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Polish Experiences in Design of Treatment of Disused Mine Shafts

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ABSTRACT: In last ten year a lot of polish hard coal mines have been closed down. A very important part of the mine closure is process of the treatment disused mine shaft, especially when the are last shafts in the mining area. Disused mine shafts use to be closed down by filling them with the granular material and covering by concrete cap. Stability of shaft fills ensure the safety for the underground workings and disused shafts sites. For ensure the equilibrium of shaft fills and decreasing costs connected with shaft closure shaft plugs built of concrete can be replaced by hardcore plugs made of coarse aggregate partly aggregated with concrete. The paper presents a some polish experience in preparing end executing of the shaft closing procedures.

ПОЛСКИЯТ ОПИТ ПРИ ПРОЕКТИРАНЕ НА ОБРАБОТВАНЕТО НА НЕИЗПОЛЗВАЕМИ МИННИ ИЗРАБОТКИ
РЕЗЮМЕ. През последните десет години бяха затворени много от полски мини за добив на антрацитни въглища. Съществен момент от процеса на закриване е обработката на неизползваните минни шахти, особено когато в района им много шахти. Неизползваните минни шахти се затварят посредством запълване с насипен зърнест материал и се запечатват с бетон. Устойчивостта на запълването на шахтите е гаранция за безопасността на подземните изработки и обектите с неизползвани шахти. С цел осигуряване на равновесие на запълването и намаляване на стойността на затваряне на шахтите запълването с бетон може да се подмени със грубозърнест агрегат, слабо свързан с бетон. Докладът представя известен полски опит от подготовка за затваряне и изпълнение на процедурите по затваряне на шахти.

Introduction

A permanent and complete liquidation of mines, which started in Poland after 1990 proved in a sense to be a fully new problem for the majority of mining engineers. Till that time the process of transformation in the mining industry had been carried out mainly by means of restructuring through consolidation of mining areas functioning within bigger units

The first example of a complete liquidation of a coal basin in the Polish history of the mining industry was the closing down of the Wałbrzych Basin which after 400 years of production definitely ceased its activities in 1999. The liquidation of the four last shafts that had functioned till the end of 1998 marked the end of the rich and beautiful history of the Basin.

The last decade of the 20th century was a hot period for the whole Polish mining industry. At the end of 1990 in Poland there were 73 mines in operation (three of them were under construction). The mining industry employed 387.9 thousand people and produced 147.4 mln tons (Szlązak, 2004). The changes in the Polish mining industry are presented in Table 1.

Table 1.
The characteristics of the Polish hard coal mining industry in the years 1990 – 2002 (Szlązak, 2004)

No	Parameter	unit	Year												
			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1	No of mines in operation	pieces	70	70	69	65	63	62	58	57	54	48	41	40	41
2	Production	mln tons	147.4	140.1	131.3	130.2	132.6	135.3	136.2	137.1	116.0	109.2	102.2	102.8	102.0
3	Employment	thousands of employees	387.9	352.9	336.4	319.6	291.9	274.8	251.9	243.3	207.9	173.6	155.0	146.0	140.7
4	No of longwalls	Pieces	766	702	654	545	464	415	335	302	252	233	183	161	151
5.	Production in one longwall	tons/24 hrs	863	918	962	1082	1286	1470	1678	1880	1890	2210	2437	2729	2814
	Productivity	Tons/manshift	1,46	1,53	1,50	1,57	1,75	1,89	2,02	2,16	1,99	2,23	2,46	2,70	2,79

Table 1 shows very precisely the dynamics and the range of changes that occurred in one decade . It should be pointed out that similar changes in West Europe took several decades.

In the period of the profound economic transformation of the country, especially in the fuel and power sectors, the specialists in underground mining faced several problems that had not been known and coped with on such a vast scale so far. The experience of other European and non-European countries that had been analyzed then indicated the necessity to be particularly careful at the final stages of closing down mines or whole basins, especially in the cases when all natural hazards occurred there.

In the process of closing down a mine the phase of engineering design is of vital significance. Its main purpose is to decide on the technology of the liquidation itself and to point at the hazards that may occur in the course and after the liquidation process. Technical solutions applied when closing down mines must conform to the situation and development of the mining industry in the basin in question. There are many cases in the world that mining regions were closed down or "deserted" without any liquidation procedures. That is why the world is making attempts to deal with the hazards related to abandoned mines. For example, in the United States in most "coal states" special institutions have been established which are responsible for the minimization of hazards and reclamation of former mining areas. Since 1840 only in the state of Iowa approximately 6000 mines have been abandoned (VanDorpe, 1992); they covered about 32 000 hectares out of which about 1 520 ha are highly urbanized at present. It is a frequent paradox that the inhabitants of mining areas are affected by the mining industry twice. The first time is when the area is dewatered by an operating mine and the second when the mine stops dewatering the area and as a result overflow land appears in subsided sites.

It is estimated that in the British mining industry there are 100 000 abandoned shafts (Dun, 1982, Georgy, 1982). What is more, it is quite common that there is lack of information concerning their location, size and the liquidation method applied. Some scientific methods have been recently developed to search such shafts.

A coal basin that has been closed down poses a significant danger to the atmosphere. From the abandoned workings huge amounts of gases are released, especially of methane, whose presence in the air - according to recent research - is very harmful to man. A United States Administration report states that only in 1994 280 000 tons of methane were released from the abandoned mines. Similarly an incredibly large amount of methane is released into the atmosphere from the area of the former Ruhr Basin (Germany) which has been practically closed down.

In 1991 in the three mines in Wałbrzych there were 26 active shafts with a total depth of approx. 15 km and 16 active levels with the total length of workings amounting to 270 km. Moreover, in the mines there were several abandoned and unavailable levels.

Already in the middle of 1999 all Wałbrzych mines were completely closed down. The aim of the liquidation process is that the mines that had contributed to the economic development of the region should not become a burden after being closed down. The burden is associated not only with the commonly known problem of mining damages but also with such newly recognized phenomena as the increased emission of methane and carbon dioxide or the changes in water conditions caused by the increased level of underground waters. In order to bring back the previous beauty of the Wałbrzych's landscape, all heaps and storage yards of waste must be reclaimed.

Basic methods of shaft liquidation in Poland.

The rules applied to the liquidation of mines or their sections are formulated by the Mining Law (Section X) which imposes several responsibilities onto the liquidators in the field of:

1. the protection of the deposit and the buildings on the surface with the consideration of public safety,
2. the safety of work conditions in the course of the liquidation activities, especially in the cases when such phenomena occur as water and methane hazards, squealers or rock outbursts.
3. the determination of a unit responsible for financing the damages that will occur after the liquidation of a mine,
4. filing all the materials concerning the underground and surface installations and buildings in liquidation, especially the mining maps, in accordance with the PN-84/G-09000/03 standard,
5. the preparation of suitable documents that will help the Poland's Chief Geologist qualify the unexploited sections of a deposit, if any.

The permanent and temporary liquidation of workings should be conducted on the basis of:

- detailed regulations of the Ministry of Mining and Power Industry on mine operating and deposit management in hard and brown coal underground mines– 1984.
- the Ministry instruction on the liquidation of unnecessary shafts – 1975 r..
- the accepted application for the shaft liquidation and the conditions included.

There are following basic techniques of the liquidation of workings:

1. filling them with fine-grained rock (unsorted) – applied in shafts with an insignificant inflow of water,
2. filling the working with coarse-grained rock (16 – 40 mm) – applied in the case of an inflow of water into the shaft and the necessity to protect the neighbouring workings against water hazard,
3. backfilling with concrete-like materials, water-fly ash mixtures including, which have binding properties – applied mainly in the case when there is a necessity to backfill tightly, for example, a non-reinforced ladder compartment (together with shields and landings),
4. filling the working with rock and closing it with a tight reinforced concrete panel with a manhole,
5. closing the shaft without filling the shaft column – applied to small winzes at big depths,
6. flooding the shafts.

As a rule, the most correct and safe liquidation of a shaft consists in designing a multilayer shaft fill which serves several functions; one of the most important functions is to guarantee the stability of the lining.

Liquidation of a shaft by filling

Considering the safety of a shaft column and its immediate neighbourhood, the liquidation of a shaft by filling it with a rock material is the most efficient method. However, in order to carry out a correct liquidation by filling, several conditions must be fulfilled. Otherwise, a major catastrophe may happen. The greatest hazard to the shafts of mines that are liquidated by flooding is constituted by gradual filling of the shaft column with water. The change of the wetness of the rock material may result in its liquefaction. As a result the hydrostatic pressure increases by several times, which may cause the destruction of stanks and the escape of the material to the workings adjacent to the shaft. Thus, the section of the shaft column which has not been filled may become a gas reservoir or a well that will gradually be filled causing rock slides around the shaft. The unfilled shaft II in the Kirklees mine (UK) collapsed in 1955, which resulted in the formation of a crater that was 80 m in diameter and into which several buildings and constructions were pushed down from the surface (Gregory, 1982). Similarly, the Dobrava shaft in the Ostrava Basin (the Czech Republic) has collapsed causing much damage on the surface. When designing a liquidation by filling one should analyze thoroughly the behaviour of the filling material in various conditions.

The paper presents the latest trends in designing shaft liquidations by filling with rock material.

General remarks

Proper liquidation of a shaft consists first of all in filling it in such a way that the shaft does not become a reservoir of water or gas, the movement along the shaft fill of these media is made impossible and the stability of the shaft lining is ensured both in the course of the liquidation process and a long time afterwards. These conditions can be met only when the shaft fill has been given proper constructional parameters.

In the last few years dozens of shafts have been closed down in Poland, which resulted in gaining considerable experience, either positive or negative in nature. It is required by the Polish mining law that all horizontal workings running from the shafts that are to be liquidated must have stanks and resistant and non-combustible shaft plugs. Their purpose is to stop the outflow of gases from the workings to the shaft column and to protect the shaft fill from sliding into the workings of the shaft bottom. If they are to be water- and gas-tight, a very costly separate ventilation must be provided in the course of the building activities.

The requirement of constructing a shaft plug in accordance with the Polish design standards (PN-G-05019: 1997) that would be sufficiently resistant to the hydrostatic pressure (of the liquefied fill) valued at $p = \gamma^{*}Z$, where Z is the depth of the shaft, will result in the fact that at greater depths the shaft plug will be a highly complicated and expensive structure to be constructed underground (Czaja et all., 2002).

Having taken into consideration the fact that some shafts have several connections with the workings, e.g. the "Lompa" shaft in the Rozbark hard coal mine in liquidation had 17 entries to the levels – and the majority of them were two-sided (Czaja, 1999) – one must conclude that it is not feasible to construct expensive shaft plugs. One should rather consider the application of such solutions of a shaft fill that would ensure its stability without the necessity to construct shaft plugs at the entries. Such a solution has been presented in this paper.

The structure and parameters of the shaft fill

Contrary to common belief, the shaft that has been closed down cannot serve as a storage site for superfluous and troublesome materials. The shaft fill is a construction whose function is to:

a) exert horizontal pressure permanently onto the shaft lining,
b) seal off the underground workings from the surface,
c) stop the migration of water between the water-bearing strata,
d) make it impossible for mine gases, such as methane and carbon dioxide to come up to the surface.

In order to meet these conditions the structure must be durable, stable and water- and gas-tight. Thus, the shaft fill should consist of several typical elements:

a) hardcore or hardcore free draining plugs which constitute a load-carrying element of the remaining part of the shaft fill,
b) insulation plugs over and under the shaft bottom that would make the movement of water and gases along the shaft column impossible,
c) concrete shaft plugs introduced in places where the shaft lining has been weakened,
d) stone-concrete layers to protect the shaft plugs from silty fractions entering them from the overlaying strata of the shaft fill,
e) filtration layers over the insulation shaft plugs that enable the intake of the water coming from the upper parts of the shaft fill,
f) sections that can be filled with any non-toxic rock material,
g) a suitably constructed and equipped carcass panel that finally secures the shaft top.

The efficiency of the shaft fill depends entirely on the stability of shaft plugs formed in the entries to shaft bottoms.

The parameters and stability of the shaft plugs formed by an autogenous talus

In the phase of formation the shaft plug formed by an autogenous talus will have a shape of a pile with its lateral surface inclined like a natural slope. If the rock material fills the shaft column over the entry to the shaft bottom at the length bigger than approximately eight shaft diameters, the vertical pressure p_z in the horizontal plane at the height of the entry will be given by the Jansen formula (for significant depths) (NCB, 1982):

$$p_z = \frac{k_2 \gamma F}{fU} \tag{1}$$

where:

γ - weight by volume of the filling material, kN/m^3,
F - surface of the shaft cross-section, m^2,
U - shaft perimeter in the clear of the lining, m,
f - friction factor between the filling material and the shaft lining,
k_2 - vertical to horizontal pressure ratio, acc. to Koenen :

$$k_2 = \frac{1}{\lambda}$$

in which λ is the horizontal pressure factor given by:

$$\lambda = tg^2(45 - \frac{\phi}{2}) \qquad (2)$$

where : ϕ is the internal fraction angle of the filling material .

If one knows the value of the vertical pressure in the shaft fill in the plane of the roof of the shaft bottom entry, the value of the lateral pressure at the depths *Z* and *Z+h* can be defined as:

$$p_{x1} = p_z \cdot \lambda \qquad (3)$$

$$p_{x2} = (p_z + \gamma h)\lambda \qquad (4)$$

In order to determine the length of the slope of the breakstone pile whose friction against the floor and the walls compensates the lateral pressure of the rock at the entry, a simplified analysis of a computational scheme (presented in fig.1) was carried out.

Assuming that the value of the static friction of the rock pile is T_1, and the value of its friction against the floor - T_2, the condition of equilibrium will be given as:

$$P_x = T_1 + 2T_2 \qquad (5)$$

where:

P_x -the value of the total breakstone pression at the surface of the entry.

For a working with the average width *s*, the average value of pression P_x will be given by:

$$P_x = \frac{p_{x1} + p_{x2}}{2} s \cdot h \qquad (6)$$

Similarly the friction of the rock material against the floor and the walls will be determined in a simplified way by the formulae:

$$T_1 = \frac{s \cdot l \cdot h}{2} \cdot \gamma \cdot f_s \qquad (7)$$

$$T_2 = \frac{\gamma \cdot h^2 \cdot \lambda \cdot l \cdot f_s}{4} \qquad (8)$$

The value of the pression P_x equals:

$$P_x = \frac{(2p_z + \gamma \cdot h)}{2} \lambda \cdot s \cdot h \qquad (9)$$

Having introduced (7), (8) i (9) to the equation of equilibrium (5), after reductions a formula for a minimum length *l* of the slope in the shaft bottom that would ensure the equilibrium of the shaft plug has been obtained:

$$l = \frac{(2p_z + \gamma h)\lambda \cdot s}{\gamma \cdot f_s (s + h \cdot \lambda)} \qquad (10)$$

It can be concluded from the formula (10) that the length *l* of the slope will reach a value that will depend– apart from the size of the working – on the vertical pressure in the shaft column p_z, the horizontal pressure factor λ that depends only on the angle of the rock internal friction ϕ and the coefficient of friction of the breakstone against the floor and the walls f_s. The equation of equilibrium (5) does not take into consideration the resistance forces given by the planes of the inclined parts of the entry and the vertical walls of the basement in the shaft bottom. Most probably it is due to these forces that such shaft plugs, despite the stability factor equalling one, still play their role after the static force system in the liquidated shaft has been changed. An attempt to force in breakstone plugs into narrowing workings results in the formation of an artificial rock vault (fig. 2) which resists successfully the pressure of the breakstone from the shaft column.

It is obvious that the introduction of a fine-grained material (of sand or clay) into the structure of the shaft plug is unacceptable. However, the increase of the grain diameter improves the load capacity of the shaft plug for two reasons:

a) the increase of the natural coarseness of the potential sliding surfaces,
b) the decrease of the impact of humidity (of the watering of the shaft plug) on the value of the friction factor f_s and the angle of the internal friction ϕ.

Shaft plugs aggregated with concrete

The shape and the size of the breakstone shaft plugs in the shaft bottoms which are formed by an autogenous talus result from the condition of equilibrium (6). In this situation the factor of safety of such a structure equals one. A slight change in the geotechnical properties of the material that constitutes the shaft fill must lead to a change in the original geometry of the shaft plugs, i.e. the slopes in the shaft bottom workings will be lengthened. In this case, flowing away of the filling material to the shaft bottom workings can be prevented by an additional portion of breakstone accumulated in the shaft column over the entry. To achieve this, the height of the shaft plug measured from the roof of the highest entry is significantly increased.

The common practice is that when designing a shaft fill it is a rule that the height of the shaft plug over the entry must be at least five times the diameter of the shaft in liquidation. Thus the increase of the vertical pressure over the shaft plug or the decrease of its load capacity – e.g. due to watering – should not result in the movement of the material from over the shaft plug to the horizontal workings.

A problem arises how the factor of the stability of the shaft fill can be increased immediately after it has been Constructed so that the construction of a shaft bottom in the working will be unnecessary. A partial aggregation of the breakstone shaft plug with the application of concrete seems to be one of the simplest ways to deal with this problem.

In the area of the shaft bottom entry a sealed stratified load carrying section should be constructed as in fig. 3. After the concrete has set and hardened, the aggregated laminar structure will significantly increase the shear strength of the breakstone pile in the horizontal plane. The application of a high-early strength cement (with the R symbol) ensures the strength of up to 15 MPa already two days after the preparation of the mix

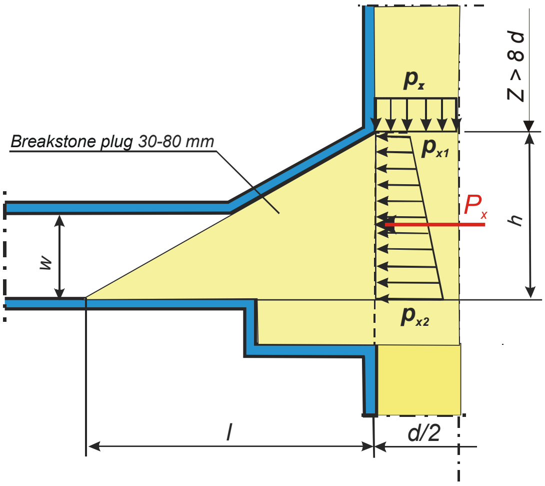

Fig. 1. Computational diagram applied to determine the slope length of the shaft plugs

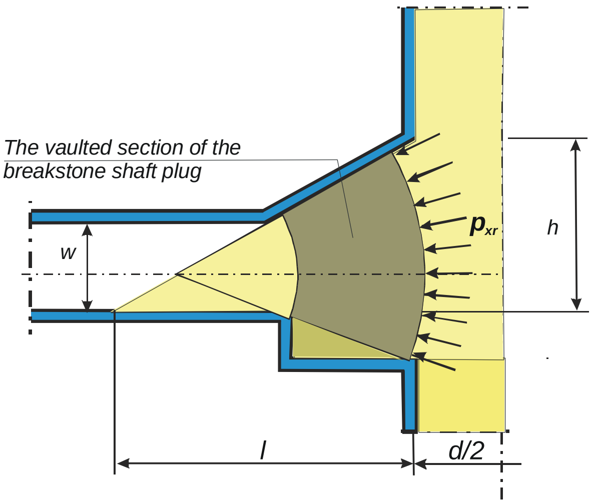

Fig. 2. Hypothetical artificial vault in the shaft plugs

As the volume of the shaft plugs may be even several hundred cubic meters, their construction must be planned in time carefully so that the results are as advantageous as possible. It is vital that in the course of building such a structure there is a technical possibility to lower the components freely from the shaft top. There are two important factors in the presented technology: the volume of the layers must be precisely determined and the consistence of the concrete mix must be carefully selected.

All the considerations indicate that the breakstone shaft plugs that have been aggregated with concrete in layers will have significantly higher load capacity than typical shaft plugs since:

- the grain diameter of the rock material will increase locally, and in some sections loose breakstone will aggregate into big-size blocks which will substantially improve the stability of the shaft plug (and such blocks cannot be introduced from the top of the shaft due to the safety of the structure),
- the introduction of layers of a set concrete formed at the sides of taluses to the pile of breakstone will result in their stabilisation,
- the binding of the pile of the aggregate with the reinforcement of the shaft by means of the layers of concrete will constitute an element of additional stability of the shaft plug.

The formation of shaft plugs that are aggregated with concrete that are combined with each other through the structure of the shaft reinforcement which is fixed to the shaft lining constitutes a spatial load-bearing structure and its removal from the shaft column will be unlikely.

The aggregation with concrete should be continued until the fill reaches the roof of the shaft bottom entry at the height *h* equal at least to the distance between the main girders of the reinforcement (compare fig. 3).

The additional advantage of this solution is the water- and gas-permeability of the plug until the formation of the stone-concrete and clay plugs. Thus the run-off of the water that dribbles along shaft lining and the flow of some ventilation air is made possible, which is vital in gasified mines.

As the concrete mix may constitute up to 20% of the volume of the plug that has been aggregated, doubts may arise concerning the increase of the construction costs. Nevertheless it can be stated that the difference of costs between a partially aggregated shaft plug and a common one will never exceed the construction costs of stoppings in shaft bottoms.

The issue requires further investigation into several problems concerning the technologies applied when constructing the aggregated plugs, the monitoring of the plug formation, the determination of the influence of water on the formation process and the strengths obtained after the setting of the cement.

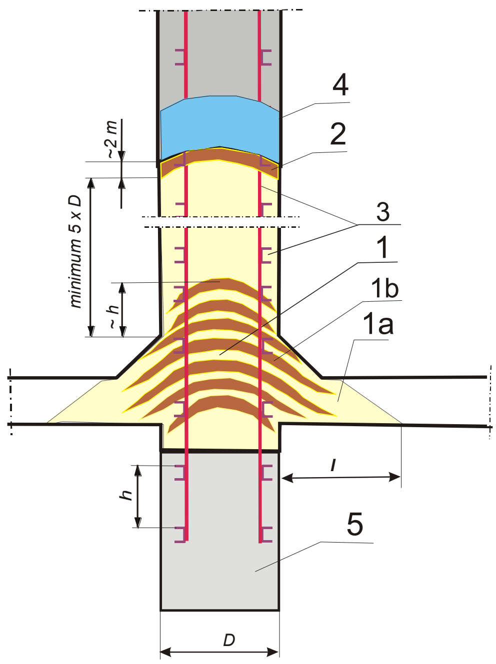

Fig. 3. Scheme of a shaft plug aggregated with concrete
1 – hardcore or hardcore free draining plug, 1a –gallery section of the plug, 1b – shaft section of the plug, 2 – stone-concrete layer that protects the plug from the clay material, 3 – structure of the shaft reinforcement, 4 – clay insulation plug, 5 – unsorted rock material

Conclusions

The suggested solution is a logical and realistic set of technological procedures that make the liquidation of shafts easier. The expanding and laminar structure of the concrete panels which is fixed to the shaft reinforcement will play the identical role as the one played by a root system which helps a tree to stand vertically despite strong winds. It is a significant force which is also visible when exerted in the other direction . A tree which is blown down by a hurricane loosens through its roots an immense lump of ground. In the same way the shaft reinforcement – through a network of concrete panels submerged in the stone pile – will protect it from falling away into the shaft bottom workings.

However, many aspects of this problem require further theoretical studies and laboratory, model and numerical research investigations. In situ research on a particular shaft to be closed down would be a valuable experience. This, however - due to a complete inaccessibility of the place where plugs are constructed - can be done only by a remote control system of cameras that have been prepared and suitably installed underground well in advance.

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