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SEISMIC MONITORING APPLIED TO MINES SAFETY AND OPTIMAL DESIGN OF MINE LAYOUTS IN HARD ROCK MASS SITUATIONS

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ABSTRACT : The paper intends to show how seismic data can be usefully integrated in daily, mining operations and contribute to make mining safer in terms of daily decisions of mine management as well as planning of mine layout design. Thus, case examples from French coal mines facing rockbursting problems in longwall faces are discussed and detailed.

1. INTRODUCTION

Mining operations in hard rock, tabular situations are usually associated with induced, seismic activity, i.e. the occurrence of dynamic rock failures ranging from surrounding audible rock noises to large scale failure phenomena as: air blasts in tabular shallow mining conditions, rockbursts along working faces or roadways in deep, longwall extraction, sudden safety pillar failures or tectonic fault slips. Clearly. seismic behaviour of the rock mass and orebody creates hazardous working conditions for people underground, damage to equipment and delays to production.

Severity of rockbursting is affected by many parameters. However, high induced stress changes are a basic parameter of large scale disruptions in the rock mass, and this happens to be especially the case in tabular mining. The openings and large voids created by the mining operations cause pre-existing force to be redistributed and largely magnified in the sound rock. When the stress exceed the strength of the rock mass, generally in the vicinity of the openings, failure occurs, generating a seismic tremor, noticeable or not. Only few seismic events give place to damages and are then classified as rockbursts.

Rockbursts and air-blasts are one of the major problem for the mining industry all around the world. These are special seismic events and their mechanisms are not clearly identified when compared to those of other seismic events. In other words, exact rockbursting prediction in the time-space domain still remains a challenge open to the research area. However, better understanding of those phenomena can be approached within details using available methods like field stress measurements, numerical modelling, and moreover seismic monitoring.

1.1 In situ stress measurements

Natural stress measurements are important in the way that induced stresses (that triggers eventually failure mechanisms in the rock mass initially at equilibrium) around the mine layout are directly dependent of the initial, in situ stresses in the virgin rock mass; depending on the tectonics of the site and the vicinity of old workings, natural stresses may change considerably in the same zone (presence of folding or faulting zones, geological anomalies). Overcoring technique is a stress relief method that call be applied on a quasi routine basis in order to map with accuracy stresses from place to place following the mine layout underground and its tectonic changes.

Overcoring technique is based on the measurements recorded from a cell equipped with strain gauges. After being placed in a small borehole away from a mine opening (Fig. 1) overcoring of the cell induces full destressing of the core and strains recorded are used to back calculate natural stresses (σ_1, σ_2, σ_3), in terms of module and orientation. Fig. 2 shows plotted strain curves versus drilling advance from data monitored during a measurement trial in Lorraine Collieries, France.

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Accurate stress knowledge represents a key parameter in order to achieve correct numerical modelling of a mining zone.

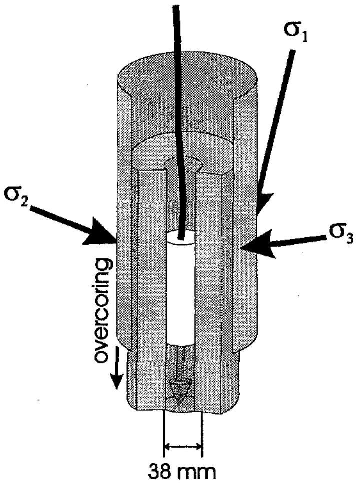


Fig. 1: (right) Principle of overcoring technique

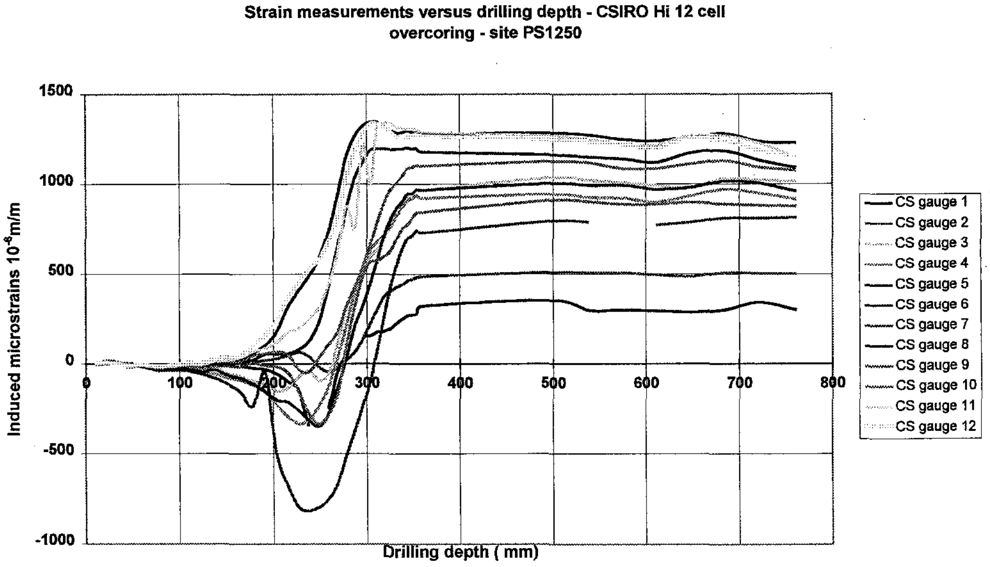


Fig. 2: (below) example of strains recorded during overcoring, on CSIRO Hi 12 cell., Final values are directly related to the insitu stress field. Compressive stresses found are (Bigarre, 1996) : (σ_1, σ_2, σ_3) = (-27, -19.5, -17.5) MPa.

1.2 Numerical modelling

Numerical modelling is a basic approach when stress prediction is needed inside a large volume of rock. As soon as voids and openings are large, or close together with ancient mine workings overlying or underlying the volume of interest, potential instabilities become very difficult to assess.

When field stress measurements are available and elastic parameters of the bedding rocks are known, numerical modelling offers a low-cost, efficient means to study and identify stability conditions following a lot of situations encountered in practice in mining engineering concerned with mine layouts and critical stability problems: stability of pillars in pillar-and-room extraction, stability of upper roof in shallow tabular mining method, influence of older panels lying in the vicinity of new mined out openings.

However, if numerical modelling techniques are nowadays widely used, most of the codes marketed present specific limitations when dealing with tabular mine layouts in 3 dimensions, especially when superimposed seam levels are considered by the mining engineer. These geometries are bidimensional, that is ratio of height over length/width of the opening is at least two orders of magnitude, and stress redistribution over a large volume of rock all around the voids modelled usually provides for non consistent solutions in stress or displacement prediction at least in one direction.

In order to address the particular problem of multilevel tabular orebodies, INERIS has developed the code SUIT3D, based on the boundary element method, and incorporating algorithms and graphic facilities fully suited to this kind of application. Running on PC based computer, SUIT3D permits to model panels extracted by longwall or room-and-pillar methods of different geometries, distributed on different seam levels with different dip and dip directions. Numbers of panels and seams modelled are restricted to the computer capacities. Eventually, SUIT3D has been optimized to set up simulations of different mining sequences.

Fig. 3 shows an application of SUIT3D applied to the modelling of the stress field around and inside a stiff pillar at U.E. Reumaux, Lorraine Collieries (Al Heib, 1996). Here, the study is based on the project of mining out a future panel crossing from south to north this pillar surrounded by 15 old workings lying in 4 different seams. Analysis of the calculated stress field permits to the mine management to decide proper safety countermeasures (local monitoring, destressing action, support design, etc.) to be taken in regards to the past experience and previous modelling results conducted in similar conditions.

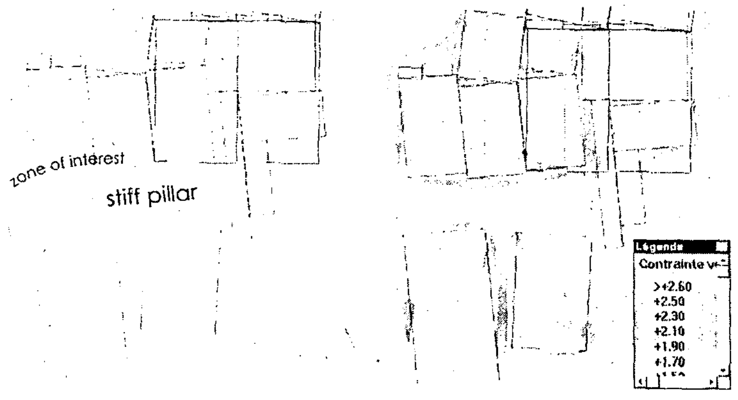


Fig. 3 : a) orthogonal projection of the mine layout around the zone of interest
b) contours of the ratio of total vertical stress to initial vertical stress $\sigma_{ZZ} / \sigma_{ZZO}$

1.3 Real time, permanent seismic monitoring

Real time, permanent seismic monitoring provides the most useful set of data when dealing with frequent and violent disruptions of rocks and instabilities of openings. In tabular mining, seismic data are usually continuous and thus constitutes a fundamental source of information about the rock mass response to mining operations.

Seismic tremors, whatever is the range of magnitude considered, are not predictable. Thus, seismic monitoring systems need to be designed in order to :

- provide information as fast and detailed as possible on each new, recorded event: reliable real time processing of waveforms must include at least calculated ground motion parameters: peak particle velocity, acceleration, duration, frequency, etc., and source parameters: location, energy and magnitude;
- permit to back analyze as quickly as possible recent sequences of seismicity in order to study the space-time patterns related to the different zones of interests as far as they are covered by the seismic network.

2. SEISMIC MONITORING IN FRENCH COLLIERIES

2.1. Presentation

Nowadays. Charbonnages de France operates two collieries facing rockbursting problems. At Houilleres du Bassin de Lorraine, four mining units mine coal down to 1.250 meters deep, following different methods depending on the dip of the seams: caving longwall, mechanised working face or hydraulically stowed, rising faces. Thickness ranges from 3 to 5 meters. At U.E Provence, the coal deposit lies sub-horizontally, with a thickness varying between 2.2 and 3 metres, and is presently mined at a depth of 1.300 meters by the caving longwall face method, equipping panels of 220 meters of face width. Acoustic and seismic monitoring has been a major aim since 1985 with research programs to improve rockburst control.

2.2. Description of the monitoring networks

In both Provence and Lorraine coalfields, real-time seismic monitoring is operated in order to analyse and track seismic activity generated by the underground workings. Mine scale networks (4 and 10 km extension respectively) are equipped as follows:

- surface seismic stations, tridirectional or vertical, with radio transmission of the preamplified modulated signals towards central site, reception and demodulation, analogue filtering and then digital conversion on an acquisition unit based on PC computer. All seismic sensors are 1 Hz geophones (Fig. 4);
- underground seismic stations, tridirectional or vertical, with cable transmission up to the shaft entrance. Here again, 1 Hz geophones and preamplifiers are used based on intrinsically safe equipment.

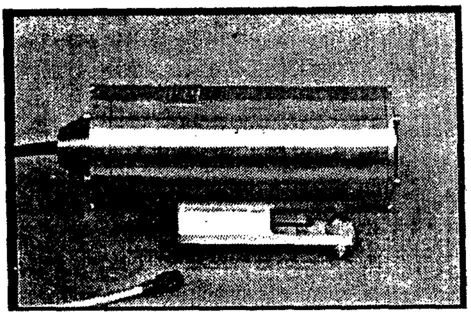
Local magnitude coverage ranges in both cases from magnitude 1.3 up to 3.2 with sufficient, reliable location estimates (Senfaute, 1994). Lower magnitude events are generally poorly located. Most surface seismic stations are equipped with dual gain, increasing largely the dynamic of the system. Digital data acquisition and processing architectures are showed in Fig. 5 and 6.

The large extension of the mine scale seismic network deployed in Lorraine (>10km) impose to run local sismo-acoustic networks concentrated around working faces. In this case, stations are equipped with 14 Hz geophones and magnitude covered comes down to 0.

2.3 Seismic data interpretation on a routine basis

On a real time basis, seismic data are processed and edited in order to get ground motions and source parameters as soon as needed.

igure 4 : 1 Hz intrinsically safe conditioned eophone for coal mine : underground horizontal omponent lying on its base.



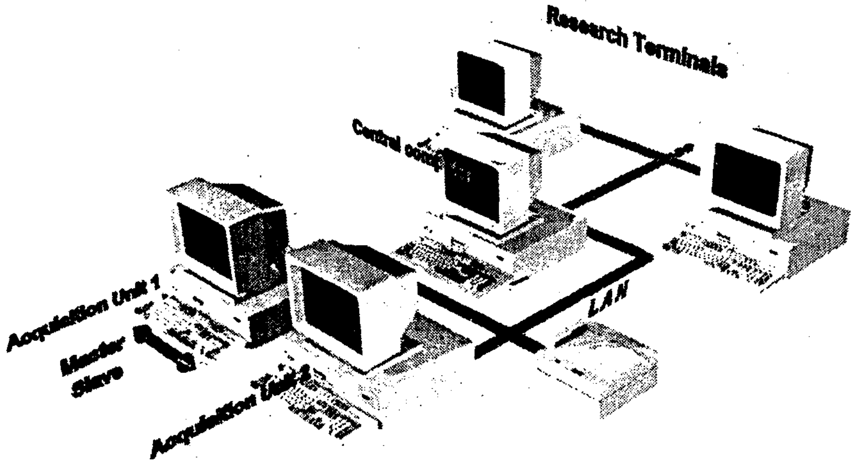


Figure 5 : description of the monitoring system of mine scale seismic network operated at Provence and Lorraine Collieries. Master/Slave protocol integrated in two parallel acquisition units offers full safety in case of intervention or failure. Newly recorded seismic event on master acquisition unit is immediately sent to the central computer through the Local Area Network for real-time, automatic data processing, database updating and report editing. Interactive, processing of the data or more in depth studies may be done from central computer or any connected on the LAN (Bigarré, 1994).

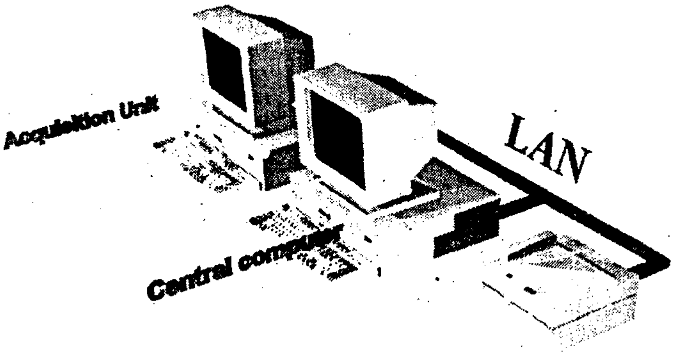


Figure 6 : description of a monitoring system operating a sismo-acoustic network in Lorraine Colliery, at each shaft entrance (Felt, 1996).

In practice, at Provence Colliery for example, dozens of seismic events are recorded daily when mining face advance is normal. Special attention is then brought only to the major events, i.e. for which local magnitude is approximately greater than 2.5. In this particular case, waveforms may be interactively checked up and hypocenter location is attentively detailed while information is collected from underground. Figure 7 shows an application of such a routine while rockburst MS-5 was not felt by miners working on T21 face. The mapping detection of large seismic tremors in unexpected, active seismic areas is an efficient mean to lead to appropriate measures as quick inspection and fast decisions like floor slotting, with optimal time planning.

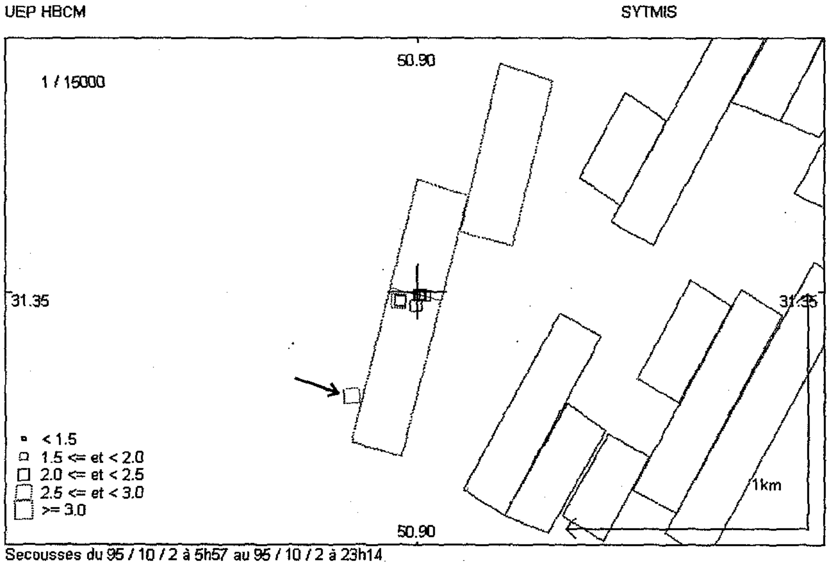


Figure 7 : seismic activity of 02/10/95, panel T21, district Arbois Sud, U.E. Provence

daily face advance : 6.7 m

seismic events of local magnitude > 2 : 7

1 seismic event (arrow pointed) of local magnitude 2.8, 400 meters back the working face, associated with large floor heavage along the roadway : rockburst MS-5.

Fig. 7: seismic activity of 02/10/95, panel T21 district arbois Sud. U.E. Provence.

Every month, special seismic report is edited for each currently mined panels, including updated parameters such as (Bigarre, 1994):

b-value: this widely used parameter is the slope of the linear tendency of the distribution of the number of seismic events per class of magnitude (Fig. 8). It merely quantifies how much large seismic tremors are present in the current seismic activity of the zone of interest;

a-value: this parameter is calculated as the linear tendency of the daily seismic energy released versus the face advance. It quantifies the rate of seismic energy release per meter of advance of the panel (Fig. 9).

These parameters and others are routinely used to quantify and characterise the seismic activity of the working faces relatively to the coal extraction rate. They are examined in terms of classification of mining areas and panels and for a same panel during its whole mining phase.

Fig 10 shows cumulative seismic energy versus face advance plotted for the last 9 panels mined out at Provence between April 92 and August 96. This representation offers large means of classification of panels in terms

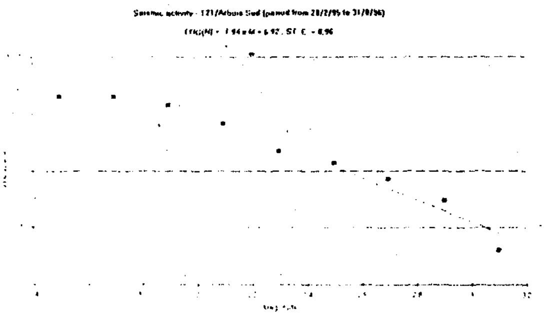


Figure 8 : the parameter b-value : 1.94, (slope) of the linear trend, indicates proportion of large seismic tremors over overall seismic activity for a given active mining face.

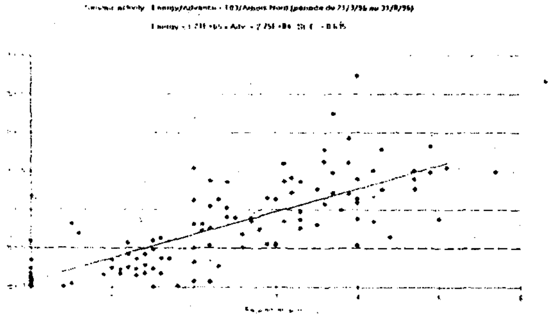


Figure 9 : a-value : 1.21E+05 J/m has been defined as the positive slope of the distribution seismic energy release on a daily basis versus face advance. It quantifies seismic energy release rate.

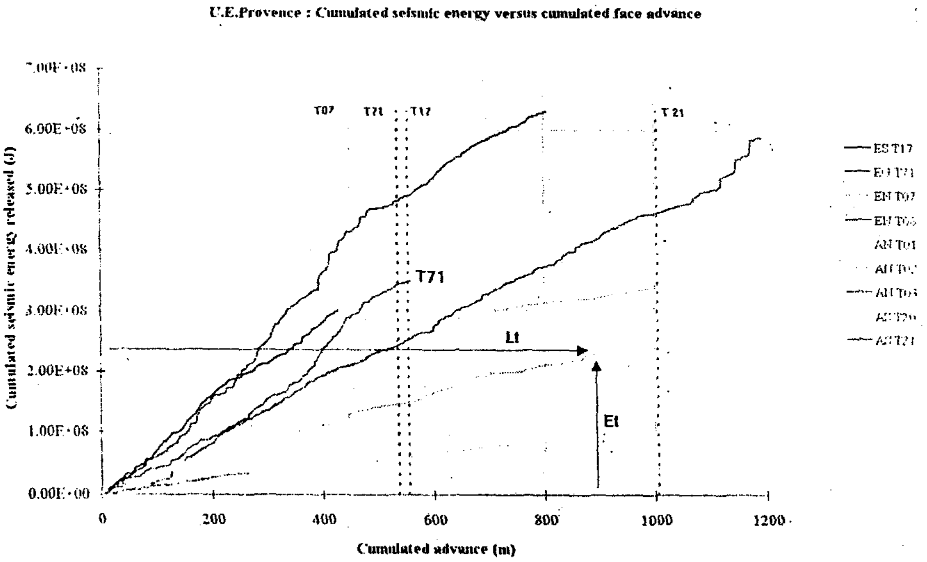


Figure 10 : plot of cumulative seismic energy release versus cumulated face advance concerning 9 panels from 4 differents districts sparsed in the mine layout. Levels, trends and changes of seismic regime are routinely and comparatively examined in order to classify current working faces.

of seismic energy release and then rockbursting potential.

Related to Fig. 10, Fig. 11 shows the ratio of total seismic energy release E_1 over total face advance L_1 per panel versus number of recorded rockburst. When correlated with other parameters, such a basic approach provides for a rough but fast and easy mean to quantify the susceptibility of currently mined panels to rockburst occurrences.

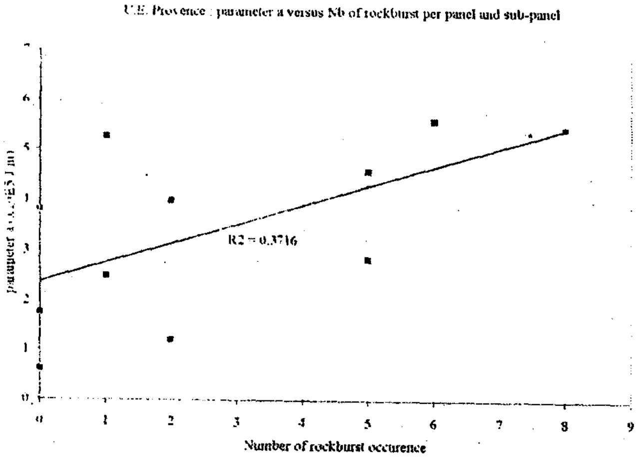


Fig. 11 : ratio of total sesmic energy release E_1 over total face advance L_1 per panel versus number of recorded rock burst at UE Provence.

Fig. 10 shows the cumulative seismic energy release versus cumulated face advance concerning panel T71, mined out southwards in direction to the shaft pillar (Fig. 12). Recorded Small seismic impacts with small associated damages observed underground, in relation with increase of seismic regime during the previous 140 meters of face advance. permitted to conclude that stresses were shifting at a higher rate than expected inside the safety zone.. These seismic observations did conduct the mine management to the stopping of the panel, in order to preserve a sub-critical stress regime in the northern part of the shaft pillar.

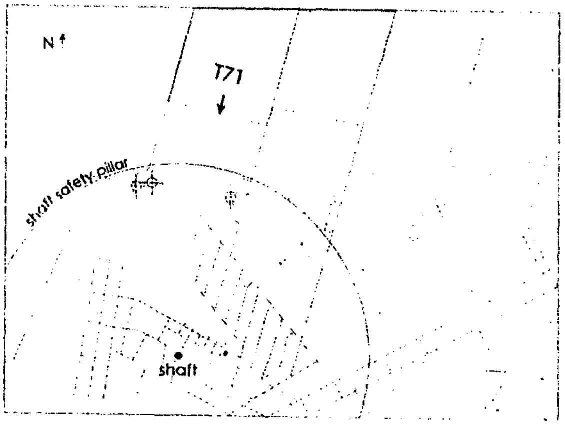


Fig. 12 : localization of sesmic events inside shaft safety pillar related to panel T71 geometry, following a plane view

Considerations described here-above intend to illustrate the importance of seismic monitoring applied. to mine induced seismic activity and instability control. Seismic routine analysis offers large means to investigate response of underground structures without considerable efforts and help to save time in terms of safety countermeasures to be taken by mine management.

2.4 Seismic prediction

Rockburst are seismic events associated with damages but without other clear distinction and thus very difficult to predict, whether studying intrinsic source mechanisms or patterns of seismic sequences. Senfaute (1995) did study prediction of large seismic tremors (Es $>10^{e}6$ J) as a data bank that contain most of the times rockbursts associated with large damages, study based on data analysis techniques.

The discriminant analysis technique undertaken over the seismic activity induced by the mining of a particular panel has been applied successfully, determining a function Y=f(X1,X2, X3,..) (linear discriminant function of N variables); able to classify days with large tremors occurrences and days without, where X1, X2, X3,...X12 are variables as: face advance the day before and two days before, Logarithm of seismic energy released the day before and two days before, number of seismic tremors per class of magnitude the day before and two days before, etc. More Details can be found in (Senfaute, 1995).

Fig. 13 illustrates the discriminant function <<Y>> determined with its value along x axis and number of days along y axis, following two classes (days with and without large tremors). The graph shows clearly that all the days with large tremors are predicted with positive Y value, except for 1 day (arrow pointed), i.e. with 97% of rate of success. Days without large tremors are successfully predicted as such with 76% of rate of success.

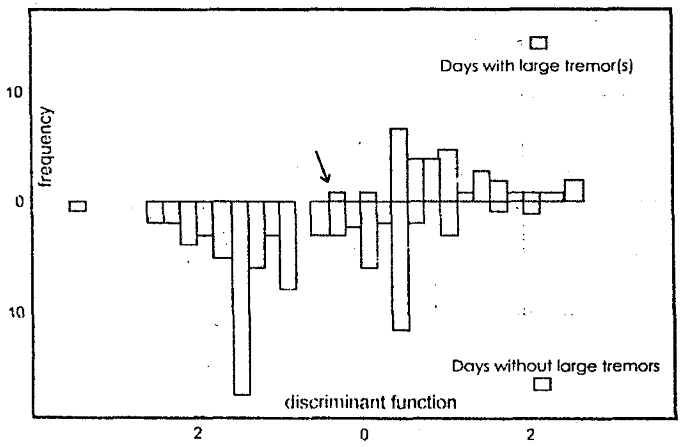


Figure 13 : discriminant function plotted for the days with large tremors (34 days) and without large tremors (87 days), panel T07 geometry 1. U.E. Provence. Success of prediction of days with large tremors to appear is 97% (Senfaute, 1995).

These results show clearly that data analysis techniques can provide a valuable mean to predict large tremors to occur for the current starting 24 hour window time, as soon as others factors (mining method, geological conditions) remain constant. Research is going on as to real-time implementation of such indicators.

3. CONCLUSIONS

Many advances have been made these last years in stress prediction techniques related to tabular mining as well as in seismic instrumentation and processing techniques.

Presently, in French, deep coal basins, stress prediction rely essentially on in situ stress measurements based on stress relief techniques and then large and/or local scale numerical modelling of the mine layouts, in order to optimise safety and economical mining. These two stages are systematically undertaken for each future panel in order to assess and design better countermeasures and mining phases if needed. Results and data are always confronted with the past experience and regular observational procedures.

As stress prediction from numerical modelling is inherently based on a simplified problem, real-time seismic monitoring is used to overall control the effective, rock mass response to mining operations. Seismic data are integrated at different time window scales into the set of data collected and interpreted following pre-defined procedures. Objectives are to improve knowledge as far and fast as possible on the working conditions in order to rationalise mine management decisions confronted with instability occurrences underground.

Some examples of on site routine analysis commented here above answer clearly to the need and contribution of rock mechanics engineering techniques, included applied geophysics, in making mining safer in terms of daily decisions of mine management as well as planning of mine layout design. Research carried on focuses on source mechanisms of seismic tremors and fractal analysis of seismic patterns (Lanchy, 1996) and is hoped to improve in the very near future reliability of indications available in terms of major instability prevention.

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