The prevention of rockbursts in Gardanne colliery

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THE PREVENTION OF ROCKBURSTS IN GARDANNE COLLIERY

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ABSTRACT : This research is based both on numerical modelisation and geophysical measurements. Before mining each new longwall, a numerical modelisation is made to determine the increase of stress created in the areas surrounding the new longwall. Therefore, the smallest distance between the longwall and the existing roadways can be assessed. Permanent seismic monitoring is used to calibrate the numerical modelisation. During the mining operation geotechnical measurements are carried out in order to verify the results of the numerical modelisation. These measurements concern the convergence of the roof and wall and the expansion in the coal. Bore-testing and electro-magnetic measurements on the coal under stress are also carried out. The efficiency of these methods has been perfected by carrying out systematic prevention plans for each new longwall. This plan was constructed with a rigourous methodology using the full range of geotechnical, geometrical, tectonic and historic data for the concerned area.
A quality control procedure provides the means of checking the successful application of the prevention plans and creating a data bank to use in future developments.

I - INTRODUCTION

The Gardanne colliery lies between Aix-en-Provence and Marseille and is part of the south-east complex of H.B.C.M. (Subsidiary of the Charbonnages de France group).
The coal deposit is from fluvio-lacustral origin and was formed some 75 millions years ago. The stratigraphical sequence is mainly composed by limestone (qualified as hard and brittle) and mudstone.
The general geological setting of the basin is quite simple. After Gaviglio and al (1988), the structure is overridden by a major thrust sheet overthrusting northward with 25 degrees average dip.Strike-slip, subvertical faulting is present all over the area, with lengths of several hundreds of metres. Most faults have throws less than 2 metres.
The stratas dip westward around 15-20 %. At present, the coal is mined from a depth between 1100 m (longwall faces) and 1400 m (development works). Drill-core and vibroseismic profiles show that the maximum depth of the seam is about 1450 m.

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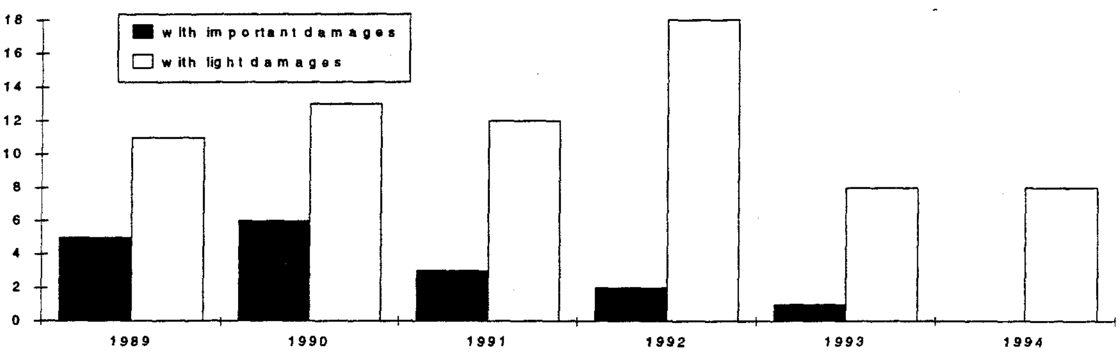
Only one seam with a thickness averaging 2,5 m is economically recoverable. This seam is embedded in limestone which forms competent stratas and has a uniaxial compressive strength of up to 150 Mpa.
The principal stresses of the surrounding rocks are measured by the hydraulic fracturing method. These measurements show a strong anisotropy of the principal stress components, characterized by high horizontal tectonic stresses (between 20 and 40 Mpa) and a sublithostatic vertical stress.In spite of faults, the coalfield is quite regular. Combined with, in average, good strata conditions, this allows a large scale mechanization. The longwall faces method with caving process is used; the length of span is 220 m; The faces are equipped with plough and hydraulic powered supports. The faces progress between 4 and 8 metres a day per face.
During 1994, the seismic network recorded 125 events of magnitude comprised between 2,6 and 3,2. Most of these events are attributed to the goafing process associated with the longwall mining operations. During the last years, many of these events result in more or less damageable rockbursts (Figure 1).

Figure 1 : Number of Rockbursts



Classified with regard to rockbursts locations and effects at the Gardanne colliery, three main types (figure 2) have been recognized as :

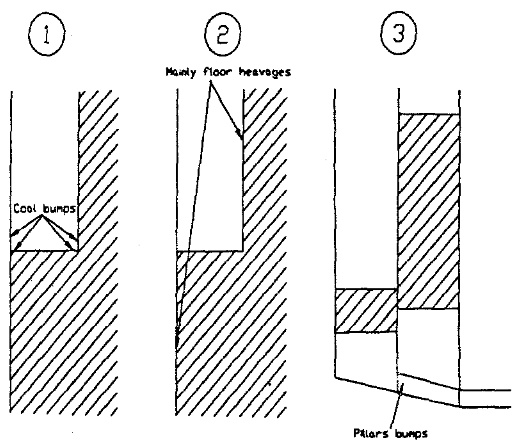


Figure 2

Type 1 : coal bumps at the ends of the faces, mainly on the old panel side.

Type 2 : mainly sudden floor heaves which can reach 1 m (with a slight ejection of the coal seam), over lengths up to 100 m. They take place either ahead of the face (in tail gate) or behind the face (in main gate) at a distance ranging from 50 to 150 m.

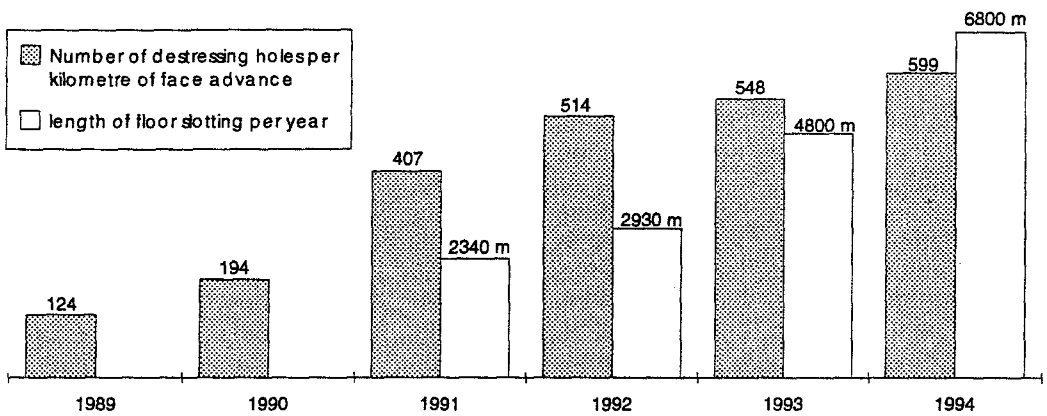
Type 3 : coal bumps in unmined , overloaded stiff pillars.

To prevent the rockbursts, two destressing methods are used in Gardanne colliery :

- near the end of the faces, destressing holes (diameter 108 mm, length 10 m) are drilled with an interval, depending of the stress level, comprised between 2 and 3 metres; their progressive generalization (figure 3) since 1991 explains the decrease of coalbursts near the faces.

- before the face winning, the floor of the two gates is slotted (width 0,15 m, depth 0,9 m). This technic is also used around weak pillars in the surrounding of faces. This technic, introduced in 1991, seems efficient against most floor heavages.

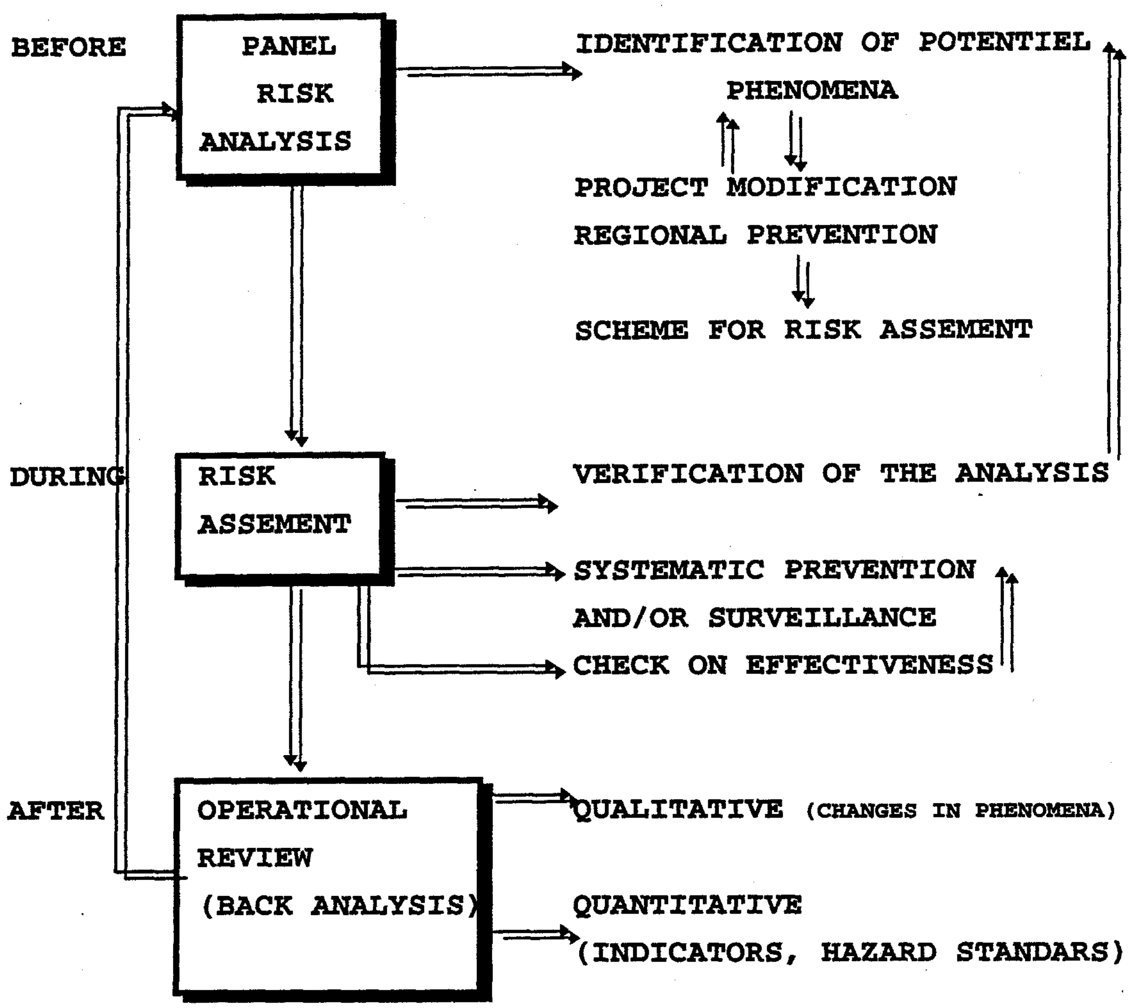
Figure 3 : evolution of the utilization of destressing methods



II - METHODOLOGY FOR CONTROLLING GROUND HEAVE

Rock burst is a complex phenomenon. Its control requires the application of an overall methodology as indicated on figure 4.
This methodology is based upon the feedback of experience (back analysis), in other words the risk analysis is based on analogy with other, previously worked sites. Our efforts in recent years have therefore concentrated on organising the collection of information - in the form of a geotechnical database - with its effective retrieval in the planning stage of a face project.
The methodology leads to a procedure for dealing with the risk of rock burst, a procedure which is applied from the project planning stage through to the completion of each panel.

figure 4 : controlling dynamic phenomena methodology for action



In the planning phase, the risk analysis is based upon:

- knowledge of the natural state of stress based on measurements using hydraulic fracturing in each district;
- simulation of stress modifications due to earlier and planned workings;
- a geotechnical plan of the future face combining all the geological and geotechnicaldata together with operational information such as pressure effects during the driving of gates.

This phase ends with the preparation of a prevention plan jointly by the operators and the specialists who indicate the surveillance and stress relief measures to be taken and their location in space and time.

During operations, the procedure primarily includes the controlled introduction of the assessment plan but also:

- verification of the validity of the risk analysis using remote seismic surveillance;

- checks on the state of the rock mass and on the efficiency of the preventive measures carried out. Substantial progress in this field should result from the completion of the IMPULS system based upon electromagnetic monitoring of the rock mass developed by VNIMI (Russia).

Following the operational phase, the review stage is essential for completing the "knowledge base" which will enable future sites to be dealt with more effectively.

III - PREVENTION SCHEME FOR FACES 02 AND 20

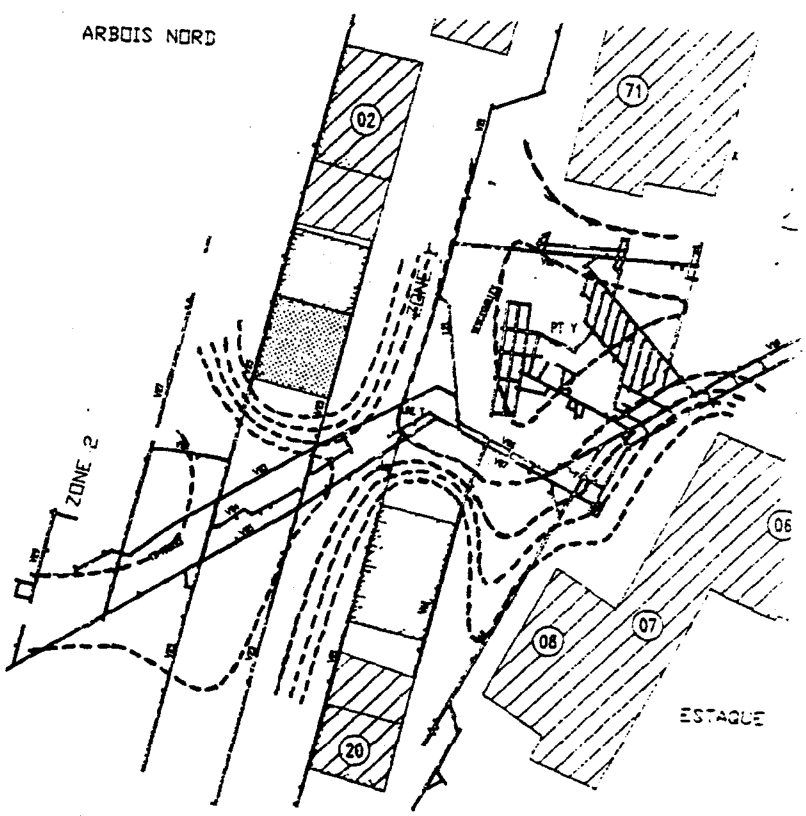
The application of this strategy for controlling rock burst will be explained using an example: the case of faces 02 and 20 in the Arbois district. These faces occupy a decisive position for the future of the workings because they complete the cutting of the principal shaft barrier pilar (Y) and abut on the permanent infrastructure that will serve the western extension of the mine (figure 5).

In order to simulate stress changes due to the workings, software was needed that would be sufficiently easy to use for studying the different configurations of the working geometry during the project. Programs using finite element methods which can represent the mechanical properties of the different strata, and distinct element methods which explicitly represent discontinuities (faults, etc.) are too involved, especially in three dimensions, for routine use in planning all the workings. For this reason, a boundary element program was selected: SUIT 3D. This has the advantage of taking the horizontal stresses into account; these are asymmetrical and high in the area prone to rock burst. It uses an empirical model for the behaviour of the caving areas based upon the VNIMI experience.

For the Provence mine, this program was calibrated on the case of a rock burst which affected a pillar to the east of the Y shaft barrier pilar. In this area, distinct element modelling was done using the 3DEC (ITASCA) code; where displacements along faults are not too great, the variations in vertical stresses obtained with 3DEC and SUIT 3D are comparable, which confirms that SUIT 3D is suitable for project planning.

Figure 5 shows the contours of the supplementary stresses due to simultaneous working of faces 02 and 20 in the final stage of the planned workings. According to the additional stress values, the infrastructure and barrier pillars were fitted with pressure cells and with convergence and expansion cells. The evolution of these measurements were used to determine the positions at which the face workings were actually terminated.

figure 5 : plan view of face 02 and face 20 contours of supplementary vertical stresses

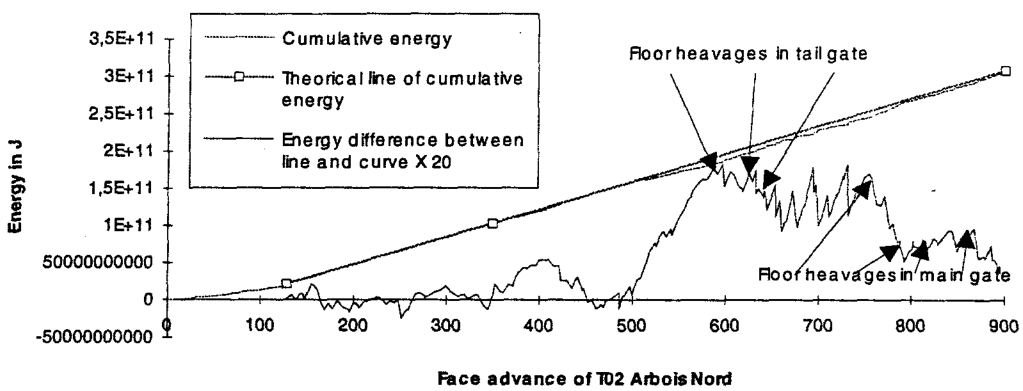


IV - MONITORING OF THE FACES 02 and 20

IV . 1 - seismic measurements

For 3 years now, every morning, the locations of the events of the day before and a criteria based on the evolution of the seismic energy versus the face advance have been given to themanagement of the mine. This criteria is not always satisfactory. Thanks to the recent improvements of the seismic network, new results give more operationnal indications.

Figure 6 : Cumulative energy versus face advance of T02 Arbois nord



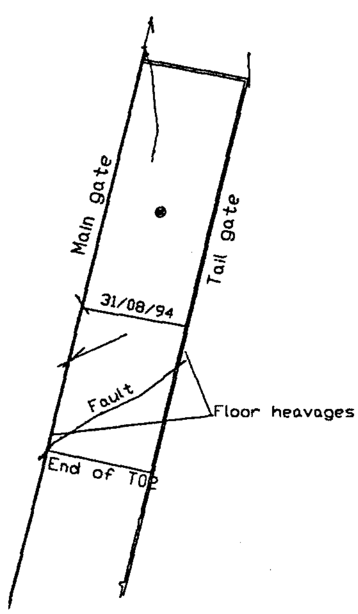


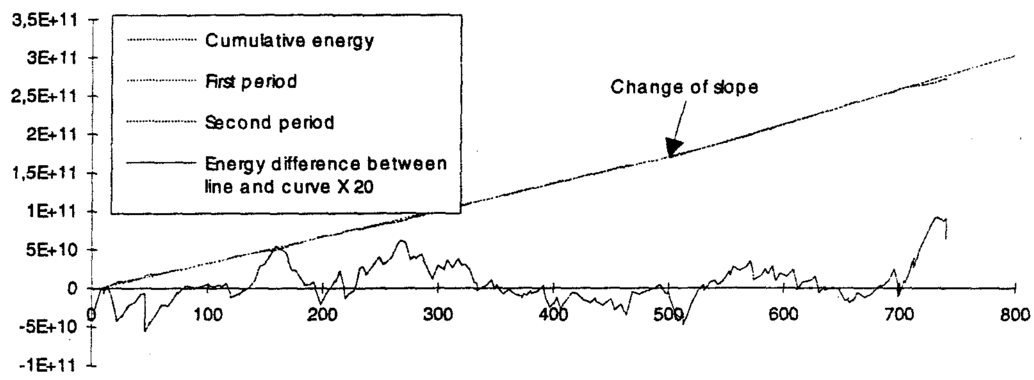
Figure 7 : T02 Arbois Nord

The graph of the cumulative energy dissipated by seismic events versus the face advance (figure 6) give us interesting informations :

- during the 500 first metres (until 31/8/94), the evolution is linear. All the seismic energy was dissipated in small tremors (magnitude max 2,81); during this period neither a small rockburst nor a little heavage happens.
- during the last 400 metres, the cumulative energy slightly slowdown; when the energy difference was more than 4 10^9 J, 15 tremors of magnitude between 2,9 and 3,17 and 7 floor heaves occur.

These floor heaves and this seismic activity are likely linked to the fault which crossed the face during the second period (figure 7). Studies about the focal mechanism are carried out to confirm this interpretation.

Figure 8 : cumulative energy versus face advance of T20 Arbois Sud



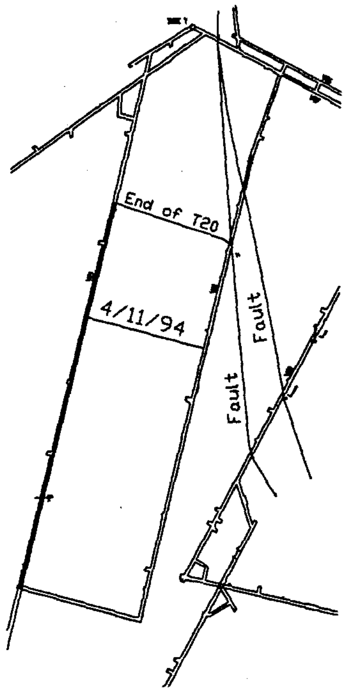


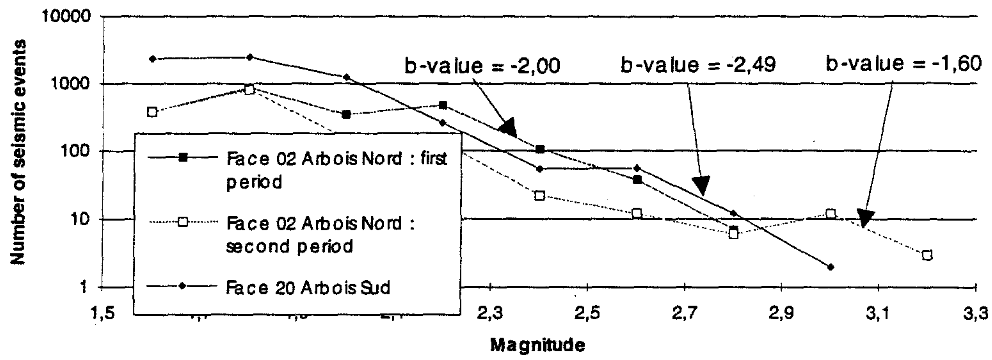
Figure 9 : T20 Arbois sud

Concerning the graph « cumulative energy » versus face advance (fig.8), 3 periods can be observed :

- The first and second periods are distinguished by different slopes of the lines associated; among the 7300 seismic events recorded, only 2 have a magnitude higher than 2,9; as for the first period of face 02, no rockburst, even small, happens. Additionnal studies are necessary to determine if the change of slope is linked to the faults which are within 60 m from the tail gate (figure 9); in other cases, in similar configurations, rockburst occur.
- just before the end of the face, when the faults crossed the tail gate, the cumulative energy slows slightly and the differential energy increases; this fact is partially at the origin of the decision to stop the face.

As we dont know a priori ,with enough precision, the energy level of a face, this kind of criteria, based on the energy deficit, cannot be used during the first 200 metres of face advance. And even after, it is only an indication of the risk of occurrence of high magnitude events.

Figure 10 : log(N) versus magnitude and B- values



The distribution of events in function of their magnitude and the b-values (figure 10) distinguish clearly the second period of the face 02. The number of events recorded (40 per day and per face) allows the processing of these graphs each week for the last month. This kind of criteria, even if it is possible to process it sooner than the energy deficit, must be put in correlation with other indications to be usable.

IV . 2 - Electro-magnetic measurements

Principles of the measurements

When stressed, stratas emit electro-magnetic signals. The VOLNA apparatus, by mean of a receiver, detects the signals emitted by the rocks within a radius of 10 metres. Simultaneously, it processes and records the datas. Finally, it indicates the operator a level of risk.

Successively on 11 levels of energy (Ei), the apparatus counts the number of times (Ni) that each energy level is reached during a space of time. The representation of log(Ni) versus Ei is approximately linear and can be characterized by two parameters; the first one (N), is representative of the average of the eleven values Ni and the second one (B) indicates the slope of the line. The risk increases when N increases and when the absolute value of B decreases.

To make the apparatus operationnal in the Gardanne colliery conditions, it was first necessary to determine the frequency of the receiver, to find in which energy interval the signals are correctly received and to fix the duration of the recording so as to obtain usable values of Ni. Then, several months of measurements were necessary to find the relation between the measures and the risk level. The level of risk is represented by a number between 0 and 3 (0 and 1 = no risk ; 2 = «suspect area »; 3 = « a rockburst is possible »).

The measurements are done once a week, in main and tail gate with an interval of 5 metres near the face and 10 metres further. The table 3 indicates the average values for each concerned area.

Table 3 : T02 ARBOIS NORD - electro-magnetic measurements						
Date	Tail gate			Main gate		
	Destressed area	Before the destressed area	Observations	Destressed area	Before the destressed area	Observations
21/04/1994	1	1		1,7	2	
20/05/1994	1	1		1	2,4	
			3 heavages			
17/11/1994	2,7	3		1,6	1,6	
21/11/1994	1,2	2,3				
01/12/1994	2,2	2,8		2,8	2,8	
19/12/1994	1,7	2		2,2	2,4	
06/01/1995	1,5	2,2		2,7	2,8	
13/01/1995	2	1,9		2,4	2,4	heavage
						heavage
03/02/1995				2,6	3	
08/02/1995	2,2	2,3		2,8	2,9	
13/02/1995	2	2,2		2,8	2,8	heavage
21/02/1995	2,2	2,6		2,2	2,8	

During the first period of the face 02, the electomagnetic measurements indicate that there was no risk in tail gate and that destressing operations were efficient in main gate. Unfortunately, on account of electrical agreement procedures, we have no measurement before the 3 heaves in tail gate. On the 17th of november, in tail gate, the apparatus indicated the risk maximum so the mine management decided to drill again the destressing holes from the face end. After destressing, the measurements were correct again. In main gate, since the beginning of december, the apparatus indicates a high level of risk equally in the distressed and in the non destressed area. In spite of the drilling of new destressing holes (on each side of the gate) and in spite of the floor slotting, 3 slight heaves occur. These facts (and the effect of the face upon some pillars) leaded the mine management to stop the face.
<u>This exemple shows that, even if the electro-magnetic measurements are not reliable enough to characterize alone the level of risk, it is possible to use them as a mean to control the effectiveness of the destressing operations.</u>

IV . 3 - <u>MONITORING of PILLARS</u>

The monitoring of the pillars between the two faces is realized by :

- <u>The seismic network</u> :
  Each month, usually, 1 to 3 events are located in the neighbourhood of the pillars between the two faces. Their number began to increase during December 94; during January 95, two events are noticeable; one of magnitude 3 but without any damage

and one of magnitude 1,7 with very slight damages (a coalbump of 2 cubic metres!).
The maximum rate of events (6 per month) occured during February and March.

- The evolution of the deformations of the pillars : measurement and recording are done each week and transmitted to the mine management

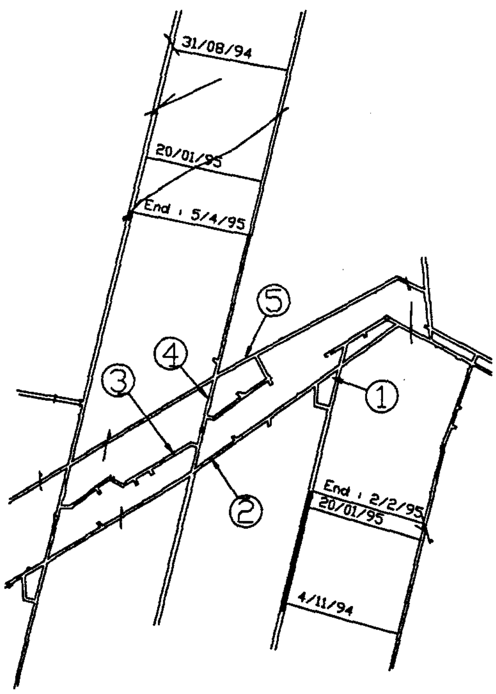


Figure 11 - pillars

Each measurement station (spotted 1 to 5 on figure 11) has a convergence device, two ribside extensometers and a pressure cell.
The first evolutions (convergences of respectively 2 and 1 mm) were detected in January (stations 1 and 2) just after the event of magnitude 3. The face 20 was within 300 metres and the face 02 at about 500m of the concerned pillar.
The second evolutions, more important (12 mm of convergence, 41 mm of expansion of a ribside) appeared in February (stations 1, 2, 4 and 5). The face 20 was stopped and the face 02 was between 350 m and 400 m (depending of the pillar concerned).
So, we can notice that these results (seismic events and deformation measurements) are in accordance with those of the numerical modelling which indicates that :

- the face 20 has little influence on the pillars area.
- the influence of the face 20 will begin only when the face will be at a distance of less than 350 m.

V - CONCLUSIONS

In recent years the seam mined in the Provence coalfield became much more susceptible to rock burst because of depth and unfavourable tectonics. However the number of rock burst incidents was reduced by introducing a control methodology that was highly effective in our working conditions.

The main features of this methodology are:

- an overall procedure defining the *steps* to be taken, from the stage of planning the workings. This procedure which is based on a ***quality approach, is*** being reviewed as operations proceeded in the light of site monitoring data.;

- extensive use of stress relief techniques, made economically viable by mechanisation of stress relief hole drilling and floor slotting roadways;

- improvements in the methods used for prediction (computation software) and monitoring (seismic and electromagnetic techniques) in order to increase their performance and include them in routine operational practice;

- close co-operation between the operators, the specialized departments of the mine and the research institute including international co-operation in the development of new technical facilities.