Case studies and analysis of mine shafts incidents in Europe

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Abstract

Entry to mine workings is normally gained by means of vertical shafts or horizontal or inclined tunnels called adits. Other mining objects such as fan drifts and wheel pits are often associated with mine shafts. Such mining objects may or may not have been filled, wholly or partially, or otherwise sealed to prevent entry when the mine was abandoned. Nowadays mine entries are usually adequately protected on abandonment to prevent accidental ingress. Many earlier mine entries remain open, however, and may pose a threat to human safety. Within the framework of MISSTER (Mine shafts: improving security and new tools for the evaluation of risks), a European RFCS project (Research Fund for Coal and Steel), a selection of representative cases of mine shafts incidents was reviewed. This work was carried out by INERIS (France), GEOCONTROL (Spain), University of Nottingham and Mine Rescue Service Ltd (United Kingdom), Central Mining Institute and KWSA (Poland). The experience accumulated through this work will allow a fuller determination of risk scenarios associated with mine shafts.

1. INTRODUCTION

MISSTER is a European Project within the framework of RFCS (Research Fund for Coal & Steel). It is a three year research project that aims to develop innovative cost-effective tools to:

- enhance the understanding of hazards that may affect mining shafts and
- optimize safety conditions for active shafts maintenance and disused shaft treatments.

The project partners include research institutes, universities and mining companies from France (INERIS), United Kingdom (University of Nottingham and Mines Rescue), Poland (Central Mining Institute and Kompania Węglowa), Germany (DMT) and Spain (GEOCONTROL).

An important work was carried out to collect representative case history data concerning shaft instability in Europe. Rather than being comprehensive of all events, the case data are representative of a range of potential behaviour in European conditions. In all coal mining areas, several cases of incidents or accidents relevant to mining shafts are related. These may occur both during and after mining operations (during design, mine extraction, after closure). The design, monitoring, and maintenance of mine shafts all incur significant costs during the operational lifetime of a mine. In addition, at the end of mining operations, closure of shafts often constitutes an sizeable expensive, depending on the treatment technique applied.

Although fatalities associated with past incidents are rare, they constitute a important constraint on mining operations as well as on land planning. Collapse of shaft linings or of shaft walls (particularly in unconsolidated superficial deposits) and collapse of shaft fillings (especially if partially filled or founded on wooden staging part way down the shaft) pose an obvious threat to life and safety as well as to any buildings or structures in the vicinity. In unconsolidated superficial deposits, a funnel-shaped crater may form which is considerably more extensive than the area of the original shaft.

2. METHODOLOGY

In order to provide a representative analysis of cases relative to incidents directly involving mine shafts, a collection of incidents has been researched by each partner for their respective country. To obtain the most representative cases, a list of the incidents which can be induced by the presence of a mine shaft has been created. The different kinds of incidents and accidents considered are:

1. a collapse of the filling material column

In the case of a shaft, collapse of the shaft filling material is a rough and dynamic remobilisation of the filling material which propagates down abruptly and rushes into the old works, generating a collapse of the surface if no structure or protection was installed at the head of the shaft. Collapse of the shaft filling material occurs generally after a slow degradation of the conditions of the filling material, in particular during mine water rising within the shaft column after exploitation. These progressive modifications end in the establishment of a limit balance and the intervention of an aggravating factor can be enough to activate the dynamic mobilization of the column. Some collapses of the shaft filling material result from the formation of a void in the column during the dumping of filling material. These voids can result from the blocking of materials within the shaft column.

Examples:

Cases of shafts n°8 and n°8 bis, at Noeux-les-Mines in France, illustrate this kind of collapse. A detailed analysis is presented in Section 3.

The case of Lancashire n°6 upcast shaft, in England, also illustrates this kind of incident. This 4.1 m diameter circular shaft, around 200 m deep, was filled in 1927 with soft material. In January 2007, a void about 4 m diameter at 20 m depth was observed from ground level. Brick lining remained suggesting a collapse of filling material that did not lead to the rupture of shaft head (Figure 1).

Figure 1 : Collapses of LancashireNo.6 Upcast Shaft
(Source: UK Coal Authority).

2. <u>a failure of the shaft head</u>

Many shafts were closed by old techniques presenting no guarantee of sustainability. Some old mine shafts were closed by a single on-surface or near-surface wooden platform, eventually completed by filling material on the shaft head but leaving the whole column empty.

The case of West Midlands Shaft, in England, illustrates this kind of situation. This 3 m diameter circular shaft, 144 m deep, suffered a collapse of ground approximately 3 m diameter and 2.5 m deep in a car park area in 2000. Collapse became apparent when surfacing failed over a void due to weight of a car (Figure 2). Two occupants in the car escaped with only minor injuries.

Figure 2 : Collapse of ground in the car park area
(Source: UK Coal Authority)

Some structures, such as more recent concrete slabs, can break when they are subjected to excessive loads (motor vehicle transit, building…), or when surface ground materials on which they rest fail.

This kind of failure is illustrated by South Yorkshire shaft, in England. This 3 m diameter circular shaft, 170 m deep, was filled and closed in 1919. A depression in a wooded land at the location of a recorded shaft was reported on 1 March 2005. Three features on the site were observed. Firstly, a feature appeared that was shaft like, some 3 m in diameter, and the fill within the feature appeared to have sunk by about 1m with parts of brick lining exposed. Secondly, there was a ground collapse some 1.5 m diameter and 1.2 m deep. Both of the two features are associated with the area around the South Yorkshire filled shaft. Thirdly, a brick structure some 4 m square projecting 600 mm above ground level with 150 mm thick concrete slab on top was found. It is believed that this is the surface cap for the shaft. According to the desk investigation, it was found that the shaft was 170 m deep and was filled in 1919. While excavating the shaft top a brick lined inset was uncovered. The Inset roof was collapsed which probably caused the depression of land.

3. <u>a failure of the shaft lining</u>

The most frequent failures of the shaft lining result from a decrease of its resistance or from an increase of the pressure of grounds. When the strength of the lining is exceeded, the lining (bricks, stone blocks, concrete, cast iron and steel) deforms and eventually breaks. It may collapse in the shaft with part of the surrounding ground.

The decrease of the mechanical properties of a lining material with time is an inevitable phenomenon resulting from the progressive ageing of the constituent materials. Shaft backfilling operations made without sufficient precautions may also damage linings. Stones or blocks dumped from the surface opening are subjecte to free-falls of several hundreds of meters and can sometimes damage sections of the lining. Also, closure structures badly or insufficiently designed may sometimes stress the shaft lining.

Examples:

- Coal shaft V, Knurow-Szczyglowice colliery, in Poland. A detailed analysis is presented in Section 3.
- Shaft n°1 and n°2 at Barony Colliery Ayrshire Scotland (England): sunk between 1906 and 1912, shaft n°1 and n°2 are rectangular (resp. [6.4 m x 3.3 m] and [4.9 m x 3.3 m]), wood lined and 633 m deep. In 1960/62, modification of ventilation systems took place. N°1 shaft was originally used as the Downcast / coal winding until 1962. Following completion of works at the shaft head, it was re-commissioned as an upcast. N°2 shaft was an Upcast. After conversion of ventilation system, shaft n°2 collapsed following deterioration of wood lining (Figure 3), that may have been caused by contact with upcast air of high humidity.

Figure 3 : N°2 Shaft following Collapse (Source: MRSL)

4. a failure of deep closure structure located into the shaft galeries

Galleries or mining works with connecting shafts may have been closed before the shaft was backfilled in order to avoid spreading of the backfilling material in the galleries. Structures generally consist of walls in hollow blocks, metal dams or concrete plugs. For old mining shafts, galleries may have been closed with remaining items but without particular design. Because of various causes, for example concrete segregation or poor lining design, a rupture of this deep closure structure can occur allowing the filling material to spread into the galleries, resulting in a collapse of the shaft.

Monitoring of shaft n°1 and n°2 (Vieux Condé, France) backfilling has illustrated this problem. Shaft n°2 in Vieux-Condé (France) is a 5 m diameter circular shaft, 501m deep. It was filled in 1982 after the construction of a concrete plug at the bottom of the shaft. Other stages of shaft were closed by various undefined remaining elements. The follow up of the stowing shows that filling material volume is similar to shaft column volume (i.e. the shaft was completely filled). In 1987, the first 305 m of shaft n°2 were observed empty from the surface. Also illustrating collapse of filling material column, this incident suggests that filling material spread through shaft galeries because of poor design of their closure.

5. a specific focus on surface development

Occasionally, a brutal collapse may occur in the vicinity of a mining opening due to the constraints applied on surface. Several causes are likely to lead to these instabilities of the ground level. For example, an overload on the surface, in the immediate surroundings of the shaft head, such as storage of exploited material, heavy vehicles or construction. Vibrations generated by explosions or blasting near the shaft head or by intense circulation of very heavy vehicles can also cause instability.

Examples:

- West Midlands shaft (England), introduced previously.
- Low Hall n°7 (New Zealand Pit) at Abrams Lancashire, in England. The shaft is circular (3.66 m) and 305 deep and was sunk circa 1885. All mining via the shaft was abandoned in 1919 (1924?) although the shaft was retained for ventilation until 1932 (1931?) when it was filled with a reported 8,120T of debris. In April 1945, some 13 years after the mine shaft had been filled the locomotive was shunting a train of 13 loaded coal wagons (full length 86m) when the ground beneath the line cratered and collapsed (Figure 4). The last wagon entered the crater pulling the rest of the train and eventually the locomotive with it. A few days later, when the dust cleared, the front of the locomotive could be made out 30m below pointing upwards.

Figure 4 : Infilling Shaft Post Collapse (Source: MRSL)

6. <u>a rupture due to water effect</u>

When an inflow of water occurs in a shaft, either by the rise of water levels, or by infiltration, this can become a triggering factor:

- of failure of the filling material. The additional water within the column of the shaft adds weight and may reduce fill strength due to pore pressure generation, thereby disturbing the equilibrium state within the column and generating failure.
- of the rupture of the shaft lining, by increasing pressure on the lining.

Examples:

Shaft located at Tirphil, New Tredegar (England): this circular, 10 m diameter, shaft was last recorded in 1965. The collapse of shaft was reported at in November 2010. It was described as a hole in the road, 4 m deep, 4-5 m diameter, brickwork was visible and water was entering the hole from a culvert. The collapse was near the railway line and road between Brithdir and Tirphil. Due to water ingress from the culvert, the collapse grew in size and the following morning was approximately 10 metres diameter, 15 metres deep and filled with water to approximately 4 metres from road level (Figure 5). Whilst the cause of the collapse is unknown the location corresponds with a recorded mine shaft.

According to the desk investigation of Coal Authroity data, it was found that the collapse is on the position of a mine entry. Shallow recorded mining exists beneath the site at approx 22m below road level and deep mining between 370 m and 480 m. The Shaft is connected to an adit. The adit is detailed as "the lowest free drainage for the Brithdir Seam in the Rhymney Valley" on abandonment plan 6467. The workings within the Brithdir Seam dip at 1in15 to the SSW. The roadway between the shaft and adit ran on the strike of the seam and the adit was c.20m below the surface level of the shaft.

Figure 5: the collapsed shaft at road between Brithdir and Tirphil (Source: UK Coal Authority)

7. a rupture due to particular geologic formations

The presence of particular geological formations, such as soluble horizons (gypsum / salt) or soil seams lacking cohesion which are susceptible to flow (sand for example) may induce the creation of voids behind the lining. This void may destabilize the lining of the shaft and induce its collapse.

Examples:

- Coal shaft V in Pniowek colliery (Poland): Sunk from 1974 to 1980 to the depth of 1018 m, this shaft is 7.5 m diameter circular. The geological cross-section around shaft „V” encompasses: Quaternary formations (up to a depth of 49,60 m), Tertiary (from 49,60 m to 270,80 m) and Carboniferous (from 270,80 m to 1017,85 m). In upper part of the Quaternary formations (up to a depths of 23,1 m) there are dusty clays with intercalations of sand, and from a depth of 15,3 m dusty sand and dust with sporadic intercalations of clay. From a depth of 23,1 m to 30,1 m there is dusty clay that constitutes an aquitard. Below that, up to a depth of 49,6 m there is a series of dusts and fine-grained sands with intercalations of dusty clay and gravel.

  On 5 December 2007 at 12.15 o'clock during an inspection a ground surface deformation was observed between shaft V and a ventilation shaft over a length of 8.0 m. At the beginning, two 1 - 1,5-m deep craters were observed on the south-eastern and north-western side of shaft V, which already on 7 December 2007 had a diameter of circa 5,0 - 7,0 m each. The craters were located on both the sides of ventilation drift at a not large distance to shaft “V”. Not later than the first days after the aforementioned event the craters united into one that continuously grew.

  What caused the catastrophe was the inrush of a quicksand strata into the shaft. The strata found a way into the shaft in a leak of the shaft lining at the connection of the ventilation drift to the shaft. This caused loosening of ground under the drift and its vertical displacement by about 2,0 m (Figure 6).

Figure 6 : The crater in the neighborhood of shaft “V” (Source: GIG / KWSA)

- Coal shaft BolesŁaw, Bobrek-centrum colliery (Poland). Sunk from 1906 to 1910 to the depth of 779 m, this shaft is 6.4 m diameter circular.

  The geological cross-section around shaft Bolesław encompasses formations of the Quaternary (represented by sands and clays from 0,0 to 63,0 m), Tertiary (mostly formed of limestones and dolomites from 63,0 to 114,0 m) and Carboniferous (represented by clay slates, arenaceous shale, sandstones and coal from 114,0 to 779,0 m).

  The catastrophe of shaft Bolesław took place on 6 September 1975. On the western side of the shaft a crater came into being that uncovered foundations of the shaft bank house. After several hours the increasing crater caused a collapse of the shaft bank building which leaned against the headframe's angle struts breaking them and causing a collapse of the headframe (Figure

7). The event was characterised by a very dynamic course and lasted merely 15 hours.

The primary cause of the accident was a quicksand inrush into the shaft at a depth of 24 m. An increased outflow was observed during the nightly shaft inspection before the catastrophe and a vertical fracture of the lining was located below the outflow point. As a result of falling out of an concrete gutter element a 0,8-m long and 0,2-m wide vertical fissure came into being throughout the whole thickness of the shaft lining. Although a provisional packing had been placed in the gap in lining, made of ventilation fabric and planks, a considerable and violent increase of the gap in the lining was observed after a short time since it began, along with an intensive outflow of sand and water. As a result of water influence and changes in load exerted on the shaft lining the latter began breaking along a considerable length. The quicksand inrush caused that it was necessary to fill the shaft at a depth of from 6,0 m to 160,0 m.

Figure 7 : *View of the collapsed headframe (Source: GIG / KWSA)*

8. a risk of subsidence due to remobilisation of filling material or surface development

Occasionally, a slow and progressive remobilisation of the surface layer (shaft backfilling material and low cohesive ground material) occurs in the vicinity of a mining opening. Settlements occur within the backfilling materials as a result of compaction. Under the effect of outside disturbances (on-surface overload, vibratory stress) or due to a remobilisation of filling materials, grounds or backfill material can settle and induce movements of low amplitude (generally the maxmimum amplitude is a few decimeters).The results are mainly surface differential settlement that may affect buildings and infrastructure.

Example:

Coal shaft Nord at Noyant d'Allier in France is a circular shaft, 4 m diameter and 217 m deep. Filled in 1995, a cumulative 4 m height of extra filling material was required to fill the settlement in 2001. A settlement of filling material column of a few percent of filled shaft column height is to be expected in the years following filling.

9. <u>a risk of gas release</u>

The presence of harmful or potentially explosive gases (monoxide and carbon dioxide, methane…) in old mining works can result from:

- a concentration of gas in the rock which is released into cavities generated by the mining;
- the decomposition or the chemical weathering of materials or products which remain within the mine.

Shaft may constitute a preferential flow path from mine working up to the surface for gas. The release on the surface can occur during the exploitation, but also during the phase of filling the void after the end of the works (the gases migrating to the surface by piston effect).

These gases can migrate to the surface according to various phenomena:

- thermal variation, due to the difference between gases' temperature or openings altitude;
- variations of the external atmospheric pressure: gases dilate in period of decline of the outside barometric pressure. On the contrary, in case of increase of the external pressure, the air rushes into the mine;
- rise of water levels: under its effect, gases are pushed upward through the openings of access. The level of the underground aquifer can vary according to the seasons or the precipitation and induce slow or rough rises of gas.

Example:

Coal shaft Barrois at Creutzwald, in France: this 4 m diameter shaft is 512 m deep. Closed in 1988, it was equipped with various device in order to monitor gas migration during and after mine water rising. The monitoring since 2005 shows that gas migration (CH_4, CO_2) between mine working and surface is mainly governed by variations of pressure. When atmospheric pressure decrease, shafts flow out because pressure in mining voids is larger and differential pressure is sufficient (*Lagny, 2004*).

3. <u>CASES</u>

Two detailed cases are presented in this paper. The first case illustrates the collapse of the filling material column (failure scenario 1 from above), which is one on the most frequent scenarios found. The second case illustrates a collapse due to the rupture of shaft lining (scenario 3) leading to the shaft head rupture (scenario 2).

3.1 COLLAPSE OF THE SHAFT FILLING MATERIAL – COAL SHAFT N°8 AND N°8 BIS, NOEUX-LES-MINES, FRANCE

3.1.1 LOCATION AND CHARACTERIZATION OF THE SHAFT(S)

Pithead of shafts n°8 and n°8 bis is located on the territory of the municipality of Verquin (North region of France, Coal mine closed in 1990). Both shafts n°8 (main shaft) and 8 bis were dug in 1899 and opened in 1901. The distance between the two shafts is 40 m (Figure 8).

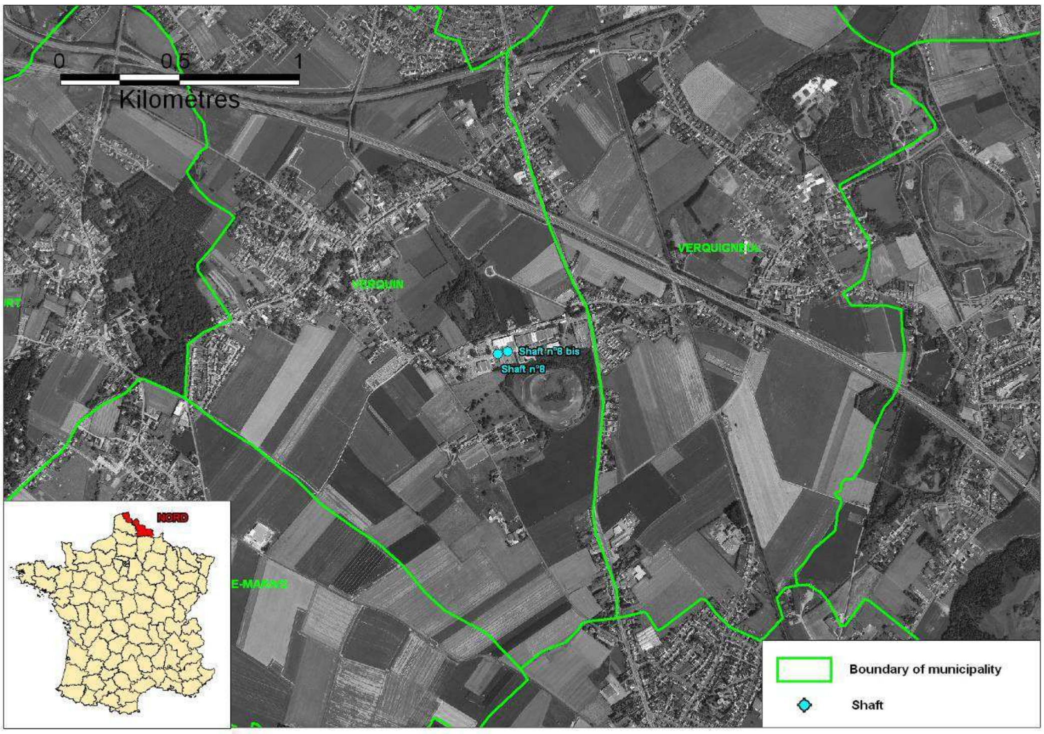

Figure 8 : Location of shafts n°8 and n°8 bis (Source: INERIS)

They were intended for the extraction of thin coal veins. The concerned veins are about ten, rather flat and regular, with a dip of 30-35°. The total production of the site was 14,5 Mtons. The closure was pronounced in 1968, and their backfilling began in 1968 and ended in 1969.

Shaft n°8 is a circular 100 m deep shaft with a regular diameter of 4.8 m (that is 13,800 m^3). It contains 13 stations. Shaft n°8 bis is a circular 600 m deep shaft with an irregular diameter ((3,6 m from the surface to depth 102 m, then 4,1 m from depth 102 to 539 m, and finally 4.2 m from depth 539 to 600 m) that is around 8,900 m^3). It contains 14 stations.

Considering a density of 1,7 t / m^3 to for backfilling material (schists and ashes), the expected equivalent tonnage required to backfill shaft n°8 is 23,000 t and the shaft n°8 bis of 14,800 t, that is a total tonnage of 37,800 t.

3.1.2 GEOLOGIC AND HYDROGEOLOGIC CONTEXTS

The cross section of shafts head shows the following succession of near surface grounds:

Geologic formation	Shaft n°8	Shaft n°8 bis
Clay	From 0 to 3.50 m	From 0 to 3 m
Sandy clay	From 3.50 m to 5 m	From 3 m to 4.90 m
Flint	From 5 m to 5.15 m	From 4.90 m to 5.05 m
chalk without flint	From 5.15 m to 31.71 m	From 5.05 m to 31.47 m
chalk with flint	From 31.71 m to 55.17 m	From 31.47 m to 62.10 m

3.1.3 DESCRIPTION OF THE INCIDENT

The follow-up of stowing indicates the following quantities:

- 1968/69 shaft n°8 backfilling :
  - Tonnage of schists: 11,900 t (equivalent volume: 7,100 m^3) ;
  - Tonnage of ashes: 3,600 t (equivalent volume: 2,200 m^3).
    - → Total volume of 9,300 m^3 (that is 67 % of the theoretical volume)
- 1968/69 shaft n°8 bis backfilling:
  - Tonnage of schists: 8,900 t (equivalent volume: 5,300 m^3) ;
  - Tonnage of ashes: 2,500 t (equivalent volume: 1,500 m^3).
    - → Total volume of 6,800 m^3 (that is 76 % of the theoretical volume)

The actual poured tonnages are much less than the theoretical volumes.

On November 24th, 1999 (30 years after shafts backfilling), it was noticed that shafts n°8 and n°8 bis had unrammed. The level of backfilling materials were measured at a depth of 45 m for shaft n°8 and 186 m for shaft n°8 bis.

	Shaft n°8	Shaft n°8 bis
Unramming volume	800 m	2,100 m
Theoretical minimum volume	13,800 m	8,900 m
Stowed Volume	9,300 m	6,800 m
remaining Volume	4,500 m	2,100 m

Note that on November 2nd, 1987, approximately 20 years after the backfilling, a complement of backfill material was made for both shafts: 9 m^3 of backfill material were added to shaft n°8 and 13 m^3 to shaft n°8 bis. The small volume of missing material in shaft head, indicate that it is a classic phenomenon of progressive and residual settlement of backfill material.

On the other hand, decrease of 1999 measured levels, rough and of great amplitude, cannot be the result of the only phenomenon of collapse of backfill material.

3.1.4 PROPOSITION OF ANALYSIS

The historic curves deducted from the follow-up of backfill data show sharply the appearance of void formed from the first works of stowing. Figure 9 and Figure 10 show a sensitive and constant distance between the level of backfill material measured in the column of shafts and the level equivalent to the volume of the dumped backfill material. The first one is upper than the second indicating the presence of one or several voids in the column of shafts. Let us note that shafts were not deinstalled before the stowing and the presence of metallic structures within the column of shafts can ease the creation of backfill material vaults.

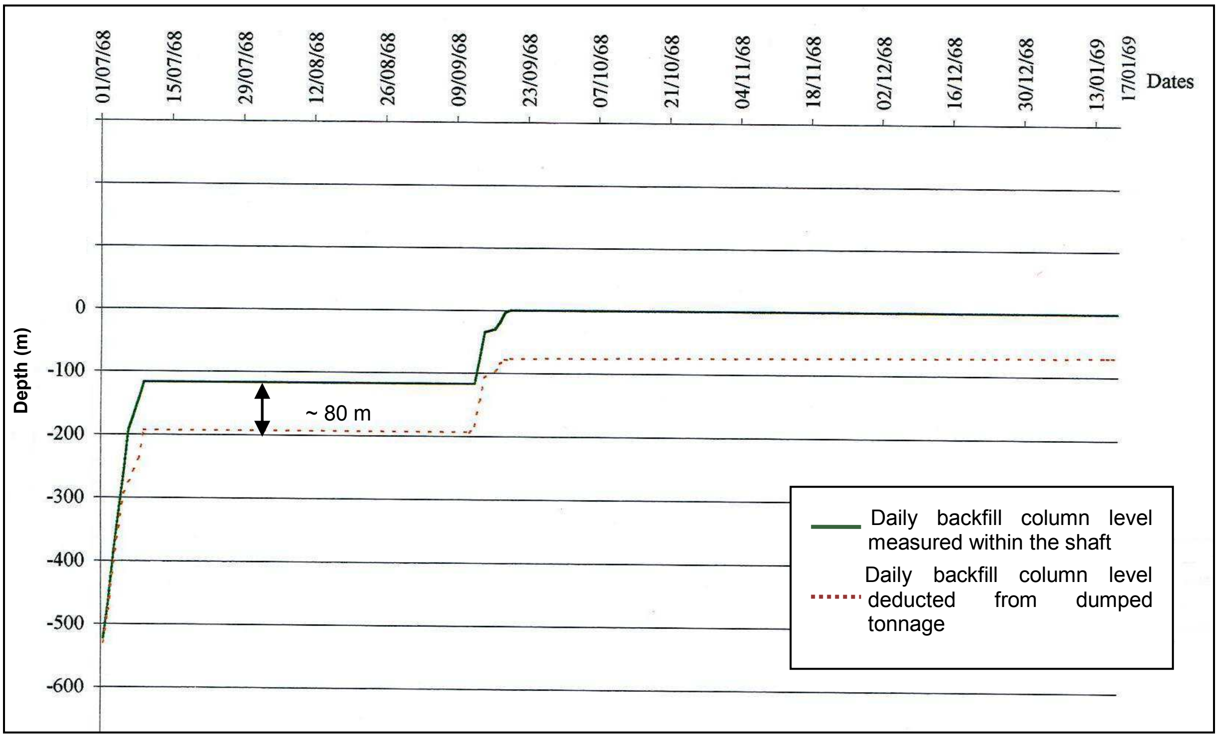

Figure 9 : backfill level evolution – Shaft n°8 – from 01/07/68 till 17/01/69

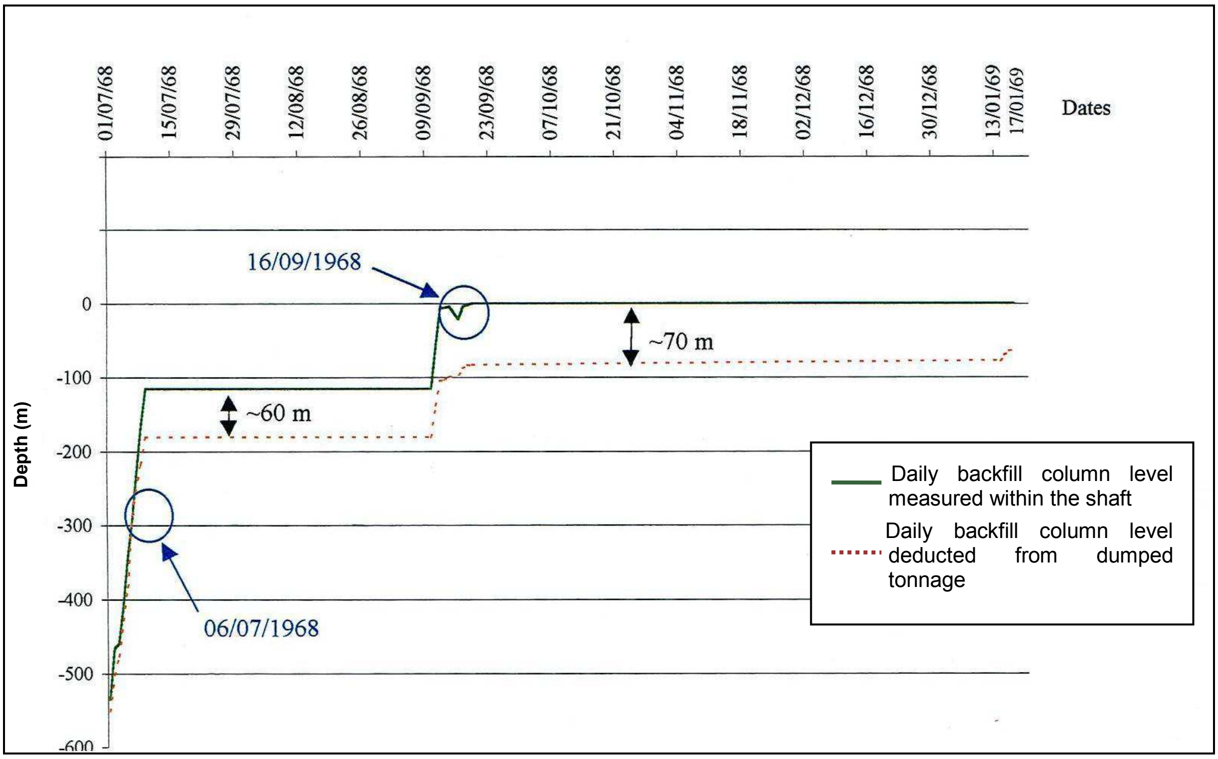

Figure 10 : Backfill level evolution – Shaft n°8 bis – from 01/07/68 till 17/01/69

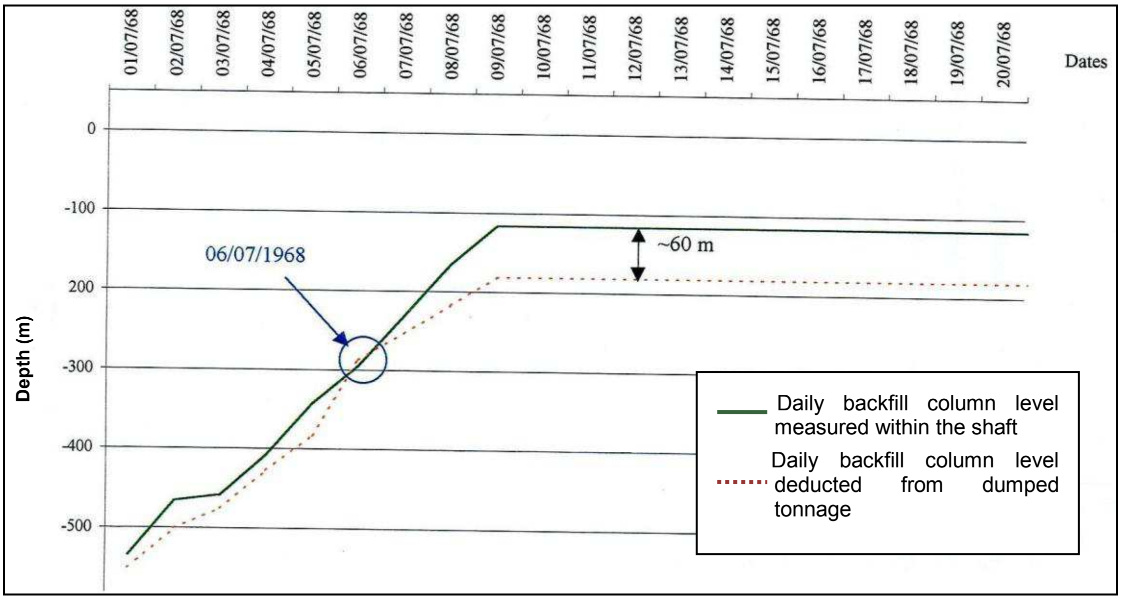

Figure 11 : level evolution – Shaft n°8 bis – from 01/07/68 till 20/07/68

Figure 11 shows the detailed history of the first days of shaft n°8 bis backfilling. It shows that on July 6th, 1968 the measured level is lower than the equivalent level of stowing. 2,035 t of backfill material were dumped. They should have filled an equivalent weight of 92 m but the measure showed that only 48 m of the shaft column were filled actually. The phenomenon of settlement of backfill material in the bottom of shaft column under the weight of superior backfill material does not explain the observed difference:

- the adjustment of the level of the backfill material by filling of the void created previously;
- the failure of the system of closure of one or several stations the departure of backfill material in one or several corresponding galeries.

The volume of backfill material unrammed in the column of the shaft n°8 bis is equal to the volume of missing backfill material during the stowing (2,100 m^3 opened for 2,100 m^3 missing).

The volume of backfill material unrammed in the column of the shaft n°8 is less than the volume missing of backfill material during the stowing (814 m^3 unrammed for 4 528 m^3 of missing backfill material). Even in the hypothesis where backfill material does not dump in galeries, the risk of unramming of the backfill material within the column of the shaft n°8 is not to be excluded long term basis.

The case of shafts n°8 and n°8 bis illustrates the risk of unramming due to the creation of void within the column of shafts during the phase of stowing.

3.2 RUPTURE OF THE SHAFT LINING AND SHAFT HEAD - COAL SHAFT V, KNUROW-SZCZYGLOWICE COLLIERY, POLAND

3.2.1 LOCATION AND CHARACTERISATION OF THE SHAFT(S)

Pithead of shaft V is located on the territory of the municipality of Knurow in Poland.

The ventilation shaft V was sinked to the depth of 326.5 m from May 1972 to May 1973. In the period from March 1985 to May 1986 the shaft was sinked to the final depth of 632.05 m.

The shaft has a diameter of 6.0 m and contains 5 stations:

Up to a depth of 41.5 m the shaft has a brick lining with a thickness of 0.5 m – 0.9 m and below a concrete lining with a thickness of 0.3 m – 1.3 m. The water inflow to the shaft sump was below 35 l/min.

3.2.2 GEOLOGIC AND HYDROGEOLOGIC CONTEXTS

The geological cross-section around shaft V encompasses Quaternary formations (from 0.0 to 18.4 m), Tertiary formations (from 18.4 to 165 m) and Carboniferous formations (from 165 to 632.05 m).

The Quaternary formations are represented by arenaceous clays with interlayers of sand.

The Tertiary formations with a thickness of about 120 m mainly occurring in a form of hard-plastic clays are prone to swelling under water influence. At depths from 73 m to 84 m the clays are interbedded with gypsum and marls. Below in an interval from 142 m to 146 m and 161 m to 165 m (i.e. up to the Carboniferous top) fine-grained sandstones, arenaceous dusts with interbeddings and interlayers of water-bearing dusty sand with a small thickness and prone to become liquid.

The Carboniferous formations are composed of strata of argillaceous shales, arenaceous shales and sandstones, among which coal seams with a thickness of up to 4.5 m occur. A fragment of geological cross-section along shaft V is presented in *Figure 12*. It represents the geological setting in the area of the catastrophe.

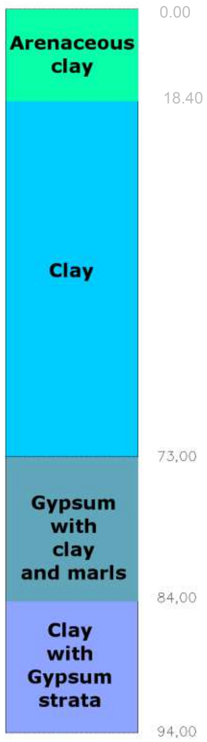

Figure 12 : Geological cross-section in the area of catastrophe occurrence

3.2.3 DESCRIPTION OF THE INCIDENT

On 4 September 2008 at 4.35 o'clock a catastrophe took place which resulted in shaft lining damage up to a depth of circa 70 m, and afterwards the shaft was spontaneously filled with overburden soil material. This caused that a large crater came into being at the surface that in turn caused damage of building facilities present in its impact zone.

Figure 13 : General view of the scene of the catastrophe of shaft V from the south (Source: GIG / KWSA)

Displacement of ground into the shaft caused its filling. The shaft inset workings were also filled with ground material at the following levels:

- Level 650 m – inset opening was filled over a length circa 30 m,
- Level 550 m - inset opening was filled over a length circa 50 m,
- Level 450 m - inset opening was filled over a length circa 16 m,
- Level 350 m - inset opening was filled over a length circa 10 m,
- Level 250 m – no data as the level was earlier abandoned.

The crater had a diameter at the ground surface about 60 m, a depth of around 11 m and an estimated volume of about 30,000 m^3. Horizontal range of fracture zone at the ground surface affirmed on 4 September 2008 amounted to 67 m.

3.2.4 ANALYSIS

The primary cause of the accident at the shaft was damage to its lining at a depth of 61 m – 67 m. The damage was a consequence of:

1. Irregular mining repeatedly performed in the neighborhood of the safety pillar of the shaft which influenced hydrogeological conditions which in turn destroyed building-engineering stability of the ground-lining system.

2. Poor technical condition of the lining of shaft V.

The dimensions of the collapse are exceptionally great compared to other shaft head collapses. This is inducing by the nature of ground surface materials surrounding the shaft head. The quaternary formations are constituted by arenaceous clays with interlayers of sand that is to say a great fraction of low cohesive material more than 18 m thick. The angle of stability of such a material is very low and may be affected by possible surface or near-surface water circulation.

Considering the characteristics of the surface collapse, the equivalent angle of stability of ground surface material is around 15° which is coherent with the nature of geological surface materials.

The measures to eliminate consequences of the catastrophe were undertaken right after it occurred. Firstly building emergency stoppings were set in order to make the ventilation stable. At the next stage 2 m thick isolation-and-pressure-resistant stoppings were built using mineral binders located in the shaft insets vicinity at levels 350 m, 450 m, 550 m and 650 m. The space between theses stoppings and the shaft fill was filled with an ash-and-water mixture using the hydraulic-filling installations existing in the colliery.

Empty spaces in the shaft section where the lining damage took place up to the crater bottom were filled with a binder characterised by compression strength of not less than 15 MPa. The spaces were filled after building stoppings at levels 450 m and 350 m. The filling material was supplied through holes drilled from the ground surface in the direction to the shaft at 10 m distance one to another. Before they set to injection, an exploration borehole was drilled to assess the crater’s range and scope of damage. Locations of the injection boreholes and the exploration hole are presented in *Figure 14*.

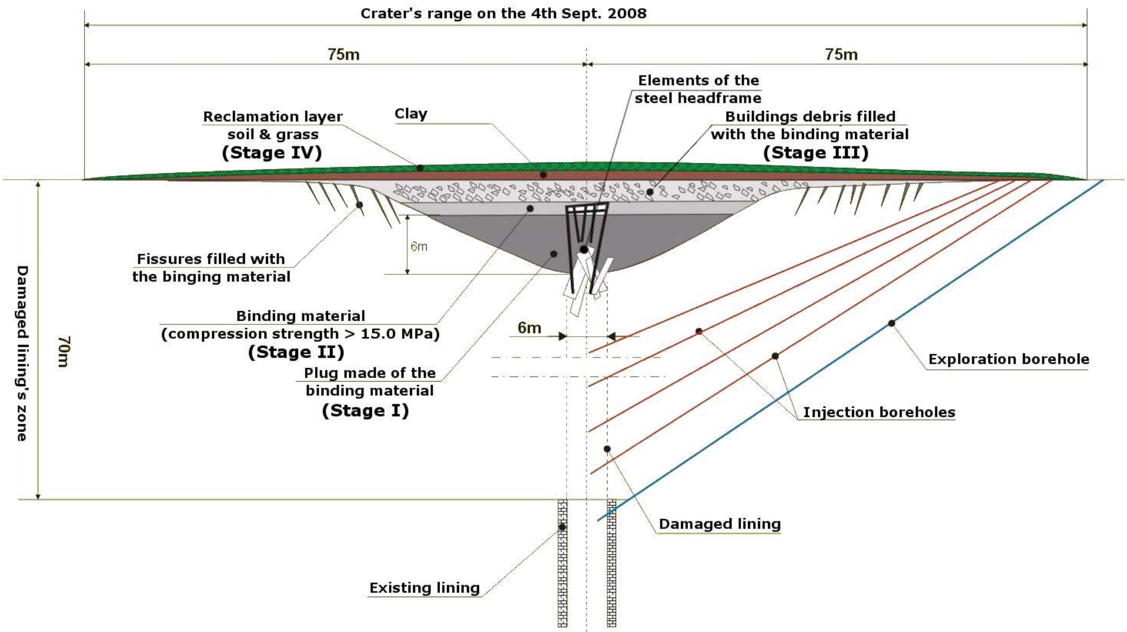

Figure 14 : Schematic illustration of the crater resulting from the catastrophe of shaft V and its fill

The crater was filled in four stages.

At the first stage (Stage I) the crater was filled up to a height of 6 m above gathered water level with a fine-grained binding material with a compression strength of not less than 15 MPa and a fluidity of 150 ÷ 160 mm.

The fine graining and fluidity of the binding material ensured good penetration between the protruding elements of the headframe, large-dimension reinforced-concrete elements and building debris. The compression strength allowed obtaining high parameters of the monolith set. The fill of binding material after setting became a plug that effectively stopped and stabilised the above lying shaft fill material.

At the second stage (Stage II) the crater was filled with a ca. 1 m thick layer so as to completely cover protruding elements of the steel headframe. The material used was a binding material with a compression strength of not less than 10 MPa, which, after setting, allowed light building machines to ride on it. The layer allowed using of mechanised equipment during demolishing and planting the building debris at the third stage.

The third stage (Stage III) included further filling the crater up to the ground surface by means of a mixture of building debris (stemming from demolishing) and a binding material with compression strength of at least 5 MPa. Moreover all fissures that came into being in the vicinity of the crater were filled with the binding material used at the second stage.

Figure 15 and *Figure 16* present results of work performed at Stage II and III.

Figure 15 : The load-bearing layer at the crater – 5 May 2010 (Source: GIG / KWSA)

Figure 16 : Final crater fill with building debris mixed with binding material – 31 August 2010 (Source: GIG / KWSA)

The fourth stage (Stage IV) was a form of reclamation, at which the crater was covered with a layer of clay slate up to a height of 1.5 – 2 m in the central part of the crater with a slope in the direction from the middle to the outside of the crater so as to make precipitation waters to run outside the reclaimed area.

At the end stage of the work a borehole with a diameter of 200 mm was drilled along the shaft centre line up to a depth of ca. 75 m in order to observe settling of the material in the shaft. Moreover the mine workings in the locality of shaft V at level 250 m were filled with a material with compression strength of min. 10 MPa through boreholes drilled from the surface.

4. CONCLUSION

Mine shafts, during or after mining operation, may induce risks for operational staff or people and buildings in their vicinity. This paper details two historical cases illustrating three scenarios associated with mine shafts: collapse of backfilled shaft column and failure of a shaft lining leading to a surface collapse. These cases enable the understanding of key parameters in the securing process of shaft, or the evaluation of risks associated with old shafts, choice of backfilling material nature, follow up of backfilling process, ageing or deterioration of lining, impact of ground surface geology on shaft head collapse extension. Many other incident cases underline other key parameter.

Cross exchange between mining countries of mine shafts incidents should be developed in order to help mining operators to better anticipate mine shaft closure constraints. In post mining contexts, it constitutes a reference list of possible scenario for a better long term risks evaluation.

Acknowledgements

The authors wish to acknowledge the contributions of partners of MISSTER European project, which made this paper possible. Thanks also goes to the UK Coal Authority for providing access to its database of mine shafts within the UK.

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