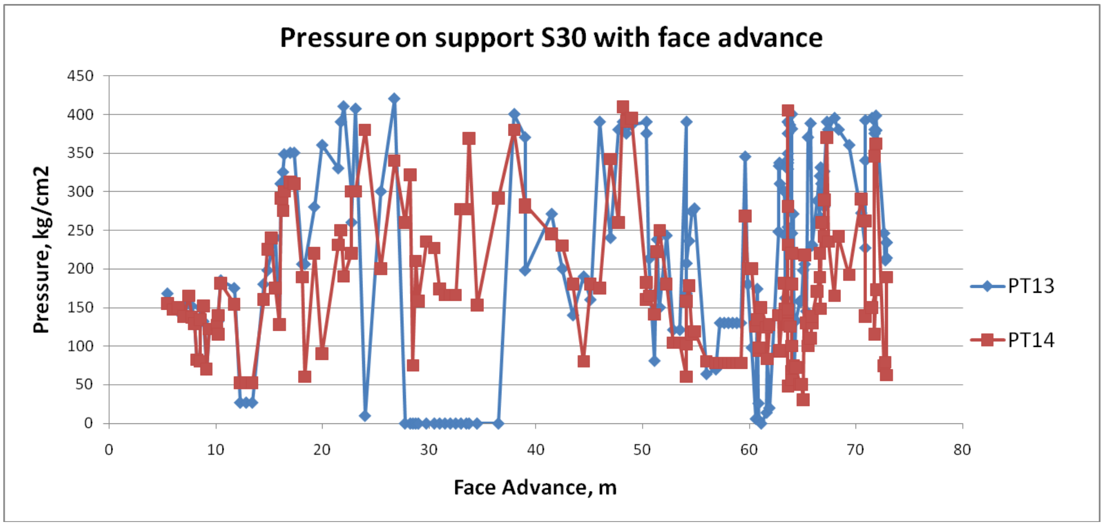

Figure 7. Variation of hydraulic pressure in supports S30 with face advance

The load on a support was calculated by adding load on each hydraulic leg of the support. The load on each leg was calculated by multiplying the leg pressure with the bore area of the leg. Figure 8 shows plot of variation of load on the supports S29 and S30 with face advance. The plot shows that the on support gradually increases till face advance of 25 m. This indicates that the main fall has occurred at this stage of face advance. In this panel, it is difficult to correlate the load on the support with behavior of strata. It is because, in 25 to 50 m section, there were stone bands. The face becomes almost standstill during drilling and blasting of the stones at the face. Sometimes the supports were lowered to blast the stone.

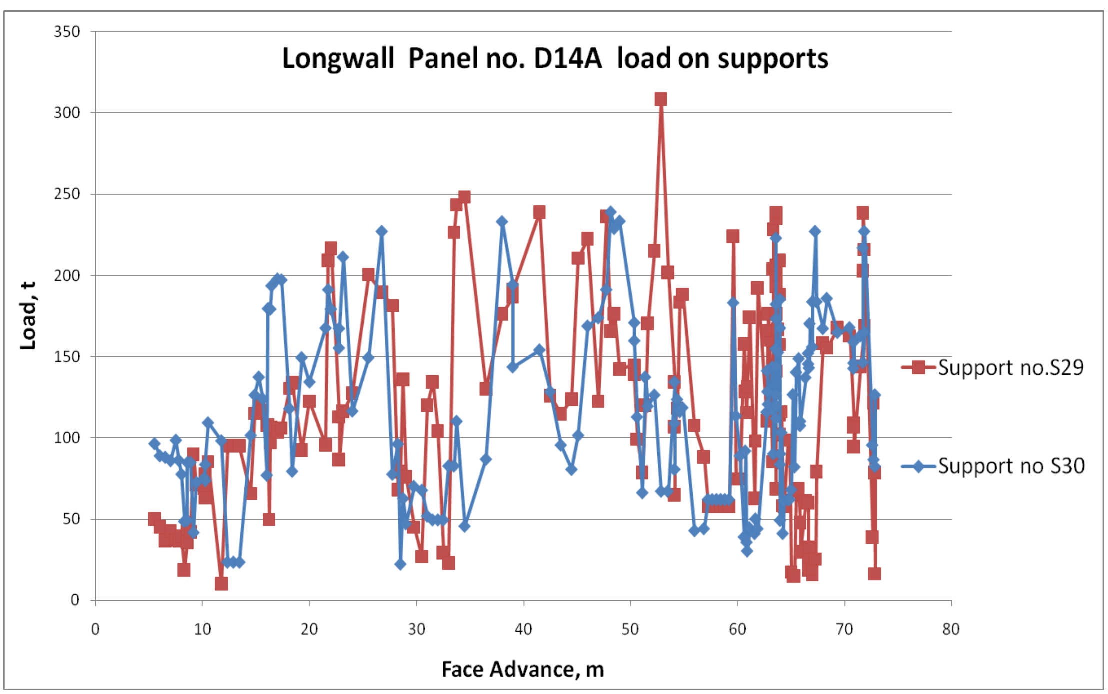

Figure 8. Variation of load on supports S29 and S30 with face advance

Records of maximum leg pressure in cutting cycles (Fig. 9 and Fig.10) show that in some of the cutting cycles, the maximum pressure remained below the setting pressure of 150 kg/cm^2 in some of the legs. This indicates leakage in the hydraulic circuits of the legs.

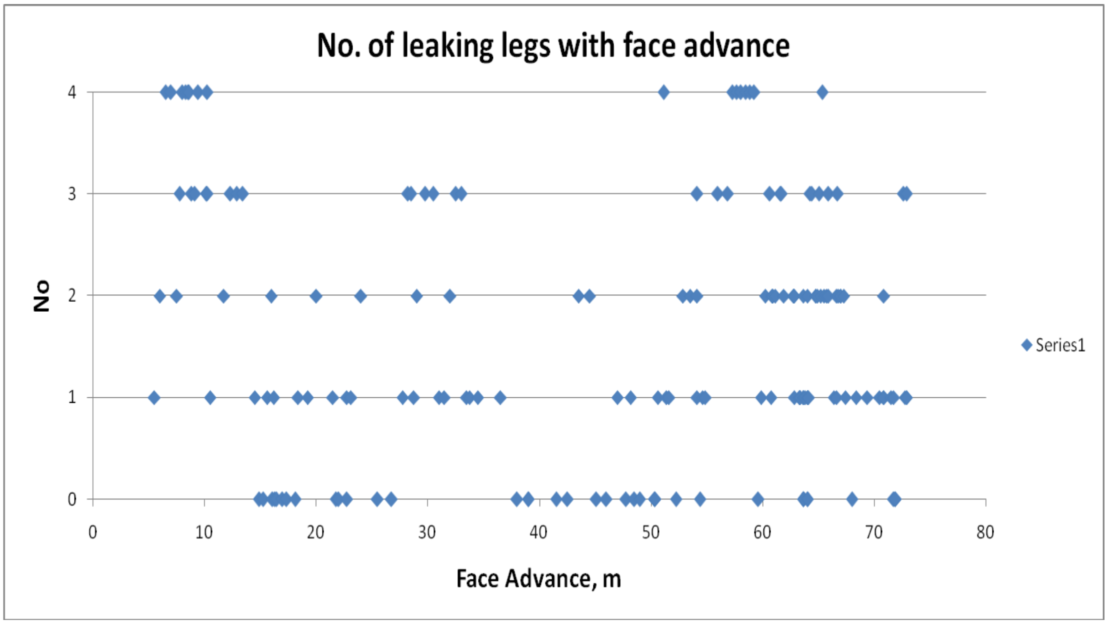

Figure 9. Variation of leakage (i.e. pressure <=150 kg/cm^2) in hydraulic legs in supports S29 andS30 with face advance.

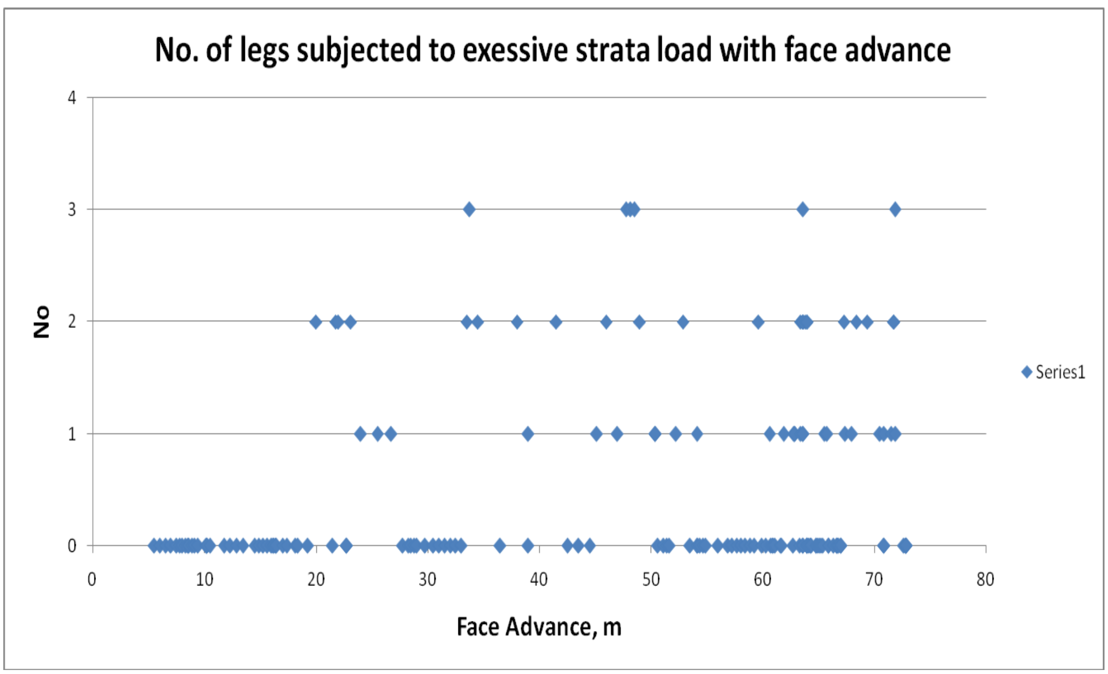

Figure 10. Variation of pressure >350 kg/cm^2 in hydraulic legs in supports S29 and S30 with face advance due to excessive strata load

The condition of the hydraulic legs of the supports in D14A panel has been summarized in Table 2 on the basis of records of maximum pressure in the legs in various cutting cycles. It shows that leakage occurred in 30 to 40% of the cutting cycles in individual hydraulic legs of the roof supports. The leakage was in maximum 45% cutting cycles in front leg on rise side of the support no S30. In a few cutting cycles, there was leakage in all the four legs of the two supports. Hence, these two supports were not effective at all during those cutting cycles.

Table 2. Condition of the Hydraulic Leg of supports S29 and S30

Sl. No.	Hydraulic leg conditions	Support no. 29		Support no. 30	
		PT11, %	PT12, %	PT13, %	PT14, %
1	Leakage <150 kg/cm^2	40	31	32	45
2	Under performance:>150 and < 250 kg/cm^2	33	30	25	33
3	Proper performance:>250 and < 350 kg/cm^2	13	21	21	16
4	Weighting >350 kg/cm^2	14	18	21	06
5	Over loaded > 400 kg/cm^2	09	05	02	01

The dip side leg of the support S29 was over loaded in maximum 9% of the cutting cycles. Due to excessive strata load on the supports, legs were loaded greater than 350 kg/cm^2 in maximum 21% of the cutting cycles corresponding to weighting of the support. Besides problem of leakage, the performance of the support in controlling the strata movement during the cutting cycles was satisfactory. The observation also showed that the maximum strata load on the support was 250t during the operation of longwall face in the experimental panel.

6. Discussion and conclusion

Support and face convergence are the two crucial parameters that can be used for quantification of support performance in a given geo-mining condition. The manual system for monitoring for support load and closure characteristics is not suitable for a proper assessment of its performance during progressive face advance. We deployed a prototype in the coal mine to test system validity. System error was measured during both the detection and reconfiguration processes. The detection latency, packet loss rate, and network bandwidth were also measured. Based on the data we collected in experiments, we conducted a large-scale simulation to evaluate the system scalability and reliability. On the basis of result of several trials, the logging system is found to be very suitable for real time monitoring and analysis of the shield performance and to know the support rock interaction at any moment of time in a longwall panel. These parameters are most influencing parameter governing the success of the longwall.

The field trial of the continuous monitoring system has been found to be helpful in delineating the peak loading, normal and leakage condition of roof supports. This information can be retrieved by the strata control and the maintenance departments of the mine on real time basis for taking over necessary maintenance or follow up tasks to ensuring better performance of roof supports during their useful life for safer longwall operation. The optical fibre cable connection in coal mine underground mainly employs high pressure discharging welding technology at present, which has some inherent safety problem. It is required to develop mechanical method and device for single mode optical fiber cable connecting with less welding attenuation less than 0.1dB and without electric spark or should be done by intrinsically safe system.

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