Prediction of Change in Stress Pattern, Rock Mass Behaviour and Stability of Underground Excavations using Microseismics

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Abstract

During underground excavations, rockmass behaviour around the openings undergoes significant changes which results in to deformation or displacement. Study of geomechanics of underground structure, during it's construction and in operation is of utmost importance in understanding the time dependent deformation vis-a vis stability of the structure, Many conventional instrumentation and monitoring techniques are in practice, which gather the geotechnical data related to load, pressure, displacement, stress, pore water pressure etc,. In recent years, microseismic/Acoustic (MS/AE) monitoring has gained importance with the advancements in computer based instrumentation, for long term stability monitoring in real time of large underground openings like Mines, Storage caverns for Oil and Gas, Transport tunnels, Power house caverns etc,. This microseismic monitoring technique has found very wide applications for real time monitoring to have useful information about state of rockmass in terms of changes in strain and stress regimes and in the rheological properties of rockmass deformation associated with seismic radiation which are emitted during the process of micro fracturing as elastic waves. This method is more effective, reliable, advantageous and has an edge over conventional monitoring, as the prediction of rockmass deformation / instabilities or rock failures well in advance and early enough to take the necessary precautionary measures.

Introduction

Underground excavations are used for a wide variety of civilian and military purposes, including mining, road/railway tunnels, atomic waste disposal, hydroelectric generation underground airbases, and caverns for oil and gas storage. With increasing world population, demand for underground space is expected to accelerate in the future. Design of tunnels in rock medium is still largely empirical and addressing a rock failure in underground mines and tunnels during and after construction is still a challenging job. The tunneling industry is continuously plagued by frequent rock failures and the associated high costs due to unknown geological conditions ahead of the tunneling/mining face. If we are capable of mapping stress regime changes in real time during the construction or in operation stage of underground space, sufficiently in advance, the preventing or remedial measures can be taken to improve the safety and stability of the structure.

During the underground excavation rockmass behaviour around the opening undergoes significant changes which results into deformation or displacement. The magnitude of these time dependent deformations depends mainly on the strength of rockmass and in-situ stress and pattern of redistribution or readjustment of stress during and after the excavations. The deformations around the underground structure are frequently witnessed in the regions of high stress in a complex geological setup, like in the Himalayan regions, where compression is continuing and thrust environment exists.

In large underground structures, high horizontal stress causes instability of the structure by inducing stress concentrations

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and rock displacements in the roof and sidewalls. When the magnitude of the in-situ major principal stress is greater than compressive strength of rock, localized brittle failure accompanied by popping and spalling may possibly occur in rock mass. Regions of such highly stressed rock mass exist in underground openings during construction. In response to this type of over-stressed instability, modifications are necessary in excavation designs and additional supports required to be installed.

Unknown stress concentrations ahead of the face affect the stability and safety of a tunnel. An example of a problem effecting the stability and safety is the occurrence of rockbursts. Virgin stresses are unlikely to be uniformly distributed in geologically undisturbed rock. In the vicinity of major tectonic features like megashears, thrust and faults, the strain energy is typically higher even prior to excavation. Therefore locating faults and mapping highly stressed areas ahead of the operational face can help in the safe excavation of a tunnel.

The process of underground excavation, whether in tunneling or mining, generates stress in rockmass around, which is released in the form of fracturing. Failure and displacement or movement along preexisting structures like joints, faults, shears etc. Stress release generates seismic waves that propagate outwards from the source. These seismic events of various magnitudes can be recorded by microseismic systems.

Monitoring programs are necessary for providing the rock engineer with data for a variety of purposes, from support design to numerical modeling. There is a wide range of instrumentation available to fulfill this function, but reliance is often placed on a relatively few tried and tested instruments and methods which have proven to be reliable in the harsh underground environment.

The conventional instrumentation like stress cells, extensometers, multiple point borehole extensometers and convergence meters which record only strata behaviour of the region very close to the instrument and do not have the capability to collect information in real time about actual fracture zone, fracture propagations and failure mechanisms, during and after the underground excavations

However, due to limitations of the existing conventional monitoring methods, a new method of monitoring the regional (total structure) behavior of the rock mass across the highly stressed zones became necessary in order to ensure the structural stability and the safety of the workers during excavation processes. Many researcher's laboratory experiments revealed that Acoustic Emissions (AE) or Microseismic events (MS) are emitted during process of fracturing in rock samples subjected to high stress conditions. When applied to field-scale rock mass, the microseismic events can be used as a reliable indicator of unstable regions/ conditions and thus enables assessment of the intensity and extent of mining induced rock strata degradation. Monitoring of microseismic events is useful in predicting and comprehending hazards, and in evaluating the overall performance of a excavation design. In particular to the study on geomechanics of longwall mine face, LPG storage caverns and hydro electric dam tunnels this technology was widely used in Australia, France, China and South Korea.

The microseismic monitoring technique uses the signals generated by the structure, which may be resulted either crack growth under stress or energy released into rock mass by fresh cracks, to parameterize the fracture/ failure process. This unique monitoring mechanism distinguishes the technique from other nondestructive testing methods and makes it the only method capable of real time mapping of fracture/failure processes. In addition to real time source location of the captured microseismic events, the magnitudes of the detected events can be evaluated to provide immediate evidence to quantify the damage in the rock mass. A particular engineering advantage of the microseismic monitoring method is its capability for global monitoring reliably in that a large and complex structure can be monitored with a sophisticated advanced computerised instrumentation

Underground space instrumentation and monitoring

Numerical modelling, . geotechnical investigations and empirical methods are generally used for designing underground excavations. But to validate and optimise the design methodology during actual construction and to evaluate the stability of designed structures during and after construction is very essential with suitable monitoring methods and good reliable instrumentation setup. The rock mechanics instrumentation provides vital information about the changes in surrounding rock mass conditions due to excavation in underground rock. This is good old practice of collecting the engineering parameters of underground structures at various stages of building the structure using best possible instrumentation methods comprising of different types of mechanical/electro-mechanical and electrical instruments and transducers.

In order to evaluate a particular situation, the relevant parameters relating to the situation need to be identified and particular values measured. Based on these measurements, conditions can then be compared, conclusions drawn, models calibrated, and designs finalized.

Need for Monitoring or Instrumentation Programme

There should always be a clearly defined and valid purpose for undertaking a monitoring or instrumentation programme, and very specific questions need to be answered. Dunnicliff & Green (1988) make the following statement in this regard: "Instrument on a project should be selected and placed to assist in answering a specific question: if there is no question, there should be no instrumentation." The basic challenge of instrumentation is thus in making the correct decisions about what should, or should not, be instrumented. In rock engineering there are four main reasons for conducting instrumentation or monitoring programs:

- To record the natural values of, and variations in, geotechnical parameters before the start of a project.
- To ensure safety during excavation by giving warning of unexpected or excessive definitions.
- To confirm the validity of assumptions and the modelling used in design calculations (i.e. calibration of models and back analysis).
- To confirm support and layout performance in particular environments.

Most monitoring is carried out for the second and third of these reasons. Monitoring for safety and to check the response of the rock mass, and hence to adjust designs or take remedial action, is an important and an integral part of the rock engineering and planning function. The complexity and uncertainty of rock as a medium makes predetermination of rock mass response difficult. The models used to predict various aspects of rock mass response to different tunneling excavation scenarios are necessarily based idealisations, assumptions and simplifications. It is thus absolutely critical to obtain checks on the accuracy of predictions made in design calculations. This process is part of a feedback loop that will allow design changes and optimization with time. Instrumentation programs can be very sophisticated and expensive. However, it must always be remembered that valuable conclusions can also be reached about rock mass response through visual observation and use of simple monitoring devices.

What can be monitored?

The parameters that may be monitored in underground operations can be divided into those that can be measured directly and those that are derived indirectly. The following are a list of parameters that can be monitored directly in underground conditions:

- Movement across a fracture/joint/fault
- Fracture or slip
- Relative displacement or convergence of points on the boundary of an excavation
- Displacements in the rock away from the excavation periphery
- Stresses generated in backfill
- Changes in load in support elements

Conventional Monitoring Systems

Rock Mechanics instrumentation used for monitor the underground structures may be categorised as

a. Strata monitoring systems

- Rock mass Deformation/Displacement measurements
- Stress/Pressure changes
- Ground water loss / Pore pressure

b. Support monitoring systems

- Deformation in Supports
- Load/ Pressure on Supports

The various types of instruments/systems that are generally in use for field measurements are tabulated in table -1 bellow.

These conventional monitoring systems can be broadly divided in to two types as follows.

Non Automated Mechanical / Electro-Mechanical Systems

The Monitoring system designed with mechanical/electro-mechanical instruments and data points /reading will be collected manually using dial gauges, Vernier caliper, micrometer etc,. Example Telescopic & convergence indicators for closure measurements, Tape Extensometers, etc,. These instruments will be installed at selected / suspected potential locations and readings will be collected once or twice day by approaching the instruments every time using various types of mechanical readout units. These data point will be plotted to observe the trend or variations of engineering parameters. These systems are become obsolete after the introduction of electrical transducers and remote data reading units.

Automated Electrical / Electronics Instrumentation systems

These systems are become popular in the

Table 1: Type of instruments/systems used for field measurements of underground strata behaviour

Ground movement monitoring	Closure meters	• *Tape extensometer* • *Telescopic type* • *Suspension type*	Mechanical / Electro mechanical Type	
	Borehole Extensometers	• *Single point* • *Multi point*	Rod type Wire type Magnetic type Sonic type	Manual reading Remote Indicating
Support Monitoring	Load Monitoring	• *Load Cells* • *Instrumented Bolts*	Mechanical Electrical Hydraulic	Manual reading
	Pressure Monitoring	• *Pressure Cells*		Remote Indicating
	Rock Bolt Quality	• *Bolt-meter* • *Pull out Tester*		
In-Situ Rock Properties	Rock Stress Measurements	*Stress Monitoring*	Stress Meters	
		Stress Measurements	Hydro fracturing Over Coring methods	
	Borehole Shear tester			

last three to four decades and comprise electrical transducers like strain gauge, vibrating wire etc., based transducers which provides electrical signal out put corresponding to the physical phenomena variations of media under measurement. These transducers out put can be read by using direct read out units in analog and digital form manually and also the same can be transmitted to considerable distance to read remotely. This helps in obtaining data from unapproachable locations to collect data manually. These systems improved accuracy, resolution/sensitivity and repeatability of measurements. These systems are reliable and having improved range/precession. These systems brought a new trend in rock mechanics instrumentation/monitoring methods. In the recent times these systems can be classified in to mainly offline data measuring systems and real time data measurement systems apart from the same systems divided based on analog and digital systems, portability, and data measuring facility type etc,.

Off-line automated data acquisition systems

In this measurement systems data will be collected form properly installed instruments/ transducers manually or remotely using proper analog digital readout units and brought to surface data processing laboratory to feed to the data processing computer in each shift or once in a day. In the recent times battery operated data logging units also come to use to collect the data from several instruments and can be copied to secondary memory devices to bring the data to surface. In all the cases the interpretation will not done in on-line dynamically which contributes to missing links to explain the changes in physical phenomena of strata condition.

Real time data acquisitions systems

At present this is the latest instrumentation and measuring system, which comprise

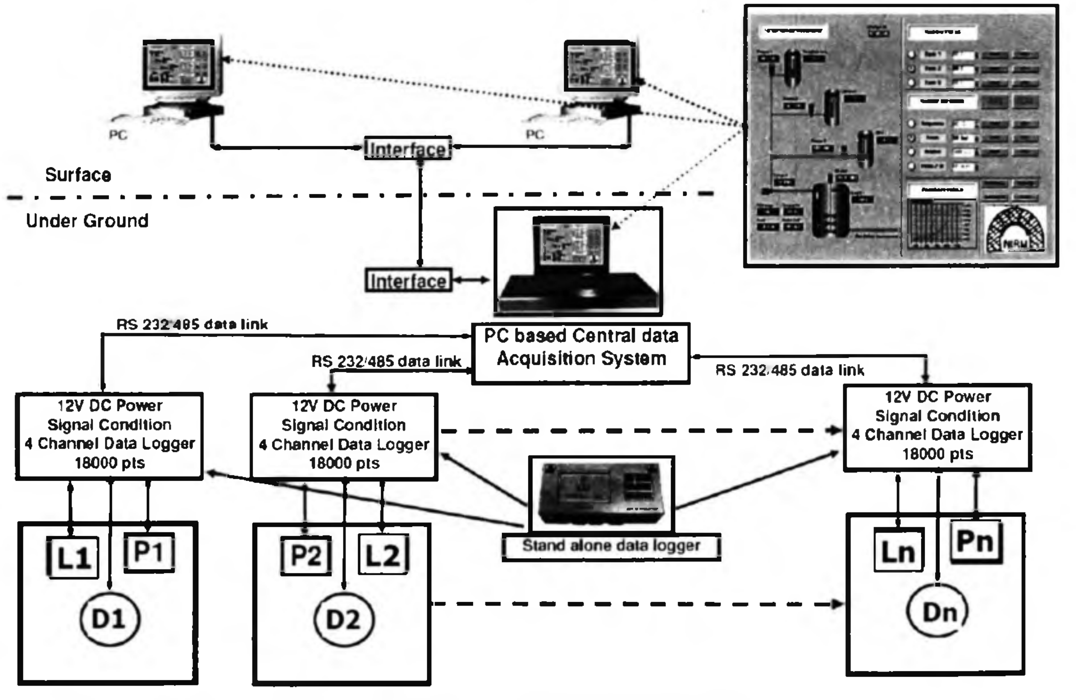

Fig. 1: Instrumentation layout and components of Real time monitoring system

advanced intelligent transducers and high dynamic range data acquisition system using wireless data transmission techniques, built around distributed networking technology. The Fig. 1 shows the instrumentation layout, components and block diagram of real time data acquisition system and on-line data processing system.

Real time data acquisition systems with remote monitoring have the following advantages:

1. Data will be collected by computers so human involvement is avoided
2. Data can be collected at a desired intervals of once in a minute to once in a 24 hours
3. Battery operated systems and battery life will be around 2 to 3 years for continuous operation so chances of data lose is very minimal.
4. Data can be analysed in online and results with data can be made available at different far away locations simultaneously in real time including alarm signals.
5. Different type of transducers like current, voltage and frequency based can be interfaced easily as group

It is recommended to use a monitoring systems which provide real time, automated electronic information from underground structural strata and it should become the norm for monitoring rather than relying on the human factor of reading/collecting data points and interpretation.

Existing Monitoring Methodology in India

Present day strata monitoring in India is done by convergence and deformation sensors, Load cells, pressure sensors, extensometers, piezometers etc,. Remote monitoring will be done by using electronic signal condition systems and read out units. In case of manual monitoring method, one is collecting(noting down) data by approaching sensors end points which are extended few meters using display/readout units and other one is using offline data loggers (either electronic type of Chart recorder type). The electronic data recorders are also not being used in India due to lack of operational knowledge etc, which can help in post analysis of any event with reliable data. In few cases remote monitoring also carried out using portable data loggers, which are used for store the data for some time and brought back the same to surface for downloading and analysing the data. After the installation of the instruments a person carrying read out unit can make only two to three visits a day at the maximum and analyze the at surface lab to interpret the same. This data is very much inadequate to give a fore casting of any emergency information. These methods are also not possible to obtain data from multiple sensors installed at multiple locations. Collecting data from different type of sensors required number of different readout units. Continuous data logging systems were not in use due to lot of maintenance problems due to extensive cabling and high power signal condition electronics. Because of this reason installation of more number of sensor locations is practically difficult. Installation of more number of monitoring points has great importance because these instruments provide only site specific information for strata monitoring. It is advantageous if we can identify these senor locations using microseismic technology to optimise locations and get more useful data. In all the above methods the data will be processed in offline thus we are missing the opportunity of taking decision regarding roof condition at right time. This is possible with only with real time monitoring with online data analysis. Hence there is a need for using replacing cabling system and use of advanced technology data acquisition systems designed using better communication techniques described as follows.

Limitations of Conventional Systems

1. **Manual data collection (More Errors and unreliable):** Data collection at random intervals and Reading analog data points and connection of digital data display units etc., involves errors due to human involvement.

2. **Insufficient data points:** Data points will be collected only very few times a day and at random intervals unless used electronic data loggers or paper recorders. These data loggers also need to be brought out to surface once in a day or so for data collection and data analysis. These procedures also provide only off-line data for analysis at later dates.

3. **Not suitable to study Dynamic strata behaviour:** As the data dynamic data is of very important and very useful. The data collected by data loggers need to be analysed in real time and on-line. At the same time data logger's parameters like sampling interval etc., control in on line is required with out duplex communication.

It can be concluded that the conventional monitoring methods for detection of underground structures strata conditions like structural & support deformation, rock fracturing, dynamic stress changes etc., by measuring stress/strain in strata, convergence with borehole extensometer, piezometer monitoring, observation of water lose in experimental boreholes etc., can only give information at only measuring points ie., very much pertained to site specific information. Moreover this information is available only at the final stages of instability occurrence. Hence even if we use advanced real time data monitoring systems the information available is subjective and in adequate to address the dynamic process of strata instability occurrence behaviour.

Microseismic Monitoring Systems

The best solution to over come the limitations of conventional monitoring systems in the recent years is Microseismic Monitoring Systems (MS) which has been successfully used in number of underground structural environments to address the strata behaviour due to its capability and advantages of regional monitoring capability and other following advantages over conventional monitoring systems. In order to obtain the large amount of three dimensional information strata failure process, high stress zones and changes in stress with respect to time etc., the microseismic monitoring technique is one of the best suitable monitoring method. This measurement technique provides information of a selected region in real time to know the initiation and propagation of fractures which ultimately leads to failure. One of the unique feature of microseismic technique is to locate the source of roof fractures precisely from large monitoring region with only a few measuring stations. Mapping of rock fractures is possible in real time safely and remotely. The data recorded can be used for simulation of numerical models.

Advantages of Microseismic Monitoring Systems

1. With the help of few sensors whole regional data can be obtained

2. The monitoring systems are cost effective in long run and serve for life time monitoring of intended structure

3. Once installed instrumentation is useful during construction and after construction monitoring of structure

4. The systems have high dynamic range (24bit digital) and the instability process can be detected even from the initiation period.

5. Real time continuous data with on line data processing and analysis can be done to interpret the dynamic instability process, when actually taking place. Ie,. Mapping of rock fracturing process, high stress zones detection in advance can be done.

6. The total system can be operated remotely and automatically even to generate the alarm system for cautioning instabilities. ie., prediction and estimation of impending rooffalls time period, accurate location and intensity of fall is possible
7. These systems provide highly reliable data for validation and modification of models.
8. Performance of remedial measures taken for various deformation conditions, Support systems, destressing operation can be studied / observed faithfully, including optimising the same techniques.

Microseismic Monitoring technology (Concept)

The microseismics is based on the fact that rock under load responds by making small scale displacements to reach a state of equilibrium. If equilibrium is not achieved these adjustments become more frequent and are characterized by the release of seismic/acoustic energy (audible rock noise/ Splitting/Rock talking). In addition to these rock talk a much larger amount of sub-audible rock noise also generated, which can be detected only with suitable and sensitive geophysical equipment.

Microseismic emissions generated by deformation and cracking of the rock around an opening as the rock tends to achieve equilibrium in a new geometry under changing stress conditions have been found to provide useful clues to study the instabilities in stressed rockmass. Since the spatio-temporal patterns of occurrence of such microseismic emissions are known to be intimately related to stress changes within the rock mass, the typical characteristics of these emission patterns state the diagnostic value in sensing an advance major instability that invariably follow such emissions.

Microseismic Monitoring Method

The detection and analysis of microseismicity in underground excavations provides an ideal method for remote volumetric sampling of the rock masses. The nature and uniqueness of microseismic monitoring method is outlined in the context of hardware and software advances of latest computerised instrumentation systems. Large number of recent publications resulted from many laboratory and field investigations can be cited, which highlighted the potential of the applications of microseismics. These topics reflect some of the current interest areas in seismology, namely 'b' values and source parameters, fault-plane solutions, modes of failure and moment tensor inversion, imaging and seismicity velocity correlations. These studies suggest potential correlations between High stress zones, high microseismic activity and maximal stress drops, which can be interpreted spatially to be the locations of highly stressed ground with a potential for rock failures. Fault-plane solutions are shown to be useful in determining the slip potential of various joint sets in a rock mass.

Source parameter studies and moment tensor analysis clearly show the importance of non-shear components of failure, and 'b' values for microseismicity appear to be magnitude-limited and related to spatial rather than temporal variations in effective stress levels. Since the sources of microseismic activity are caused by rock fracturing, microseismic sources locating and plotting can point to areas of structural adjustment to changing stresses induced by excavation/mining. Microseismic techniques have been used to delineate potential areas of ground failure (Rowell GA, 1989). The microseismic signals contain information about the source characteristics such as magnitude, energy and other source parameters.

In the case of longwall mining when face advances the roof behind the face caves and causes ground control problems such as roof falls and weighting on powered supports.

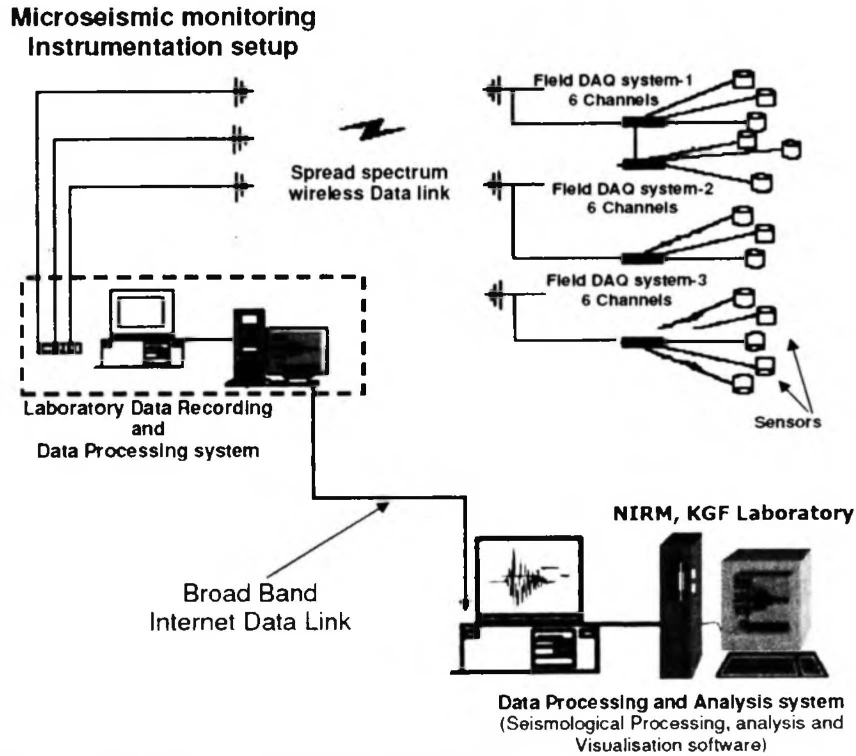

Fig. 2: Microseismic Monitoring instrumentation layout

This technique helps to locate the high stress zone and obtain prior information regarding roof falls. Thus the microseismic technique allows the whole process of mine fracturing to be observed remotely and dynamically in three dimensions. The microseismic monitoring deployed at Gordenstone Mine, Australia was to establish the height of rock fracturing above the working face and to investigate the potential fractures to breach the tertiary boundary (Peter Hatherly, 1995, Xun.Luo, et.al, 1997). The instrumentation lay out of microseismic monitoring system is depicted in Fig. 2.

The system comprises vibration sensitive transducers like Geophones, Accelerometers etc., to detect the vibrations generated due to rock fracturing, data transmission link, computerised data acquisition, process and analysis system loaded with necessary software. The system detects and acquires the micro cracks information as input in real time and process for the source parameters like source location of crack, Magnitude, energy released, Microseismic activity rate, Seismic moment, Energy Index, Schmidt number, Apparent stress, Apparent volume, Seismic Energy etc., in online and store the data and parameters in data base to quarry and carryout the intensive off-line data analysis.

Microseismic monitoring found applications in various sectors like Engineering, Mining, Petroleum, environment etc., to address different types of problems some are mentioned bellow

Applications of MS Technology:

Engineering

- Tunnels & tunneling
- Slope stability
- response of structures
- Dam
- Nuclear waste disposal

Mining

- Stability of tunnels & excavations
- Cave evolution
- Goafing in underground coal mines
- Slope stability
- Blasting

Petroleum

- Tunnels & tunneling
- Fault delineation
- Well stability
- Fault stability
- Reservoir management
- Hydro-fracturing

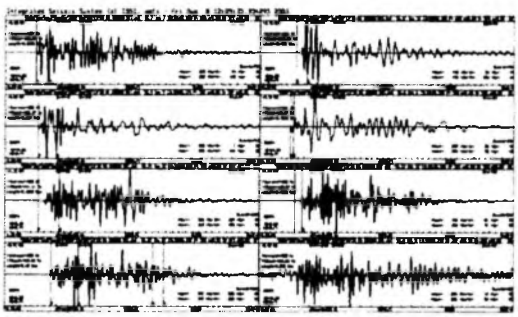

Fig. 3: Typical micro-crack signature recorded by Microseismic system.

Microseismic monitoring case Studies

COAL MINES (Case Study-1)

An advanced 24bit digital high dynamic range (>155db) sophisticated 18 channel microseismic monitoring system was installed to monitor in real time the behaviour of a 80m deep 150m wide and 1000m longwall face of coal mine roof strata at Rajendra mines, South Eastern Coal fields (SECL), India. Some of the results obtained were presented as case studies as follows. It is a very difficult environment compared to LPG and Hydroelectric caverns with 3 to 5m advancement of 150m working face under support of movable powered hydraulic supports. Fig. 3 shows the typical micro-crack's signature recorded by 8 channel MS system.

High stress zones detection using microseismic data

The data acquired by microseismic system given the locations of micro fractures that generated during different stress conditions was analyzed and obtained stress contours. These contours indicate the high stress concentration zones in the roof strata from time to time. These stress contours were generated in real time from microseismic events locations and energy released by them. These contours help in studying the changes in stress concentrations that took place at different locations of roof strata. The stress changes can be mapped accurately location wise and intensity wise ie., right from the initiation of the stress concentration zone to stress concentration saturation level. As the location of this stress concentration zone

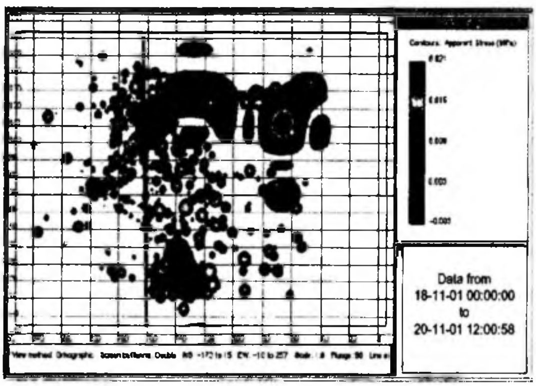

Fig. 4: High stress zones mapped using microseismic data

is very accurate and X, Y and Z coordinates are available to take necessary safety measure operations like destressing operations.

Fig. 4 shows the typical stress contour obtained using microseismic data of a longwall panel.

Roof fall occurrence time and location prediction

Microseismic events ranging from local

magnitudes of-4.0 to -3.0 were recorded under normal caving process as well as during accelerated deformation process with induced blasting. Clearly distinguishable 174 prominent seismic events with magnitudes ranging from -0.9 to 0.0 were also recorded along with thousands of precursory micro seismic events. Among these seismic events only 76 events were resulted in rockfalls. The data thus obtained was analysed and interpreted in order to apply the microseismic technique to study the deformation process of coal mine roof strata. During the microseismic monitoring in coalmine scaled microseismic event release rate (ERR) and Apparent Volume (?VA) plots (time series) of the processed microseismic data was used to derive the Empirical Potential Instability Indicator (S?) to give seismic warning to the mine authority through daily reports indicating the estimated time of impending rockfalls and high stress zones. Energy index (EI), Apparent stress (?S) and other source parameters were also examined to find out stability indicator but the ERR was found to be the most prominent parameter for short

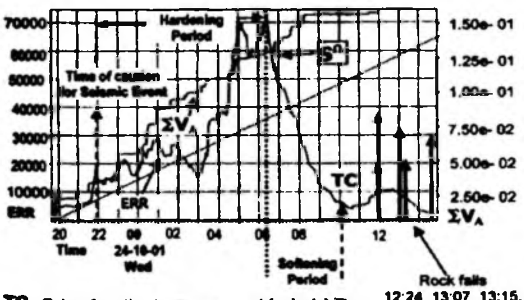

Fig. 5: Time series Plot of ERR and ?VA vs Time to obtain the Instability Indicator S?

range prediction of rock mass instability. S? can be used to provide the daily roof strata condition report and prior information of impending falls. Fig. 5 shows the procedure of obtaining the instability indicator (S?), with successful seismic event prediction time (cautioning time-TC) and actually occurred rockfalls.

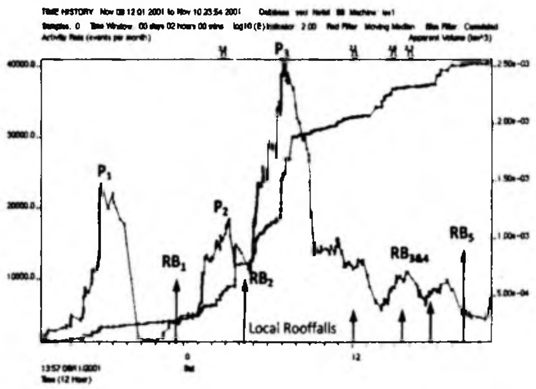

Fig. 6: ERR Vs time for the period of 48 hours

The Fig. 6 shows the ERR Vs time for the period of two days. Many rooffalls were taken place during the period of 8 to 12 November and resulted as goaf pack. In the figure the rooffalls shown are local rooffalls took place before large rooffalls in the goaf. ERR Peaks P1, P2 and P3 were resulted as RB1, RB2 and RB3-Rb5 respectively. These local rooffalls took place at different locations and these locations can be obtained before the falls with the help of stress contours. It can be observed from the figure that the peaks are of 2 to 4 times of ERR threshold (10000

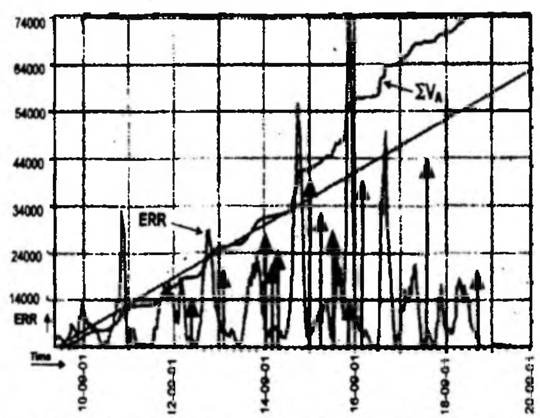

Fig. 7: Microseismic event rate (ERR) and Cumulative Volume Vs Time with Rockfalls

events per month (scaled)) and raise and fall times are very short but a lead time of 2 to 4 hours available for warning the instability in real time.

Microseismic events data with time series plot (ERR and ?VA) with rockfalls recorded

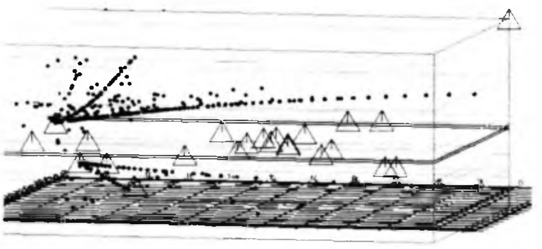

Fig. 8: Real time fractures mapped using microseismic data - 3D side view

(shown as upward arrows) for 30days (one month) is shown in Fig. 7.

Mapping of fractures in the roof strata

The location of fracturing associated with excavation area was of great importance for understanding the mechanism of roof caving and control of the roof movements. Fracture, which develops around a zone of rock extraction, will radiate energy as microseismic event and some times larger seismic events.

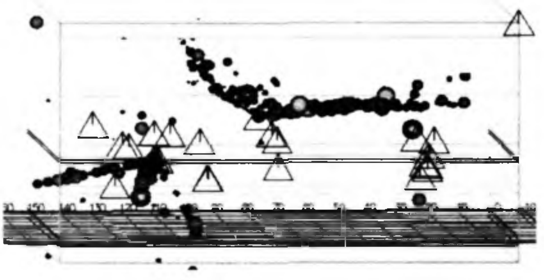

Fig. 8a: Real time fractures mapped using microseismic data - 3D front view

The location of these microseismic events, provide pattern of fractures and state of stress present around the area of extraction. The fractures recorded at different working face positions of mining have been considered to find out the extent of fracture and mapping of fracture in real time. Fig. 8 and 8a shows the fractures mapped on the 3D-Plan of excavation for the selected time period, side view and front view respectively.

In Hydroelectric projects (case study - 2)

In China: In the JinPing hydropower dam, currently under construction in china, in order to understand the mechanisms of fracturing and structural movement around the diversion tunnels (20m diameter each) and underground powerhouse, microseismic monitoring was carried out. It was difficult to estimate the change of stress state in rock mass and the stability of rocks around the tunnel openings using the most sophisticated modeling programs due to complicated geological structures, different rock types and heterogeneity of geomechanical parameters (Luo et al. 2006).

During construction of tunnels micro cracking in rock mass gives first sign of redistribution of stresses. Under certain stress conditions the micro cracks grow to become a fracture. This process is continuous and generates seismic signals which transmit outwards from the source, through the rock mass as an elastic wave. Analysing the recorded seismic waveforms enable to obtain information on the locations occurrence characteristics, strength and source mechanisms of the fracture events (Luo et al. 2006). Microseismic monitoring was carried out at the project site, in order to increase the geophones coverage and ensure the accurate event locations to be determined fourteen tri-axial geophone sensors were deployed in several openings like tunnels and exploratory drifts at different levels.

All the geophones were cemented into 1m deep boreholes in order to have better coupling with rock mass. The geophones were connected to the microseismic data acquisition system through cables. After the installation, the monitoring system was calibrated using hammer hitting on rocks in the vicinity of geophones. The microseismic system had 48 channels inputs, 12-bit ADC solution, and sampling rate up to 2 KHz per channel with software selectable gains from 10 to 10000. These incoming seismic signals from each channel processed in real time to

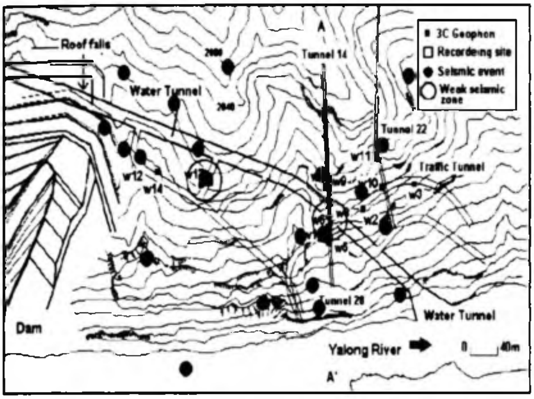

Fig. 9: Two weak seismic zones detected, seismic events and 3C geophone locations

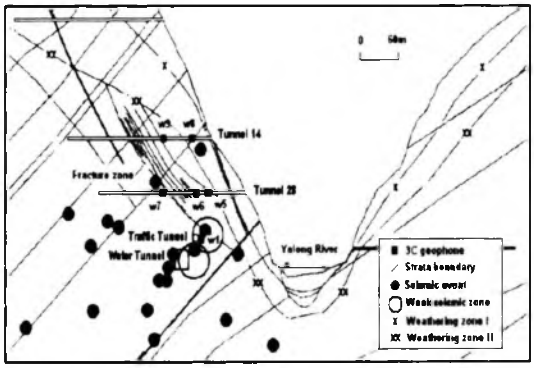

Fig. 9a: Two detected weak seismic zones and Sensor locations

calculate their short-term average (STA) and long-term average and the ratio STA/LTA was obtained which was used for microseismic event detection. The recorded system was set that if any geophone was triggered the system records data from all channels. The triggered seismograms were saved into local hard disk and downloaded to a USB memory stick or to a optical drive for offline data processing. Microseismic monitoring of tunnel was started on 21 January 2006, when the tunnel was excavated through and supported. The monitoring continues for 20 days and during the period 3000 events were recorded. Several types of events, high frequency events (HFE 150-200Hz), strong events (SE 35-135 Hz), low frequency events (LFE 25-30 Hz) and noise signals (from heavy truck movement, drilling/blasting, water pumps, generators) were recorded. The accurate event locations were applied to the events that were recorded by more than 4 geophone stations and their p-wave velocity was determined using the seismographs. An average-wave velocity of 5.2 km/sec was determined and used for event location. The two weak zones detected by microseismic system as sown in Fig. 9 & 9a.

One weak seismic zone was located at the intersection of the tunnels where the stress concentration is high and brittle rock cracking/fracturing was expected to occur. The other seismic zone detected near to a geophone No.W13 by the observation of many small high frequency events. A small rock displacement was observed in the vicinity of geophone. Some events due to the fractures/strata boundary movements were also detected.

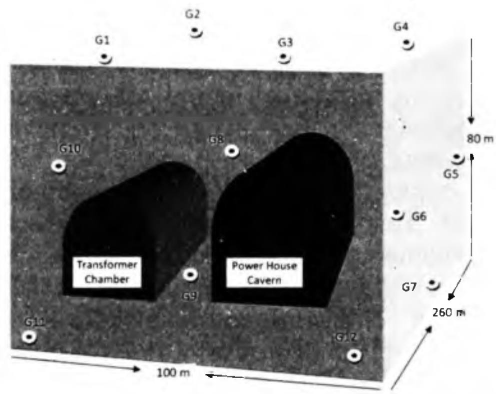

Fig. 10: Microseismic sensors proposed layout

Case study-2a

In Bhutan recently NIRM has designed and proposed a microseismic monitoring programme for monitoring of power house chambers. A microseismic monitoring program has been planned for real time monitoring of continuing rock mass deformations around the underground powerhouse caverns of Tala Hydroelectric project (1C-1020 MW) in Bhutan, which was commissioned in July 2006. Here, continuing deformations in upstream and downstream walls of underground machine hall resulting in to failure of more than 130 rock bolts and visible cracks in the strata have been reported since 2004. This underground powerhouse is located within the highly stressed area existing in the close vicinity of Main Central Thrust (MCT) of Himalayas. The sensors layout / plan for proposed microseismic monitoring has been depicted in Fig. 10.

It is worth mentioning that monitoring by conventional instrumentation is in progress and regular analysis by numerical modeling is being carried out by NIRM.

Expertise and capabilities of NIRM in microseismic monitoring

National Institute of Rock Mechanics (NIRM) has been using micro seismic real time monitoring techniques for the last 3 decades in understanding the fracture mechanics well in advance of the failure in coal mines, hard rock mines, hydro electric dam slopes etc. NIRM has the capability of design, development and installation of microseismic monitoring systems with suitable sensors network for underground structures of hydroelectric projects, LPG Caverns, Landslides, Metrorail tunnels, Mines etc,. Anomalies that are caused in underground or surface structures (Bridges, Dams etc.) due to mass blasting or high impacts can also be monitored for attaining stability condition after jolt.

Discussion

The microseismic data obtained from the deep hard rock mine show how the particular area responds to changes in mine geometry and to the loading conditions. Increasing rate of microseismic events and the corresponding energy factor due to a rooffall in the area indicate increasing stress and growth of micro cracks within the rock mass in that area. The microseismic technique has been successfully used to assess the stability of mine workings and forewarn the occurrence of rooffalls.

The microseismic technique used in shallow coalmine has reflected some salient aspects of monitoring the event release rate towards evaluating the overall ground stability. Based on the trend of event release rate as the guideline, a return of stable ground condition can be inferred if the event release rate count returns back to the previous background as monitored before the blast. But, practically, this may not always be the case, as the event release rate may assume a new high, return to original levels or even drop down to a new low depending upon the new stress state and the resulting geomechanical condition. The application of microseismic monitoring has demonstrated that it is the best scientific tool to monitor the longwall mine roof strata in real time to obtain the location and prediction time of impending roof falls.

In the similar manner it is easy to monitor the highly supported LPG storage and Hydro electric tunnels and caverns.

Conclusions

The conventional strata monitoring systems used for monitoring the underground structures with out real time and online facility are of not much use and provide only inadequate data points to address the dynamic behaviour of the structural roof strata. These conventional monitoring systems provide data only pertained to site specific nature and can't provide advanced information regarding the instability.

Microseismic monitoring systems are best solution to over come above drawbacks on instrumentation systems, which provide very good precursory information for prediction and locating the instabilities. This technology also capable of provide global information of structure under observation with very few sensors installed. In the recent times this technology successfully demonstrated in mines, LPG storage caverns, Land slides, Hydroelectric Tunnels/caverns stability monitoring during construction and after the completion of the structure by providing information about high stress zones, impending falls and fracture mapping in real time.

Recommendations

At the outset it is strongly recommended to apply microseismic technology monitoring systems to address the dynamic strata behaviour of underground structures, which is cost effective in long term real time monitoring solution. For further more to refine the instrumentation strategy microseismic systems which are also capable to accept the conventional sensors (The sensors need to be installed at locations from the results of microseismic monitoring) input to have an integrated real time monitoring and on-line data processing. It is also recommended to install the microseismic systems right from the beginning of structure construction for validating and optimization of the models and design.

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