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Significance of Strata Monitoring Instruments in Roof Fall Risk Assessment of an Underground Coal Mine

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Abstract: This paper refers to the role of strata monitoring instruments in risk assessment of roof falls in an underground coal mine. Detailed investigation in to the factors responsible for roof fall was carried out in an underground coal mine situated in Central India. The investigation was supplemented by In-situ stress assessment by drilling yield measurements and convergence recording by strata monitoring instruments. It was observed that strata monitoring instruments gives early indications about initiation of strata movement and potential roof fall. The proper analysis and interpretation of the readings from strata monitoring instruments is very much helpful in updating the risk assessment and preventing the roof fall by risk management.

Index Terms- Risk Assessment, Strata monitoring instruments, Roof Fall, underground, coal mine.

I. INTRODUCTION

Roof fall is the major contributor towards fatal and serious accidents in underground mines. A risk assessment technique is frequently used worldwide to manage and reduce the consequences of roof fall. The mining conditions changes with time after the initial exposure of roof and sides. The risk assessment of roof fall, done before or immediately after the drivage of gallery must also be updated from time to time with changing mining conditions. Close monitoring of the strata monitoring instruments enables to update the Risk Rankings and act accordingly in time to manage the risk.

The analysis in to the causes of fatal accidents in Indian coal mines during the period 1998 to 2010 revealed that, roof fall is the major cause of fatal accidents. In spite of all the precautions taken in this regards, trend of accidents due to fall of roof and sides is not arrested. (D.G.M.S, 2011) [1] Fig.1 shows the cause-wise classification of fatal accidents in India for the period 1998 to 2010 and it can be seen that 32% of the total fatal accidents were occurred due to roof falls. (D.G.M.S, 2011) [1]. According to D.M. Pappas & C. Mark, 2009 [2] from 1999 through 2008, ground fall events resulted in 75 fatalities, 5,941 injuries and 13,774 non injury roof falls in U.S. underground coal mines, according to the U.S. Mine Safety and Health Administration (MSHA).

The main consequences of these accidents can be in the form of human disabilities, fatalities, production downtimes and deterioration in industrial relations which ultimately results in economic loss to the industry. Shahriar, Oraee & Bakhtavar, 2005 [3] used the decision analysis tree for comparison between estimated costs of accidents & the cost of preventive measures to arrest them and shown that the application of later is economically feasible. Employing proper education system, accurate supervision on safety considerations and support improvements are the Risk Management tools applied to reduce the severity of consequences.

As per the recommendations of 11th conference on Safety in Mines held on 4th & 5th July, 2013 at New Delhi, India.[4] - In every Coal mining company, strata control cell shall be established at corporate and area levels within a period of one year, to assist mine managers, for formulation of Systematic Support Rules, monitoring strata control measure in a scientific way to ensure efficacy of support system and for procurement/supply of quality supporting materials. Risk assessment exercise shall be carried out in the mines for assessing for risk from the hazards of roof and sides falls and identifying the control mechanism with specific responsibility for implementation. This exercise shall be reviewed at regular intervals not exceeding a year. Every mine should employ a sound risk analysis process, should conduct a risk assessment, and should develop a safety management plan to address the significant hazards identified by the analysis / assessment.

Mustanir Ali (2014), [5] described Strata monitoring Instruments, which typically measure the strata movement. They are low cost and installed at frequent intervals. They are commonly installed to monitor the roof near working faces, along travelling roadways and at other places frequented by workmen. They are there to warn mine workers about the danger. As such they are designed to show strata movement on a clear and easy to interpret scale of measurement, accurate to at least 1 mm. Analyzed collectively they can provide data for design verification. Safety and design of monitoring equipment forms an important part of efficient, cost-effective rock bolted roof-support systems in underground coal mines.

David Conover, Tim Ross and David Bigby (2010) [6] compared the results of strata monitoring by manual and automated instruments. Extensive arrays of tell-tale roof monitoring instruments were installed in a Mexican copper mine and a large underground mined storage facility in the eastern U.S. The data were used to evaluate roof stability during development and retreat mining and after installation of supplemental supports. The response of tell-tale in relation to known events affecting roof stability, including nearby pillar extraction, roof caving, and installation of supplemental cable bolts and separation of the immediate roof layer was studied. The strategy for processing the large quantity of data, presenting the data for review, monitoring the system remotely, and identifying and reporting critical events was described.

Anthony T. Iannacchione, T.S. Bajpayee and John L. Edwards (2006) [7], examined the potential for monitoring microseismic emissions activity as a means of forecasting roof falls. There has been a persistent need to forecast roof falls, so that miner's exposure to hazardous underground environments can be minimized. Several monitoring techniques have been developed and are used today with varying levels of acceptance in the mining industry. The microseismic activity collected from Moonee Colliery demonstrates that techniques to forecast roof rock instabilities in underground mines are possible.

T. S. Bajpayee, A. T. Iannacchione, NIOSH and S. R. Schilling (2008) [8] described a case study where a surface-based microseismic system, using triaxial geophones in boreholes drilled from the surface, was deployed at a large limestone mine for detecting strata fracturing and roof failures. It detected the first rock fracture event 17 minutes before the rock fall event. The geophone array was sensitive enough to identify all large rock fracture, impact, and blast events as well as medium-size rock fracture events occurring close to the geophone array.

Razani, Chamzini and Yakhchali (2013) [9] applied Fuzzy inference system (FIS) to predict roof fall rate more in accurate, precise, and sure way for controlling, mitigating, and/or even eliminating the risk of roof fall. A technical report by McDonnell and Haramy (1988) [10] states that, if mine operators can locate high-stress and potentially burst-prone zones, they can then use stress-relief methods to control the burst condition. One method of locating the high-stress zone is the probe-hole-drilling or drilling-yield method. Singh Rajendra, Singh A. K., Mandal, Singh M.K. and Sinha, 2004 [11] done assessment of stress level by instrumentation and monitoring of strata movement during underground coal mining. They concluded that the hostile impact of these stresses can be managed effectively by instrumentation and monitoring of strata control parameters. Mark K. Larson, Douglas R. Tesarik, J. Brad Seymour and Richard Rains (2000) [13] described different types of geotechnical instruments in underground mines to study ground control problems and develop means of reducing accidents and fatalities caused by ground falls. The advantages and disadvantages of various sensor technologies, various instruments, sensors, and data acquisition equipment that have been used for studies were explained. The practical recommendations regarding the use of specific instruments and data acquisition systems were provided. The general approach to the design and implementation of a successful instrumentation plan was also outlined.

R. R. Yerpude and Deepak V.Walke (2014) [14] investigated in to the factors affecting roof fall risk in an underground coal mine. During investigation, the real time developments in roof instability before actual occurrence of roof fall was assessed with the day to day observations of strata monitoring instruments like tell-tale, glass bearing plate and rigid convergence recorders. Aveek Mangal (2013) [15] described Support resistance as the most promising and effective scientific tool to predict various aspects related to strata mechanics of Longwall mechanized workings. The characterization and understanding of geo-mechanics of longwall strata is very important for determining support requirement and planning and design of panel layout so as to ensure safety, stability and higher productivity. To understand actual fracture zones, fracture propagations and failure mechanisms of the longwall face, the geo-technical field investigation with various forms of field measurements techniques have been carried out using instruments like stress capsules, extensometers, convergence measurement devices, subsidence surveys, borehole camera, observation of water loss in experimental boreholes etc. He used observations of the strata monitoring instruments as one of the inputs for development of software to estimate the required support resistance.

II. MATERIAL AND METHODS:

Risk assessment is a methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihoods and the environment on which they depend. The Standards defines Risk as 'the chance of something to happen that will have an impact upon objectives. It is measured in terms of consequences and probability.

Risk = Consequences x Likelihood

The term ***Consequence*** can be defined as the outcome of an event or situation, such as a loss, injury or even as a gain. The loss events could include: Death, Serious injury, First aid treatments, Acute or chronic disease, Loss of production, Equipment damage, Environmental damage, Loss of reputation etc.

Likelihood: Is used as a qualitative description of probability and frequency.

Likelihood = Probability x Frequency

Probability: Is the likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes.

Frequency: Is a measure of likelihood expressed as the number of occurrences of an event in a given time.

Investigation:

The mine selected for the study is situated in central India near Nagpur. There are four workable seams having thickness ranging from 1.8m.to 5.5m.and the Rock Mass Rating (RMR) from 32 to 57. The method of work adopted is Board & Pillar. The uppermost seam is having RMR of 32. It is overlained by clay band of about 1m.thickness and water charged sandstone - Kamptee Series. There is history of roof falls in that seam, total 73 number of recorded & un-recorded, small & large roof falls were occurred in this seam during last 10 years. Almost all the roof falls occurred either in the vicinity of major angular discontinuity, at roadway junctions or near active working faces. Therefore, these areas were considered as vulnerable locations for roof fall. The various phases of investigation include -

- Study the history of Roof-falls in mine.
- Selecting the locations of monitoring stations.
- Recording the initial roof condition by physical observations.
- Recording the initial status of fixed and variable factors affecting roof fall and their sub-categorization.
- Installation of strata monitoring instruments.
- Assessment of In-situ stress level by Drilling Yield measurements.
- Observing the changes in strata behavior and roof movement with time.

- Observing changes in selected variable factors with time.
- Recording the read data of strata monitoring instruments on daily basis.
- Recording the data of physical observations and measurements just before or at the time of roof fall.
- Analysis of the observed data.

The various factors considered for the Risk assessment of roof fall were:

Geological Factors: Large angular discontinuities, Joint frequency, Roof layer thickness and bedding contact Strength.

Mining Induced Factors: Shear rupture surface, Joint separation, Lateral strata shifting, vertical strata separation, Roof rock debris on floor and Roof shape.

Moisture factors were also taken into account for risk assessment.

Strata monitoring: Observations of Strata monitoring instruments were considered as a important factor. The roof to floor Convergence records by- Tell-tale, Glass bearing plate, and telescopic gauge/Steel tape measuring were used as inputs for Risk assessment and its updating from time to time.

In order to make the Risk assessment realistic and practical, the attempts were done to convert the roof fall probability in quantitative terms. The Spirit of Fault Mode Effect analysis (FMEA) method is used and two measures have been considered for the purpose. The first one is to assign the probability factor (Pf) for each sub-category of risk factors ranging from 0 to 4.This indicates different levels of roof fall risk and the increasing values represent higher potential for failure. The probability factor is an index which represents the probability of roof fall for each sub-category. The second one is to give a weight (W) to each parameter which ranges from 1 to 3. Since the effects of different parameters on roof fall are not the same, it is necessary to give a weight to each parameters based on its importance on roof fall occurrence**.** Sum of the weighted probability factor is then used to derive the predictor equation as an indicator of roof fall. Once the RPRI for a particular station is calculated it was then converted in to the standard scale of Likelihood - 1 to 5, for fitting in to the established method of risk ranking.

Risk Probability Ranking Index:

$$\text{RPRI} = [\sum (Pf1*W1 + Pf2*W2 + \ldots Pf13*W13) \div \sum (MPf1*MW1 + MPf2*MW2 + \ldots MPf13*MW13)] \times 100$$

Where, Pf1 = Probability factor for each factor,
W1 = Weightage number for each factor
MPf = Maximum Probability factor for each risk factor
MW = Maximum Weightage number for each risk factor.

The Consequences level of 1 to 5 is then assigned to all the situations .The levels of consequences is then multiplied by the Likelihood levels to derive the final Risk Ranking Index. Thus the RPRI and Risk Ranking Index for every monitoring station were calculated.

Strata Monitoring:

Strata Monitoring Instruments: Optimization of safety and recovery during coal mining involves a number of measurements through instrumentation and monitoring. Rajendra Singh, A.K. Singh, P.K. Mandal, M.K. Singh & Amalendu Sinha (2004) [11] stated that the hostile impact of highly active nature of mining induced stress development over the natural support under a hard and massive rock can be tackled through effective underground instrumentation and monitoring strata control parameters. Prediction of strata behavior by theoretical analysis becomes unreliable due to almost impossibility of simulation of the real field conditions in mathematical, physical or numerical models. Thus, S Jayanthu (2011) [13] stated that the empirical formulation, based on in-situ measurements of strata behavior parameters, is an accepted way to estimate the strata behavior. There is a need to be more innovative in application of the existing instrumentation with proper planning by experienced strata control engineers which may lead to possibility of modification in existing practices for better safety and economy of mining venture. Convergence of advance workings in depillaring panels has been widely believed to be a reliable indicator for warning of goaf falls.

The real time developments in roof instability before actual occurrence of roof fall was assessed with the day to day observations of strata monitoring instruments. The convergence recording at selected sights was done with the following instruments:-

Tell-tale: It is the simplest mechanical device consisting of strata movement indicator positioned in the mouth of a drilled hole and attached to an anchor installed up to the hole. It provides pre-emptive warning of roof-falling by detecting any unstable trends in the strata by estimation of bed separation in the roof so that timely remedial action can be taken. The Dual Height Tell Tale is used in the present investigation with highest anchoring 0.15m below the clay band.

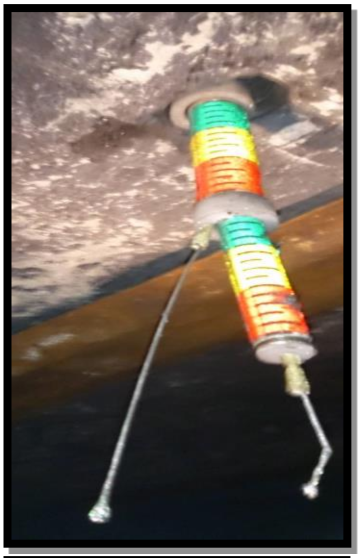



Figure 1: Convergence - 12mm **Figure 2: Convergence – 14m**

Glass bearing plate: Figure 3 shows the assembled glass bearing plate placed on steel bearing plate and a dome washer. It consists of a square type bearing plate made of glass and having cuts at its corners. This plate placed diagonally over the steel bearing plate fitted with acrylic sheets having 3mm and 6mm thickness just at inner side of the cuts at glass plate. The roof bolt is point anchored at roof and this complete assembly is just tightened on it by dome washer and nut.

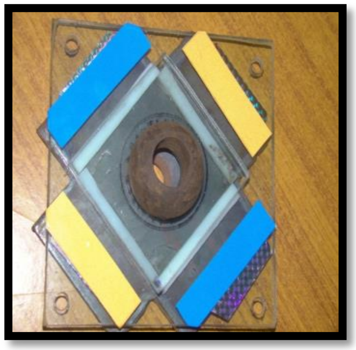
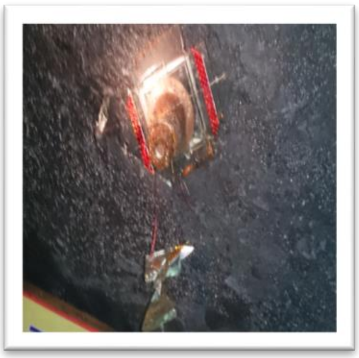



Figure 3: Assembled Glass Bearing plate **Figure 4: Glass bearing plate installed underground**

The principle behind this is that when the roof layers separates, the converged roof exerts pressure on the glass bearing plates which is indicated by breaking the pre-cut corners of the glass bearing plate. Initially the corner placed on 6mm acrylic sheet breaks and then on the 3mm sheet, indicating the convergence of 3mm and 6mm respectively. When the roof convergence above 6mm occurs the plate breaks completely.



Stage 1 Stage 2

Stage 3 Stage 4

Figure 5: Broken Glass bearing pates Showing Convergence

Roof-to-Floor Convergence recording: Convergence points were installed at suitable locations for recording roof to floor movements at different stages. The steel rods with pointer arrow welded to it were grouted on roof and floor. The telescopic rod convergence meter was used to measure the distance between these two pointers, one in the roof and the other on the floor vertically below it. The monitoring was done on 8 hourly basis and readings were noted on day to day basis. One or the other of above three monitoring instruments was installed at selected sites. The various instruments installed at various stations are given in table 1.

Figure 6: Rigid convergence Recorders installed underground

III. OBSERVATIONS

Total 57 nos. of monitoring stations were installed & readings were recorded during the period of investigation. All the 57 vulnerable zones selected for investigation were closely monitored on day to day basis during the period of investigation. In totality 7 numbers of roof falls occurred during this period. It is observed that all the factors identified for investigation were present with almost highest severity at all the sites of roof fall. On the other hand there were number of cases where roof falls did not occur even after presence of one or more of these factors with moderate or high severity. On the other hand strata monitoring the instruments recorded convergence at every site of the roof fall.

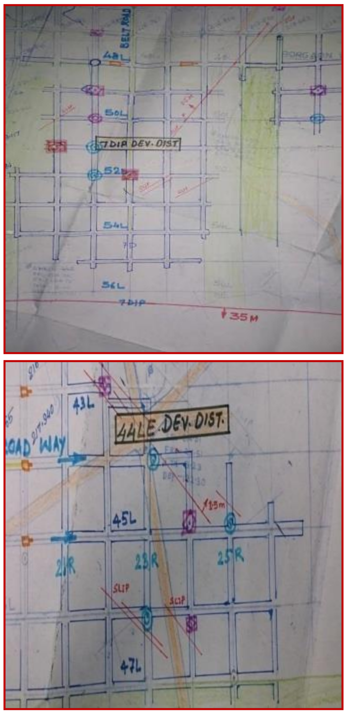


Figure7: Typical Strata Monitoring Plans of the workings

The Strata monitoring plans showing locations of various instruments were maintained and updated as and when required

Table-1 Details of strata monitoring instruments installed at various stations

Region	RMR	Type of instrument	No. of stations	Not Considered	Monitored	Remark
Seam "A"	62	Tell-tale	3	-	3	Some Stations were damaged due to mining or human activities at initial stage therefore not considered.
		Glass Bearing Plate	2	-	2	
		Convergence recorders	3	-	3	
Seam "B"	43	Tell-tale	3	3	Nil	
		Glass Bearing Plate	3	3	Nil	
Seam "C"	32	Tell-tale	10	-	10	
		Glass Bearing Plate	12	-	12	
		Convergence recorders	21	-	21	
Total			**57**	**6**	**51**	

Table 2 - The summery of strata monitoring instruments used during the investigation

Type of instrument	No. of stations	Not Considered (No.)	Monitored (No.)
Tell-tale	16	3	13
Glass Bearing Plate	17	3	14
Convergence recorders	24	0	24
Total	**57**	**6**	**51**

Some of the important observations were:

1) Total 7 no. of roof falls occurred during the period of investigation. The strata monitoring instruments shown early indications of the convergence at all such sites.

2) All the roof falls occurred at places after the convergence recorded by Glass Bearing plate is more than 6mm.

3) Roof fall occurred after the convergence of 16 to 20 mm was recorded by tell- tale.

4) Most of the roof falls occurred with the gap of 3 to 4 days after initial convergence recorded by the instrument.

5) At five no. of sites risk assessment was updated after recording the convergence by strata monitoring instruments. The further deterioration of roof was arrested by additional support and roof falls were saved.

6) Roof movement near discontinuity, running across the roadway was controlled by positive support even after recording the convergence.

Table-3 Observations of strata monitoring instruments and comparison with RFRI and RRI

Station	RFRI	Risk Ran king	Instrumentation Results	Remarks
(GBP-1)	43	6	No crack	No physical indications
(GBP-2)	41	8	No crack	No physical indications
(GBP-3)	42	10	No crack	No physical indications
(GBP-4)	52	9	Damaged	Indicator prop erected
(GBP-5)	88	10	12.5.13 - 3mm	**Supported by Girders**
(GBP-6)	69	16	20.5.13 - 6mm	**Supported by Girders**
(GBP-7)	41	8	No crack	No physical indications
(GBP-9)	83	20	Broken on 28.11.13	Roof Fall
(GBP-10)	47	6	No crack	**Steel cogs erected**
(T.T.-1)	49	10	1.12.13 – (0,5))	No physical indications
(T.T.-2)	46	6	5.5.13 - (0,1)	No physical indications
(T.T-3).	49	10	18.12.13-(3,10)	**Steel Cog erected.**
(T.T.-4)	50	8	Damaged	**Positive support**

				Erected.
(T.T.-9)	41	**8**	Damaged	Indicator prop erected
(T.T.-12)	47	**8**	14.11.13 -(0,5)	No physical indications
(T.T.-13)	44	**6**	23.12.13- (4,3)	No physical indications
(R.C.-1)	41	**6**	Nil	No physical indications
(R.C.-2)	41	**10**	Nil	No physical indications
(R.C.-3)	44	**6**	Nil	No physical indications
(R.C.-4)	59	15	23.12.13-(6mm)	**Positive support Erected.**
(R.C.-5)	42	**6**	Nil	Indicator prop erected
(R.C.-6)	44	**6**	19.12.13 -(1mm)	No physical indications
(R.C-.7)	41	**8**	Nil	No physical indications
(R.C.-8)	43	**10**	Nil	No physical indications
(R.C.-9)	44	**8**	19.12.13-(3mm)	No physical indications
(R.C.-10)	44	**10**	5.12.13-(3mm)	No physical indications
(R.C.-11)	41	**8**	Nil	No physical indications
(R.C.-12)	41	**8**	Nil	No physical indications
(R.C.-13)	41	**8**	Nil	No physical indications
(R.C.-14)	44	**4**	10.09.13-(1mm)	No physical indications
(R.C.-15)	**38**	**4**	Nil	No physical indications
(R.C.-16)	44	**8**	2.12.13-(1mm)	No physical indications
(R.C.-17)	44	**8**	13.12.13-(2mm)	No physical indications
(R.C.-18)	41	**10**	Nil	No physical indications
(R.C.-19)	44	**10**	25.11.13-(1mm)	No physical indications
(R.C.-20)	41	**10**	Nil	No physical indications
(R.C.-21)	44	**10**	29.11.13-(1mm)	No physical indications
(GBP-8)	**92**	**20**	Complete break in 4 days	Roof fall on 5th day
(GBP-13)	**92**	**20**	Complete break in 3 days	Roof fall on 3rd day
(GBP-14)	**94**	**20**	Complete break in 3 days	Roof fall on 3rd day
(T.T.-5)	**98**	**20**	Up to 16mm in 3days	Roof fall on 4th day
(T.T.-10)	**92**	**20**	Up to 20mm in 4days	Roof fall on 5th day
(R.C.-11)	**92**	**20**	Up to 20mm in 3days	Roof fall on 4th day
(GBP-11)	42	**10**	No crack	No physical indications
(GBP-12)	48	**10**	No crack	Steel cog erected
(T.T.-6)	50	**10**	2-5mm	Steel cog erected
(T.T.-7)	52	15	1 mm	Supported by Girders
(T.T.-8)	49	**10**	NO Convergence	Supported by Girders
(R.C.-22)	49	**10**	NO Convergence	Supported by Girders
(R.C.23)	49	**10**	NO Convergence	Supported by Girders
(R.C.24)	45	**10**	NO Convergence	Supported by Girders

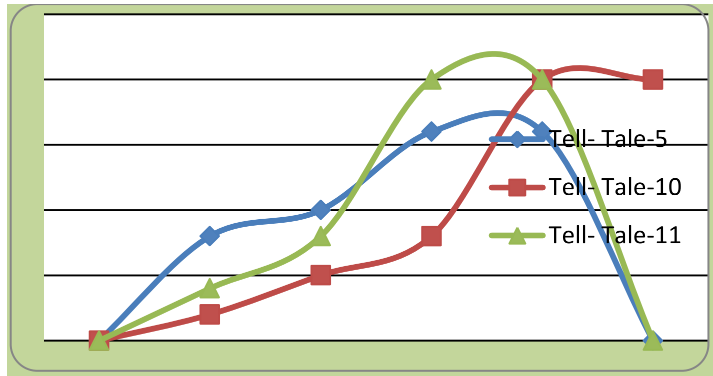


Figure 8 Time elapsed between start of convergence and occurrence of roof fall –Tell Tale

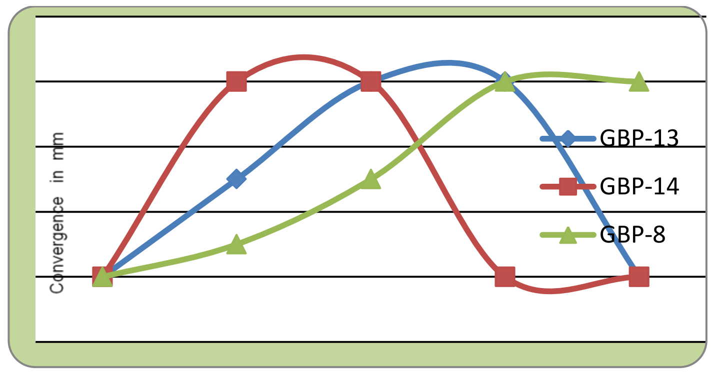


Figure 9 Time elapsed between start of convergence and Occurrence of roof fall – Glass Bearing Plate

IV. DISCUSSION AND ANALYSIS

Roof falls represent a great hazard for the workmen in underground mines. The modern, highly productive underground mining operations need to assure the safety of their work force. This could be achieved by proper risk assessment exercise and updating it from time to time by understanding where major strata fractures and roof failures could occur. The strata monitoring systems with sufficient number of stations can be used to provide the information required for risk assessment. These in-mine systems must be robust in design and moved regularly to keep up with the mining advancement. Installing two instruments that measure different parameters at the same location increases the probability that collected data will be more realistic.

On the whole, 1/6th of the accidents are attributable to lack of prior knowledge of unsafe conditions. S Jayanthu (2011) [13] thinks that, experienced strata control engineers with proper understanding of the field problem, and sufficient knowledge on interpretation of the so generated data are primary requirements for a successful instrumentation program.

Mark K. Larson, Douglas R. Tesarik, J. Brad Seymour and Richard Rains (2000) [13] stated that under varying conditions, the amount and type of roof support may greatly affect stability. It is therefore desirable to optimize roof support, i.e., the density and/or type should be sufficient to minimize the risk of ground fall, yet minimize costs. Technical personnel must determine this point using good engineering judgment.

Instruments have been used increasingly in mines to measure deformation, stress, strain, and load. Such measurements serve two purposes. First, they provide quantitative information that can be useful in determining the mechanics of stability and in aiding engineering decisions. Second, they can be useful in verifying and tuning numerical models. Because one of the goals of an instrumentation program is to monitor ground stability and take corrective action for any imminent problem, instruments that sense

In addition to estimating the Warning limit of potential strata failures the strata monitoring instrumentation is useful in many ways like - obtaining data needed for mine design, such as rock mass deformability or rock stresses, Verifying design data and assumption, thereby allowing calibration of computer models, Adjustment of mining methods to improve stability, Assessing the effectiveness of existing supporting system and directing the installation of additional support. Aveek Mangal (2013) [15] Surface and underground inspections must be done carefully and with the assistance of high intensity inspections lights if necessary; miners, supervisors, engineers and geologists all have an important role to play in carrying out regular inspections for strata monitoring. Monitoring of strata conditions can be done either visually as given above or with the help of specialized instruments.

During the present investigation it was experienced that, the process of risk assessment is highly dependent on the technical knowledge, skill and experience of the person performing it. Therefore the Risk Ranking of particular site, process or operation may vary when the assessment is carried out by two different persons. This makes the process less reliable .The records of strata monitoring instruments, if correlated carefully with physical observation at the site, provides great help in Risk assessment of roof fall. The final risk ranking and RPRI can also be again correlated with the strata monitoring records for taking any corrective actions like providing additional support or the withdrawal of persons from site. Analysis of the observed data shows that:

- Almost all the risk factors considered for investigation were present with high to moderate severity at all the roof fall sites but there are many cases where roof fall did not occur even in the presence of one or more of these factors.
- The continual convergence was recorded at all the sites of roof fall well before its occurrence.
- All the Roof falls occurred in the cases having RPRI values between 83 and 98 (Highest ranking level).
- All the Roof falls occurred in the cases having High RRI levels (20 in all the sites).
- The convergence values recorded at greater RPRI and RRI stations were also high.

After going through the observations and analyzing the results, it is revealed that strata monitoring instruments gives early indications about initiation of strata movement and potential roof fall. The proper analysis and interpretation of the readings from strata monitoring instruments is very much helpful in updating the risk assessment and preventing the roof fall by risk management.

V. Conclusion

Measuring roof deflection is the most common method of detecting roof instabilities. These measurements aid in monitoring mine roof performance and in determining where, and often when, a roof fall may occur. The experience demonstrates that Risk assessment techniques can be utilized to forecast roof rock instabilities in underground coal mines. Risk assessment techniques, suitably supplemented by Strata monitoring technology can provide a means to warn of hazardous roof fall conditions.

The success and growth of underground coal mine is very much required to meet the growing needs of energy in the country. The safety in underground mines by awareness amongst the technocrats about basic rock mechanics and best strata control practices is the pre-requisite for this success. There are no cases of roof fall in the investigation where roof fall occurred in absence of any of the factors considered and roof to floor convergence. Though various factors influence the process of roof fall to different extent, their collective effect is responsible for the final occurrence.

It was observed that strata monitoring instruments gives early indications about initiation of strata movement and potential roof fall. The proper analysis and interpretation of the readings from strata monitoring instruments is very much helpful in updating the risk assessment and preventing the roof fall by risk management.

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