HAL
archives-ouvertes.fr

Importance of failure mechanisms for management of surface instability risk above abandoned mines

Christophe Didier, Jean-Pierre Josien

▶ To cite this version:

HAL Id: ineris-00972429
https://hal-ineris.ccsd.cnrs.fr/ineris-00972429

Submitted on 3 Apr 2014

Importance of failure mechanisms for management of surface instability risk above abandoned mines.

C. DIDIER[*], J.P. JOSIEN**

¨INERIS, Parc Technologique Alata, BP N°2, 60550 Verneuil-en-Halatte, FRANCE.
Tel : +33-3-44-55-68-36. Fax : 03-44-55-67-00. E-mail : Christophe.Didier@ineris.fr.
**GEODERIS, 15 rue Claude Chappe, 57071 Metz Cedex 3, FRANCE.
Tel : +33-3-87-37-78-14. Fax : 03-87-37-78-18.
E-mail : jean-pierre.josien@industrie.gouv.fr.

ABSTRACT: France now faces the closure of most of its mining sites. Surface instability risk may sometimes remain, especially where large underground voids exist. This paper illustrates the importance of failure mechanisms identification in order to define properly how to manage the residual risk.

RESUME: La France fait aujourd'hui face à la fermeture de ses exploitations minières. Des risques d'instabilités de surface peuvent persister, notamment lorsque des vides résiduels existent au sein des travaux souterrains. L'article illustre l'importance que présente la nature des mécanismes de rupture potentiels dans le choix des mesures compensatoires à adopter pour gérer le risque résiduel à long terme.

ZUSAMMENFASSUNG: In Frankreich stellt sich derzeit das Problem der definitiven Schliessung des meisten Bergwerke. In manchen fällen ist die Stabilität der Oberfläche nicht garantiert, speziell wenn unter Tage nicht verfüllte Hohlräume verblieben sind. Dieser Bericht zeigt die Wichtigkeit, bei der Auswahl geeigneter Langzeit-Risikomanagementmethoden, der verschiedenen Mechanismen mit denen ein eventueller Bruch an die Tagesoberfläche geraten kann.

Introduction

After exploiting its underground mineral resources for centuries, France has witnessed the gradual closure of its mining sites. These closures have often taken place without any satisfactory analysis being performed to identify the possible consequences which could have long-term impact on persons, property and the natural environment.

Of the various risks inherent in a post-mining period, the surface instability may be particularly significant where large residual voids remain underground once mining has ended. This "ground movement" risk can be evaluated by combining the predictable damage and surface occupation. It is used to judge the need to envisage the implementation of appropriate compensatory measures.

Treatment such as backfilling or providing support in voids are indeed often technically and economically impossible because of the volume, depth and accessibility of the mining works concerned. Although priority is traditionally given to solutions for managing the surface occupation in sectors which are still uninhabited, when the risky zones already show surface instability, this solution is no longer adequate and moving populations would generate socio-political and financial problems which are difficult to solve.

When there is no other suitable solution in the context, monitoring potentially unstable zones may provide an interesting alternative. This solution is intended to provide risk management by detecting the signs of unfavourable evolution of the undermined land. In this way populations can be maintained in a "doubtful" zone while making it possible to evacuate them in the event of an alert judged sufficiently serious by the competent authorities.

Using a monitoring system requires the failure mechanism, particularly its dynamics, to be identified as accurately as possible, so that it can be determined whether it is possible to detect preliminary signs and whether they are adequate for operational risk management (trigger a warning).

In-depth investigation must therefore be conducted on the type and dynamics of failure mechanisms liable to affect mine working and to spread to the surface (gradual or sudden, smooth or discontinuous phenomena). In this context, INERIS and GEODERIS have recently developed techniques and tools for risk analysis and management concerning mining subsidence for various mining contexts.

Two examples of mine fields in the process of being closed, for which residual risks have been identified, will illustrate this article. For the Lorraine iron basin, with many examples of instability in the past, it was possible to determine methods based on back analysis to characterise failure mechanisms and classify the risky zones on the basis of a multicriteria analysis. For the Provence coalfield, on the contrary, the very small number of instabilities in the past means that a deterministic approach has to be used, based on numerical modelling of particularly complex failure mechanisms.

The Lorraine iron basin

Context and objectives:

The Lorraine iron basin extends 120 km from North to South and 20 km from East to West in North-eastern France. It covers more than 1,500 km².

The iron deposit outcrops in the North and East and falls with a shallow 3% dip towards the West. The depth of

mining operations varies from zero to 260 m, a range of depths particularly sensitive for surface instability effects.

The age of the iron deposit is Aélenien with thickness varying from just a few to about sixty metres. It takes the form of alternating iron layers, 3 to 7 metres thick, alternating with marly or limestone beds. This very rich deposit has been exploited in several layers (up to 6), sometimes with very thin middlings (up to 1 m) which must be taken into account when determining mechanisms leading to degradation of mining underground structures.

The overburden consists of several Bathonian and Bajocian marl and limestone beds, some of which show major lateral variation in facies. Depending on the thickness and the facies of the overburden, its behaviour may be relatively plastic (metric limestone bed) or brittle (decametric bed).

Production, which began in the Middle Ages on outcrops, grew industrially between 1870 and 1997, when the last mine was closed. The quantity of ore extracted is estimated at 3 billion tonnes (or more than 1 billion m^3).

The ore was extracted using room and pillar method with rooms varying in time from 4 to 7 m and pillars of varying shape in widths of 5 to 25 m. Extraction ratios are very variable from 30 to 80%. The pillars could then be reworked, stoping leading to collapse of the recovery and consequently surface subsidence.

This second operation was not used in certain zones, particularly where the mining company wanted to protect vulnerable surface structures (residences, roads, railways). In this case, remains a question concerning the long-term stability of the pillars left in place underground.

The Briey-Longwy basin concerns 110 villages covering an area of 110,000 ha. 50% of the area of these communities has been affected by mining operations. Variable zones, where long-term stability is not proved, cover 8,600 ha of which 1,300 ha have house buildings and 800 ha have infrastructures.

It is impossible to eliminate risk over the entire region; it would require the use of one hundred million cubic metres of backfill, which is technically and financially impossible, or the transfer of population to an extent, which is impossible at regional level.

Since the number of instabilities fortunately remains small (about 1/year), risk management has been organized on the basis of the following principles:

- Guarantee personal safety, damage to property giving rise to compensation;
- Classify the risk, taking into account the importance of surface effects and the likelihood of collapse of mining structures;
- Set up a monitoring system to detect preliminary signs of failure and make sure people are moved to safety;
- Reserve risk management to zones where safety cannot be guaranteed.

This risk management involves accurate knowledge of the nature and amplitude of possible instabilities and the mechanisms responsible for these instabilities so as to define appropriate monitoring and classification of the

different zones according to their risk level. This information has been obtained by retroanalysis of old (during exploitation) and more recent events.

Surface instabilities

The shallowest zones are likely to be affected by sinkholes of several metres wide and several metres deep. The conditions of appearance of this type of instability are well known. Under natural conditions and those governing iron-ore mining in Lorraine, mining at a depth of more than 50 m eliminates the risk of sinkhole development.

For mine workings at greater depths, deterioration will be reflected in subsidence, the surface formation of a depression which may be several hundred metres in diameter. The maximum subsidence at the centre of the depression is proportional to the voids left in mining works (working height x extraction ratio); the coefficient of proportionality depends on the width of the zone mined. Surface subsidence is almost non-existent for a width less than 0.4 time the depth (H), remains very slight up to 0.6 H, when it begins to accelerate rapidly. This is interpreted as support given to the roof by the abutments of the mined zone, limiting subsidence.

In some cases, surface phenomena no longer occur as more or less rapid formation (one day to several months) of a subsidence depression. They occur suddenly, in just a few seconds and are accompanied by a seismic shock. The rocks fall in parallel ranks above the mined zone with the formation of open fractures in a step formation on the edges. Eight cases of sudden collapses (called generalised collapses also) were recorded between 1902 and 1974. Some of these occurred during operations, others when mining had been completed for many years in the zone.

Mechanisms of instabilities

The appearance of a surface instability results from a process of degradation which has affected mining operations and the overburden. Several mechanisms have been observed.

In single level mining, it is mainly the pillars which are the weak point of the structure. One zone will be characterised by the mean stress in the pillars calculated by the tributary area. Stresses in pillars are not uniform throughout the mined zone, either because of the variation in their dimensions, or because of their position (overload linked to adjacent stoping, for example). Pillar rupture can cause the hanging wall to collapse immediately, but for an instability to be reflected on the surface, the affected zone at the bottom must be sufficiently wide. The main hanging wall will collapse when the area is more than 0.6 time the depth.

Pillar rupture leads to a process which, by spreading the stress, overloads the adjacent pillars. The process duration depends on the pillar stress with respect to their strength, but it is hard to believe that it could be instantaneous for a slightly fragile rock such as the Lorraine iron ore.

In a multilevel operation, stability must be assessed for all mined layers and middlings. Thin middlings deteriorate in the form of roof falls or crushing failure. Rupture of middling weakens the pillars: decrease of its w/h

(width/height) ratio, formation of a composite pillar formed by the various layers and middlings. Impact on stability is particularly high when the pillars in the different layers are not exactly superimposed. These phenomena are difficult to quantify during a global stability study, particularly because of the importance of detailed geometry in these workings. To be on the safe side, for every middling less than 7 m thick, the tributary area is only applied to the part of the pillars that appears after superimposing the planes of the 2 layers.

These degradation mechanisms are not appropriate to explain sudden collapses. Indeed, the description of phenomena which occurred during mining operations indicated the apparently good condition of the workings during the months preceding the collapse. Precursor signs such as increased pressure, flaking pillars, were only reported during the very last days preceding the event.

The presence of thick, rigid beds in the overburden, in all the cases analysed, means that a mechanism can be proposed to explain the sudden rupture of overburden and pillars within a few seconds. These beds help stability by bearing part of the overburden load, thus relieving the pillars, which explains their good condition before failure.

Over a period of time, creep acting on the pillars increases the stresses inside the rigid beds which cannot follow this deformation. The rigid beds fail, leading to a simultaneous increase in load on all the pillars in the zone and causing their simultaneous failure up to the surface, sometime over several hectares.

The sudden collapse mechanism involves two essential conditions (Tincelin 1962) :

- The presence of a rigid bed (thick and strong) in the overburden

- "Brittle" mining geometry which will deform and then suddenly break when the bed fails; it is characterised by high extraction ratios, large areas of mining operations, small, not very strong, slender pillars.

Distinction between the risk of subsidence and the risk of collapse.

The factors defined above within the context of a sudden collapse mechanism must be quantified in order to define the criteria used to classify a risk zone.

A back-analysis has been done of 16 events, 8 sudden collapses and 8 cases of gradual subsidence (Table 1). The presence of thick, strong beds in all these cases did not enable this criterion to be quantified so the analysis was based only on the mining works geometry.

Sudden collapses are characterised by a higher level of mean stress on pillars (14 MPa vs 10 MPa), a lower w/h ratio taking into account all the layers worked (0.9 vs 2.0) and higher openings (7 m vs 4.5 m) but only the extraction ratio really discriminates between the 2 phenomena. Sudden collapses all have an extraction ratio greater than 60%, gradual subsidence all have a level below this limit.

Using statistical techniques, a linear function of the operating parameter used to discriminate between the

2 types of instability can be defined. Taking into account existing links in our sample between different variables (for example, the w/h ratio of pillars is strongly correlated to the total opening), some variables only have been selected.

Table 1 : Main instability cases in Lorraine iron basin.

BRUTAL	Audun	1902	Drifting in progress	122	70	13,5	0,3	10
	Escherange	1919	Stoping adjacent	170	65	6,0	1,0	18
	Sainte Marie	1932	Stoping adjacent	153	65	5,0	2,0	16
	Moutiers	1940	4 years after drifting	121	70	11,0	0,9	10
	Roncourt	1954	Stoping adjacent	147	70	7,5	0,9	15
	Roncourt	1959	Post-mining	140	75	5,0	2,4	17
	Rochonvillers	1973	Post-mining	190	62	4,5	1,3	15
	Rochonvillers	1974	Post-mining	190	61	4,5	1,7	15
PROGRESSIF	Jarny	1949	Drifting in progress	200	56	5,0	1,7	11
	Aboué	1972	Extension in progress	150	45	6,0	1,7	12
	Crusnes	1977	20 years after mining	180	50	3,8	2,9	11
	Ville Montois	1982	Post-mining	166	55	4,5	2,0	9
	Aboué	1996	20 years after mining	170	53	5,0	1,3	11
	Aboué	1996	20 years after mining	150	45	6,0	2,0	11
	Moutiers	1997	20 ans après traçage	120	55	3,0	4,0	8
	Roncourt	1999	50 ans après traçage	140	53	2,5	2,4	9

Of the 11 parameters known for each case, 7 have been selected as giving the best discrimination: extraction ratio, stress on pillars, depth, hydraulic diameter (ratio between the area and the perimeter of the pillars) width of rooms, presence of adjacent stopes (El Shayeb 2001).

Applying these criteria to risk zones beneath buildings (1,024 ha) has enabled a level of risk of gradual subsidence to be allocated to 1,021 ha. There are 103 ha remaining for which the risk of sudden collapse is not excluded by this statistical analysis. For these zones a geological study of the recovery is performed to detect whether or not there is a rigid and brittle layer.

Methodology of risk management

For zones likely to be affected by gradual land subsidence, the risk level is classified on the basis of the surface factors vulnerability, the importance of effects likely to be felt and the susceptibility of bottom workings to collapse (Piguet 1999). The classification method is based on multicriteria analysis techniques, particularly the Electre method. This method, having been adapted to a mining context, has been systematically applied to the whole Lorraine iron basin. Risk management has thus been implemented, based on the following principles.

For zones without buildings or infrastructures, the zone is classified as unsuitable for construction while waiting for the " Mining risk prevention mapping " to be drawn. Those reglementary tools will define the terms for land usage according to risk types and levels as well as social factors.

For zones with risk of gradual subsidence, monitoring is implemented for the highest levels. This monitoring is mainly based on microseismic measurement of ruptures in rocks, made by sensors installed below the surface. This method has been qualified and calibrated by a site test when the last mine to be worked in the field was still in operation. Seven networks are currently in operational service. Three levels of alarm have been defined according to the process of degradation of mine workings: local degradation of pillars or intervening layers, pillar rupture or roof cave-in,

evolution of damage in the overburden. The adequacy of alarm criteria was verified at a site which was still accessible and where the evolution of degradation was noted at the bottom (Bennani 2003).

An alert procedure was introduced which, depending on its level, mobilises the DRIRE (regional technical management body), the Prefecture, State departments, Town halls and populations concerned depending on the specific emergency plans.

For zones in which the risk of sudden collapse is not excluded, monitoring has also been set up. However, in the context of the Lorraine iron basin, the operational efficacy of this monitoring system has not been proved. Indeed, the particular part played by the rigid bed in the shear mechanism is likely to change the alarm criteria. Considering the short period during which preliminary events precede the collapse, a rapid alert is necessary. The probability of a false alarm is difficult to manage in a long-term monitoring system. Specific experiments concerning the phase of overburden rupture would be necessary to calibrate the monitoring system in each particular case.

The Provence coalfield

Geological and mining context

The Provence coalfield is located in South-Eastern France, close to Marseille. With a mainly East-West orientation, it extends over a distance of 70 km long and 12 km wide.

The coal deposit is found entirely in a massive Upper Cretaceous limestone formation, close to 200 m thick and consisting of continuous beds, often very hard. It consists of seven layers of varying thicknesses, of which only the 4 deepest have been largely mined, mainly the thickest, known as the "Grande Mine", the thickness of which varies between 2 and 5 m according to the sector of the field.

Mining began during the 16th century, and the last workings were closed at the end of January 2003, taking the total area of undermined land to slightly less than 200 km².

For reasons of simplification, it will be considered that until 1930 the Grande Mine vein was worked using the room and abandoned pillar method (area of more than 3,000 ha). The extraction ratio, τ, close to 75%, has varied very little with time and depth (approx. 0 to 500 m). The most recent and deepest (500 m to 1,300 m) workings were mined using the longwall caving method and do not pose any major problems in terms of surface stability.

Several sources of information (oral surveys, aerial photographs, archives) have revealed the low level of the Provence field's susceptibility to major instabilities on the surface. Over the past two centuries, only one major event has been discovered throughout the field: a massive collapse of several hectares in 1879.

Several exploratory visits have been made to previous sections which are still accessible and were mined using room and pillar methods. Observations revealed a gradual yielding of pillars leading to significant deflection of the limestone roof with convergence values approaching one metre (Figure 1).
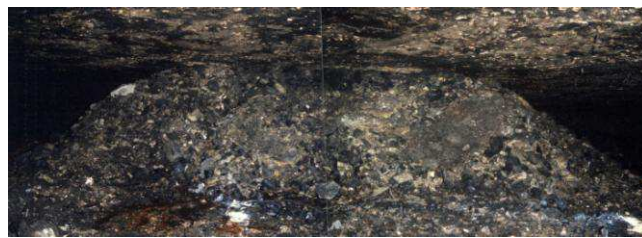

Figure 1: Photograph of a collapsed coal pillar.

Although these observations help eliminate the risk of dynamic pillar failure (there is no elastic energy available in the supports), on the other hand they raise questions on the ability of the rigid overburden to absorb such large deflections without rupture.

To obtain more calibration data, a borehole and logging campaign was undertaken in various sectors of the field now inaccessible, with the intention of characterizing the height of residual voids in the centre of panels judged to be representative and located at various depths.

Choice and development of the model

Simple analytical modelling of pillar stability (tributary area) indicates that pillars located deeper than 100 m have a safety coefficient of less than 1. Although this diagnosis is validated by observations (collapsed pillars, high convergence) made in relatively deep sections (approx. 350 m), it is refuted by inspections made on workings at medium depth (150 m to 250 m), which reveal an absence of convergence and hence of collapsed pillars.

Such a different behaviour cannot be explained without taking into account the interaction between deformable pillars and a rigid hanging wall, which plays an essential part in the behaviour of the Provence coalfield rock mass. Indeed, the rigid overburden acts like a slab supported on the unmined edges and, thereby, relieving the subjacent pillars, which, on the other hand, make the hanging wall susceptible to the risk of failure due to deflection.

Only numerical modelling of the rock mass on a global scale of mining panels can take into account " overburden – pillar" interaction. The deformation and failure mechanisms thought to occur in the Provence field are strongly influenced by the presence of heterogeneities, particularly stratigraphic. The calculation code chosen is then UDEC, as this tool allows one to take into account the existence and behaviour of the numerous discontinuities in rock masses.

Faced with the complexity of the environment and mechanisms to be modelled, a "pragmatic" approach aiming to give priority to calibration using the available operational data has been chosen. We then built a robust model able to reconstruct accurately the mechanisms observed or suspected, while retaining enough flexibility to be adapted to the various configurations encountered.

For each representative sector, a parametric analysis (mainly based on the parameters of the law governing the behaviour of coal) was used to calibrate the model on the basis of information collected during the exploratory phase (residual opening of workings). The current state can then

be extrapolated to evaluate the future behaviour of undermined land.

We selected an elastoplastic softening behavioural model to model the limestone and coal. This model is used to locate meshing elements for which the plastic criterion has been reached (plastic points). In fact, the criterion for major collapse of a panel is considered to be due to a combined high density of plasticity points affecting most of the roof beds, and significant lowering of the overburden.

Main results of simulations

Sectors at medium and extreme depth (beyond 250m)

The results of many calculation simulations reveal that at medium or extreme depth, the coal pillars were, from the time of extraction (mechanical characteristics not reduced by the effect of ageing), subject to stresses too severe to be withstood without being crushed. The crushed pillars caused deflection then gradual rupture of the overburden (Figure 2). This rupture is reflected by a smooth profile on the surface (subsidence with no effect on structures).

The results of the calculation match the testimony of ex-miners who describe multidecimetric subsidence of the workings from the first days following excavation.
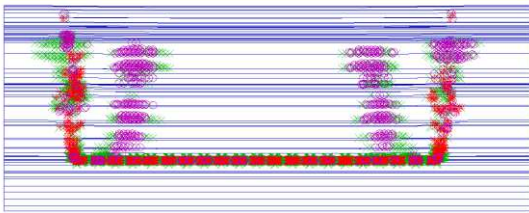
Figure 2: Deep panel with ruined pillars
and shear of the overburden.

The workings therefore behave more or less identically to a classical longwall exploitation with a "overburden degradation face", with the difference that the overburden did not collapse but was gradually deflected leading to the creation of fractures in the hanging wall beds. Calculations show that only major plastification of the overburden can produce a level of convergence as high as that observed in the underground workings (up to one metre).

In this configuration, once the panel has been worked and subsidence has occurred, there is no more elastic energy stored in the pillars (crushed and in a state of post-rupture), nor in the hanging wall (fractured and resting all its weight on the subjacent pillars). Any risk of sudden rupture of the overburden in the long term can therefore be eliminated. On the other hand, continuing (or further) smooth subsidence is still possible in the event of residual crushing of the collapsed pillars.

Shallow sectors (up to 250 m)

Figure 3 illustrates the evolution of convergence in shallow workings in accordance with the gradual reduction of characteristics attributed to coal pillars.
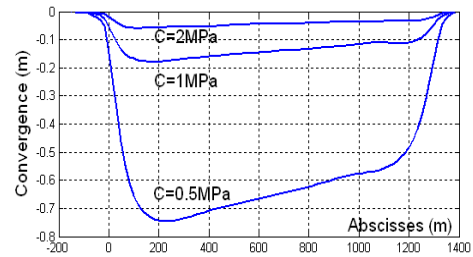
Figure 3: Evolution of pillar convergence in a panel
as a function of coal cohesion values.

Analysis of the result of these simulations (in the knowledge that at present the sites concerned have not experienced any definite convergence), combined with the analysis of the result of an identical procedure carried out in deeper sections (where major convergence has already occurred) is used to identify the equivalent characteristics of materials most appropriate for the model developed.

It has therefore been deduced that, in the medium term, to reconstruct site degradation mechanisms accurately, the most satisfactory equivalent value of coal cohesion is close to 1 MPa. We have decided to vary only coal cohesion, the internal angle of friction, close to 30° being judged less susceptible to degradation within time. It will be noted that this couple of values (c=1MPa, ϕ=30°), obtained by simple retroanalysis within the context of the model, corresponds to a range of *in situ* resistance which is absolutely classic for altered French coal (R_C around several MPa).

It is then possible to extrapolate the very long-term behaviour of the sites by reducing pillar characteristics, distinctly but credibly (possible effects of rock ageing phenomena).

Simulation of the degradation of coal characteristics between c = 1 MPa and c = 0.5 MPa reveals a very distinct difference in behaviour (Figure 4).
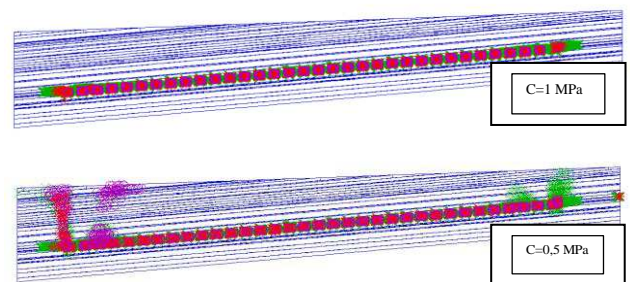
Figure 4: Simulation of the behaviour of shallow workings
for c = 1 MPa and c = 0.5 MPa

While c = 1 MPa confirms the current level of stability of the workings (stability provided by the "slab effect" of the rigid hanging wall and not the pillar dimensions), using c = 0.5 MPa reveals the appearance of rupture points on the edge of the panel. Several scenarios can then be envisaged concerning the long-term evolution of these configurations.

The first considers that the workings are stabilized because there is a very little reduction in the resistance of the rock mass, up to now. Its main argument results from the fact that the sectors concerned are more than a hundred years old, some having been successively flooded and drained.

In spite of the pertinence of this hypothesis, using a safety-oriented approach imposed by the presence of surface factors, it is difficult to categorically exclude any evolution in the sectors concerned toward general "hanging wall-pillar" failure. The main problem is, as in Lorraine, to identify the dynamic or progressive nature of instabilities.

The experience feedback indicated that almost all surface movements affecting the Provence field have been smooth and gradual. Only one example of massive collapse has been noted for the whole field. This collapse, characterized by a fairly specific context (overburden affected by several faults), developed in the configuration identified as being most susceptible to the risk of major movement (room and pillar mining at low or medium depth).

In addition, although it is not enough on its own to determine the dynamics of the phenomenon, modelling provides some important information on rupture development. Although, in deep sections, pillar crushing and hanging wall degradation developed during mining operations and followed the extraction face, the same does not apply to shallow sections which have not suffered any major convergence. In this case, it is the eventual subsidence of the rock mass due to the ageing effect which could be the source of instability.

This type of degradation would not be propagated gradually in space like a longwall, but would simultaneously affect all the workings, causing general deflection of the rigid roof with a risk of rupture along the abutments, which would transfer the weight of the rock suddenly onto pillars not dimensioned to support such stress.

Therefore, in the interests of safety with respect to the surface factors, it seems to us to be reasonable not to categorically exclude the possibility of sudden movement, even if it is unlikely and even highly unlikely that it would actually occur. Appropriate measures in the context of risk management will therefore be defined and implemented.

Conclusions - prospects

Within the context of studies on a regional scale, as it is the case of the mining fields used to illustrate this article, detailed analysis of each panel is inconceivable and global methods of diagnosis must be defined. The two examples have clearly revealed the importance of accurate identification of failure mechanisms and the dynamics of any instabilities.

In this context, the search and implementation of available experience feedback must be systematized. Sorting and interpreting the instabilities developed in the past, when there are enough of them and accurate information is available, do indeed provide valuable information on the type and occurrence of instabilities. They can also help, as was possible in the case of the Lorraine iron basin, to define rupture criteria, usually based on a combination of operating parameters (recovery factors, pillar slenderness ratios, superposition of workings, panel dimensions…) and geological data (sedimentary deposit or vein, type and thickness of the overburden).

When there is not enough well-documented experience feedback or if the mechanisms involved are particularly complex to understand and define in terms of criteria, "large scale" numerical modelling methods applied to mining operations probably provide one of the most promising prospects as long as the time and financing needed for the model calibration phase (exploratory work, material characterisation…) are available.

The calculation codes available, in constant development, and based on the capacities of increasingly powerful computers have made considerable progress over the past twenty years. Rock mechanics engineers are now excellent at defining criteria so that a working configuration offers guarantees of long-term stability.

However, there are still some major gaps in interpreting the dynamic nature of failure mechanisms which may occur and experts, required to make long-term forecasts on possible instabilities (date and occurrence of damage), soon reach the limits of the current state of knowledge and available calculation tools. Dynamical analysis of failure (essential in terms of identifying the potential danger for people exposed to it) is difficult to envisage as long as the mechanism of initiation and propagation of rupture is not better understood and reflected in the available constitutive models. This type of progress would raise the hope of using high performance dynamic modelling methods instead of the "almost statistical" methods used today.

Common research (rupture theoreticians, rock mechanics engineers, numerical analysts…) based notably on ambitious in situ experimentation and operational tools development will lead to significant progress in the field of understanding rock instability phenomena. These tools would help to overcome the still large uncertainty and to limit recourse to the principle of precaution, still practically systematic today and sometimes excessive, with its eventual consequences in terms of the development of undermined land.

References

BENNANI M., JOSIEN J.P., BIGARRE P. (2003): Subsidence monitoring in post-mining: needs and methods. *Colloque GISOS Après-mine*, Nancy 2003.

EL SHAYEB Y. & al. (2001): Towards the determination of surface collapse type over abandoned mines in the Lorraine iron basin. *Congress Eurock*, Espoo, 2001.

PIGUET J.P. & al. (1999): Contribution of Rock Mechanics for Risk Assessment in abandoned mines. *Proceedings of the 9th Congress ISRM*, Paris, 1999, Vol. 1 pp. 317-322.

TINCELIN E., SINOU P. (1962): Sudden collapses, rockbursts. *Revue de l'Industrie Minérale*, April 1962.

Acknowledgements