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Geophysical investigations on discontinuous deformations recognition

Key words

Mining, environmental impact, discontinuous deformation, geophysical methods

Abstract

In Poland, in some sites of mining Zn-Pb/Fe ore and hard coal, the shallow exploitation caused discontinuous deformations on the surface. The complicated geological and mining conditions create difficulties in describing the mechanisms of forming and propagating the deformations. In such conditions the geophysical methods are useful for recognizing the anomalies in rock mass and for predicting its development. Some of them like gravimetric, resistivity, ground penetrating radar and seismic are the most applicable. This work gives also some basic remarks on advantages and limitations of geophysical methods related with recognition of discontinuous deformation causes.

Introduction

In Poland, the process of mining transformation puts also stress on making inventory in environment. One of the needs is to determine a potential of mining sites suitable for building as well as to estimate the damages caused in environment. The shallow exploitation of Zn-Pb/Fe ore as well as hard coal caused a lot of problems with use of mining sites in the Upper Silesian Basin. The danger of discontinuous deformations, very difficult for detection and prediction, is one of the most serious obstacles against construction development in these sites.

The discontinuous deformations occur especially in the sites of exploitation, which was performed from several ages. For example, in the region of Bytom–Tarnowskie Góry that is really endangered by discontinuous deformations, the exploitation began in XII century

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(Pilecki 2003). Depending on geological and mining conditions the discontinuous deformations can take place in a different way. This implies a different descriptions and classifications of the danger. More detailed explanations of the influence of the exploitation on the objects situated on the surface in Upper Silesian Basin can be found in the monograph edited by Kwiatek (1997).

The different methods of the detection, as well as limitation and liquidation of this danger have been elaborated. In plenty of cases, geophysical methods are used for location and occurrence prediction of discontinuous deformations. One can assume, the most effective methods are gravimetric, seismic, resistivity and ground penetrating radar (GPR). The geophysical logging methods are helpful when site investigation is supported by exploratory wells. Other methods like magnetic, geothermic or radon have not been used wider in Polish mining sites conditions.

Experiences related to the observations of discontinuous deformations over the shallow exploitation let to formulate the classification of the mining sites. The basic criteria are the dimensions of expected deformations. Such approach appears helpful for the assessment of the danger of the surface and objects as well as for the effective construction planning and their protection. Popiolek and Ostrowski (Popiołek, Ostrowski 1999) described general rules of formulation of this kind of classification. The most popular, for Polish mining conditions, is the general classification proposed by Chudek and Janusz (Chudek et al. 1988). The classifications determine the usability of geophysical methods according to the category of mining site. The one of the aim of this paper is to present the ability of geophysical methods in the assessment of the sites endangered by discontinuous deformations.

1. The physical causes of arising of discontinuous deformations

Discontinuous deformations can rise as sinkholes, ground thresholds, cracks and subsidence plugs (Fig. 1), when geological and mining factors create appropriate conditions. Kwiatek (1997) widely discussed theoretical considerations connected with geomechanic processes that cause such deformations. The use of geophysical methods, in the Upper Silesian Basin geological conditions, was presented mainly by Fajklewicz (1986, 2001) Goszcz (1996) and Marcak (1999).

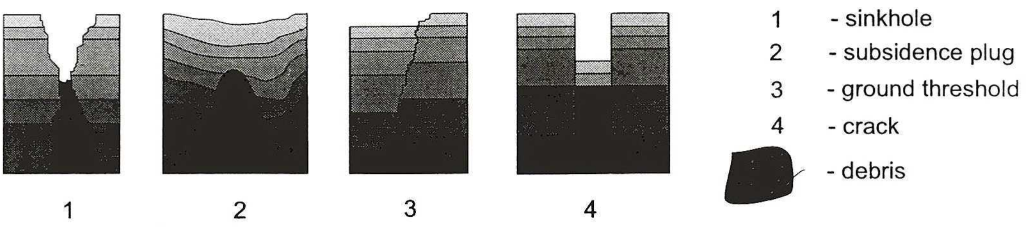

Fig. 1. The forms of discontinuous deformations observed in Upper Silesian Basin, Poland (Goszcz 1996)

Rys. 1. Typy deformacji nieciągłych obserwowanych na terenach Górnego Śląska (Goszcz 1996)

The most problems connected with disturbing the surface by discontinuous deformations are caused by the exploitation voids. Discontinuous deformations haven't occurred over each region of the shallow exploitation. The time and place of their occurrence are very hard to predict. The observed deformations had been occurring after the exploitation in a very short time as well as after a hundred and more years. The presence of voids in the rock mass creates permanent, undetermined danger of the surface. A lot of old, shallow workings are not documented on the existing maps.

The set of geological and mining factors decides about the type of the deformation and its dimension. Especially dangerous state takes place when the underground water infiltrates to the opening. Exploitation void can be filled with water. But if such void is drainaged as a result of the mining works performed closely, the suffusion process as well as the destructing process may begin. The water infiltration is a frequent cause of the reactivation of void in the rock mass. It is also related with the void, which is partly or fully filled with fine — grained, or clayey material. This material can be washed out as a result of water flow through the rock mass fractures. The washing out from the fractures can also cause fault activation and in consequence the formation of discontinuous deformations on the surface.

The mining running near old exploitation workings can reactivate the destruction process. Generally, the extension of the void takes place when a new exploitation is started in sufficient neighbouring vertical distance. The activation of void existing in the rock mass can also takes place as a result of mining tremors or blasting. The heavy motor traffic can also cause ground vibrations and void activation.

Generally, the causes of the formation of discontinuous deformations on the surface in the mining site can summarize as:

— the changes of hydrogeological conditions, related with water infiltration into the rock mass,

— the weakening of the rock mass properties as a result of weathering and reological processes,

— the loss of the lining's bearing in abandoned, shallow workings,

— dynamic loading caused by the traffic vibrations, mining tremors, blasting etc.,

— mining in the neighbourhood of void, which activates the destruction process in the rock mass

— the excessive static load of the ground,

— the occurrence of the fires in the remainders of shallow beds.

2. Geophysical testing for recognition of the void in the rock mass

2.1. Void geophysical model

Geophysical testing, considering the possibilities of the measurements and interpretation, requires distinct changes of physical properties in the rock mass. Geophysical recognition of the void is related also with surrounding fracture zone. Figure 2 illustrates the characteristic zones that create the geophysical model of the void. Zone I represents a void which is most often filled

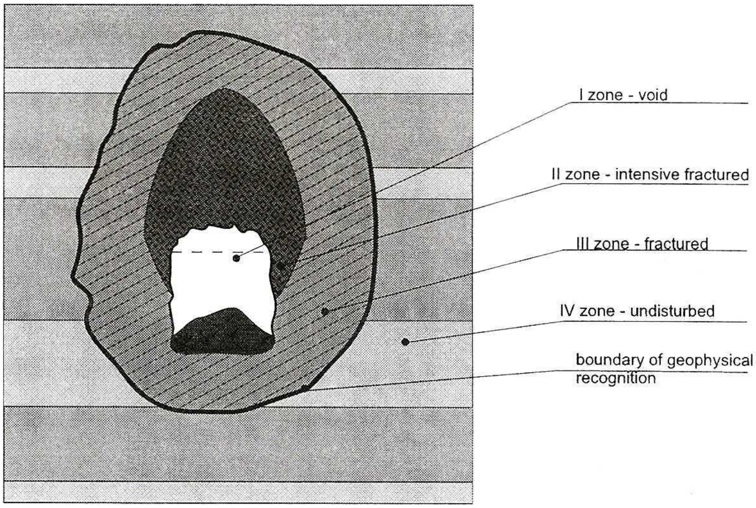

Fig. 2 Geophysical model of the void (on the basis of Marcak 1999)

Rys. 2. Model geofizyczny pustki (na podstawie Marcak 1999)

with water and debris originated mainly from the roof of destructed opening. The destruction process, which starts the "migration" of the void upper, extends in the zone II. Zone III is the characteristic fracture zone created as a result of the working performance. It extends due to weathering and rheological process. The boundary between zone III and IV describes the essential changes of physical properties between rock mass disturbed and undisturbed, and it is the boundary of geophysical recognition.

Generally, this boundary can't be determined explicitly, because of its temporary character related to the change of the fracture intensity. It influences the geophysical view of this zone. Generally, the fracture zones around the void cause the reduction of the seismic waves velocity, decrease material density and change of dielectric constant giving the anomalous effect in the geophysical field.

2.2. Gravimetric method

Gravimetric method lets to observe a void as a decomposition of the gravity level or its vertical gradient. The change of the void location and shape can observe basing on the periodical measurements of the microanomaly of the gravity (Chudek et al. 1988). In great simplification this method is based on the measurement of the changes of the gravity in the points located near the region endangered by the void occurrence. The measurements of the vertical gradient of gravity can be similar. Negative anomalies, occurring in the distribution of differential anomalies of gravity and vertical gradient show the occurrence of the void and surrounding zones of density changes (Fig. 3). Observations of the increases of these anomalies create the possibility of definition of the stage of void development as well as to determine the direction of its movement. Together with the depth increase the distribution of the method decrease.

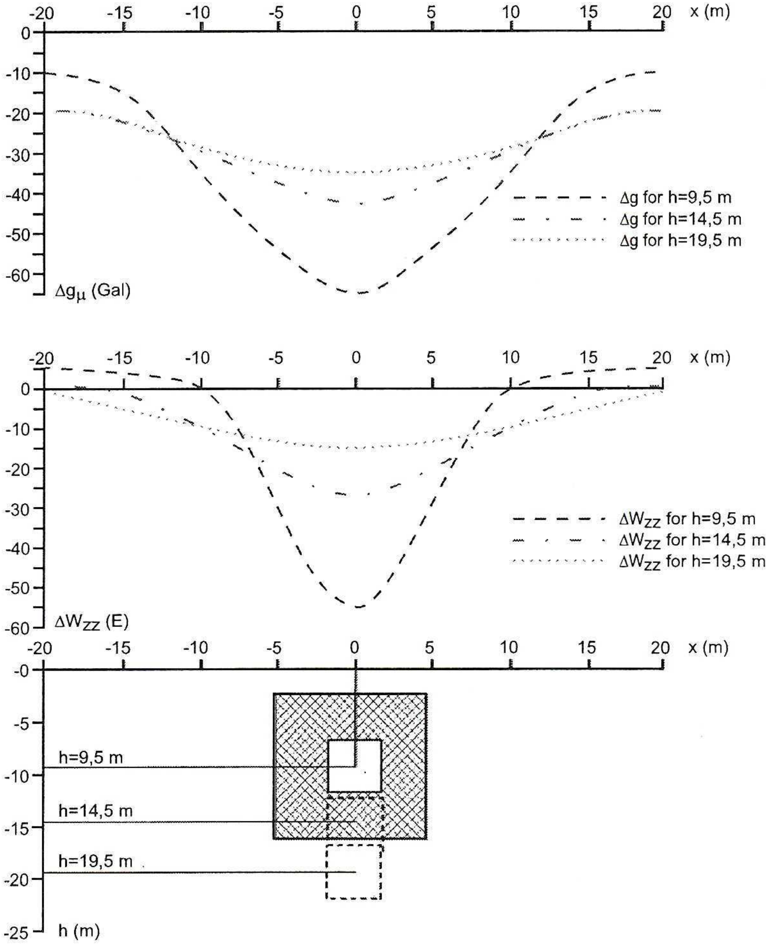

Fig. 3. Distribution of the microanomalies of the gravity and its vertical gradient in depth function h over the mining gallery of 4.5 m width (Chudek et al. 1988)

Rys. 3. Rozkład mikroanomalii grawimetrycznej i zmian jego gradientu z głębokością na wyrobiskiem o szerokości 4,5 (Chudek i in. 1988)

Increasing depth of the void occurrence causes the decrease of the value of anomaly, and the "flatten" of the distribution curve.

2.3. Seismic method

The seismic testing shows the presence of weak zones on the giving seismograms by the creation of diffraction waves, decrease the seismic waves velocity, attenuation or decay of the waves. The results are used to prepare the maps of distribution of velocities, modulus of elasticity or attenuation coefficient. More detailed location of the voids is performed by the use of seismic tomography technique (Kasina 1999).

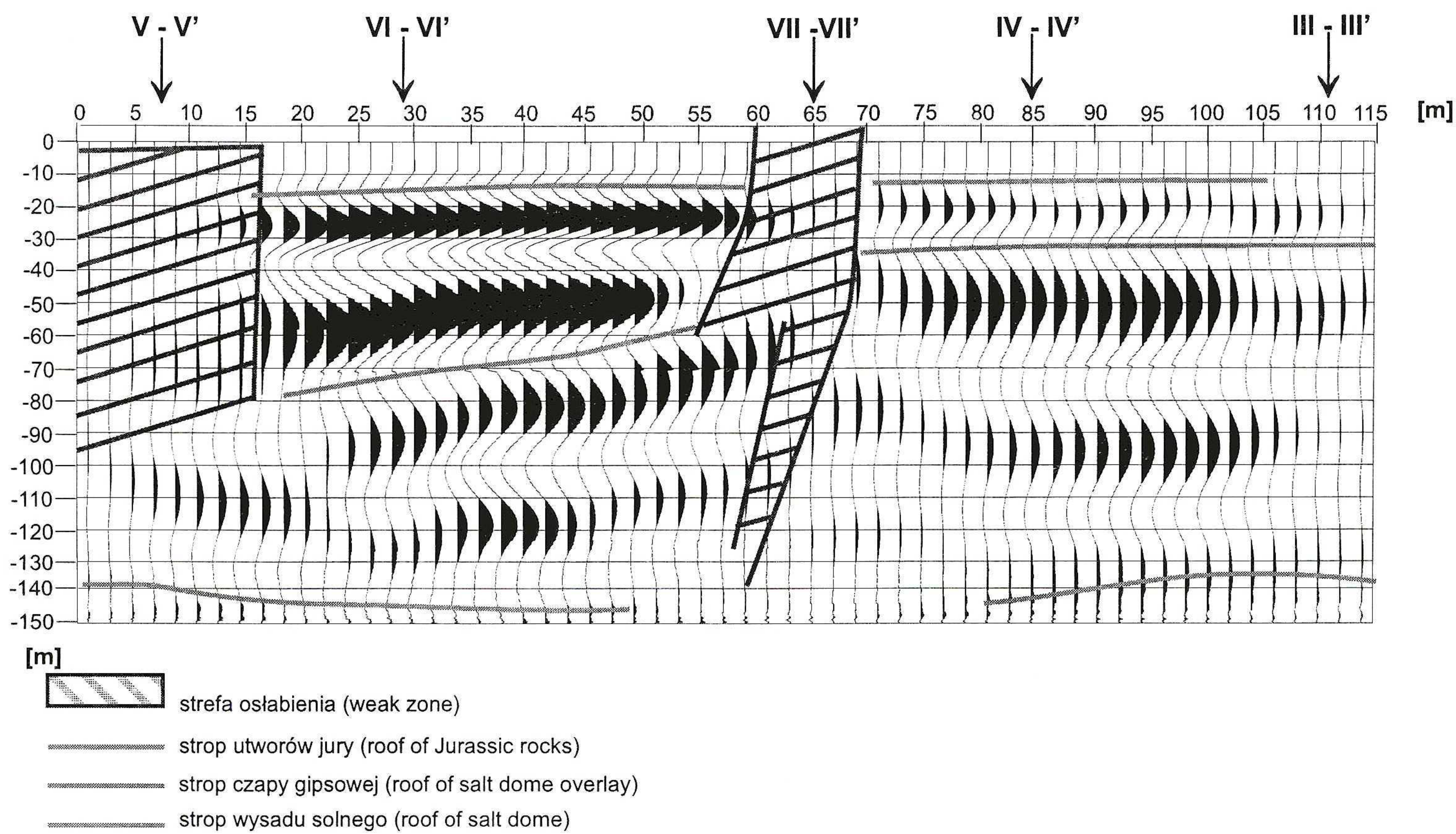

Fig. 4. Seismic reflection cross-section (depth section) through zone endangered sinkhole occurrence (Pilecki et al. 2003)

Rys. 4. Refleksyjny przekrój sejsmiczny przez strefę zagrożoną wystąpieniem zapadliska (Pilecki i in. 2003)

The model testing proved the possibilities of the use of seismic tomography when the length of seismic wave is at least three times smaller than the void diameter (Zakolski 1974). Only in this case the seismic waves recorded opposite the void, were considerably attenuated. It was shown, that in the presence of fracture zone, the relation of the seismic wavelength to the width of the disturbance is not so essential comparing to the void dimension. Interesting results are given by the connection of the seismic method with seismoacoustic method in the scheme of the zonal observation. The complementation of both methods allows locating the voids and monitoring their stability (Hardy, Belesky 1987).

2.4. Resistivity method

The void with the fracture zone are characterized by the changes of resistance or dielectric constant in relation to the surroundings. Just as in the case of "seismic" or "gravimetric" parameters, not only void has the essential importance but also the surrounding fracture zone. Resistivity profiling has been used for the void location most often from among all resistivity surveying techniques. Resistivity sounding gives the information concerning the depth of the voids' occurrence and their size. The observations of temporary changes of the resistivity in rock mass can be performed in order to estimate the dynamic expansion of the void. The process of void and fracture expansion can be seen in the changes of the difference between maximum and minimum values of the resistance, as well as the changes of the average level of this resistance in a giving time. Miecznik and Antoniuk (1973) considered the problem of the resistance profiling over non-conducting sphere. They concluded that the main factor that decides about the quality of resistance anomaly is the relation between the depth of the object occurrence and its size, but the type and length of measuring system are secondary factors.

2.5. GPR method

The electromagnetic wave of GPR, passing the rock mass, gives the information about its structure on the basis of changes of dielectric, magnetic constants and permeability as well as to the electric conductivity. For GPR, such phenomena as reflection, diffraction, and attenuation have the essential importance for the wave propagation. Every small dislocation with dielectric constant different from the surroundings creates diffractional wave, which is very important for location of the subsurface structures. The electromagnetic wave is subjected of high attenuation in the geological medium. Quantity of wave attenuation and its dependence on the frequency results that maximum depth of testing decreases rapidly while the frequency increases. The relation of the depth from the frequency is connected with the dimension of detecting objects. The lithological contacts are detected in the range of low frequencies of tens MHz. Small objects require the use of higher frequencies what limits the depth of their detection. GPR method has a lot of analogies with the seismic method in data processing and their presentation.

Summary

The results of geophysical investigations depends strongly on physical contrasts between weak zones or cavities and sourrounding rock mass as well as its depth and size. The optimisation of selection of research methods in given geological structure conditions as well as the knowledge about the factors disturbing the state of equilibrium in the rock mass, has the main importance during designing the methodology of geophysical investigations. Very important problem related with interpretation of observed geophysical anomalies is the study about the mechanism of void extension. So, it is a necessity of performing the periodical measurements of changes of physical properties. Such measurements can be a form of "geodynamic monitoring" if they are made for longer time.

It should be noticed, that informativeness of geophysical methods increases together with concentration of the measurements. In the case of small, several meters "objects" a decrease of the quality of information can cause the uncertain results. In such situation, geophysical testing should be directed on performing a "detailed view" according to the size of investigated area. It is also important that geophysical testing should be reduced to measurements connected with the solution of strictly determined task or realization of designed investment.

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ZENON PILECKI

BADANIA GEOFIZYCZNE DLA ROZPOZNANIA DEFORMACJI NIECIĄGŁYCH

Słowa kluczowe

Górnictwo, deformacje nieciągłe, metody geofizyczne

Streszczenie

W Polsce na terenach płytkiej eksploatacji rud Zn-Pb/Fe i węgla kamiennego występuje zagrożenie deformacjami nieciągłymi. Złożone warunki geologiczne i górnicze powodują trudności w opisie mechanizmu tworzenia się i propagacji deformacji. W takich warunkach wykorzystuje się metody geofizyczne do rozpoznania anomalii identyfikowanych ze strefami osłabienia w górotworze i oceny ich propagacji. Do najbardziej rozpowszechnionych metod opisanych w pracy należy zaliczyć grawimetryczną, elektrooporową, radarową i sejsmiczną. Praca ta omawia również podstawowe wady i zalety metod geofizycznych wykorzystywanych do rozpoznawania deformacji nieciągłych w warunkach eksploatacji na Górnym Śląsku.