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SEISMIC MONITORING IN SURFACE MINES

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Abstract This paper gives a brief review of seismicity and seismic monitoring in surface mines. A summary of various researches related to seismicity is presented. Our research focuses on the understanding of seismicity and the application of analytical techniques to seismicity. Seismic monitoring plays an important role in the identification of potential failure planes and thereby predict potential failures. Much of the instrumentation used in our research is derived from earthquake monitoring systems. The major aspects in seismic monitoring are an instrumentation used, size of the network and data acquisition systems. Seismic monitoring in surface mines could be successfully applied to the improvement of safety standards in slope stability.

Key words micro seismic energy, slope stability,seismic sensors, seismic monitoring

1. Introduction

The limit equuilibrium method is widely used in slope stability analysis. This method considers the static mechanical forces and strength parameters like cohesion and internal friction that exist in the slope. The conventional method of analyzing the effects of seismicity is the pseudo static method coupled with the linear Mohr-Coulomb failure criteria. The kinematic approach of slope stability analysis is recently used in addition dynamic responses like blasting, earthquakes coupled with appropriate constitutive laws. However, quasi static analysis using the seismic coefficient is appropriate for slope stability analysis (Yang, 2007).

Rocks radiate micro seismic energy at lower stress levels than that of failure, and relative motion between two blocks of rocks radiate micro seismic energy of high levels. These micro seismic energy levels can be used to characterize the potential planes of failure and thus provide an understanding of failure character (Hardy & Mowrey, 1976). In a mine, an elastic energy stored in the overburden and the sidewall is suddenly released when mining induced stresses are relaxed (Gaviglio et al., 1996). The micro seismic energy levels can be used to develop conceptual and numerical models for the prediction and prevention of risk (Abdul-Wahed., et al 2006). Seismic monitoring has been used in mining for many years to calculate the location and magnitude of mining induced seismicity (Mendecki, 1997).

In surface mines, it is important to monitor slopes to identify any impending failure. Although there were many efforts to use seismic monitoring in surface mines, it has been unsuccessful. Neverthless, Lynch et al., (2005) put great emphasis on seismic monitoring systems with the availability of state of the art seismograms, GPS and low power highly efficient embedded processors.

2. Seismicity in Surface Mining

Mining induced seismicity can be defined as the incidence of seismic events created by rock movements or change in state of stress resulting from failures (Cook, 1976).

Excavation of huge volume of rock in surface mining creates stress redistribution that causes fracturing and rock mass movement along fracture planes. It is observed that 90% of the damage caused in the rock mass is aseismic (Tapponier and Brace, 1976). Seismic

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sources are generated by shearing and crack propagation within the rock mass. Thus it could be related to an elastic deformation in the rock mass (Amitrano et al., 2007). These processes result in the generation of seismic waves (Li et al., 2007). Fracturing in rocks radiate seismic waves. If these waves are recorded by sensors, seismograms can be produced. The origin, location and source of seismic waves can be determined by seismograms. This makes way for quantifying failures in three dimensional rock mass. Using seismic data, the fracture sizes and location are obtained. The fracture sizes are used to infer the ground movements arising from it. The ground movement due to fracturing is observed only after a period of 1-2 months. The reason for the delay in ground movements is due to the rheology that arises from inhomogenities in the rock mass (Lynch and Malovichko, 2006). Micro cracks have a significant effect on the elastic properties of rocks and on the velocity of propagation of seismic wave (Walsh, 1965; Budianski and O' Connell, 1976).

The seismic studies help to understand gravitational instabilities and precursory failure patterns used for failure forecasting and hazard assessment (Amitrano et al., 2005). There are two fundamental levels in mine induced seismicity, the macro level and the micro level. The macro level events are rare but their effects are damaging such as failure of slopes. The micro level events are plentiful but their effects are not damaging. Seismic data have an important role to play in the validation of numerical models. Advanced seismic processing methods has helped in the understanding of rock mass properties and thermally induced stresses (Young et al., 2004). Rock slopes tend to fail under tensile stresses at high seismic loads. This occurs in steep slopes with a high seismic coefficient (Li et al., 2008). Though rock slopes fail under seismic loading, the analysis of such kinds of failure have not received much attention (Fatemi Aghda, et al., 1993; Maugeri et al., 1993). Seismic acceleration reduces the stability and yield acceleration of a rock mass (Ling and Cheng, 1997).

The overall effect of seismicity on a slope is the accumulated displacements at the failure zones (Newmark 1965; Seed, 1979). The slope is considered to be under large lateral seismic displacements (Seed, 1979). During a seismic displacement there is a change in inertia all the time, resulting in the dynamic change in the factor of safety (Sawada et al., 1993). The pseudo static approach is the most common technique used for seismic slope stability analysis (Baker et al., 2006). Baker et al. and Loukidis et al. have used pseudo seismic method widely in limit analysis and limit equilibrium analysis to provide chart solution for soil slopes. The kinematic approach of yield design theory combined with pseudo static method can be used to access the stability conditions of a particular fractured rock slope in a seismically active zone (Siad, 2003). If the complicated dynamic responses coupled with constitutive laws are used, a more precise seismic evaluation of the slopes could be obtained (Li et al., 2008).

Numerical modeling can be also used in the comparison of the zones of failure in the model and the rock mass (Hazzard and Young, 2004). The integrated analyses from a number of mine sites indicate the relationship between the stress distribution obtained by numerical modeling and the seismic energies radiated from the rock mass (Mercer and Bawden, 2004). The potential for rock mass failure and the seismic energy distribution are the most important factors that affect the induced seismicity in a mine (Beck and Brady, 2002). The effects of joints on the propagation of seismic wave in rock have received little attention theoretically and mathematically (Cook, 1992). From a statistical approach of an integrated analysis of mine induced seismicity and numerical stress estimates it is easier to predict the stress values compared to the seismic values (Mercer and Bawden, 2004).

3. Seismic sensors

Seismic sensors are instruments to measure the ground motion when there is a disturbance. The modern day seismometers give a dynamic variable in response to the ground vibration, whereas in older instrument the response is the amplitude of displacement. The aim of seismic sensors is to measure the ground displacement of a point relative to the same point, but this is not so easy and there are problems with the measurement. First, the sensor itself moves with the ground, so there is no undisturbed reference frame available. Second, the sensors must be able to cover a wide range of displacement and frequency. The displacements can vary between 0.1 nm (nano meter, 10^{-9} m) to 10m and the frequencies can vary between 0.01 Hz to 1000 Hz. As there is a wide range of frequency and displacements, the seismic sensors are divided into short period (SP), long period (LP) or strong motion. Today it is possible to make instruments with large dynamic frequency ranges called the broad band (BB) sensors. Seismic sensors are based on the principle of inertia of a suspended mass which remain stationary in response to external motion. The relative motion between the ground and the suspended mass will be a function of the ground motion. The mass spring system serves as a model to understand the basics of seismometry. This is a simple model as the mass can move in all directions in response to the direction of vibration (Havskov & Alguacil, 2004).

The traditional mechanical sensors cannot be used for low frequency measurements. For measuring low frequencies, sensors are built according to the force balance principle. According to this principle an electrically generated force is compensated to the applied force so as to keep the suspended mass at rest. The force is generated by current passing through a coil and the current is proportional to the force applied on the mass, and thereby the external acceleration can be measured. Geophones are devices that convert ground motion into voltage, which is recorded. They are normally spring mounted mass moving within a coil to generate electrical signals. Normally geophones respond to ground vibration in the vertical direction, but they can be designed as triaxial, which measure the ground vibration in all the three directions. Accelerometers are another type of sensors which typically measure large accelerations typically in the order of 1-2 g. They are made by a mechanical sensor having a high natural frequency. Initially accelerometers were designed to measure high acceleration, but now they are available to measure values as low as 5×10^{-7} m/s^2 and this corresponds to a displacement of 1 nm at a frequency of 1 Hz. The recent development in sensors is the velocity broadband sensor which covers the complete band of frequency covered by the LP and SP sensors, and this eliminates the need for two types of sensors (Havskov & Alguacil, 2004).

The presently available geophones have natural frequencies between 4.5 Hz and 14 Hz with a bandwidth between 3 Hz and 2000 Hz. Accelerometers have a better band width ranging from 0.2 Hz to 2300 Hz with a low intrinsic noise level.

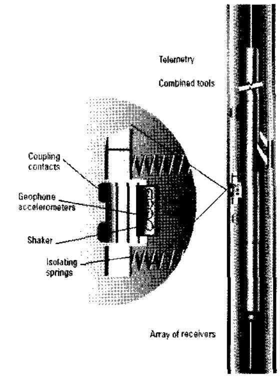

Fig. 1. Tri Axial Seismic Sensor

The seismic monitoring for surface mines uses mainly data loggers and tri axial seismic sensors (Fig 1).

4. Seismic Recording

Seismometers give out electrical signals that can be measured in the laboratory. To preserve these electrical signals they are recorded. The signals are of low amplitude and contain noise, so they need to be amplified and filtered and then recorded. The recorder plots the signal in a permanent way like a chart or drum recorder, and the plot is called seismogram. The present ways of doing it is digitizing the signal with an analog to digital converter and record it in the computer device (Havskov & Alguacil, 2004).

5. Seismic Stations

The geographical location of a seismic station is an important aspect to be discussed. The station can be part of a global network or a local network, depending on the use. A station that is a part of the local network cannot be located anywhere, but the optimum location of the station is important. The practical issues that govern the location of a seismic station are power, communication, noise, security, access, weather, topography and geology. These factors might conflict with each other in the location of the station, but the low cost of operation and long term operational stability decide the location of a seismic station (Havskov & Alguacil, 2004).

A seismic station can either be located on a bed rock or on soft ground, but the noise level from the bed rock will be much less than of the soft ground. Apart from these considerations, a careful analysis of the site must be done, as a big boulder could be assumed to be bedrock, and there can be variations in the geology. Hence a noise survey needs to be done before the installation of seismic sensors. When the site for installation is determined, the next step is the installation of sensor and possibly a recorder or transmission equipment. Sensors are mainly placed on glass, non porous ceramic or plastic plates to avoid stray currents and the corrosion of sensors when contact with cement. The sensors are to be oriented in a particular direction using a magnetic compass. The orientation of the sensors must be well within ± 2 degrees. Various methods of installation of sensors are available. In most of the cases the sensors are mostly installed in air tight tube, to prevent influence from the wind. The cement used must be of a water proof type (Havskov & Alguacil, 2004).

Fig 2 shows the installation of a three - component station and optional equipment. The box used is made of aluminum. Part of the bottom box is removed and cement is filled in it for insulation and iron holes are drilled in it.

The power supply to seismic sensors can be through various types of batteries that can be dry cells, lead acid batteries, lead-calcium batteries, nickel-cadmium batteries, Ni-Mh batteries, Li-ion batteries. Most of the seismic equipments run on 12 V batteries, and they operate in a wide range of 9 - 16 V. The batteries are mainly used in series operation. The batteries have common properties such as capacity, self discharge and temperature dependence (Havskov & Alguacil, 2004).

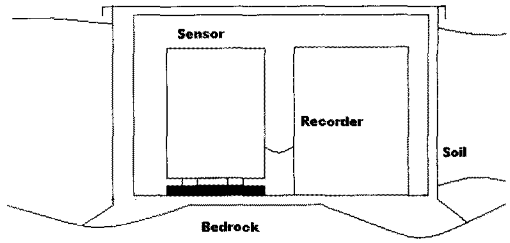

Fig. 2. Network of seismic sensor and recorder

6. Seismic Networks

The basic problem to be solved in seismology is the location of seismic networks. There should be a network of three stations for data collection and analysis atleast. The primary aim of all seismic networks is the location of seismic events whether local or global. While the location of earthquakes requires a long period capability, other research tasks might require a long period or very long capability. The various types of available networks and their purpose are presented in Table 1.

Table 1. Types of networks and purposes (Havskov & Alguacil, 2004).

Type of Network/Purpose	Distance (mts)	Frequency Range (hz)	Sensor
Mining & Earthquakes	10	5 - 2000	Geophone, accelerometer
Dam induced seismicity	50 - 100	0.1 - 100	Geophone, SP, accelerometer
Volcano monitoring	30	0.1 - 50	Geophone, SP, BB
Strong motion monitoring	1000	0 - 100	Accelerometer
Local seismicity	100	0.1 - 100	Geophone, SP, accelerometer
Regional seismicity	1000	0.01 - 50	All types
Global Seismicity	All	0.0001 - 20	All types, depends on specific purpose
Refraction surveys	2000	1 - 20	SP, geophone
Global earth structure	All	All	BB
Test ban Treaty monitoring	All	All	SP,BB

7. Seismic Arrays

For reliable measurement of seismic activity the sensors should surround the rock volume being monitored. The sensors should be placed at the surface as well as the bottom of the drill hole. The surface sensors used for measurement of seismic events should be free from surface waves, and uninfluenced by the other free rock surfaces (Lynch et al., 2006).

The typical distances between the sensors should be 100 - 200 m and the volume of rock mass monitored must be in the order of 400 m×200 m×150 m. The sensors to be installed at the surface are in shorter holes having a length of 10m. The seismic events generated would have a frequency in the range of 10 - 400 Hz range and geophones would be much better to use when compared to accelerometers. Accelerometers are less reliable when compared to geophones (Lynch et al., 2006).

8. Data Acquisition from Seismic Sensors

As the seismic signals are of low amplitude, a wide dynamic range of signals are required for monitoring. These signals are sampled at high frequency and they are digitized using an analog to digital converter. Time synchronization can be done using GPS timing signals. The sensors are to be protected from lighting. The sensors are powered by solar power. Seismograms are developed from the triggers of sensors which are stored in a central computer. The processed data from the computer can be used to calculate the source and the spatial location of the seismic event. This data is used by mine geotechnical engineers for interpretation (Havskov & Alguacil, 2004).

9. Data Processing and Reporting

High speed internet connections are useful in the transfer of seismic data to a remote facility for processing and analysis. For each seismic event the origin time, location and the source parameter estimate can be computed. The seismic data is analysed and sent to the geotechnical engineer to be examined with the other geotechnical data (Lynch et al., 2006).

10. Conclusions

For the purpose of seismic monitoring, the seismic instrumentation, seismic networks available, and the data recording systems applicable for surface mining are reviewed. The application of seismicity in surface mining and the summary of various research work is discussed. The review indicates that microseismic energy radiated due to rock movements can be used to quantify the failures in rock mass and offer a promising method to predict potential failures.The availability of broadband sensors and real time data acquisition systems with remote monitoring have fufrther enhanced the capabilities of seismic monitoring systems.

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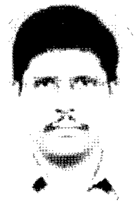

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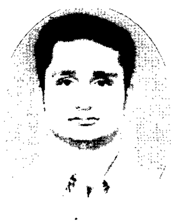

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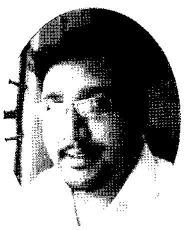

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