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Sinkhole hazard assessment in the area of abandoned mining shaft basing on microgravity survey and modelling — Case study from the Upper Silesia Coal Basin in Poland

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ABSTRACT

The article describes the results of a gravimetric survey conducted in the area of an abandoned mining shaft located on the premises of the liquidated "*Porąbka-Klimontów*" coal mine in Sosnowiec — southern Poland. After cessation of its exploitation in the past, the shaft has probably only been protected by placing a slab on a concrete pit-bank without commencing the proper liquidation. The aim of the survey was to determine whether the shaft had been backfilled and what is the condition of the rock mass where it gets in contact with the shaft barrel. In the interpretation of the Bouguer anomaly map, a forward modelling of gravity effect generated by an empty mineshaft has been used in order to eliminate its influence on the local gravitational field. That approach to survey data analysis allowed to assess not only the type of the shaft's filling but also the changes in the rock mass structure around it. The results allowed planning an adequate type of works aiming to secure the surface from potential sinkhole deformations resulting from the shaft lining collapse or wash out of the soil into the shaft barrel.

1. Introduction

Underground mining of raw materials causes permanent transformation of the near surface geological environment. That kind of transformation is a source of rock mass movement hazards which may appear even many years after the cessation of mining activity. The magnitude of the risk depends in inverse proportion on the depth of the performed exploitation and it is usually significant for mining activities performed between the surface and the depth ranging from some to 100 m. (Kotyrba, 2005; Kotyrba et al., 2006; Didier et al., 2008). Many cities in Europe and in the World have been built in the areas of former metal ores, coal or salt mines. Therefore, the post-mining surface movements put at risk human safety and can lead to structural damage of the buildings and underground infrastructure networks such as water supplies, sewage and gas systems. In the surveys aiming to recognise underground mining objects, mainly the galleries and post-mining voids, various geophysical methods can be applied (McCann et al., 1989; Fajklewicz, 1990; Anderson et al., 1998; Kotyrba et al., 2006). Their effectiveness in recognising the post-mining underground structures depends on the local geology and on the possibility of performing the surveys which would be methodically appropriate within the existing land-use on the terrain surface.

The abandoned mine shafts are one of the elements of mining infrastructure left in the geological environment after the liquidation of mines which pose a risk of rock mass stability loss around them (Chudek et al., 1988; Goszcz et al., 1991; Kotyrba, 2005). The hazard quantified by the size of potential consequences is the highest in case of the shafts which have not been backfilled. It is because of the relatively large capacity of the cavern in the shaft barrel. The soil and material from underlying strata in the geological layers surrounding the shaft may be shifted by different means towards the shaft barrel. The result of stability loss of the strata is non-continuous sinkhole type deformations emerging on the surface. Sinkholes may be of different sizes depending on the local geological structure and the hydrogeological conditions. In the geological structure the most important factors which influence the size of the potential deformation are the type of soil — loose or cohesive and the thickness of the deposits placed on the firm, rocky bedrock. Hydrogeological conditions are defined by the presence or absence of water around the caprock and by the rock fracturing and cavernosity. The surface deformations in the form of circular-elliptical sinkholes, may reach sizes from few to several metres horizontally and vertically (Goszcz et al., 1991). In cases where the continuity of the shaft walls, i.e. the rock mass or the shaft lining, is disarranged the deformations appear in the area around the shaft in the places from which the soil is transferred into the shaft (Fajklewicz et al., 2009). Therefore, in the survey aiming to assess the hazard to the surface around the shaft, it is important to evaluate the character of the rock mass where it gets in contact with the shaft barrel. The

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crucial point is where the shaft barrel passes through the non-rocky soils as sands or clays and through defragmented, weathered rock strata. In case of the non-rocky soils, it is important to determine whether their structure and properties have undergone a metamorphosis. In case of more stiff rocky strata, it is important to assess whether their natural continuity and coherence have been disarranged, as it could result in their defragmentation caused by the fissures and caverns. The defragmentation results in the creation of a rubble in the rock mass which may fall into the shaft barrel.

All the structural elements mentioned above diversify the bulk density of the subsurface geological layers and therefore influence the shape and the amplitude of the local gravitational field. The shaft itself, and in particular the void in the shaft barrel causes the most distinctive anomaly in the gravitational field. It allows one to use the gravimetric method for detecting the voids and in particular for locating the old mine shafts only covered with the slab and the ground material, by performing the superficial surveys (Fajklewicz, 2007; Styles et al., 2005). Therefore, in order to evaluate the diversification of the bulk density of the rock mass outside the shaft on the basis of the distribution of the gravitational field, it is necessary to separate its influence on the survey values and the represented field. This can be done by means of modelling of the theoretical gravimetric effect over the shaft with set geometry and by subtracting these values from the survey values. It is necessary to conduct a number of modelling tests in order to obtain an adequate level of theoretical data match with the survey results. An example and a result of such procedure are presented for the survey conducted in the area of the mine shaft located in Sosnowiec, Silesian voivodeship in southern Poland, marked in the geological documentation of the locked coal mine "*Porąbka-Klimontów*" with number IV. The mine was operating recently in the years 1974–2000 in the north-eastern part of the Upper Silesian Coal Basin (USCB). Much earlier, numerous smaller mines were operating within the area of the mining concession since the 19th century. The tested shaft is a remnant of those earlier mines.

2. Characteristics of the survey area

Shaft IV was sunken in the area currently occupied by the allotment gardens in Sosnowiec-Dańdówka, located in the northern part of USCB (Fig. 1). According to mining files its depth is 75.2 m. On the archive maps which are not presented here due to the low quality of the source material, the horizontal intersection of the shaft forms a circle with a diameter of around 3 m. The mine records of the excavations connected with the surface contain no information about the shaft liquidation method. The shaft was probably only covered with a concrete slab protecting it's barrel from unauthorised persons in the 1930s.

On the basis of the observations conducted with a borehole camera after the gravimetric survey had been finished, it is known that the shaft's lining was made of timber which decayed and fell down to the shaft's bottom. The concrete pit-bank of the shaft was founded directly on the top of compact carboniferous rock. At the moment of survey, at its entry, there was a concrete structure in a form of irregular polyhedron with a diameter varying from 4 to 5 m. In the over-ground part of the concrete pithead, from the southern and south-eastern side two quasi vertical, a few centimetres wide fissures were visible. Their presence suggests defragmentation of the pithead (Fig. 2). It is very plausible that in the past the shaft entry was only protected from bystanders for safety reasons and its re-use was planned in the future.

The geology of the test site is characterised by the occurrence of the Quaternary and Carboniferous sediments. The Quaternary overlay consists of sands and loamy sands which are approximately 4 m thick. Underneath lies Carboniferous strata, in stratigraphy of USCB named *rudzkie* beds. These sediments are stratified and represented by sandstones, mudstones and shales. Below them, at the depth of approximately 68 m, lays '510' coal seam which is approximately 7 m thick. The shaft has been hollowed in the past for the exploitation of this specific coal seam.

The geological structure at the shaft location and vertical log of the strata are presented in Fig. 3. The edge of the mining exploitation runs approximately 20 m north-east from the shaft. The '510' coal seam was exploited with a hydraulic stowage system in the years 1919–1933. The parametric description of shaft IV can be found in the data base: *Inventory control of the mining entries connected with the surface, located in the area of the abandoned mines of Zagłębie Dąbrowskie*, under the following ID symbols: ID = 500, number of the shaft: 4.268 (WUG, 2014).

The gravimetric survey was conducted in the area of approximately 2500 m^2. The ground surface is rather flat, lowering a little towards the north. That subsided area indirectly indicates that the underground coal

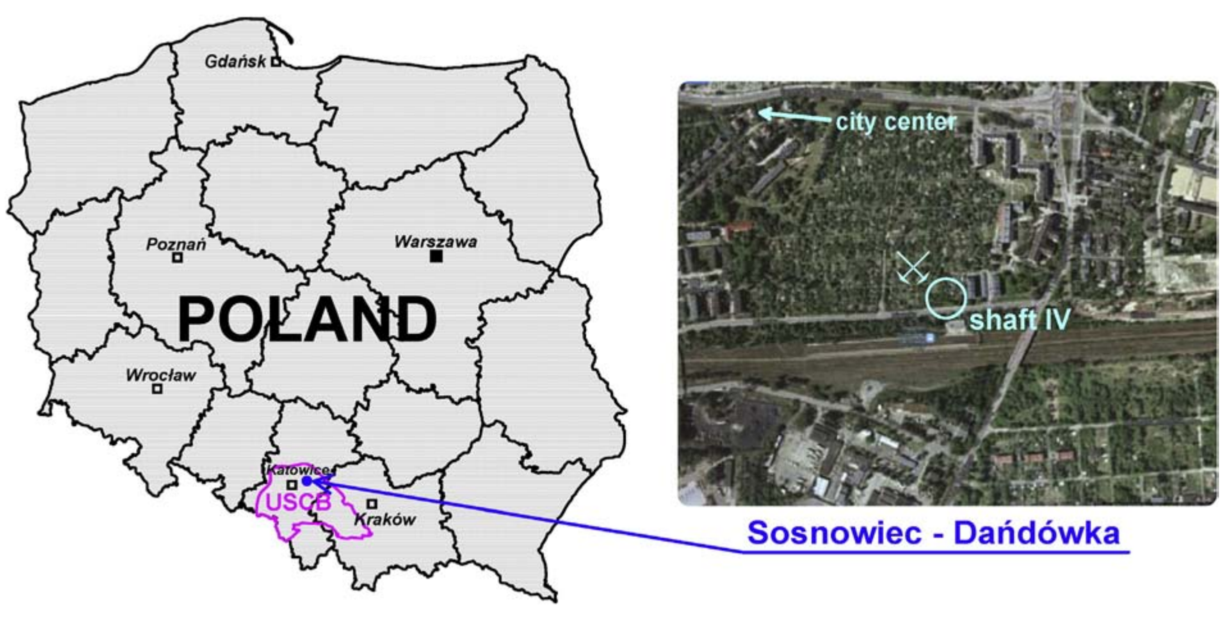

Fig. 1. Survey location on a schematic map of Poland and on a satellite image (source: GoogleEarth) of the southern part of the city Sosnowiec.