Minetech, Volume 25, No. 5, P 12-26 Sep.-Oct., 2004

INSTRUMENTATION AND MONITORING OF STRATA MOVEMENT DURING UNDER-GROUND MINING OF COAL

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आलेख में भूमिगत कोयला खनन (बोर्ड एण्ड पिलर) के दौरान स्ट्राटा मूवमेंट की मानीटरिंग और इंस्ट्रुमेंटेश्नन पर चर्चा की गई है। विभिन्न कोयलाक्षेत्रों की अलग-अलग भू-खनन परिस्थितियों में भिन्न-भिन्न प्राचलों के अध्ययन में विभिन्न संयंत्रों की आवश्यकता को स्पष्ट किया गया है। फील्ड के अनुभव के आधार पर यह दिखाया गया है कि भूमिगत खान में लगाये जाने वाले संयंत्र का चयन स्थान विशेष की भू-खनन परिस्थिति पर निर्भर करता है। तार के कम्पन के नियम पर आधारित संयंत्र भूमिगत खानों के लिए सर्वाधिक उपयुक्त हैं परन्तु डिपिलरिंग फेस में लगभग 30% संयंत्रों को बचा पाना कठिन है। यह भी देखा गया है कि डाटा लॉगर की मदद से इन संयंत्रों के सतत प्रबोधन से मजबूत चाल के धंसान से सम्बद्ध स्ट्राटा इक्यूलिब्रियम डायनमिक्स के बारे में महत्वपूर्ण सूचना उपलब्ध होती है। भूमिगत खदानों की सुरक्षा में इन-साइटू इंस्ट्रुमेंटेशन और प्रबोधन की भूमिका को दर्शाने के लिए विभिन्न फील्ड मापनों पर भी चर्चा की गई है।

INTRODUCTION

Optimization of safety and recovery during underground coal mining involves a number of measurements through instrumentation and monitoring [1]. Generally, the efforts to project likely rock behaviour in advance by theoretical analysis and modeling do not yield reliable results. This happens because the characteristics of the surrounding rock mass in a real structure is different from the usual theoretical assumptions. The depositional condition of the site plays an important role in estimating the performance of mining structures. This is the reason why most of the strata control norms are based on empirical formulations. These empirical formulations require quite dense (in time and space) field measurements of different strata control parameters. However, the field measurements of the parameters during underground mining are extremely delicate/challenging. Hazardous nature of the instrumented site during depillaring/final extraction makes the job even more difficult. Under the conditions, specialized equipments and skilled manpower becomes an integral part of the strata monitoring study.

In India, the underground coal production is mainly coming from the conventional manual faces. But economical, environmental and safety considerations for an underground coal mining project directs the planar to go for mechanization and automation. Therefore more and more underground mines are likely to adopt increasingly modern equipment to compete with the arriving global challenges of production, productivity and safety. The mechanization and automation of the underground mining, however, require matching technology, in speed and precision, for monitoring of the strata control parameters. Considering the hostile nature of underground environment, there is always a requirement of robust, continuous and precise measurement. In a continuing drive to reduce the inherent risks of danger during working around such difficult areas, many routine work is increasingly being undertaken by remotely operated systems. A number of electro-optical techniques exist and many are emerging with capabilities to provide remote and precise three-dimensional information of the object space. These techniques can very well be utilized for open cast mining environment but their scope is limited for underground mines. Beside time and space constraints, underground mining measurements involve other problems like poor light conditions, unstable and unapproachable objects and hostile surroundings. Electro-magnetic sensors, embedded in the rock mass, are normally used for the underground strata control monitoring. The information obtained by these sensors can easily be made continuous in time with the help of a microprocessor based data logger. But the information remains discrete in space and we get

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information about some points where sensors are placed. The gap between two measuring sensors/points can be interpolated through experience and knowledge about the physico-mechanical properties of the rock mass. Further, the reliability of the obtained quantitative information by these sensors is generally supplemented by the visual underground inspections of the area around the excavation. In this paper, the issue of underground strata control monitoring during bord and pillar mining is discussed along with some results of field studies to demonstrate the suitability of the of different instruments for varying geo-mining conditions of sites.

ISSUE OF UNDERGROUND MEASUREMENT

Formulation of norms for the design of underground mining structures involves measurements of different strata control parameters during excavation under varying conditions of different sites. From information point of view, it is best to measure continuous in space and time. But it is practically impossible to be continuous in space for an underground environment. On the basis of the experience and depending upon the dimension of the void and nature of overlying roof rock mass, different points/stations are selected in and around an underground panel. Developments of stress and strain at these points with the progress of the mining are monitored through embedded electro-magnetic sensors. Even for such discrete measurement, it is always better to keep large/dense number of the measuring points/stations in the panel. Considering economy of the study, the number of the observational points/stations in a panel can easily be optimized through experience.

There is not any "typical" mining environment, which can be used as a benchmark to decide the optimal parameters of the measuring system. However, from stability point of view, underground mining generates mainly three types of structures during underground mining of coal. From stability point of view, these three structures may be termed as: Long, Medium and Short term stable structures. Underground structures like pillars and galleries due to primary developments come under the first category while the erected support fall into the second category and the structures like rib and slice belong to the third category. The sophistication and remoteness of the monitoring instruments increase with decrease in stability of the structure. Instruments placed to monitor performance of structures of the first two categories need not to be of remote type as the area around them remains mostly accessible and safe. Further the required time interval between two consecutive observations of an instrument in and around a stable structure need not to be very small and, generally, shift wise readings serve the purpose. Here simple manual/mechanical type of instruments (Fig. 1) can provide the required information. However, the monitoring of short term stable structures demands remote type instruments, mainly due to the hazardous nature of the rock failure in and around the structures. Also the frequency of observations has to be very high in and around the short term stable structures like rib and slices. Here, it is preferred to be continuous in time due to the dynamic nature of the

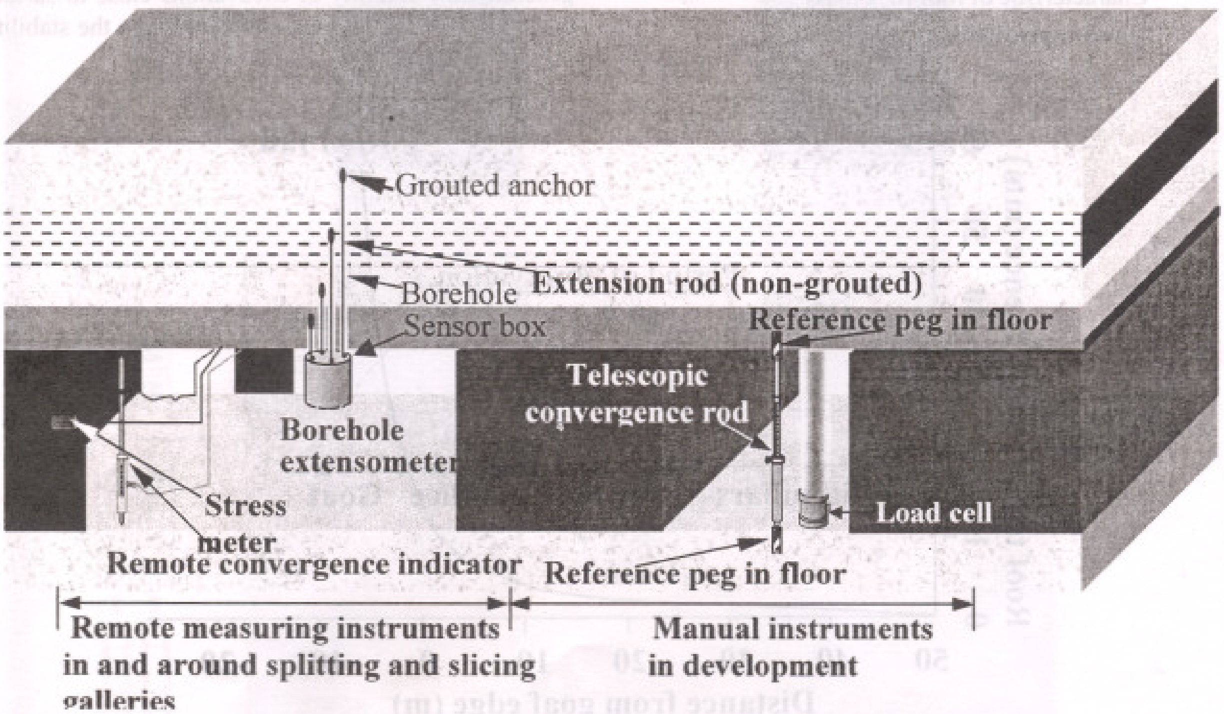


Fig. 1 : A typical sectional view of placement of placement of rmote and manual instruments for underground strata movement monitoring.

strata equilibrium. An actual roof to floor convergence measurement in and around a depillaring face is presented in Fig. 2 to demonstrate the above discussed fact. The change in roof to floor convergence remained very low in the presence of solid pillars while the rate increased with increase in percentage of extraction due to splitting and slicing. Slicing experienced relatively more change in the convergence. Withdrawal of support after slicing caused rapid increase in roof to floor convergence followed by roof fall. The measurement was done manually with the help of a telescopic rod till splitting of the pillar and then a remote convergence indicator was installed at the station, which continued up to the roof fall. The connecting cable of the remote convergence indicator was taken out of the working to a safe place to get information even after the area became inaccessible.

Geo-mining conditions of the site directly affect [2] the performance of the instruments applied for the strata control study. Success of a stratum monitoring scheme depends on large number of factors and even, some times, mercy of a underground miner becomes vital for the life of an installed instrument. Geological, technical and operational factors bring a number of threats for the safety of the applied instrument for an underground investigation. However, on the basis of field of experience of strata control monitoring at different coal fields of the country, following factors need special attention at the planning and instrument selection stage of the monitoring:

- Underground environment
- Depth cover
- Characteristic of roof rock mass
- Dimension of excavation

Underground Environment

Heat, humidity, visibility, danger of roof/side falls and space constraint of underground influence the type instrument to be applied for the monitoring work. Had it been an environment similar to that of the surface, a number of lucrative options, capable to provide information continuous in space and time, are available for the monitoring. But the underground environment provides very scanty band for the type of instruments to be applied there. Only mechanical and electro-magnetic instruments suit for this application. Mechanical instruments are non-remote type and, here, the observations are taken manually as the applied instruments are supposed to be directly accessible. Once the instrumented area becomes inaccessible, scope of the study only remains with the electro-magnetic instruments. Moreover, the electronic instruments are supposed to be intrinsically safe, portable and robust to face the rough and gaseous working environment of the underground. It is the data taking device i.e. readout unit, which involves electronic/electrical circuit resulting the issue of intrinsic safety. This problem of electrical/electronic hazard can be tackled through selection of a suitable instrument, whose data can easily be transmitted to a remotely located safe place of the readout.

Depth cover

The governing rock engineering norms of underground mining at shallow cover are different from those at deeper cover. It is worth mentioning here that, generally, the stability of excavations close to surface is mainly controlled by rock structure while the stability of

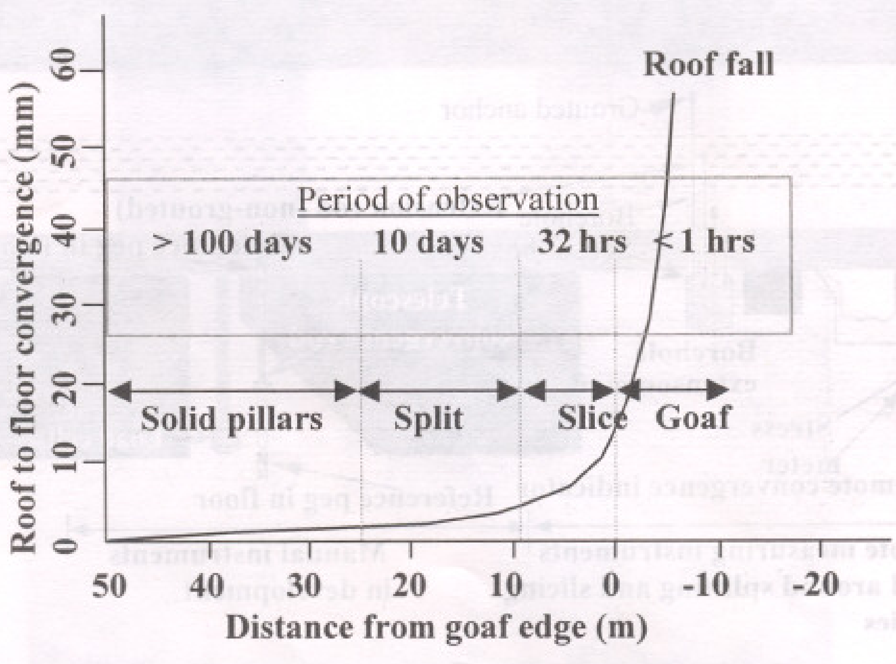


Fig. 2 : Variation of roof to floor convergence with goaf edge distance along with time period of the observation.

Table 1: Pillar size variation as per regulation 99 of Indian Coal Mines Regulations, 1957

Depth cover, m	Pillar size (centre to centre) for different roadway widths (B), m			
	B=3.0	B=3.6	B=4.2	B=4.8
Below 60	12	15	18	19.5
60 to 90	13.5	16.5	19.5	21
90 to 150	16.5	19.5	22.5	24.5
150 to 240	22.5	25.5	30.5	34.5
240 to 360	28.5	34.5	39.5	45
Above 360	39.5	42	45 48	

deeper excavations is more influenced by the properties of intact rock and pre-existing stresses [3]. The variation of *in situ* stress field with depth cover was well experienced by the mining engineers even before advent of the modern *in situ* stress concept. This is the reason of age-old concept of increase in pillar size with depth cover (Table 1), which is a well familiar example of practical understanding of the importance of depth cover for underground coal mining. Depth cover has significant impact on the *in situ* stress condition, depositional compactness and geo-physical properties of rocks. Therefore, the depth cover affects response of underground structures during strata equilibrium dynamics of the mining, which ultimately, influences the nature of the strata monitoring instruments. Depth cover even directly influences the type of instruments to be deployed during underground mining. For example, if the working is taking place at shallow cover, then a bore hole extensometer from surface can be installed to visualise the horizon of parting/caving above the underground void. The study of bed separation through borehole extensometer is extremely difficult for a deeper mine.

Characteristic of Roof Rock Mass

The behaviour of overlying roof rock mass influences the face condition of an underground mine. For an easily caveable roof strata, the goaf gets packed quite frequently (Fig. 3) during face advance. Here the bulking factor of caved material is important and the face is unlikely to experience dynamic loading. Generally, load on support, bed separation and roof to floor convergence are the parameters of interest during working below such easily caveable roof strata. A working face experiences large overhang if the roof strata are massive in nature (Fig. 4). Under this condition, stress meters may play important role to visualise nature and extent of dynamic loading [4] during *enmasse* movement of the roof strata. A careful monitoring of mining induced stress development may help in estimating the time and period of occurrence of the dynamic loading. Results of field monitoring of mining induced stresses (vertical) at two different sites are presented in Fig. 5 to show the influence of overlying roof strata on nature and amount of the stresses. Figure 5(a) shows

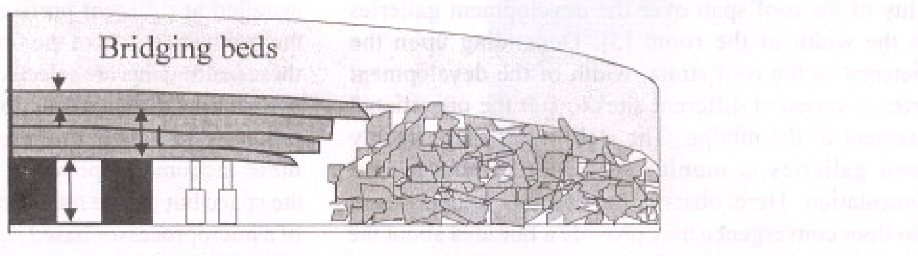


Fig. 3 : Bulking factor controlled caving of weak and laminated overlying strata.

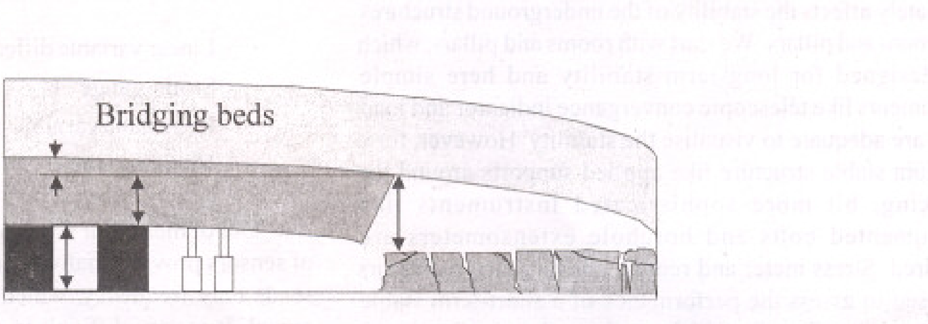


Fig. 4 : Parting plane controlled caving of strong and massive overlying strata.

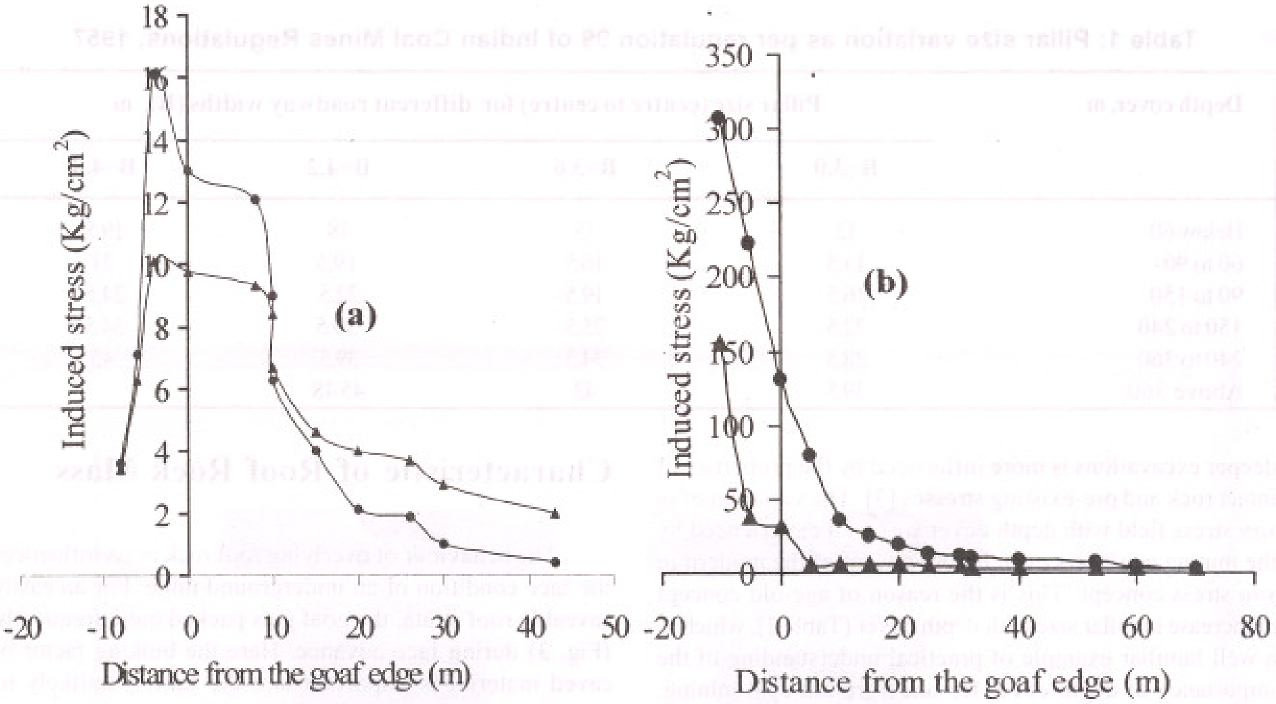


Fig. 5 : Variation of mining induced stress (vertical) with face advance for two different overlying roof strata conditions.

variation of the mining induced stress for depillaring under an easily caveable and softer overlying roof strata. Figure 5(b) represents variation of mining induced stress over a pillar for depillaring under a massive and strong sandstone roof strata. Thus the strata control parameters gets affected by the competency of overlying roof strata.

Dimension of Extraction

Percentage of coal extraction remains low during initial development of a coal seam for room and pillar working. Stability of the roof span over the development galleries limits the width of the room [5]. Depending upon the competency of the roof strata, width of the development galleries is varied at different sites to suit the operational requirement of the mining. The stability of these freshly exposed galleries is monitored through underground instrumentation. Here, observation of load on support and roof to floor convergence may provide a fair idea about the stability of the roof strata. The increase in dimension of excavation increases the percentage of extraction, which ultimately affects the stability of the underground structures like room and pillars. We start with rooms and pillars, which are designed for long term stability and here simple instruments like telescopic convergence indicator and load cells are adequate to visualise the stability. However, for a medium stable structure like applied supports around the working, bit more sophisticated instruments like instrumented bolts and borehole extensometers are required. Stress meter and remote convergence indicators are used to assess the performance of a short-term stable structure like slice/rib, which are formed at the final stage of the extraction.

INSTRUMENTS

Frequently used instruments for strata control investigations are: (a) Load cells, (b) Convergence indicator (c) Instrumented bolts (d) Stress meters (e) Strain Bars/meters and (5) Bore hole extensometer. During underground investigations, these instruments are mainly used to gather two types of information about structures in and around the excavation: (a) stress/load and (b) strain/deformation. For this purpose different electro-magnetic sensors along with some site-specific mechanical arrangements are installed at different prefixed positions of a panel before the commencement of the final extraction. The positions of these instruments are selected in such a way that they remain undisturbed during extraction of the pillars and also remain protected inside goaf till roof fall. However application of these instruments provides point to point information in the space but can be made continuous in time with the help of a microprocessor based data logger. Generally, four types of sensors are used for all these underground instruments, which are based on following four principles:

- Linear variable differential transformer (LVDT)
- Strain gauge
- Rehostant/variable resistance
- Vibrating wire

Out of these four types of sensors, the first three types of sensors provide analogue information while the last one sends only frequency, which is a fixed value like digital signal. It is very difficult to carry the analogue signals of the first three types of sensors to a distant safe place without noise and distortion. However, the frequency obtained by the vibrating wire sensor does not get affected during the transmission. This feature of the vibrating wire sensors makes it superior to other sensors because it is always desirable to monitor instrument's reading from a distant and safe place during underground mining. Further, it is always better to monitor the readings continuous in time with the help of a microprocessor base data logger system. The hostile environment of underground coal mining does not permit to place a microprocessor based system quite close to the working face. The data logger has to be placed at a distant and safe place, generally, outside the panel while the sensors are to be fixed in and around the working face. The vibrating wire sensors have got capability to tackle the data transmission issue for the required distant positions of the sensors and data logger.

The vibrating wire measuring transducer basically consists of a stretched wire (Fig. 6), one end of which is fixed to the transducer body and the other end is connected to a diaphragm which is acted on by the physical force/displacement to be measured. Stress changes in the rock cause small changes in the diameter of the gauge cylinder. These changes are measured in terms of the change in the frequency of vibrations and the uniaxial stress change from σ_1 to σ_2 is related to this frequency change [6] as follows:

$$\sigma_1 - \sigma_2 = 4\,[\,f_1^2 - f_2^2\,]\,l_w^2 r_w\, \alpha/g \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where,

f_1 = natural frequency of vibrating wire at σ_1 stress level

f_2 = natural frequency of wire at σ_2 stress level

l_w = wire length

r_w = density of the wire material

g = acceleration due to gravity

a = calibration constant

The stress meter is easily embedded in rock mass through a hole and a wedge-platen system, fastened in a simple mechanical setting tool unit. Change in rock stresses impose changing loads over the stress meter's body causing the body to deflect and this deflection is noted as change in tension and resonant frequency of vibration of the vibrating wire element. The square of the vibration frequency is directly proportional to the change in diameter of the stress meter, which is calibrated to obtain the stress

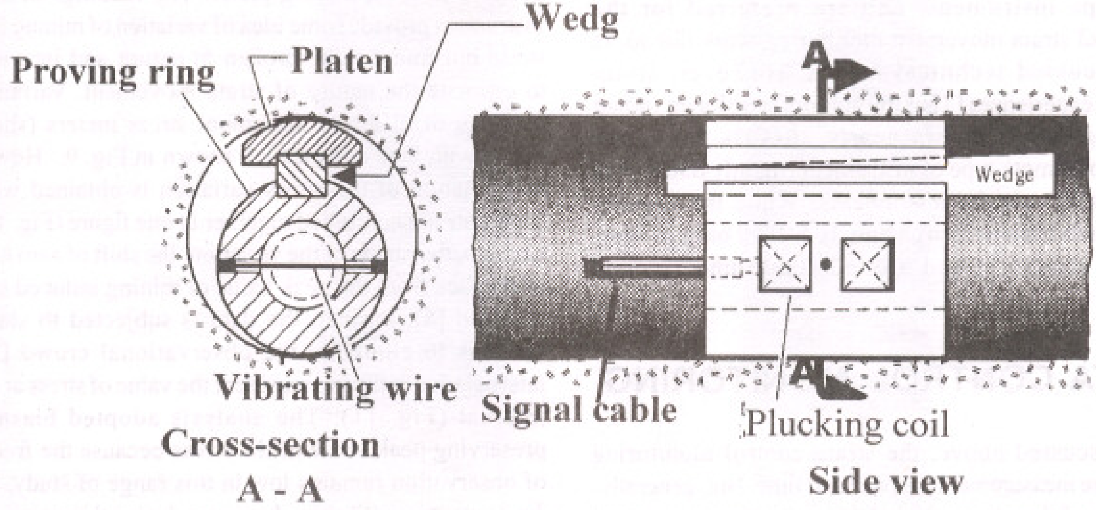


Fig. 6 : Positioning of wedge, platen and the stretched wire for the stress measurement.

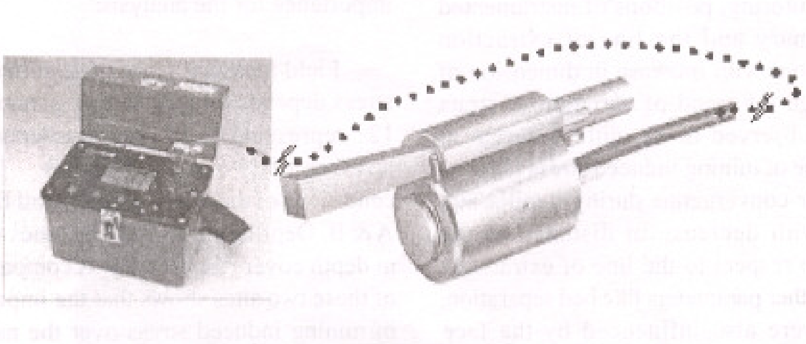


Fig. 7 : A vibrating wire stress meter with readout box.

change in the rock. A coil and magnet assembly, located close to the tensioned wire, is used to excite the wire and sense the resultant frequency of vibration. When the stress meter is connected to read out box (Fig. 7), a pulse of varying frequency is applied to the coil and magnet assembly, and this causes the wire to vibrate at its resonant frequency. The resonant frequency is induced in the pluck up coil and transmitted to the readout box, where it is conditioned and displayed.

Geo-technical investigations related with mining encounter stable to extremely unstable underground structures during different stages of mining requiring matching capability of the applied instruments. Due to this reason the applied instruments have got, at least, two variants: remote type and none-remote type. Remote types of instruments are used only when the instrumented site is likely to be inaccessible during the excavation otherwise non-remote type of instruments are preferred. In fact, the remote type instruments involve bit complex electronics while the none-remote type instruments are generally based on simple mechanical principles. Further the extended connecting wire of a remote type instrument always face threat from the hostile underground environment. Vibrating wire instruments, generally, meets the requirement for the remote type instruments and are preferred for the underground strata movement monitoring work due to its above discussed technical merits. However, strata monitoring experiences [7] of the authors at different Indian depillaring panels shows nearly 30-40% premature casualties of remote type of instruments mainly due to roof and side falls over the instruments. While the casualty figure for non-remote instruments is 5-10% only as they, generally, remain in and around stable underground structures.

STRATA CONTROL MONITORING

As discussed above, the strata control monitoring prefers dense measurement in space and time. But, generally, the number of the observational points/stations in a panel is optimized to meet the economical consideration of the study. This optimization is achieved through experience and in depth consideration of geo-mining conditions of the site. During the monitoring, positions of instrumented stations remain stationary and the line of extraction overtakes all these stations with increase in dimension of the excavation. Although the trend of variation of strata control parameters is observed to be quite different at different mines, the value of mining induced stress [7] over pillars and roof to floor convergence during depillaring, generally, increases with decrease in distance of the observation station with respect to the line of extraction. Similarly, the values of other parameters like bed separation, load on support etc. were also influenced by the face advance of a depillaring panel. Further, the peak of the strata movement problem is encountered during major roof fall. As an underground investigation needs instruments to be installed before commencement of depillaring, the peak of strata movement generally do not match [8] with the zero position of the instrument. Therefore, the actual shift of major roof fall from the zero face position of the instrumented site is adjusted [8] for analysis and development of a relationship.

Mining induced stress

It is difficult to control a stiffer overlying stratum through an applied roof support during depillaring. Laboratory and field investigations have demonstrated [9] that the proper design of stiffness of natural supports can effectively tackle the problem of depillaring under uncaveable coal measures. However, here study of mining induced stress developed over the pillars for varying dimension of excavation becomes an important issue to understand the interaction between the natural support and overlying strong and massive strata during different stages of the depillaring.

Generally, a number of stress meters (Fig. 8) are fixed to pick up the variation of mining induced stress with face advance in a depillaring panel. The readings of a single instrument provide some idea of variation of mining induced stress but found to be broken in nature and inconclusive to estimate the nature of strata movement. Variations of readings of different individual stress meters (shown in Fig.8) with face advance are shown in Fig. 9. However a better nature of the stress variation is obtained when all these data are çombined together in one figure (Fig. 10). To have a better shape of the variation, the shift of zero position of the face from the peak value of mining induced stress is adjusted [8]. Further, the data is subjected to statistical analysis to eliminate the observational crowd [8] and interpolation is dine to represent the value of stress at regular interval (Fig. 11). The analysis adopted biasness of preserving peak value of the stress because the frequency of observation remains low in this range of study, mainly due to strata equilibrium dynamics during the major ground movement. Application of a microprocessor based data-logger for continuous monitoring of the variation during major ground movement may prove to be of strategic importance for the analysis.

Field measurements suggest that the mining induced stress depends on geo-mining parameters of the site. Fig. 12 represents field measurements of mining induced stresses of two sites A and B. The overlying strata conditions of these two mines A and B are shown in Fig. 13 A & B. Depillaring at A and B mines was done at 77 and 48 m depth cover respectively. A comparison of observations of these two sites shows that the impact of dynamic nature of mining induced stress over the natural supports poses serious threat for the safety of working under a hard and massive roof rock mass.

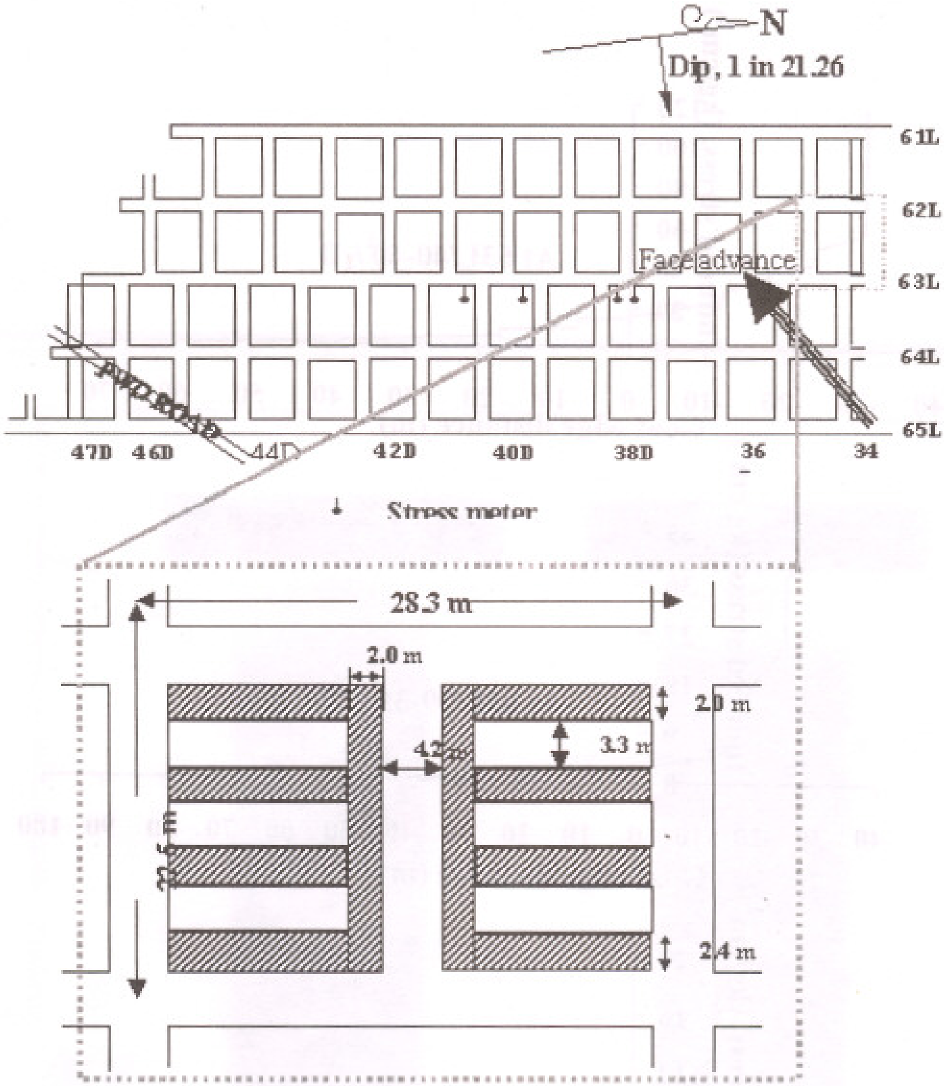


Fig. 8 : Location plan of instruments (stress meters) in an observational panel and the manner of pillar extraction.

Load and Convergence

The stability evaluation of a freshly exposed roof over a gallery is generally done with the observation of load on support and roof to floor convergence. Two reference pegs, vertically opposite in roof and floor, are fixed at each convergence station along the development gallery. The separation between these two pegs are noted at different interval of time with the help of a graduated telescopic rod to understand the roof to floor convergence. Load cells are generally placed below the applied supports like props/chocks/roof-bolts to measure load encountered during different stages of mining. The load cell performs well to pick up the load generated over the support if the applied support is stiff in nature. However, in actual practice, the stiffness of passive support keeps fluctuating and generally remains poor. To improve safety, industry is adopting stiffer supports, like pre-tensioned roof bolts, to control the roof effectively during excavation. The load cells placed over the collar of these roof bolts provides only collar load, which may mislead the analysis. If the roof strata parts then the primary function of a roof bolt is to carry the load of the parted rock blocks. Here maximum load over the bolt is developed near the parting horizon and a simple model of load distribution in the bolt is shown in Fig.14. To understand the actual load distribution along a roof bolt, instrumented bolts are used. Here a number of pairs of strain gauges are embedded along the length of a bolt (Fig. 15) to pick up axial and shear load simultaneously at each point. The readings of all these strain gauges are taken through lead wires, which can be extended to a safe observation station. Stiff and high capacity roof bolts are being used as breaker line support of a depillaring face. To optimize the design of roof bolts based breaker line support, loading of the roof bolts at different stages of depillaring was studied with the help instrumented bolts. An observed typical loading of a front row roof bolt (instrumented bolt) of the breaker line during major roof fall is shown in Fig. 16.

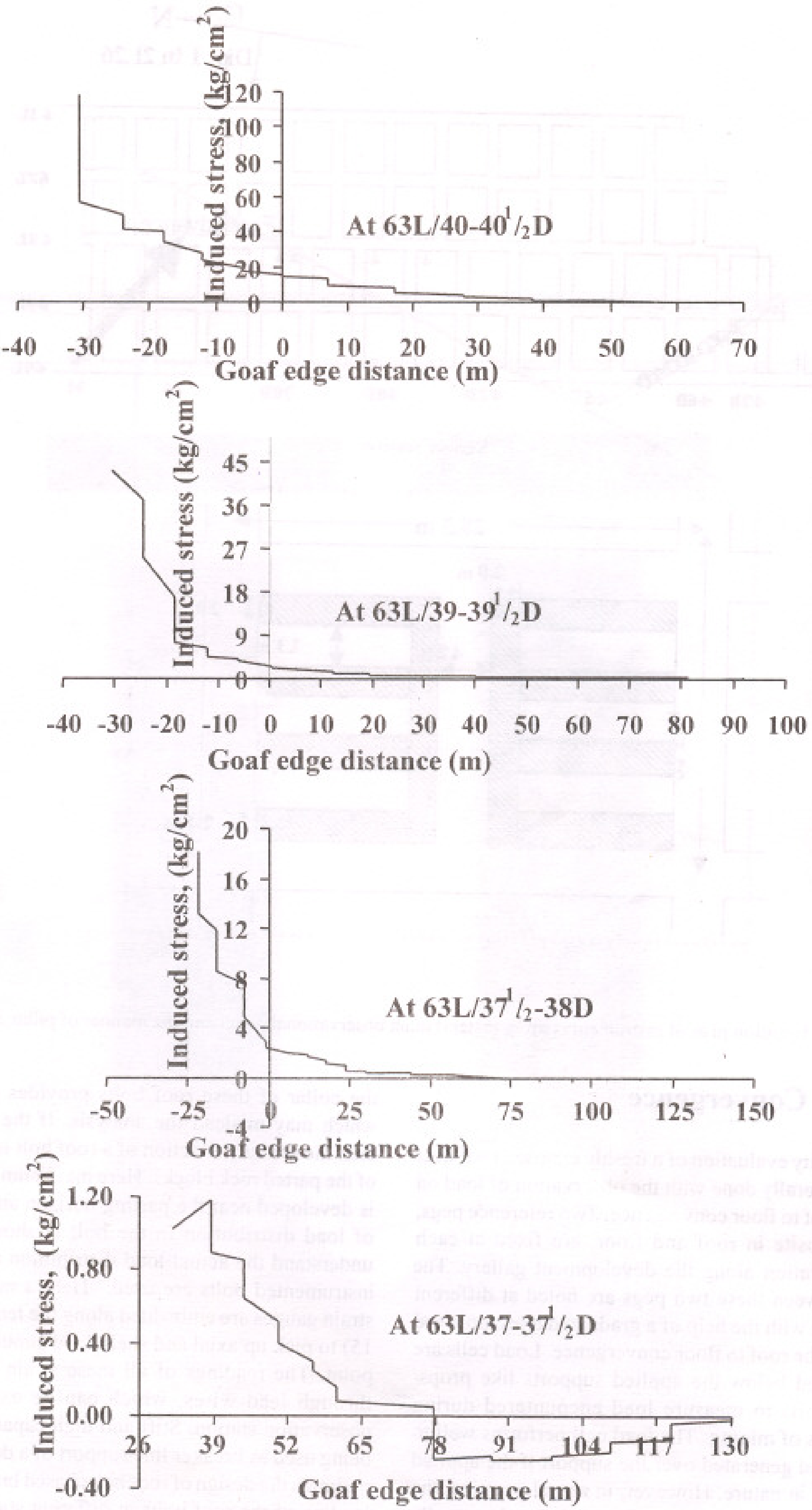


Fig. 9 : Observed variation of mining induced stress with goaf edge distance independently for each station of the panel.

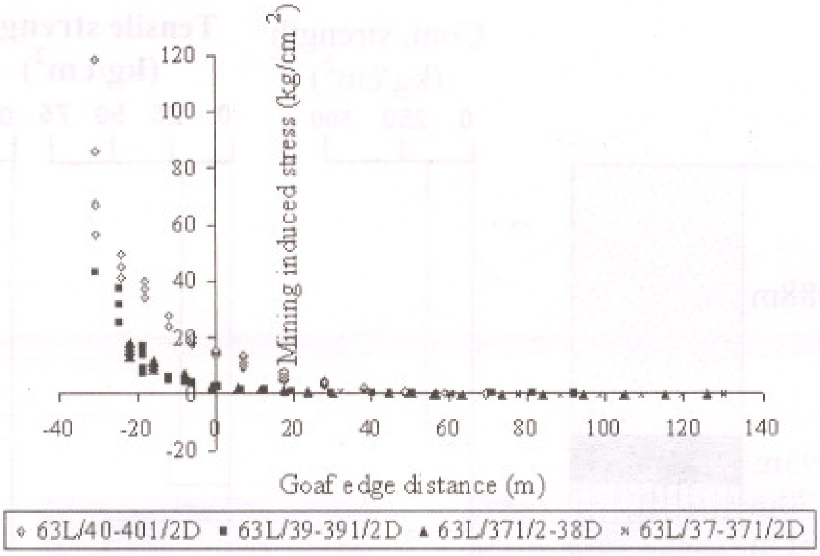


Fig. 10 : Combination of data (variation of mining induced stress with goaf edge distance) of all stations of the mine.

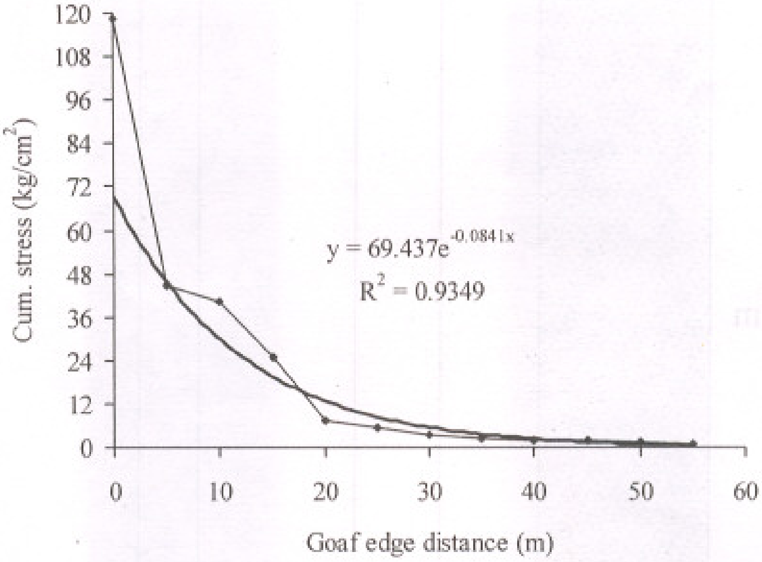


Fig. 11 : Final shape of the mining induced stress variation graph after normalization of the position shift, elimination of the observational crowd and interpolation [after CMRI, 2004]

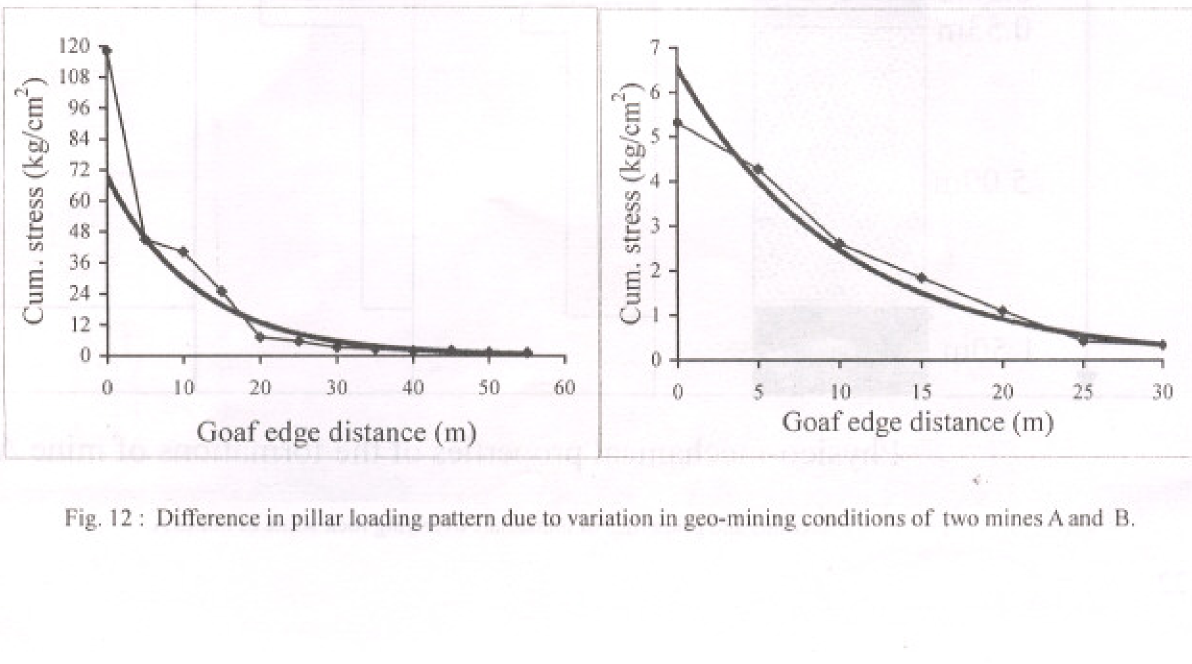
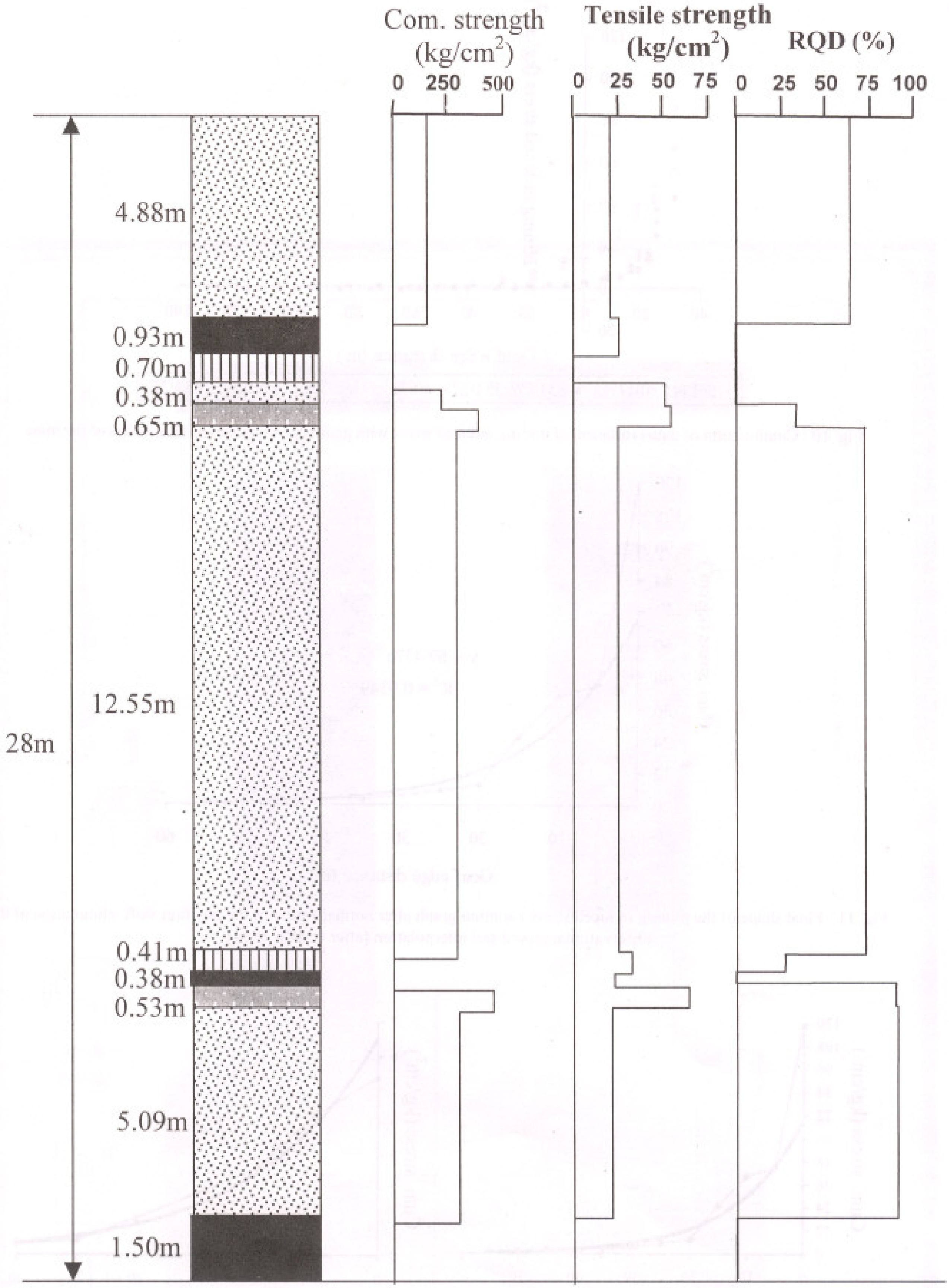
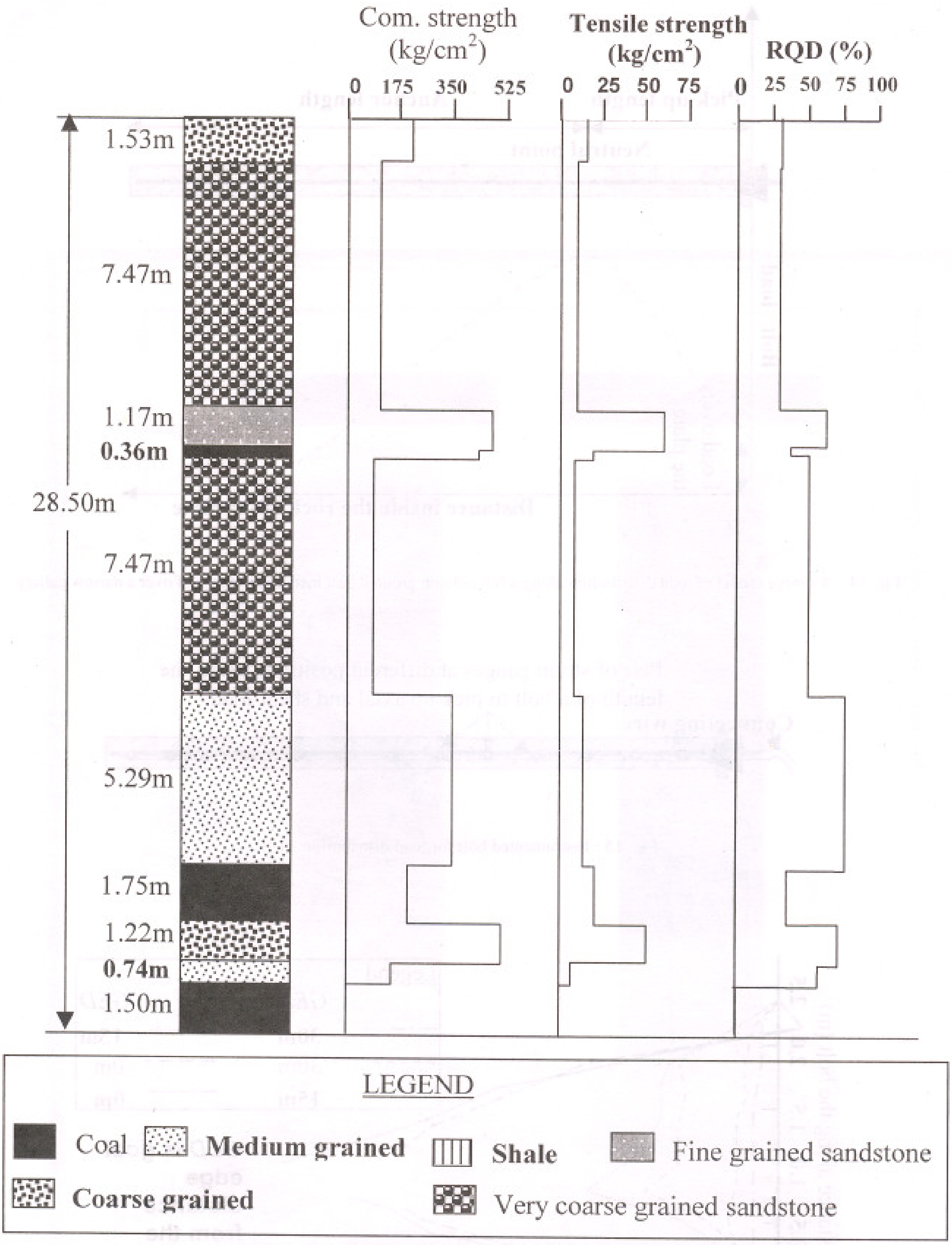


Fig. 12 : Difference in pillar loading pattern due to variation in geo-mining conditions of two mines A and B.



Physico-mechanical properties of the formations of mine A.

Fig. 13 A : Sections and properties of immediate overlying rock strata of mines A.



Physico-mechanical properties of the formations of mine B.

Fig. 13 B : Sections and properties of immediate overlying rock strata of mine B.

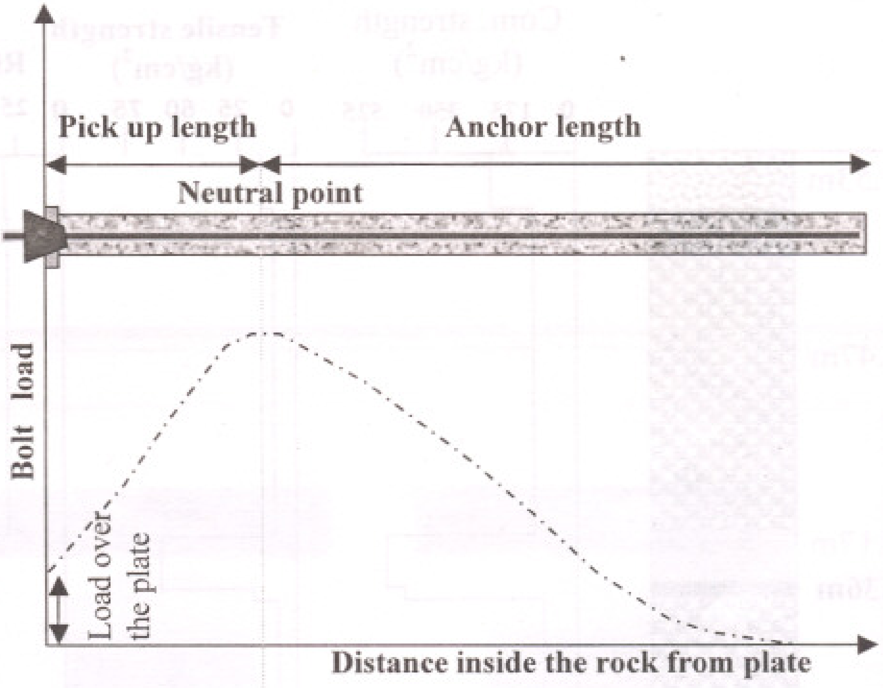


Fig. 14 : A simple model of load distribution along a full column grouted bolt installed in the roof over a narrow gallery.

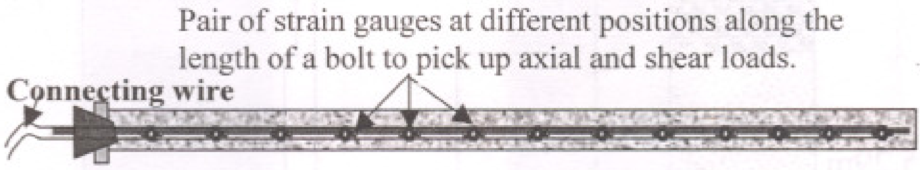


Fig. 15 : Instrumented bolt for load distribution study.

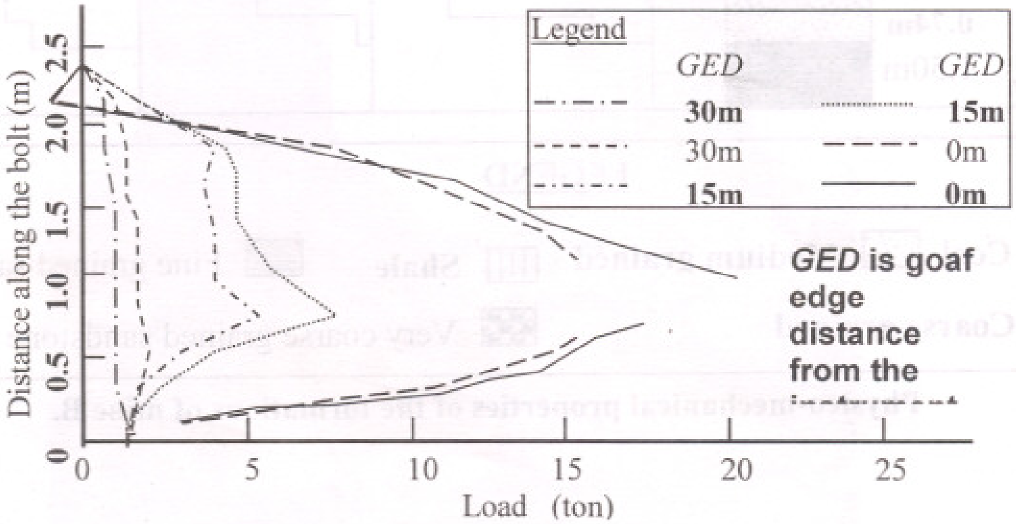


Fig. 16 : Development of axial load across an instrumented bolt at different stages of a depillaring.

Fig. 17 : A photograph showing mouthpiece of a multipoint borehole extensometer during installation in an upward drilled hole.

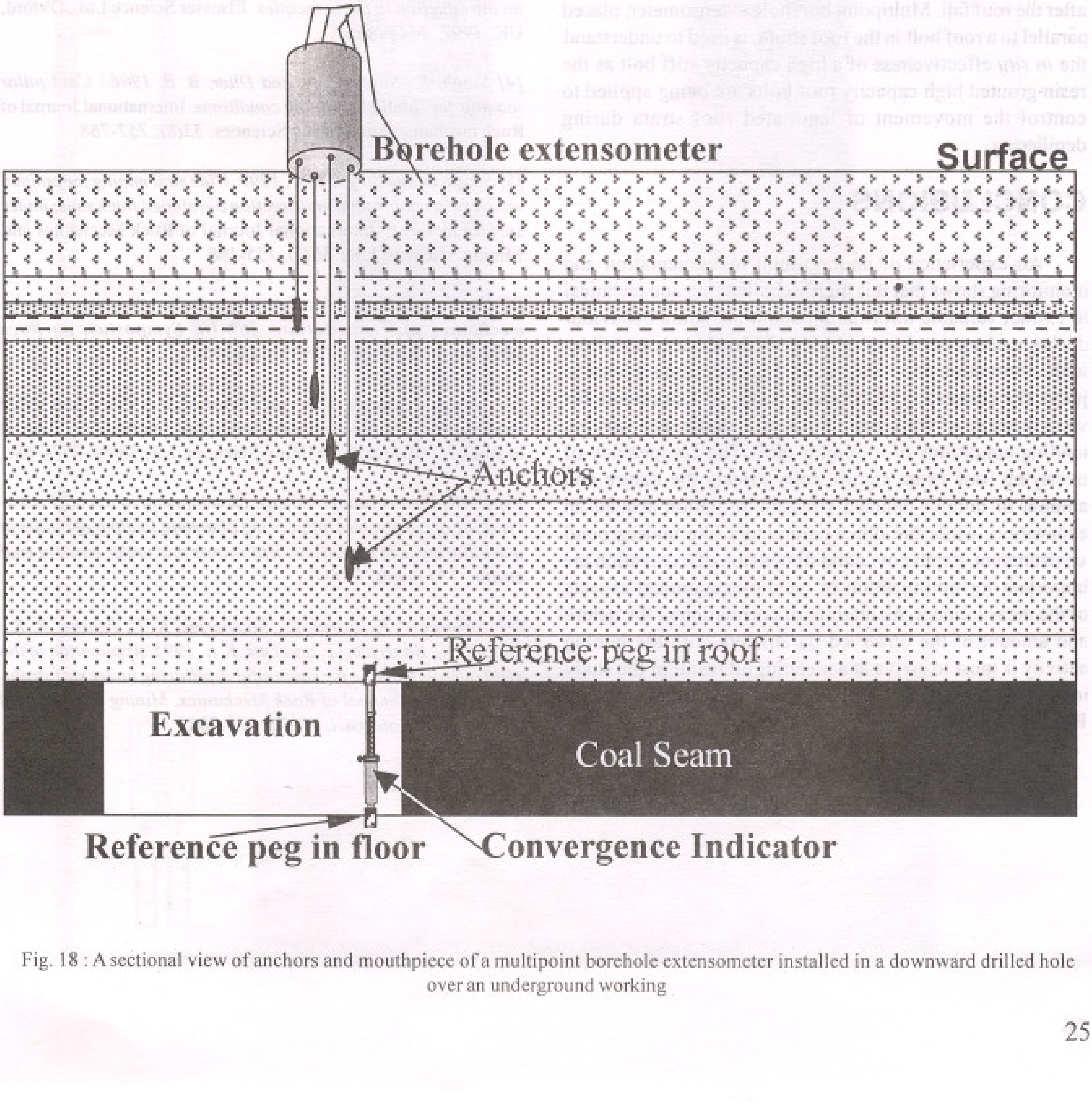


Fig. 18 : A sectional view of anchors and mouthpiece of a multipoint borehole extensometer installed in a downward drilled hole over an underground working

Bed separation

A borehole extensometer with multi-anchor facility is used to locate the parting horizon above the working because the readings of an extensometer give differential movement among the anchors. This instrument is generally fitted (Fig. 17) in an upward hole drilled from the working horizon. It provides valuable information till roof is intact as is the case of development of a coal seam. However, this instrument, generally, fails to give important information during depillaring, if installed conventionally in an upward drilled hole. In fact, the mouthpiece (containing sensors) of this instrument get damaged with the instability in the immediate roof, which ultimately ends the life of the instrument. However, if the multipoint extensometer is installed from surface (shallow depth cover case) or overlying development (multi-seam mining case) through a downward drilled hole (Fig. 18), then the instrument provides better information about the bed separation. Here, the roof fall causes loss of the lower anchors only. Overlying anchors and mouthpiece with sensors remain intact even after the roof fall. Multipoint borehole extensometer, placed parallel to a roof bolt in the roof strata, is used to understand the *in situ* effectiveness of a high capacity stiff bolt as the resin grouted high capacity roof bolts are being applied to control the movement of laminated roof strata during depillaring.

CONCLUSIONS

An experience of underground instrumentation and monitoring shows that it is highly challenging and technical to extract valuable information about the strata behaviour during underground coal mining. Field experience along with information about the geomining conditions is vital to judge the suitability of different types of instruments for visualization of rock mass response under the varying loading conditions of a mining face. The competency of overlying roof strata significantly affects the nature and amount of mining induced stress/deformation around an excavation, while the other parameters like underground environment, depth cover and dimension of excavation are important for optimization of techno-economical aspects of the measurement. An attempt of correlation of the nature and amount of the observed parameters with the mining activity is must to arrive at a meaningful result of the study in the interest of the safety of an underground mining. Hostile impact of highly active nature of mining induced stress development over the natural supports under a hard and massive roof rock mass can be tackled through effective underground instrumentation and monitoring of strata control parameters.

References

[1] Altounyan, P.F.R., Bigby, D. N., Hurt K.G. Peake H.V., 1997. Instrumentation and procedures for routine monitoring of reinforced mine roadways to prevent falls of ground. 27th International Conference of Safety in Mines Research Institute (editors: B. B. Dhar and B.C. Bhowmick), New Delhi, India, 759-766.

[2]Shephered, J. and Lewandowski, T., 1998. Fender geo-mechanics and behaviour in the Wongawilli pillar extraction system. Proceedings of International Conference on Geo-mechanocs/Ground control in Mining and Underground Construction (editors: N. I. Aziz and B. Indraratna), 14-17 July, wollongong, Australia: 263-186.

[3] Hudson, J. A. and J. P. Harrison, Engineering rock mechanics: an introduction to the principles, Elsevier Science Ltd., Oxford, UK, *1997, 444 pages.*

[4] Singh, R., Singh, T. N. and Dhar, B. B. 1996. Coal pillar loading for Shallow mining conditions. International Journal of Rock mechanics and Mining Sciences, *33(8): 757-768.*

[5] Singh, R. and Singh, T. N., 1999. Wide stall mining for optimal recovery of coal from a multisection developed thick seam under surface features. International Journal of Rock Mechanics and Mining Sciences, UK, *36(2), 155-168.*

[6] Dutta, P. K. Some recent development in vibrating wire rock mechanics instrumentation. 26th US Symposium on Rock Mechanics, Rapid city, 1985: 1043-1053.

[7] Singh, R., Singh, T. N. and Dhar, B. B. 1996. Coal pillar loading for Shallow mining conditions. International Journal of Rock Mechanics and Mining Sciences, *UK, 33(8): 757-768.*

[8] CMRI Report (unpublished), Development of a model vis-à-vis study of parameters influencing abutment loading of pillars at a depillaring face of shallow depth cover and under massive roof strata: 134 pages, (2004).

[9] Sheorey, P. R., Barat, D., Mukherjee, K. P., Prasad, R. K., Das, M. N., Banerjee, G., and Das, K.K. 1995. Application of the yield pillar technique for successful depillaring under stiff strata. International Journal of Rock Mechanics, Mining sciences and Geomechanics abstract, 32 (7): 699-708.