Influences of geo-mining conditions on strata control studies during underground pillar extraction: Some Indian experiences

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Abstract

This paper discusses issues of measurement and analysis of strata control parameters during underground extraction of coal. On the basis of different experiences of field investigations in and around underground coal mining faces, it is observed that the required type of instruments, their positions in the panel and the associated monitoring programme is site specific. It is also observed that depth of cover, depositional conditions, adopted method of mining and goaf treatment are important parameters to be considered during field instrumentation for strata control investigations. Coal mining in India, generally, encounters presence of massive roof strata, which needs to be managed effectively during underground mining. Underground instrumentation and monitoring is an integral part of this management and also for the improvement in the associated design parameters for the mining structures. On the basis of field experiences, it is observed that the continuous monitoring (in time) of installed instruments, preferably with the help of a data logger, can provide important information about performance of mining structures (bord and pillars) during caving of a competent overlying roof stratum. However, in absence of the data logger, behaviour of overlying strata is visualized through analysis of manual observations of conventional instrumentation approach by Combined-Instruments-Approach (CIA). Some actual manual field monitoring data is presented to demonstrate the scope of application of this approach to visualize the influence of geo-mining conditions on strata control studies during underground pillar extraction.

1. Introduction:

Optimisation of safety and recovery during underground coal mining requires *in situ* performance evaluation of basic mining structures like: pillar, roof strata and applied support. This evaluation requires some specialized tools and measurements through underground instrumentation and monitoring (Altounyan et al., 1997; Hebblewhite and Lu, 2004). Mentioning importance of each of these tools, Kelly *et al*. (2002) and Shen *et al*. (2008) have described their applications for assessment of different parameters for a long wall geo-mechanics. However, it is difficult to estimate the behaviour of underground structures for a given geo-mining conditions, mainly, due to complex nature of the associated coal measure formations. Theoretical analysis and modeling, generally, find it difficult to estimate likely rock-mass behaviour in advance. Performance of underground coal mining structures is being influenced by the depositional condition of the site (Smart and Aziz, 1989) and, therefore, empirical formulations are the foundations for most of the working strata control norms.

Dense field measurements (in time and space) of different strata control parameters are must for development of empirical formulations. Field measurements of these strata control parameters during underground mining are challenging (Singh et al., 2004) due to hazardous condition of the instrumentation site. The measurement becomes even more difficult during underground extraction of pillars due to inherited broken nature of a depillaring face in comparison to that of a long wall face. Underground pillar extraction is an important issue for Indian coalfields because a large scale practice of bord and pillar method of mining in the country has locked considerable amount of coal in pillars (Dixit and Mishra, 2010). Most of these locked up pillars are lying under strong and massive sandstone roof of Lower Gondwana age. This roof is known for delayed and violent failure (Singh et al., 2009; Kumar et al., 2007), generally, after creation of a large void during depillaring. Therefore the strata movement monitoring under this condition needs specialized equipments and requires skilled manpower. But, in practice, most of the conventional depillaring faces in the country adopt manual monitoring system, mainly, due to their budgetary constraints. This paper discusses experiences of different underground instrumentation and monitoring studies conducted under varying geo-mining conditions of Indian coalfields. A simple process called Combined-Instruments-Approach (CIA) is also described with the help of some actual field measurement data for the analysis of conventional manual monitoring results. The scope of this process to understand influence of geo-mining conditions on strata control studies during underground pillar extraction is presented with the help of actual field monitoring data.

2. Coal mining in India:

Coal is the major natural resource to meet the primary energy consumptions in India due to its proven geological reserve (table 1). Beginning of the First 5 Year Plan (1950-51) experienced a coal production of 33 Mt, which became 430 Mt by the end of the Tenth 5 Year Plan (2006-07). Even with this increase (nearly 13 times) in coal production, there is an estimated gap of nearly 50 Mt between production and demand in the current fiscal year. An integrated energy policy of the planning commission projects that the coal demand of 446 million tons in the fiscal year 2005-06 is likely to reach up to 2.00 Bt in the fiscal year 2031-32 with 8% growth in GDP. This projection is made after considering the maximum potential of other major resources of energy like Nuclear, Hydro and Gas.

Table 1
Status & Distribution of Coal Resources in India
(As per GSI estimation of resources as on 01-04-2007)

Resources under	Proved	Indicated	Inferred	Total
CIL	62.897*	17.077	2.954	82.928*
CAPTIVE	17.633	40.324	2.820	60.777
TISCO	2.770	0.350	0.000	3.120
SCCL	8.475	6.328	2.658	17.461
NE-REGION	0.467	0.106	0.369	0.924
NON-CIL	3.624	55.584	28.865	88.073
Established after Feb. 2007***	3.194	0.408	0.477	4.080
GRAND TOTAL	99.061**	120.177	38.143	257.380**

* Indicates total geological resources of CIL Mines and blocks (Depletion of resources due to mining have not been accounted for)

** The resources proved by allocattee in the regionally explored allotted blocks not available and hence not accounted.

*** Distribution being worked out.

Country's total coal production in 2008-09 is nearly 493 Mt. Nearly 85% share of this production goes to opencast mining due to existing favourable geo-technical conditions of the sites. Opencast method has attracted mechanization and automation and therefore, the method provided better production, productivity and safety. However, the coal reserve mineable by opencast method is exhausting and the growing environmental concern is also creating difficult situation for this method. The coal mining industry of the country inherits difficult geo-mining conditions, which is going to be even more complicated in near future due to exhaustion of coal reserve from favourable site conditions. Indigenous development of suitable mining technologies is of immense importance because it is not very straightforward to apply a foreign technology for coal production in India due to uniqueness of our coal and rock mass and complex conditions of the coalfields. For these developments, it is also important to gain experience of real behaviour of our rock mass through field measurements.

3. Field measurements:

Out of the two popular mining methods: long wall and bord and pillar, the later one is preferred by the Indian coal mining industry, mainly, due to techno-economical reasons. Most of the bord and pillar mining faces in India adopt intermediate mechanization. Splitting and slicing approach is, generally, followed for underground extraction of pillars. Conventionally, depillaring starts with splitting of pillars into two or more stooks (depends upon size of the pillar) by level/dip-rise drivage, maintaining a diagonal face line and advancing from dip to rise (Figure 1). Percentage of extraction becomes very high during slicing, which initiates roof instability. Therefore, it becomes difficult to access the area in and around a slicing face for instrumentation and monitoring. This problem further complicates if working is taking place under strong and massive roof strata because the increase in the void dimension due to advancement of extraction line may induce dynamic loading over surrounding pillars during caving of the overlying roof strata.

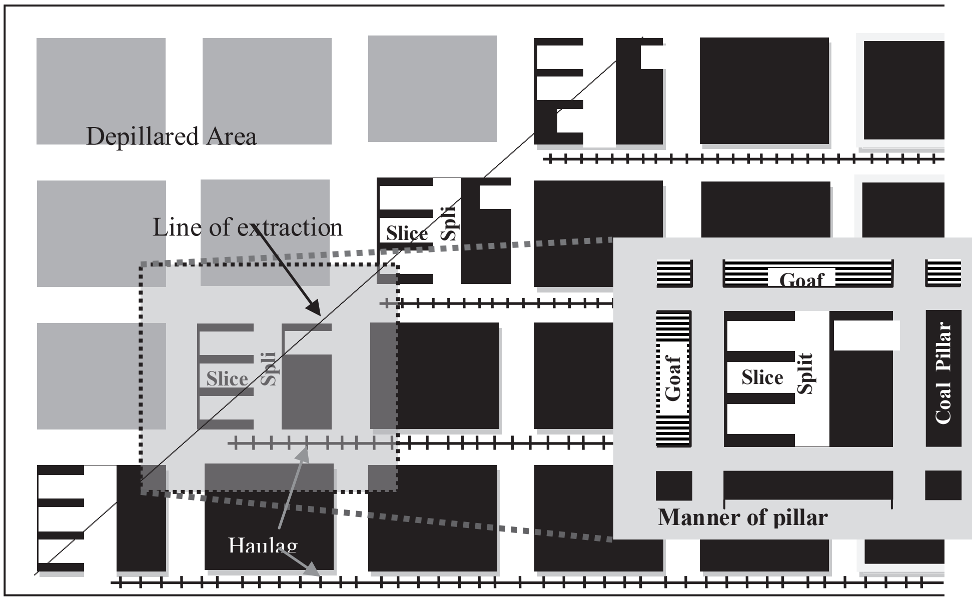

Figure 1 Typical layout of a conventinal depillaring panel with manner of pillar extraction.

With the help of a graduated telescopic rod and two reference points in roof to floor respectively, convergence study works well for strata movement study during development of a coal seam but it is difficult to be measured in and around a depillaring face due to operational constraints. Further, for a stratified formation, there is a good chance that the roof to floor convergence may provide false indication of major strata equilibrium dynamics due to movement of the immediate roof only (Figure 2). A recent strata movement study scheme (Shen et al. 2008) integrated three tools: roof deformation, mining induced stress change and seismicity for successful prediction of roof fall. In India, seismic monitoring system is not well established but stress (vertical mining induced stress) and roof deformation measurements are being widely practiced. It is observed that, for a strong and massive roof strata, monitoring of mining induced stress (vertical) provides better results (Shephered and Lewandowski, 1998; Singh et al., 1996) than the roof deformation study.

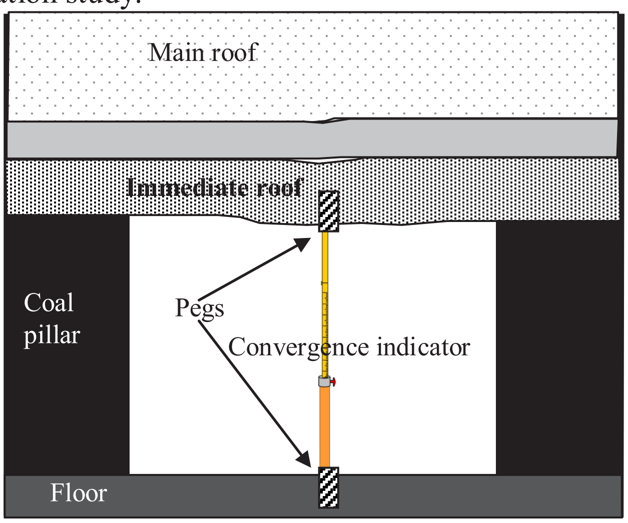

Figure 2 Roof to floor convergence study by a graduated telescopic rod & 2 reference points.

a) Influence roof strata:

The behaviour of overlying roof rock mass influences the characteristics of associated mining structures of an underground mine. For an easily caveable roof stratum, the goaf gets packed quite frequently (Figure 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 an easily caveable roof strata. An underground working face experiences large overhang if the roof strata are strong and massive in nature (Figure 4). Under this condition, stress meters may play important role to visualise the nature and extent of dynamic loading (Singh et al., 1996) during enmasse movement of the roof strata. A careful monitoring of mining induced stress (vertical) development over pillars may help in estimating the time and period of occurrence of the dynamic loading (Singh et al., 2002; Singh et al., in press). As per different field experiences of mining induced stress measurement, if more than 50% of total amount of the observed mining induced stress is developed within 0 to10 m range of the goaf edge then the pillar is said to be experiencing dynamic loading.

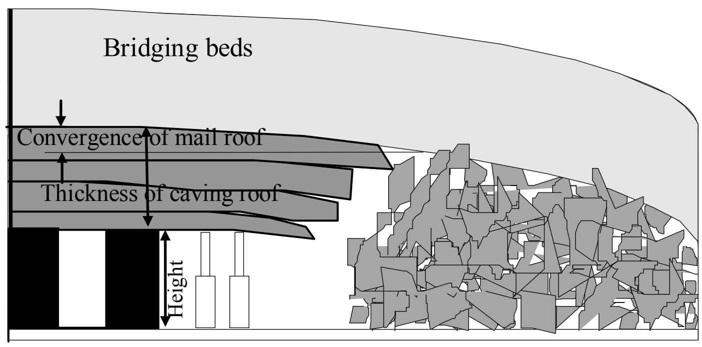

Figure 3 Bulking factor controlled caving of weak and laminated overlying strata.

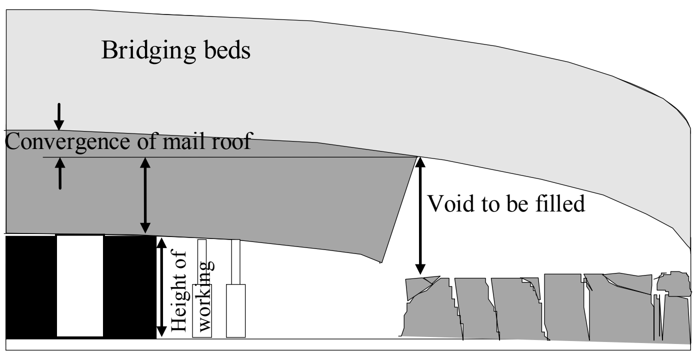

Figure 4 Parting plane controlled caving of strong and massive overlying strata.

Results of field monitoring of mining induced stresses at two different sites are presented in Figure 5 to show the influence of overlying roof strata over nature and amount of the mining induced stresses. Figure 5(a) shows variation of the mining induced stress for depillaring under an easily caveable overlying roof stratum of GDK No.5 Incline mine.

Figure 5(b) represents variation of mining induced stress over a pillar for depillaring under massive and strong sandstone roof strata of GDK No.2 Incline mine. Strength and dimensional information of instrumented pillars of these two mines are mentioned in Table 2 and borehole sections of overlying strata are shown in Figure 6. Thus the competency of overlying roof strata becomes an important factor during selection of type of instrument to be applied for a strata control monitoring.

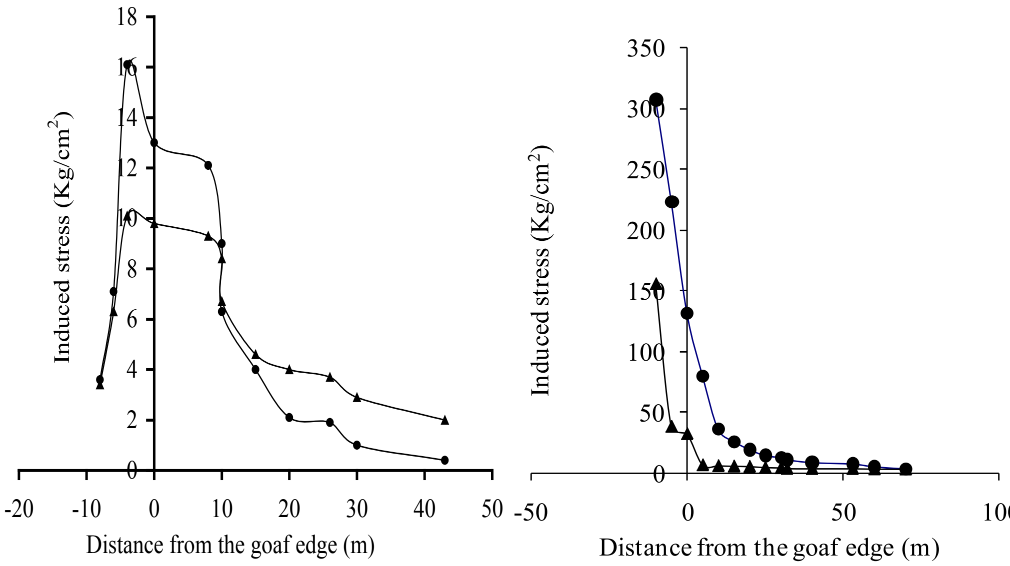

Figure 5 Two field observations of variation of mining induced stress (vertical) with face advance under weak/laminated and strong/massive overlying strata.

Table 2
Strength and dimensional information about the instrumented pillar/stook.

Geo-mining parameters	GDK No. 5 Incline	GDK No. 2 Incline
Name of seam	4 Seam	3A Seam
Size of the pillar (m x m) (corner to corner)	25 x 25	45 x 45
Thickness of the immediate roof (m)	5.79	48.76
Method of mining	Bord and Pillar (stooking & slicing)	Bord and pillar (stooking & slicing)
Compressive strength of coal, (MPa)	35.8	40.1
Stook size (corner to corner), (mxm)	8 x 8	10 x 15
Equivalent stook size, (m x m)	8 x 8	12 x 12
Equivalent width, (m)	8	12
Working height, (m)	4	1.6
Depth, (m)	45	235
Compressive strength of stook, (MPa)	7	21.75

b) Instrumentation planning

Underground pillar extraction obliges local site conditions, and, therefore, it is difficult to have a "typical" underground mining condition during depillaring, which can be used as a benchmark to decide the instrumentation scheme for the strata control investigation. However, from stability point of view, underground coal mining generates mainly three types of structures. 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 applied/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

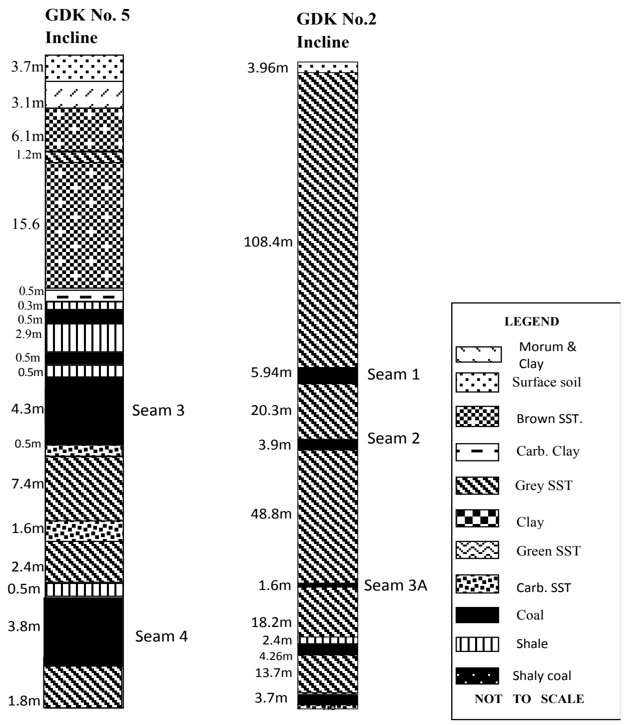

Figure 7 Strata section of rock mass above the panels of GDK No.5 and GDK No.2 incline mines.

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 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 these structures. Here frequency of observations is to be very high (neatly continuous in time) to deal with the strata equilibrium dynamics.

4. Continuous monitoring:

Caving of massive and strong overlying strata is always a problem and, generally, takes place after a large overhang inside the goaf. Pillars/stooks standing in and around the diagonal line of extraction experiences dynamic loading (Mathur, 1992) during caving of such competent roof strata. As shown in Fig. 5, the caving of massive and strong strata is sudden in comparison to that of weak and laminated strata. Sudden failure of strong and massive roof strata is difficult to be safely noticed by the conventional manual monitoring. Under this condition, it is always better to monitor the readings, almost continuous in time, with the help of a microprocessor based data logger system. The conventional semi-mechanized depillaring faces, generally, do not provide financial and technical support for such a continuous monitoring system. However, few recently introduced fully mechanized depillaring faces (Leeming, 2003) have incorporated microprocessor based data logger system with encouraging results (Mandal et al. 2004). To observe the nature and amount of mining induced stress over pillars, a number of stress meters were installed at different selected locations inside a panel. Horizontally drilled bore-holes across pillars were used to fasten these stress meters at different intervals. After gaining some experience of nature of the stress development, only one or two stress meters were installed inside a horizontal hole across the selected pillar, which was selected in such a way that it picks up the maximum amount of stress.

An observation of mining induced stress development (vertical), made with the help of a vibrating wire stress meter connected to data logger interfaced with a computer, is shown in Figure 8. Due to continuity in observations, indication of roof fall could be noticed around, couple of hours (Figure 8) before the major roof fall during the depillaring resulting safe withdrawal of man and machine. Characteristics of strata equilibrium dynamics during caving of strong and massive overlying strata could be visualized through these rich observations of a computer interfaced data logger connected to the installed instrument.

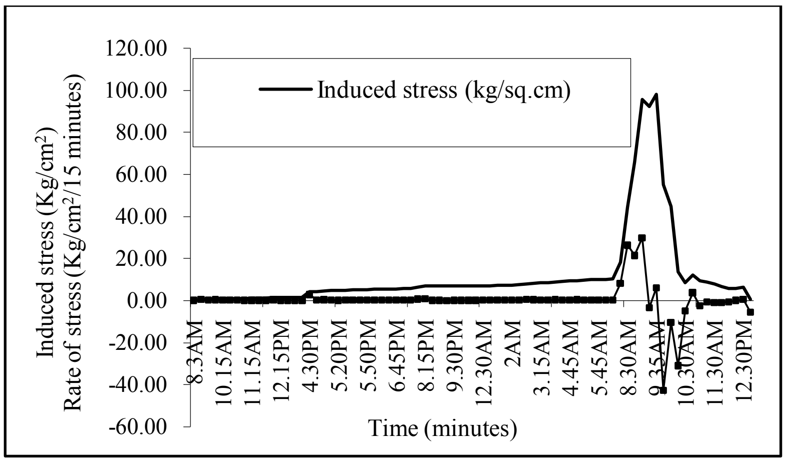

Figure 8 An obtained variation of mining induced stress (vertical) development with time during an online monitoring by a vibrating wire stress meter, connected to a data-logger interfaced with a computer.

5. Combined instruments approach:

The scope of instrumentation and monitoring utilizing a data logger interfaced with a computer is enormous. However, due to different technical and financial reasons, most of the Indian depillaring faces adopt manual monitoring approach. The connecting cables of the installed instruments are taken out of the working to a safe place and frequency of manual observations is increased after encountering a large overhang of roof inside the goaf. Conventionally, a number of instruments are installed at different selected stations inside the panel and their readings are manually monitored with face advance. Manual monitoring provides discrete readings, which may not be suitable to project the likely behavior of overlying strata. On the basis of different field experiences, a simple process called Combined Instruments Approach (CIA) developed for better analysis of the manually observed data of underground instrumentation.

a) Perception

CIA is to analyze field data, collected manually during *in situ* monitoring at different coal mines under competent roof strata. Under this approach, geo-mining conditions of the site are assessed, first, to finalise number and type of instruments to be installed around expected line of main roof fall. Selection of size of the instrumented stook for mining induced stress measurement is done as per geo-mining conditions and is discussed by Singh et al. (*in press*). In fact, during an underground 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 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. Zero position of the instrument arrives when the line of extraction approaches the instrumented station. The instrument encounters quite a large amount of strata movement at its zero position but peak of the movement, often, do not coincide with the zero position of the instrument.

In fact, peak of the strata movement is observed during a major roof movement/fall. But an underground investigation needs instruments to be installed before commencement of depillaring, the peak of strata movement is difficult to match with the zero position of the instrument. On the basis of a pre-assessment of nature of the overlying roof strata through available borehole information, different stations for instrumentation are selected and instrumentation is done before commencement of extraction in the panel. Assessment of roof strata for selection of instrumented pillar is done in such a way that the instrumented site encounters maximum stress/ground movement. Monitoring of variation of readings of each of these instruments with respect to face advance is done independently for all the stations. Such monitoring of an instrument provides broken and discrete data, but there is possibility of getting some continuity if data of all such observed stations are combined together. Here a considerable shift between zero positions of the instruments and their respective peak value is observed. This shift in peak value from zero position of instrument needs to be adjusted for each independent observation. This adjustment exercise is done mainly to compensate the deviation in the instrument positions, which were supposed to encounter the maximum value of the strata control parameter during the monitoring. The new arrangement of the data so obtained is likely to have better correlation with the major strata movement in the panel. Further, the data is subjected to statistical analysis to eliminate the observational crowd and to represent the value of the parameter at regular interval. The analysis adopts biasness for preservation of the peak value of the parameter because the frequency of measurement does not match here with the dynamics of the strata equilibrium. At some mines, even two or more types of instruments are used at each independent observational station and so they are combined separately to get values of two or more strata control parameters. The above-mentioned process of monitoring is termed as CIA and an example of its application for monitoring of mining induced stress (vertical) is given in next sub-section.

b) Mining induced stress

The significance of understanding the nature and amount of mining induced stress is mentioned in (Singh et al., *in press*) and, accordingly, a programme of its measurement at different depillaring face was undertaken. Vibrating wire stress meters were installed at different depillaring faces but monitoring of most of these instruments was done manually. From operational point of view it is, relatively, easy to maintain stress meters, which are safely placed inside horizontally drilled holes in the pillars in and around a depillaring face. To observe the nature and amount of mining induced stress over pillars, stress meters are placed at certain intervals inside the holes, drilled across different pillars of the panel. To pick up the maximum value of the induced stress, there is a requirement of dense installation (nearly continuous in space) of stress meters. However, experience of roof strata assessment is used to make the study economical through discrete placement (in space) of stress meters at selected stations of a depillaring panel.

Projection of likely behavior of the overlying strata during progress of a depillaring panel is observed to be difficult through analysis of the manually observed readings of different individual instrument. Conceiving the idea of combination of results of all individual instruments in the panel; correction for the positional biasness of the instrument is thought by shifting maximum observed values of each station to the zero position of the instrument. This attempt to get some better information through conventional instrumentation and monitoring is applied at a number of mines with good amount of success in assessing hostile impact of difficult overlying strata during depillaring. Not only systematic support of roof but the conventional design of rib (X snook) is modified at some sites after getting an indication of dynamic loading by monitoring of the mining induced stress development. An example of application of this approach for monitoring of mining induced stress development and assessment of the dynamic loading is given in subsequent section.

6. Field application:

Conventional instrumentation and manual monitoring of data is adopted during depillaring of Zero seam at Anjan Hill mine, Chirimiri Area of South Eastern Coalfield

Limited (SECL). Here, No. Zero seam of 5.33 m average thickness was developed in a single section along floor. Development was made leaving 0.6 to 1.0 m thick coal band along the roof. Average size of the developed pillars was 33 x 33 m (centre to centre) and average gallery width was 4.8 m. No extractable overlying seam was present over the Zero seam. Considered panel ‘C’ of the mine for depillaring consisted 70 pillars (Table 3). After a study of the characteristic of the overlying strata, total nine stations (Fig. 9) were selected and each station was instrumented with stress meters and convergence indicator.

Observed data of mining induced stress development through manual monitoring is shown in Figure 10. This figure shows data of only eight stations as stress meter at one station did not work. This figure shows that the maximum of mining induced stress could not be

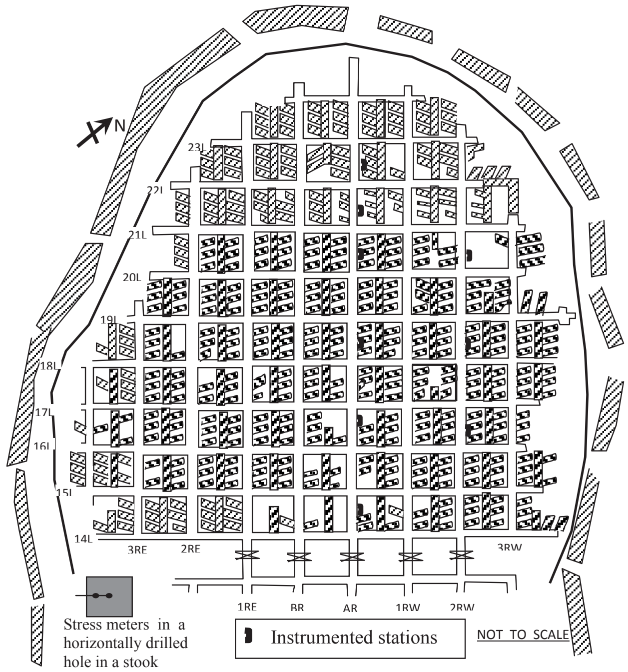

Figure 9 Plan of the instrumented panel ‘C’ showing location of instrumented stations.

Table 3
Boundary conditions of the panel ‘C’.

Parameter	**Description**
Panel extent	14L to 24L and 3RW to 3RE
Size of pillar	33 x 33 m (centre to centre)
Gallery width	4.8 m
Seam thickness (average)	5.33 m
Development height	4.5 m
Extraction height	4.5 m
Width of split gallery	6.6 m

Width of slice (maximum)	6.6 m
Depth of cover Maximum Minimum	 120 m 52 m
Gradient	1 in 30
Incubation Period	6 months
Barrier of the panel North South East West	 Leasehold barrier Leasehold barrier Standing pillars against panel 'B' Leasehold barrier

observed at zero position of the instrument. All these eight sets of data were brought together (Figure 11) to improve the continuity of observations. Combination of all individual set of observations of each instrument in this plot experienced scattering of data. This scattering could be minimized by shifting maximum of each individual observation to the zero position of the instrument followed by a linear interpolation of each set of data with

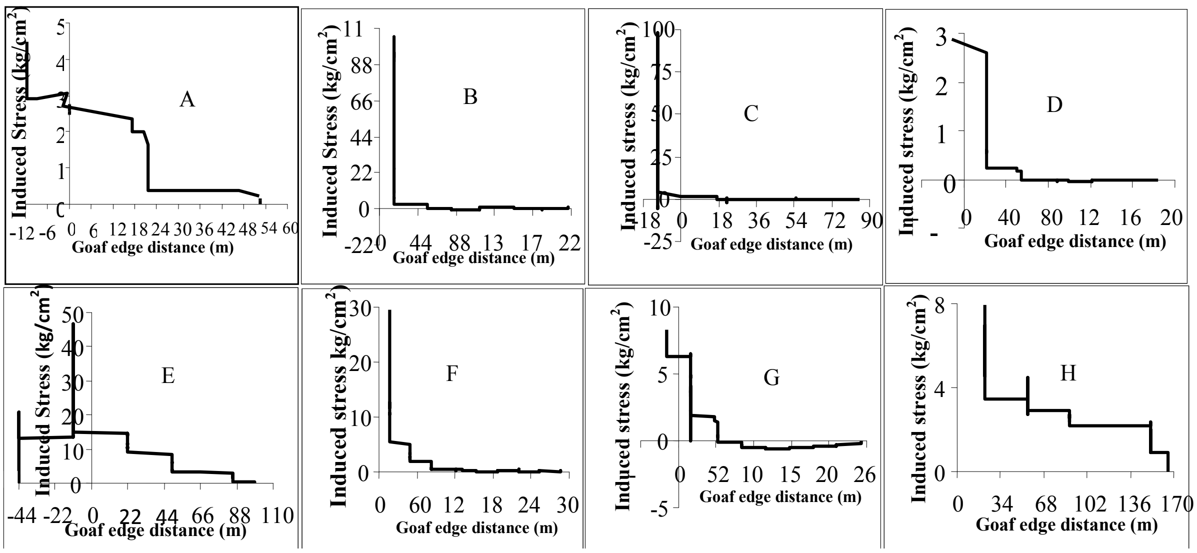

Figure 10 Manually observed variation of mining induced stress with face advance at different individual instrumented stations.

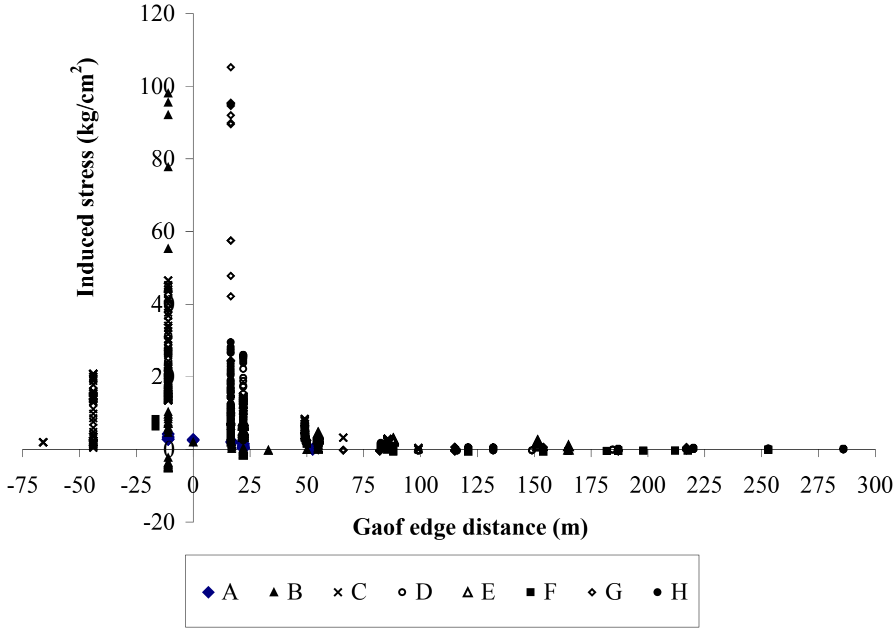

Figure 11 Combination of all individual set of observations of variation of mining induced stress with goaf edge distance.

averaging of the values at regular interval and preserving peak values within 5 m goaf edge distance (Figure 12). This figure shows that the depillaring in other surrounding panels of this mine is likely to face dynamic loading. However, a similar instrumentation, monitoring and analysis of data at another mine (Nowrozabad Colliery) did not notice dynamic loading of

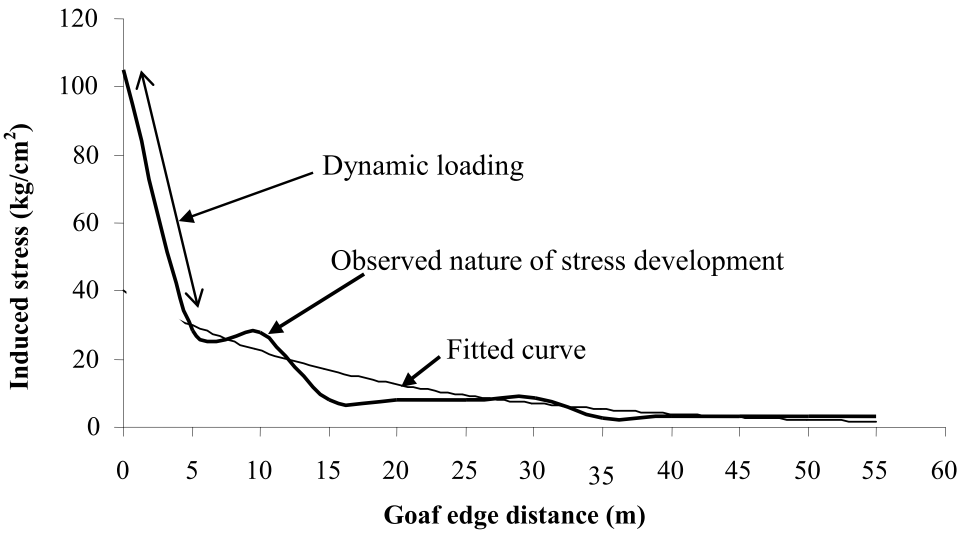

Figure 12 Projected nature of mining induced stress (vertical) variation under the geo-mining condition of Anjan Hill Mine.

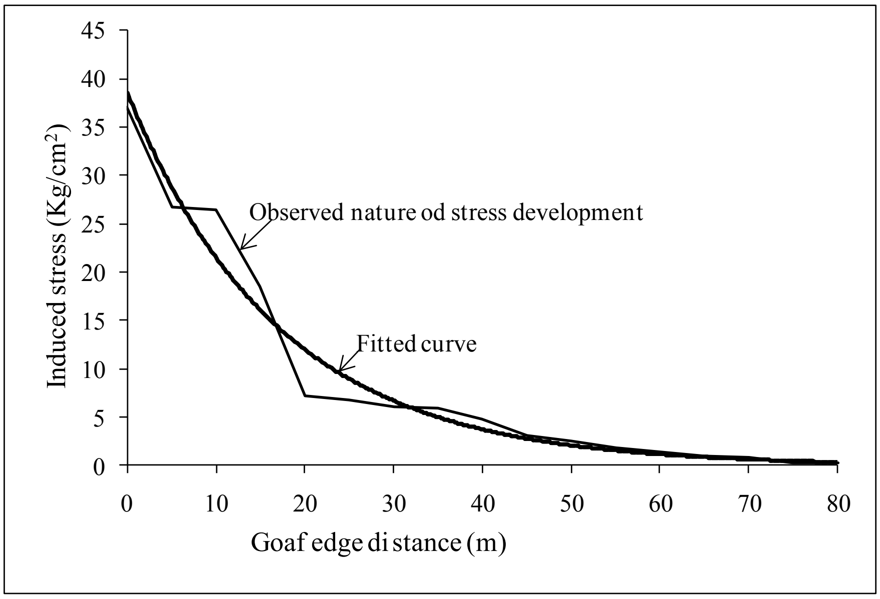

Figure 13 Projected nature of mining induced stress (vertical) variation under the geo-mining condition of Nowrozabad Colliery.

surrounding pillars (Figure 13) during caving of the overlying strata. Nearly 80% of total amount of the developed mining induced stress at Anjan Hill mine is observed within 0 to 10 m range of the goaf edge while the same range of goaf edge at Nowrozabad Colliery experienced nearly 40% of total amount of the developed mining induced stress. These field observations show the applicability of CIA during conventional instrumentation and manual monitoring.

6. Conclusions:

Field instrumentation and monitoring of actual rock mass behavior plays significant role during underground extraction of pillars under competent overlying strata. It is observed that the competency of overlying roof strata affects instrumentation and monitoring strategy considerably to understand rock mass response under changing extraction percentage at different positions of a depillaring face. Continuous monitoring (in time) of mining induced stress (vertical) development using vibrating wire stress meters, connected to a computer interfaced data-logger should be preferred for improvement in, both, safety and design of underground structures. Study of local site conditions provides important inputs for finalization of number and position of observation stations but it is very difficult to do accurate assessment of the rock mass behavior in advance. An attempt to correlate the nature and amount of the observed mining induced stress (vertical) with the mining activity is important to arrive at a meaningful result of a manual monitoring, where application of CIA process may provide better results.

Acknowledgements:

The authors are obliged to the Director, CIMFR, for his permission to publish this paper. The study reported in this paper is based on a Science and Technology (S&T) project funded by the Ministry of Coal (Government of India) and supported by Central Mine Planning and Design Institute Limited of Coal India Limited. The co-operation provided by the management of different coal companies during the field study is thankfully acknowledged.

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