Mine shafts in Nord-Pas-de-Calais coalfield (France) Risk assessment and treatment technique

Romuald Salmon, Marie Degas, Rémy Gobillot

Mine shafts in Nord – Pas-de-Calais coalfield (France)
Risk assessment and Treatment technique

Romuald SALMON, Marie DEGAS, INERIS
Rémy GOBILLOT, CDF Nord Pas-de-Calais

Abstract

In France, coal concessions abandonment is fixed by legal procedures that lead the owner to achieve studies for the identification and the assessment of residual risks associated with underground mine workings. If necessary, treatment techniques must be defined in these studies in order to mitigate the associated risks for the population and future land planning.

The multiplicity of mine shafts in coal mining areas have created many present-day problems. The main risks associated with mine shafts are the sudden collapse of their column and gas explosion, asphyxiation and/or intoxication.

The Nord and Pas-de-Calais coalfield extends 100 km from East to West and 15 km from North to South. Coal exploitation induced the sinking of more than 600 shafts from 1716 to 1960 widespread over 41 concessions.

The paper describes the work accomplished by INERIS and Charbonnages de France for mine shafts vicinity security :

- Part 1 : Risk assessment methodology : The aim of this part is to identify and evaluate risks associated with mine shafts. A methodology has been developed by INERIS to ease this analysis because of the great number of shafts ;

- Part 2 : Treatment techniques in Nord – Pas-de-Calais coalfield : The scope of this part is to describe the techniques involved in the treatment of mine shafts. The treatment technique must be adapted to the nature of risk as identified thanks to part 1 as well as the surface occupation.

1. Introduction

The multiplicity of old mine shafts in coal mining areas have created many present-day problems, particularly when the existence or location of shafts is not known. Many European countries are concerned about the assessment of risks issued from the presence of old mining shafts.

Protection of threatened population is an important worry from States and concerned local authorities. Therefore, it is of great importance to improve diagnostic tools and modelling as well as to enhance techniques for location, prevention, protection and treatment of risks.

The aim of this paper is to adress the state of the art in terms of risk analysis relating to mine shafts in Nord and Pas-de-Calais coalfield.

2. Context of shafts in Nord and Pas-de-Calais coalfield

2.1. General presentation

The Nord and Pas-de-Calais coalfield (France) extends 100 km from East to West and 15 km from North to South. The eastern limit of the basin superimposes with Belgian boundary (figure 1). The southern limit of the basin is underlined by the presence of the hills of Artois, Cambrésis and Hainaut. In this zone, altitudes vary from +80 to +180 NGF. Then, general topographic surface goes down gradually, in direction of North, towards the low zones of the area of Béthune (Western), of the area of the North of Lens and the basin of Orchies (centre) as of the junction the Escaut - Scarpe where the average altitude is +30 meters approximately.

The coalfield counts a significant number of inhabitants. Some zones, in the centre of the basin, have a strong density of population induced by many mining cities and industrial parks related to past mining activity.

2.2. Geological context

Over all the extent of the basin, the carboniferous is covered, in discordance, by grounds dating from the secondary to the quaternary era, called “morts-terrains” (overburden). From older to most recent, one can find (Figure 2):

- Wealden: these are clays and sands deposited in discontinuous pockets in the sectors of Anzin and Denain ;

- Albian: this formation deposited only very locally, in the western and extreme eastern parts, at the beginning of the cretaceous transgression. In western part, this formation is characterised by thin plastic clays (less than 10 meters). On the other hand, in eastern part, these are more or less clayey sandstones that may be 50 meters thick;

- Cenomanian formations: these are more or less marly formations whose thickness increases from East toward West from 10 to 40 meters approximately, overlying Tourtia, conglomerate;

- marls of Turonian: theses are formed by the blue ones (30 meters average thickness) and green very clayey ones (35 meters average thickness);

- the seno-turonian chalk: this chalk thickness is variable - 60 meters on average, but locally reaching 150 meters (Saint-Aybert) or only 30 meters (Saint-Amand) ;

- the Landenian layers: this formation only appears in the northern edge of the coalfield where its thickness reaches 30 meters. These series begin with several meters of clay of Louvil, on which settled sands of Ostricourt. By places, those are overlaid by clays of Flandres. In the sector of Valenciennes, Landenian is rather sandy.

- alluvia: these are silts dating from the Quaternary era.

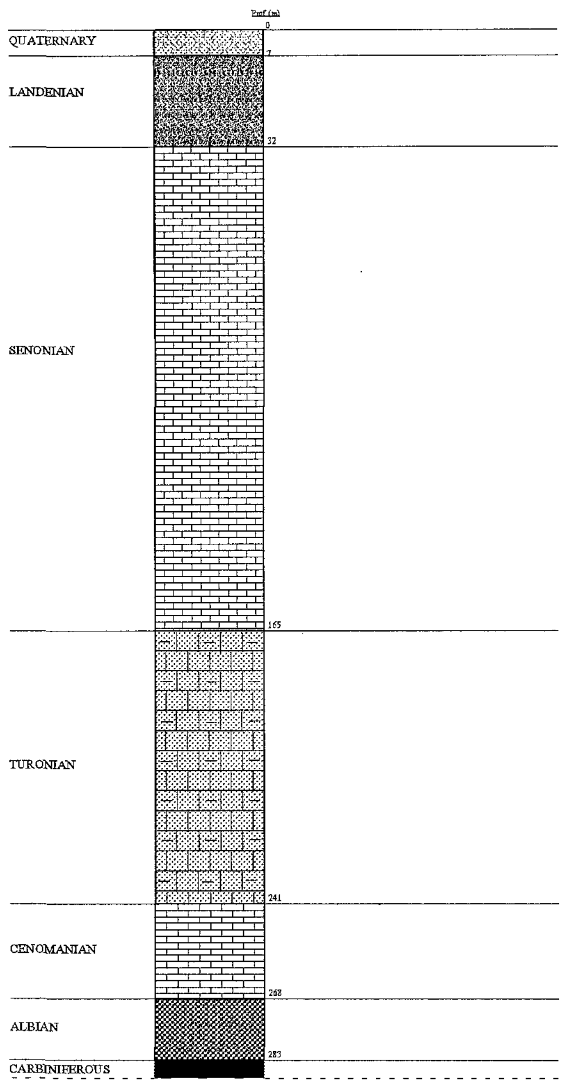


Fig. 2 : Typical stratigraphic log in Nord and Pas-de-Calais coalfield

2.3. Hydrogeological situation

The overburden described previously has variable hydrogeological characteristics:

- the sand pockets of Wealden are fully saturated and gave place locally, during shaft sinking, to very strong flows, known by the minors under the name of "Torrent d'Anzin";
- in western part of the coalfield, Albian plastic clays form a water tight stratum between aquiferous chalky Cenomanian and the Carboniferous subjacent one. Toward East the sandy formations can represent a secondary permeable reservoir;
- being given the variations of the Cenomanian deposits facies from East to West, this level plays a water tight role in the centre of the basin and East whereas it is subject to water flow West;
- the Turonian marls form the wall of the Chalk aquifer and behave as a semi-permeable material with respect to vertical water circulations between the Chalk aquifer and the deeper aquifers;
- the seno-turonian chalk constitutes the large regional aquifer of the Chalk which provides more than 80% of the drinkable and industrial water;
- clays of Louvil (Landenian) support an aquifer of poor characteristics flowing in sands of Ostricourt. On the other hand, in the area of Valenciennes, this formation is naturally not very permeable. Clays of Flandres, which finish the tertiary series in North, constitute thanks to their thickness a quasi impermeable overburden of the sandy aquifer.

As far as the carboniferous grounds are concerned, these formations are not aquiferous in their natural state. The rare water circulations which affect them are according to the fractures network or located in the altered subsurface levels. During exploitation, the mining void spaces induce the fracturing of the grounds in their vicinity. The open fractures play the role of drains, thus conferring the affected volume permeability characteristics much higher than those of the virgin sectors. Water thus infiltrates in workings and after water pumping stoppage, zones influenced by the exploitation are subject to a progressive filling by infiltrating water, leading to the creation of an aquifer. The level of this water table goes up until it gradually reaches its equilibrium level.

2.4. Mine gas emission in Nord and Pas-de-Calais coalfield

In the coalfield of North and Pas-de-Calais, as for any carboniferous layer, one is confronted with the problem of firedamp. Indeed, firedamp is naturally adsorbed by coal. During exploitation, firedamp is desorbed but the gas outburst continues after exploitation stoppage, even if the layer is not very gassy. This release will be stopped at the latest after a complete and effective submergence of the coal seams, that is once water will have gone up at least a few tens of meters above the emitting sources.

Knowledge about the basin of North and Pas-de-Calais indicate a firedamp primarily composed in great proportion of methane, in a small but usual proportion of alkane and in a very weak proportion of carbon dioxide and other gases. In the areas of Lens and Courrières in particular, but in other areas of the basin as well, one measured significant coal gas concentrations, around 10 m^3/t.

Moreover, specific releases were calculated for a score of exploitation plants between 1974 and 1987 and gave values varying between 40 and 60 m^3/t of CH_4 from extracted coal.

On the whole, one should underline the great diversity of the basin of North and Pas-de-Calais which was known to be a not very gassy to very gassy coalfield, according to areas.

Since 1978, the companies Gazonor then Méthamine exploit gas produced by desorption in old mining work, thanks to five collecting sites spread over the basin. These various pumpings thus put currently in depression the totality or the quasi totality of the coalfield which is not drowned yet.

In addition, 30 boreholes reaching the old workings were set up, in order to create preferential ways of evacuation for the firedamp and to control the pressures of the layer over the whole basin (boreholes for decompression). This device, supplemented by 23 shafts accessible for measurement, makes it possible to precisely follow the evolution of the pressures in the reservoir. According to sites, the pressure measured is included between 40 and 70 kPa, that is in obvious depression compared to the atmospheric pressure.

3. Characteristics of mining shafts in North and Pas-de-Calais coalfield

Coal exploitation in North and Pas-de-Calais required the sinking of more than 600 shafts. These shafts were sinked between 1716 and 1960 and are distributed over 41 mining concessions (figure 3). One should notice a very strong concentration of these shafts in the area of the concessions of Fresnes-sur-Escaut and Vieux-Condé, as well as in the vicinity of Valenciennes whereas they are uniformly distributed over the other concessions. Among these shafts, only around two thrid of them are precisely localised, and thus treated (backfilled, closed). As far as the other third is concerned, their Lambert co-ordinates are roughly known, with an uncertainty of 15 meters around, and thus their state of closing (backfill, flagstone…) is not known.

A shaft is a vertical excavation, of diameter varying from 1 to 6.5 meters and which can be in North and Pas-de-Calais more than 1000 meters deep. The inner wall of the shaft is covered by a supporting structure (lining) that avoids grounds collapse. Firstly constituted by a masonry or bricks, the technique evolved to a concrete covering.

In aquifers, in order to avoid water inflow in the shaft, a lining (watertight support) is set up. Originally, at the beginning of the XVIIIth century, this one consisted of pieces of wood which were assembled vertically and round-off. Then, this process being not very effective, the beams are then laid out horizontally and form a square shaft not exceeding two meters side. At the beginning of the XIXth century, the need for increasing shafts diameter led to increase the number of sides of the lining. One thus can find, at that time, of octagonal linings then decagonal. Next, a lining consisting of 16 sides which suits practically the circular shape of the shaft was chosen.

At the end of the XIXth century, wood has been given up for cast iron which has a higher mechanical strength. Lastly, during XXth century, thanks to the evolution of the techniques of cementing and injection, it became possible to sink round shafts of large diameter, with a monolithic lining made of concrete. The concrete is used the most, because it can be mended more easily in case of failure. These linings having to resist very strong pressures are prolonged with a score of meters in the non aquiferous grounds, in order to establish a tight joint against water.

Circular shafts, less practical than rectangular shafts for the installation of the equipment (cages, guidance, pipes...) have the advantage to stand very high ground pressures (case of the deep shafts).

Usually, a network of galleries develops from the shaft. These can be galleries close to surface, usually being useful for the service or installation of the ventilator. Other galleries, called shaft landings, are on the principal floors and allow to access workings.

These shafts had various uses:

- the haulage shafts, in which a cage was installed and was used to descend the men and the hardware and to go up the extracted products;

- the ventilating shafts: to allow the fresh air to enter the workings, it is necessary to have a downcast shaft and an upcast shaft, eventually equipped with a ventilator, if that were necessary. For this reason, it is not rare to observe two or three very close shafts, which belong to the same pit. The haulage shaft can be used as a ventilating shaft.

Among the shafts, one may distinguish 81 blind shafts, localised on the map shown in figure 3. These are shafts that have not been used for exploitation purposes. One can distinguish those having reached Carboniferous and those having been stopped in the overburden, in particular concerning the firedamp risk.

All these shafts were gradually closed until the closing of the last shaft in December 1990. Following its closing, each shaft is backfilled then sealed.

With time, the backfilling technique evolved. Various kinds of filling material can be distinguished:

- the schist backfill whose grain size is less than 150 mm;
- a water and gas proof plug made of cohesiveless ashes or clay, set up at the level of the base of the lining;
- concrete plugs in the form of a mine dam either right at shaft landings or just above shaft landings. This technique was used for the last closed shafts.

The plugging of a shaft is achieved in two different ways:

- most of the wells are plugged by a reinforced concrete slab;

- since 1990, shafts are plugged by a concrete dam anchored in grounds or not in one or more galleries. If it is well designed, this plug makes it possible to ensure the security of the shaft head.

The majority of the shafts is equipped at the head with an observation hole that enables to control the level of the backfill and if required to carry out control measurements with respect to gas.

From a hydrogeological view point, the carboniferous reservoir constituted by exploited zones is not flooded. As a consequence, a great number of shafts are not flooded yet. They will be filled gradually until 2150 around.

4. Risks associated with mining shafts

Abandoned shafts, still open or only covered by a flagstone, can present risks for the populations and the activities located in their vicinity. Shafts that have been backfilled in a way that is not satisfactory can also, in certain specific configurations, undergo a brutal remobilization of the filling material that may affect the stability of ground level. To facilitate the identification of the various likely scenarios of failure that may affect an old mining opening, a systematic analysis of the risks associated with their presence has been carried out for the shafts in the Nord and Pas-de-Calais coalfield.

4.1. Hazardous entry

An accidental fall in a shaft that has not been backfilled can result in serious wounds and even the death of the person. The drownings are also to fear when the shaft is filled of water.

4.2. Subsidence

It is sometimes observed, in the vicinity of a mining opening, a slow and progressive remobilization of the surface layer (shaft backfilling material, low cohesive overburden material).

For example, a time differed subsidence of the filled column in a shaft not protected on top by a concrete plug or flag can lead to a slow and progressive remobilization of the surface in the vicinity of the shaft. This remobilization can, if it reaches sufficient amplitude, damage some of the structures in the area of the shaft. Several causes are likely to lead to these instabilities of the ground level (NCB, 1982):

- an overload on the surface, in the immediate surroundings of the head of the shaft (storage of exploited material, heavy vehicles, construction of structures...) ;
- some vibrations generated by explosions or blastings near the shaft head or by an intense circulation of very heavy vehicles ;

- a loss of stability due to water influence (buoyancy of the base of the filling material column when mine water raises or water saturation of the filling materials and loading of the column resulting from water circulation coming from higher galleries or surface).

4.3. Surface collapse

Less frequent than subsidence, collapses can present more serious consequences when happening in high vulnerability zones. Collapses of shaft generally materialise by sudden subsidence hole whose diameter varies from few meters to a few tens of meters. In an exceptional configuration (presence of non cohesive sandy grounds located near surface), a particular case of rupture of well led to the creation on the surface of a sinkhole whose diameter reached 100 meters (R. POIROT, 1992).

The collapse of the surface which surrounds a mining opening can result from :

- a collapse of the filling material column (brutal and dynamic remobilization of the filling materials which goes down abruptly and in the shaft galleries and old workings, thus generating a collapse of surface);
- rupture of the shaft head closing structure. Some old shafts had been sealed by techniques not presenting any guarantee of long life expectancy;
- rupture of the shaft lining (fatigue of the lining and/or increase of the surrounding grounds thrust);
- rupture of the surrounding grounds.

4.4. Risks associated with mine gas emission

Many mining vacuums present high concentrations gases that may be harmful or explosive. In addition to the risks related to inflammability of firedamp (CH_4), one should note the dangers of asphyxia when atmosphere presents an oxygen deficit (naturally or from an accumulation of CH_4 or CO_2) and the intoxication risks in case of inhalation of gas such as CO or H_2S in too high contents.

The principal risks appear when the gases asphyxiating, toxic or flammable which accumulated in the residual vacuums of underground exploitation migrate towards surface and accumulate in non-ventilated vacuums close to surface (hollow, sewers).

4.5. Risks associated with water presence

Stoppage of mining exploitation can generate some problems in terms of quality and regime of water. Taking into account respective volumes, the alteration of the quality of water due to old workings is definitely higher than that causes by shafts or galleries.

One should note nevertheless that the use of abandoned shafts as wild discharge can be enough to make a water unfit for consumption when toxic waste is located in the vicinity of aquifer flow.

5. Mechanisms leading to surface collapse

The aim of this part is to describe and evaluate, in terms of probability of occurrence and amplitude, the steps that lead to a surface instability near a shaft. Each constitutive element of a shaft is studied, from the pit bottom to the head.

5.1. Deep structures

Shaft landings closure : galleries that connect shafts between them or with mining works may have been closed before shaft backfilling in order to avoid the backfilling material to spread in the gallery. Closings generally consist of walls in hollow blocks, metal dams, or concrete plugs, but the design and the exact nature of materials constituting these structures are seldom available. When checking the stability of these structures is not possible (in particular, in terms of resistance with respect to the water column which is likely to apply on them in the future), it is not possible to guarantee a long-term stability of the shaft.

Concrete structures within the shaft column : one can divide the various structures types in two large subsets: those which lean on the coating of the shaft and those which lean on the solid ground itself.
One should note that water resulting from Carboniferous, with a high concentration of sulphates, constitutes a recognised case of aggression with respect to the structures made of steel or concrete that are in the shafts. The calcium sulphate combines with aluminates of cement to form a salt, ettringite, whose crystallisation induces a volume expansion that causes the cracking of the concrete. It facilitates the penetration of the aggressive agents to the reinforcements which are, in their turn, attacked. The stability of deep concrete structures is thus based, initially, on the taking into account of this phenomenon in the choice of materials constitutive of the structure (Technical Collection CIMBETON, 1997 and Bulletin of Cement, 1995).

5.2. Settlement and collapse of filling materials

Settlement of filling materials : the backfill of shaft column is generally followed by a settlement of the column of fill under the action of its own weight.

During the increase of the water level in the shaft, some extra settlements are possible.

An experimental study carried out on samples of filling materials made of schists or sandstones and whose coarsest elements are lower than 13 cm, showed that under a low confining pressure of 0.6 MPa, water saturation induced a settle of 12 % approximately for the schists and 5 % for sandstones (EGRETLI and SINGH, 1988). Settlement during saturation represents less than 4 % when the schists are formerly confined to 6 MPa and is already lower than 2 % for a 2MPa confining pressure. The results show, moreover, that the share of settlement related to water does not exceed 45 % of total settlement for samples formerly confined under a low confining stress and decreases with less than 25 % when initial confining pressure, before saturation, is higher.

These experimental results show that the share of settlement of a filling material induced by its own weight remains dominant. In the case of the shafts, the flooding takes place a long time after the backfill. Consequently, settlement of backfilling material related to its own weight took already place. Its amplitude was greater with shaft depth. Thus, starting from the above mentioned experimental results (in laboratory and especially on site), one can consider that the potential extra settlement related to the increase of water table during flooding will be in all the cases lower than 1 % and could be neglected insofar as the filling materials used in the French coal basins have a grain size sufficiently high to make them, in our view, less sensitive to the possible readjustments of the structure of the filling materials with water.

One should bear in mind that a small proportion of shafts have been subject to a partial flying ashes backfill. This particular material is likely to experience some shrinkage that may affect the stability of the inner column.

Backfilling material collapse : unlike settlement, one calls collapse of the column of fill, a brutal and dynamic remobilization of the backfilling materials which go down abruptly and spread in the shaft landings and old workings, if those are not correctly closed before the backfill process. The principal difference between settlement and collapse results in the fact that the equilibrium changes are not anymore, in the second case, progressive and continuous but, on the opposite, brutal and instantaneous. This dynamic character can result from a dynamic request itself or contrary to quasi-static variations which evolve to a limit equilibrium state before giving place to a sudden collapse.

Dynamic loads resulting from vibrations on surface close to shaft head seem to be able to be enough to generate brutal remobilizations of the backfilled column. However no case of collapse, to our knowledge, has clearly been identified like having resulted from such a phenomenon in Nord and Pas-de-Calais coalfield.

Many cases denote on the other hand sudden arrival of water into the backfill, either by the rupture of a surface pipe, or by the blow out of a part of the shaft lining that was suddenly under pressure or resulting from a progressive deterioration from its wall. Water which flows in the shaft structure then soaks quickly the backfilling materials, weighs down them and can often modify the equilibrium within the column and thus generate a remobilization of this one.

Some backfilling materials collapses also result from the formation of vacuums within the column during the backfill process. These vacuums can be induced by the blocking of materials at the level of certain convergences of the shaft. Bridges or vaults then form with francs vacuums in the subjacent levels.

The collapse of backfill has not for only effect to violently decrease the level of the column. Important suction phenomena then air back blow can result from it. These stresses can sometimes contribute to alter or destroy the lining, the plug or the concrete slab, or the surrounding grounds. The structures at the head of the column hence must be designed to resist the stresses of suction such a collapse stripping could generate.

Taking into account the dynamic character of the phenomenon, it is difficult to evaluate the vacuum amplitude generated on the surface.

5.3. Coating failing or rupture

Most frequent ruptures of a shaft lining come from a **decrease of the coating strength** and/or the **increase of surrounding ground pressure**. When the first does not manage any more to contain the second, the coating (constituted of bricks, concrete or cast iron) becomes deformed and ends up breaking. If the shaft is empty (not backfilled or having been subject to a backfilling materials collapse), the coating collapse and with it whole or part of the surrounding grounds.

The decrease of the mechanical properties of the shaft lining is an inescapable phenomenon resulting from the progressive fatigue of the materials which constitute it. Some external agents, like water, accelerate this fatigue.

The increase of the surrounding rock pressure can result from the construction of structures on the surface. A building construction may apply an overload on the grounds on which it is founded. If the shaft is located in the vicinity of the foundations, its lining may experience a considerable increase in load.

5.4. Materials behaviour surrounding the shaft

Shaft surrounding grounds behaviour is closely related to the state of the shaft lining. If this one has suddenly broken and the shaft is empty, nothing retain the surrounding grounds anymore. Reciprocally, the rupture of the surrounding grounds may generate high pressures in the lining and occasionally its rupture. The shaft sinking induces a redistribution of stresses within rock massif. According to the nature and strength properties of the material crossed by the shaft, the extend of the zone affected by the shaft and the behaviour of material may vary.

In the basin of North and Pas-de-Calais, the main materials crossed by the shafts are:

- **Wealden and Albian** : during the sinking of particular shafts, water bearing strata were locally crossed before the carboniferous layer and sometimes caused water blows. These pockets correspond respectively either to sands of Wealden, or to the green sandstones of Albian. The very localised characteristic of such facies induced particular study for the concerned shaft;

- **marls** : marls have an elasto-plastic behaviour. Numerical models to evaluate the impact of a circular empty shaft on surrounding marls show that, in the particular case of Nord and Pas-de-Calais coalfield, plastic zone may develop within marls on a radius equal to 3 times the shaft radius from the lining of the shaft;

- **chalk** : chalk is more or less fissured. According to its state (saturated or dry), it has different strength properties. The compressive strength of dry chalk is around 10 MPa. This value can be divided by 2, even by 3, for a saturated chalk. Dry chalk has a behaviour of the elasto-fragile type whereas saturated chalk presents a progressive rupture type behaviour. The analysis of the effect of a shaft sinking on chalk concludes that, in the case of an empty shaft without lining, no plasticity develops within sound chalk for a depth less than 100 m (main case). The analysis also notices that a thickness of 30 m of sound chalk is sufficient to counteract the plasticity developed in marls (figure 4). It is difficult to propose such a rule in the case of a damaged chalk. The case of Marles shaft n° 2 shows that the collapse reached surface despite a thickness of very fractured chalk of 34 m;

- **cohesiveless and sandy surface materials** : surface grounds can consist of fill, clay, sands or chalk weakened by water infiltration. If the lining of the shaft breaks and the shaft is empty, nothing retains these types of material which may collapse in the shaft and form a cone which angle is 45° approximately. Sands, in particular, are materials of very low cohesion to null, and their main stability characteristic is the friction angle. Sands are very sensitive to water because of their great permeability which allows an impregnation then a fast circulation of water between grains in the event of hydraulic overload. Some sands with fine granulometry may adopt a quick sand behavior water. It is the case with Landenian sands whose grain size lies between 0.2 mm and 0.08 mm.

6. Securing measures

Table 1 summarises previous mechanisms and evaluates, depending on the shaft configuration, the possibility of each mechanism and, finally, surface collapse potentiality.

For shafts that induce an identified risk for the surface, different securing measures may be taken depending mostly on the surface vulnerability.

6.1. Radius of safety

The evaluation of the radius of safety relies on the definition of the geological context of the shaft and on the analysis as described previously. The radius resulting from this evaluation can, in some cases, be limited by that resulting from a simple volumetric approach – that is the volume of material likely to collapse cannot be greater than the volume of void in the shaft. If a shaft crosses the deep formations of Wealden or Albian sands, a specific study is necessary.

A statistical study carried out by the "Charbonnages de France" made it possible to determine the difference between archives co-ordinates and actual co-ordinates of shafts onces localised *in situ*. This analysis shows that the error on archives co-ordinates is less than 15 m. It will thus be appropriate to add 15 m for the radius of safety for a not localised shaft. Any modification of the shaft characteristics (backfill…) modifies the risk evaluation and the value of the radius of safety with respect to the geotechnical risk associated with this well. The radius of safety is defined starting from the centre of the shaft. It defines a perimeter which delimits a constructible circular zone under condition of taking into account the identified geotechnical risk of collapse.

Recommendation of radius of safety relating to gas:

- if the risk of backfilling material collapse is identified: taking into account the risk of massive gas outburst, a radius of safety related to the gas risk of 15 m is applicable until the end of shaft flooding (not before 2150);

- if the risk of backfilling material collapse is excluded: the radius of safety related to the gas risk of 15 m is applicable until the flooding of the highest landing.

6.2. Self-supporting plugs

Self-supporting plugs lean on the shaft lining to ensure their own stability. They have a cylindrical body which follow the various imperfections of the lining. They generally consist of concrete or materials with which a hydraulic binder is associated.

These structures reinforce the surrounding grounds and avoid lining and surrounding grounds to collapse in the shaft, on all their height. Concrete plugs are worked on the surface of a filling material column or on a platform anchored in the solid rocks, at the level of a shaft landing.

The preliminary backfill of the shaft remains the most commonly used method. It allows the re-use of sterile stored at the pithead and consolidates the whole lining.

Self-supporting plugs must be able to ensure their own stability under the overlying backfill load without being tributary of the presence of backfill or a support platform beneath. When these plugs are correctly designed and produced, the settlement of backfilling materials is not harmful to the stability of the structure. Hence the closing of all the galleries located under the plug is not essential. On the other hand, the plug will have to resist the stresses induced by suction likely to result from a brutal backfilled column collapse.

Generally speaking the workings can be achieved in many ways (columns of jet - grouting, injection of backfilling materials, partial excavation of backfilling materials up to the surface when the shaft is already backfilled...).

The variations of the section of the shaft along a profile ensures the stability of the plug by facilitating the phenomena of blocking in case of destabilisation of the structure (HARTMANN and al, on 1978). Taking into account the difficulty to quantify this type of heterogeneity, and considering not enough information about the shaft profile is available, one design plug generally with arguing in term of side friction against the inner wall of the shaft. The effect of shape will add so in the safety margin characterising the stability of the work. The more the height of the plug will be important and the more the contribution of the effect of shape will be sensitive. One can consider that this one becomes really significant when the size of the plug is superior or equal to twice the diameter of the shaft.

7. Conclusion

The principles developed previously have to be adapted to the context of each shaft and, in particular, according to their surface state. For example, the constitution of a plug in a shaft in urban area raises many technical difficulties that are out of the framework of this paper.

Considering the great quantity of shafts still to be treated in Nord and Pas-de-Calais, a methodology is currently under development to classify shafts in terms of likelihood of backfilling material collapse. The aim of this study is to plan the treatment of shafts in order to schedule workings in a way as sensible as possible.

8. References

BRGM, 1997
Contrôle qualitatif et quantitatif de l'aquifère Landénien des Flandres. Etude réalisée dans le cadre de l'action de Service Public du BRGM. Référencé rapport BRGM R 39678 daté d'octobre 1997.

Bulletin du Ciment, 1995
Substances chimiques exerçant une action sur le béton. Volume 63, n° 12, 1995.

Collection technique CIMBETON, 1997
Fiche technique DB1 Durabilité du béton : Définition et facteurs influents de la durabilité.

DE LA GOUPILLIERE H., 1941
Cours d'exploitation des mines. Quatrième édition. Tome Cinquième. P 536-537. Ed. Dunod.

DIDIER C., 1997
Guide méthodologique pour l'arrêt définitif des anciennes exploitations minières souterraines. Rapport intermédiaire de recherche INERIS pour le Ministère de l'Industrie. Référence INERIS-SSE-CDi/CS-97-22EP46/R04 daté du 30/01/1997.

EGRETLI I., SINGH R.N., 1988
A laboratory investigation into the effects of air void and water saturation on the collapse settlement of opencast mine backfill. *Min. Sci. Technol., 7, pp. 87-97.*

FLAKE R., Hollmann F., Hülsmann K., KAISER F., KLEINEVOβ, 1975
Das Problem aufgegebener Tagesschächte.
Mitteilungen der Westfälischen Berggewerkschaftskasse. Heft 31. WBK.

Hartmann G., Hollmann F., Hülsmann K., Meiβner H., Schöne-Warnefeld G., 1978
Sécurité concernant les puits remblayés. Fascicule 34.
Caisse syndicale minière de Westphalie(traduit de l'allemand).

HURST J.L., THOMAS G.K., 1986
The treatment of disused coal mine shafts – some case studies.
Min. Engr., 3, Apr., p. 89-100.

NCB, 1982
The treatment of disused shafts and adits. NCB library, 88 p.

LEPRINCE-RINGUET F. 1936,
Recherches récentes sur le dégagement du grisou et des autres gaz naturels dans les mines. Revue de l'Industrie Minérale. N° 363, pp. 113-119.

REED S.M., HUGHES D.B., SINGH R.N., 1987
Backfill settlement of restored strip mine sites – case histories. *Int. J., Min. Geol. Engrng., 5, pp. 161-169.*

U.S. Department of the Interior, Bureau of Mines, 1995
Closure methods for inactive and abandoned mine openings.

VAN VLIET-LANOE B., 1999
Evolution morphotectonique récente du bassin houiller Nord Pas-de-Calais dans le cadre de l'Europe de l'Ouest. Rapport d'étude USTL pour Charbonnages de France.

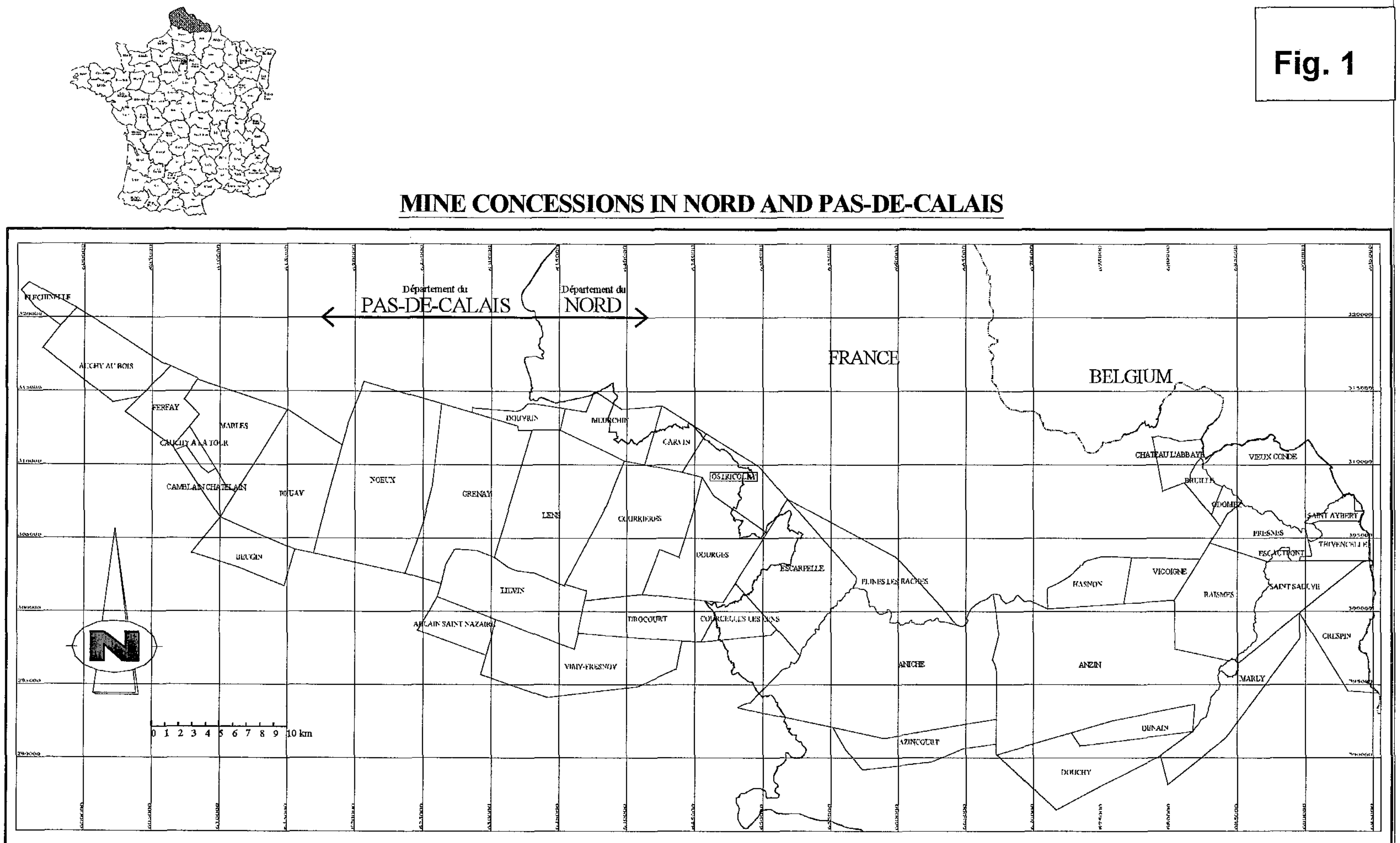
VINKLER F., 1999
Couplages hydromécaniques dans les massifs rocheux : du stockage de déchets radioactifs à la stabilité des mines abandonnées. Thèse INPL présentée en octobre 1999.

		Mecanisms leading to surface collapse					
Case	Configuration of the shaft	Rupture of deep structures	Backfilled column collapse	Lining rupture	Surronding surface grounds collapse	Head shaft structure rupture	Surface risk
1	Backfilled, *not drowned* **shaft** with a simple concrete slab or nothin on head	Nil	Yes	Yes	Yes	Yes	Yes
2	**Blind shaft**, not backfilled with a simple concrete slab or nothin on head	Nil	Nil	Yes			
3	Backfilled, *not drowned* **shaft** with a concrete plug on head	Nil	Yes	Yes	The risk evaluation depends on the availability of information about the plug design and its checked stability.		
4	**Blind shaft**, not backfilled with a concrete plug on head	Nil	Nil	Yes			
5	Backfilled, *not drowned* **shaft** with deep structures (plugs)	Depending on information available and checking of deep structures stability.					**No if deep structures are stable.** Go to case 1 or 2 if deep structures are not stable.
6	**Blind shaft**, *not drowned* backfilled	Nil	Risk of collapse of backfilling material depends on the availability of information about backfill process.				If backfill column collapse cannot be eliminated, go to cases 2 or 4. If backfill column collapse risk is eliminated, surface risk is zero.
8	**Shaft or blind shaft** *drowned* and backfilled	Nil	No	No	No	No	No

Table 1 : Risk evaluation according to the shaft configuration

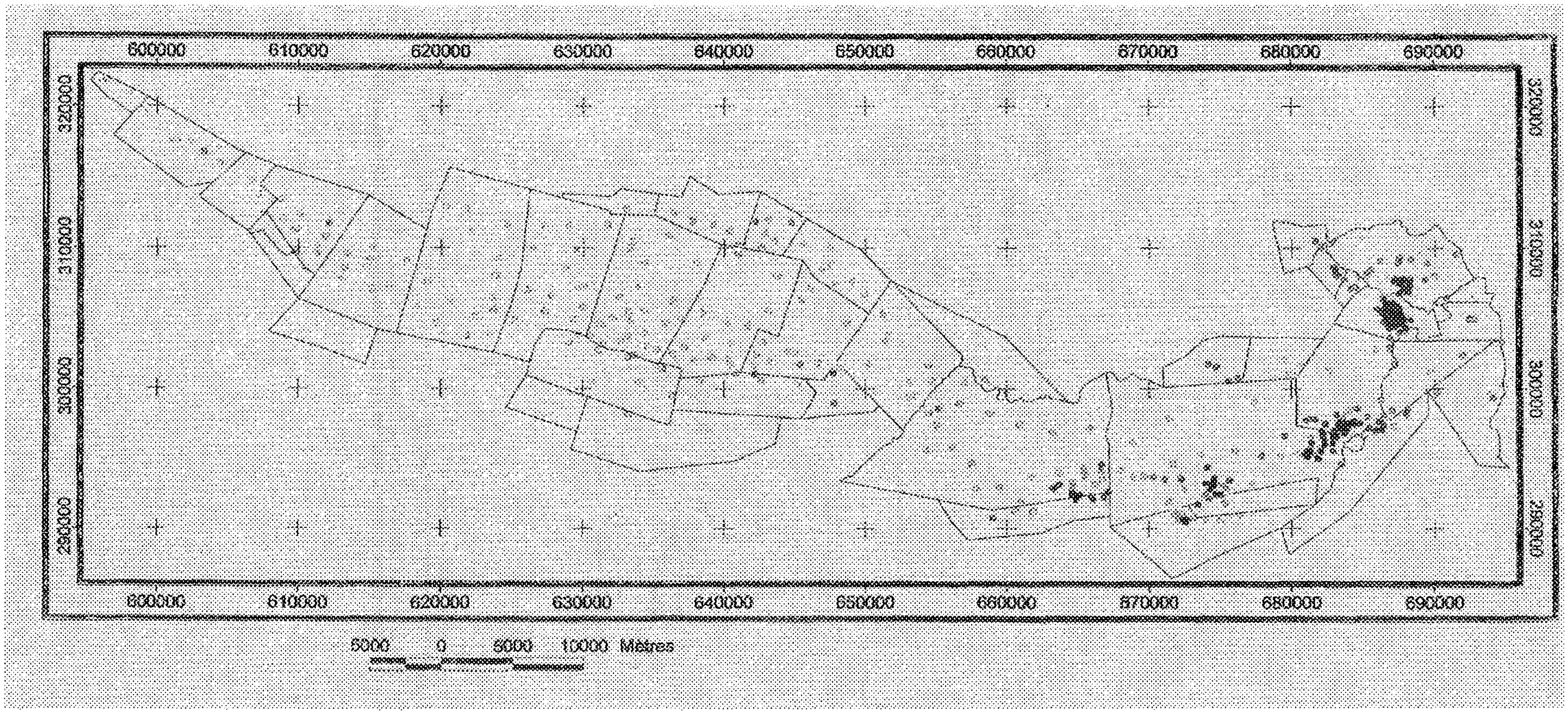
Fig. 1

MINE CONCESSIONS IN NORD AND PAS-DE-CALAIS



	Belgium boundary
	County limit
	Concession limit
OSTRICOURT	Concession name

Reference: Service des Sites arrêtés et Environnement
des Charbonnages de France Nord-Pas de Calais



● *in situ* not recognised shafts

● *in situ* recognised shafts

Fig. 3 : Distribution of shafts in Nord and Pas-de-Calais coal basin.

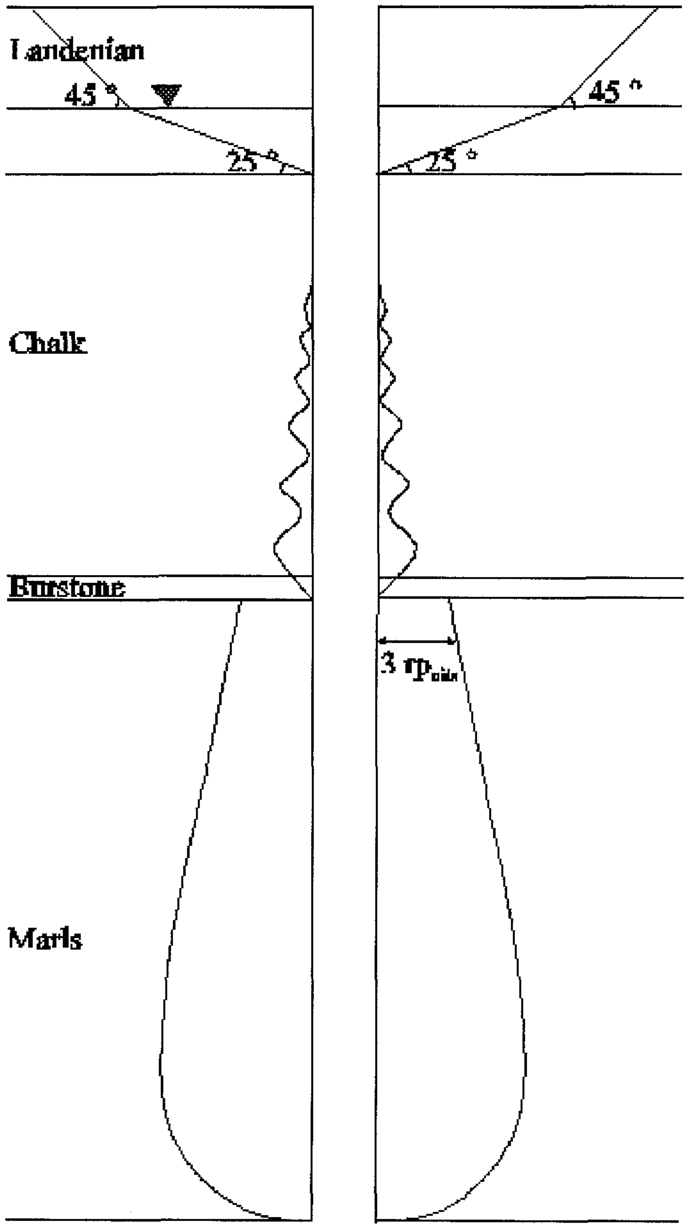


Fig. 4 : Plastic zone developing in the surrounding grounds