Liquidation of shafts’ workings with the use of the mobile installation

Piotr Pierzyna
Faculty of Mining and Geology, Silesian University of Technology, Akademicka 2, 44-100 Gliwice, Poland
piotr.pierzyna@polsl.pl

Abstract. Liquidation of unnecessary shafts and associated shaft workings is dictated by the assurance of broadly understood security. In Poland, the most common method of liquidation shafts is filling them with various types of materials. The technology of shaft decommissioning and the selection of fill materials depend primarily on the condition of the excavation and its equipment, existing connections with horizontal excavations and the degree of water and gas hazard. Properly selected materials and technology must ensure the stability of the liquidated shaft in a long time horizon. A common solution applied in the Polish mining industry is filling the shaft with mine stone or other rock material combined with its washing with ash-water mixtures or with interlayer of concrete layer in order to stabilize the whole charge. The article presents the benefits resulted from the possibility of using a mobile installation in the process of the liquidation the shaft’s excavation.

1. Introduction
Mine shafts are the most important excavations allowing the exploitation of useful minerals accumulated in the Earth's crust. Shaft workings accompanying the shaft perform auxiliary technological functions. These workings, after the planned period of activity, require effective liquidation. The necessity of liquidation of unnecessary shafts and shaft workings is dictated by ensuring safety for:

- people
- active mining excavations,
- the area of land and the infrastructure located on it,
- vegetable crops including trees.

Work related to the liquidation of shafts includes, among others:

- inventory of the liquidated facility,
- selection of materials for the construction of the charging tower and protection of inlets,
- organization of the shaft backfilling process including ventilation, dehydration and gas hazard control,
- protection against unauthorized access,
- preparation and maintenance of documentation of the conducted process.

The following types of materials may be considered for the construction of the shaft's bollard and for the protection of its inlets:

a) waste [1, 2]:

- gangue coming directly from mining works,
- postwashery stone from the coal enrichment process,
2. The methods of shaft disposal the most frequently used in Polish mining

The most effective and safe method of removing shafts and the most commonly used ones in Poland is filling them up. The method of feeding the material to the shaft can be done by means of a dozer, directly from the tipping dumps via a chute, by means of a conveyor or special pipelines [1, 2].

Liquidation of mining excavations, especially shafts, is an issue that is particularly complex in the conditions of existing water and gas hazards. The method of shaft decommissioning and the choice of charging material depend primarily on the condition of the excavation and its equipment, existing connections with horizontal excavations and the degree of water and gas hazard. In the case of liquidation of a shaft partially filled with water, the selection of the correct type of charging material is of basic importance. Under such conditions, it should be assumed that the applied mixture filling the liquidated shaft should have the features of the construction material [4]. In addition, the charging material should have a hydrophobicity that will not allow it to be dispersed in the section of the shaft flooded with water (as during concreting under water).

The liquidation of shafts in coal mine Moszczenica can be an example of the liquidation of the shaft by backfilling it with a coal stone with additional washing of the inter-grain space with the ash slurry. The volume ratio of the scale to the ash mixture was 5:1. Assuming the volume density of the stone approximately 1800 kg/m³ and the volume density of the hydromixture 1450 kg/m³, the mass fraction of stone was about 84% and the ash suspension was 16%. In this case, the hydro-ash mixture, taking into account its binding properties, was to strengthen and seal the rock hopper, which would result in its good insulation for water and gases [5, 6].

However, the resulting material can be characterized by high heterogeneity, and thus a large variation of mechanical properties and tightness.

One of the very important sections of the liquidated shaft are its pit. Theoretical examples of protection of inlet pitches are presented in figure 1 [7, 1].

In practice, among others a patented solution for liquidation of the basin can be found, consisting in making a resistance-filtration plug made of crushed stone, which successively during its formation is layered with concrete. This solution is taken into account as a substitute for a concrete plug or a block dam built in the horizontal part of the pit. The plug thus produced (stabilized with concrete) is additionally connected to the shaft reinforcement [8, 9].

In the case of the above-mentioned solution, the monoblock construction of the plug structure with respect to the traditional concrete plug also neglects the concrete properties obtained after its discharge at the place of its construction (the problem of delamination, clinging of cement shaft equipment). Problems related to the quality of concrete resulting from its discharge can be eliminated by providing
it with a pipeline (injection), whose construction and maintenance (dropping of stone) is another problem increasing along with its length in the shaft.

Figure 1. Shaft insets protection [7, 1].

The most commonly used technology for liquidation shafts by filling them directly from dump trucks, that is, providing a large volume of material (in the order of 12-26 Mg, i.e. about 6-13 m$^3$ in 30-60 seconds), which is lowered throughout the cross-section, pulls with it more or less destructive impact on the shaft buildings, its equipment and installed pipelines, and in extreme cases, which Polish mining knows, can lead to an obstruction in it.

The process of destruction of the shaft and its equipment, caused by lowering the material through the entire cross-section, can be particularly dangerous when using uncontrolled granulation, in the volume of which there are large dimensions, which in extreme cases can cause cavities in its buildings (not to mention the possibility of complete destruction of equipment or pipelines), which in turn may lead to local loss of stability of the shaft pipe.
3. Mobile mixing unit

Many of the above can be minimized or even eliminated by using a mobile mixing unit (mobile installation). The scheme of an exemplary mobile mixing unit is shown in figure 2.

![Figure 2. The scheme of an exemplary mobile mixing unit [10].](image)

The mobile mixing unit consists of the following main elements:
- a charging hopper for aggregate,
- water tank,
- silo for the binder,
- flow mixer,
- power generator,
- boom with discharge bin.

Depending on the construction, mobile units can be equipped with one or two hoppers for aggregate (e.g. stone or gravel and sand). Units with two tanks enable the control of the aggregate composition at the place of application. It is a flexible solution that allows a quick change of the aggregate pile, and thus the modification of the material properties of the chute. The mobile mixing unit does not need to be connected. electricity or compressed air. The generator is powered by a diesel engine. Only the supply of water is required. However, it is possible to refuel it from the barrel. Thus, the mobile mixing unit is "self-sufficient", which is its huge advantage, in particular when there is no access to utilities in the vicinity of the liquidated shaft.

The main advantage of the mobile mixing unit used is the ability to work in a location determined by the Investor, eg in the immediate vicinity of the liquidated shaft, voids or the place of obtaining aggregates (eg mine stone) which is a component of the charging material. In addition, such a solution (mobile) is characterized by a very short time of preparation for the production of charging material and commencement of the liquidation of the shaft or some voids created on the surface as a result of underground exploitation, for example, a sink hopper. The short time of preparation for the application is a big advantage, especially in emergency situations, when it is necessary to proceed to liquidation of the emerging threat occurring for people and construction objects, e.g. some sinkhole, escaping the liquid in the vicinity of buildings, etc. Transport of the mobile unit mixing is carried out with a standard tractor unit, as illustrated in figure 3.
After arriving at the application site, the mobile unit is positioned and then unfolded. The silo for the binder is set to a vertical position and the outrigger with the island basket is removed - as in figure 1.

An example technological line for the production of a charging material, which includes a mobile mixing unit, can consist of the following basic elements (figure 3):

- aggregate storage,
- equipment,
- screening,
- conveyor,
- mobile mixing unit,
- unloading station for the adhesive,
- the conveyor.

In the case of a distance of more than 3 m of the mixing unit from the place of application, e.g. a liquidated shaft (e.g. due to the designated safety zone), it is possible to install a conveyor belt - then it is necessary to install electricity. Electricity is required for the crusher-screen system. The technological line can function without a crusher and a screen in case a qualified aggregate will be delivered to the unit with the maximum grain size allowed for the given unit. It usually does not exceed 80 mm, but it is recommended and often used, e.g. in road construction, 63 mm.

The efficiency of this type of devices can reach up to 300 Mg/h. However, if the aggregate is not qualified in the technological process, due to the machine's safety and trouble-free operation, there must be a screen and/or crusher. It will guarantee obtaining aggregates with the required grain size due to the technical capabilities of the unit.

For the so-designed technological sequence, the required working area is around 500 m². Aggregate, for example, mine stone is delivered to the shaft yard by a car-type transport by means of a "bathtub" and stored in the form of a prism. From the prism, the aggregate is fed to the hopper feeder (qualified aggregate) or to the crusher-screening plant (unqualified aggregate) using a bucket loader. In the case of using the crusher-screening system, the material is fed back to the charging hopper of the bucket by means of the conveyor or the bucket charger again. On the other hand, the binder, for example cement, is delivered to the shaft yard with cement wagons and discharged to the silo located in the mobile mixing unit by means of compressed air. Next, the components of the charging material (aggregate, binder and water) in a precisely defined weight ratio are dispensed to the flow mixer under the silo. The dosing process (weightings) of individual components of the mixture is fully automated (electronic system of bearing weights). From the mixer, the ready mixture of the outrigger ending with the island basket is fed to the conveyor belt and further directed to the place of application, i.e. the liquidated shaft.

Figure 3. Transport of the mobile unit mixing [10].
This way of preparing the hopper material guarantees its homogeneity, and hence its high quality. Uniformity of the material ensures its constant physical parameters (e.g. density, setting time, compressibility, strength, water permeability). In comparison to the previously presented solution for the liquidation of the shaft through its backfill with rinse washed with ash and water mixtures with the possible addition of cement, the charging material obtained on the mobile unit is homogeneous and allows the construction of a charging monoblock. In addition, to wash the stone with a fine-grained mixture (ash, cement) and water, a consistency with high fluidity is required, which entails costs in the form of e.g. plasticizer addition and / or increased water quantity. Adding a plasticizer even in a considerable amount may not provide adequate fluidity of the material. It is then necessary to increase the proportion of water, which entails an increased amount of cement to obtain appropriate strength parameters of the charging material. In addition, it may be necessary to add a binding accelerator for faster consolidation of the washed stone with a fine-grained mixture, for example to shorten the time of material pressure on plugs in the pitchers, and thus accelerate the technological process. In contrast, the material produced on the mobile unit is homogeneous and can have a densely plastic consistency, which will undoubtedly affect the economy of the venture (e.g. a smaller proportion of plasticizer, accelerator or lack thereof, a smaller proportion of cement). It is well known that increasing the proportion of water in cement-based materials decreases their strength parameters. In addition, a bulk material with a densely plastic consistency will certainly cause less pressure on the plugs in the pitchers than the one described above (liquid fine-fraction mixture).

As it has been previously described, in Poland the most common technology for the liquidation of shafts is their backfilling carried out directly with rock material from transport vehicles. It has more or less destructive influence on the buildings, equipment such as pipelines for demethaning or dewatering located in the liquidated glass. In an extreme case, it can lead to a congestion in it. The only benefit resulting from the discharge of material mass up to 25 Mg is the so-called "Piston effect" causing the suction of air into the shaft. This effect is desired in the case of methane hazard involving the liquidated shaft. In this case, it should be borne in mind that the rock material discharged absolutely cannot cause sparks. The liquidated shaft in which there is a methane hazard should be subjected to demethanization by means of a pipeline, the maintenance of which is very problematic when using the above-described "dump" technology. In the case of charging material with a mobile unit, there is a constant and small stream of material leaving the incomplete cross-section of the shaft, in contrast to dump from dump trucks (one-off large volume of material moving across the whole section in the shaft). Such a solution potentially excludes the possibility of blockages in the filled shaft, as well as minimizes damage to the buildings or shaft equipment, e.g. methane drainage pipeline. Taking the efficiency of the unit at the level of 300 Mg/h, the stream of the dropping material is about 2.8 m$^3$/min. In addition, the charging material, due to the technical requirements of the mobile unit, has a maximum grain size of up to 80 mm.

A big advantage of using a mobile mixing unit is its flexibility related to the possibility of current modification of the charging material parameters by changing the amount of binder added, e.g. cement or consistency regulated by the amount of water added. The possibilities related to the modification of the binder itself as well as granulation of aggregates, which are obviously possible, have not been omitted, however, they do not result from the possibilities of the mobile unit itself.

4. Summary
The use of a mobile mixing unit for applications related to the liquidation of shafts or voids created on the surface as a result of underground exploitation ensures:

- homogeneity and consistent quality of the composition in the whole volume of the hopper produced therefrom, which allows the construction of monoblocks, particularly important - even required - on sections of the liquidated shafts bottoms,
- precise dosing of individual components of the charging material,
- strict control of physical parameters of the produced material,
- feeding the mixture with a solid and small stream, which reduces the risk of blockage in the shaft,
minimizing the destructive impact of the charging material on the housing and equipment of the liquidated shaft, eg methane drainage pipelines,

flexibility related to the possibility of current modification of the charging material parameters

short time of preparation for the production of charging material and the start of its application, particularly important during emergency situations, when there is a need for immediate action to protect a building object, and thus the safety of human life,

production of bulk material at the place of application (eg at the shaft) or at the place of storage of the raw material depending on the needs and possibilities of the Investor,

no need to provide utilities - "self-sufficiency" - the ability to work anywhere in the application.

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