CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

No. 3 2009

GEOTECHNICAL ISSUES OF SHALLOW MINING WITHIN THE UPPER SILESIAN INDUSTRIAL REGION

Krzysztof LABUS
Silesian University of Technology

Mining activity, within the Upper Silesian Industrial Region resulted in numerous mining damage - especially the discontinuous deformations. They are developed in effect of shallow coal seams extraction or are connected with Zn-Pb ore mining. Within the Syncline of Bytom the shallow ore mining, followed by coal mining, carried out at bigger depth led to reactivation of abandoned ore workings, and formation of mining damage to the surface. The main factors controlling the deformations over old, shallow workings comprise several categories of variables: size of mine workings, mining conditions, rock massif characteristics, stability of external conditions, and time. Most of the recent theories and solutions underline the role of variables defining the space and size of old workings. Existing models processes of deformation due to shallow mining allow the assessment of the character and size of sinkholes formed on the surface, over worked out parts of rock massif. They are efficient in forecasting surface deformations within the areas of simple geological setting. Problem of wider application of the forecasting methods in development planning remains still open, moreover the techniques of prevention against sudden deformation, and degraded land reclamation need to be constantly developed.

1. INTRODUCTION

Mining activity, lasting within the Upper Silesian Industrial Region for over 800 years (primarily zinc and lead, and since 18th century also hard coal) resulted in numerous mining damage. The specific type of the damage is related to discontinuous deformations caused by shallow mining. A typical features of discontinuous deformations (especially the surface depressions) are their occurrence within limited, local range, and connections with mining activities not exceeding the depth of 80 m (exceptionally several dozens of meters deeper).

The areas of shallow mining, and special intensity of discontinuous deformations within the Upper Silesian Coal Basin (USCB) are presented in the Fig. 1. The analyzed deformations are developed in effect of shallow coal seams extraction (of Carboniferous age), within regions of Rybnik, Łaziska, Chorzów, Dąbrowa Górnicza, Mysłowice and Jaworzno. In the Northern part of the USCB, in localities of Bytom and Tarnowskie Góry they are connected with Zn-Pb ore mining (stratoidal ore bodies in dolomites of Triassic). Within the range of the Syncline of Bytom the shallow ore mining was followed by coal mining, carried out at bigger depth. This led to reactivation of abandoned ore workings, and formation of mining damage to the surface (Fig. 2).

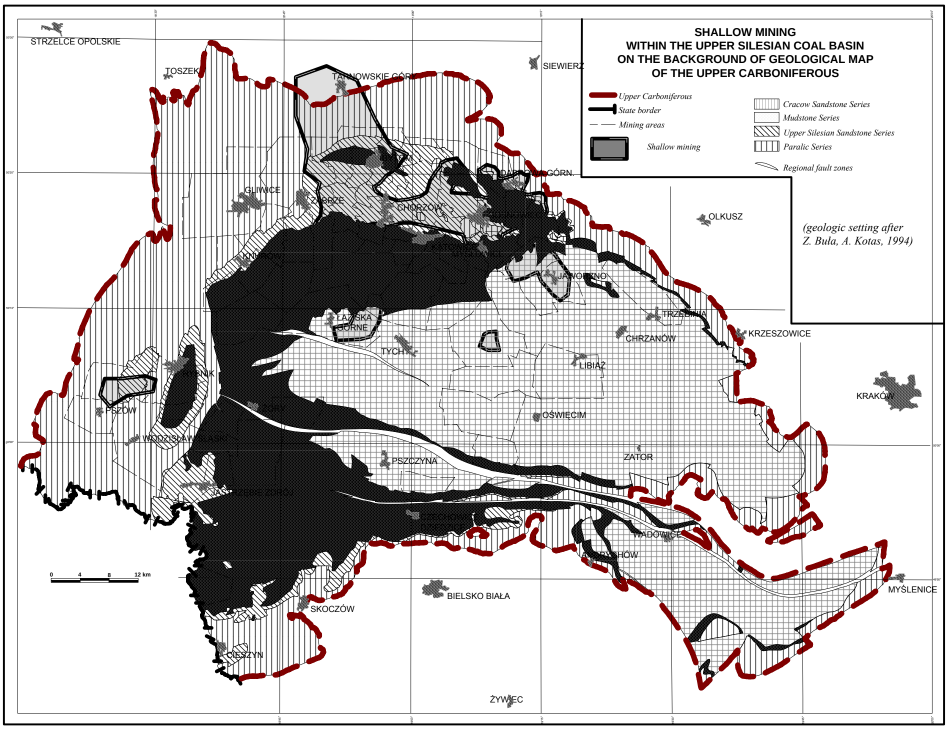

Fig. 1. Map of shallow mining within the Upper Silesian Coal Basin on the background of geological map of the Upper Carboniferous

The deformations induced by shallow mining appear with a serious delay (several to over a hundred of years) to the moment of mining activity. Their formation is only possible or probable, contrary to the typical mining subsidence.

Fig. 2. Vertical fissure (a), and a surficial scarp in an urban area (fot. K. Szafulera)

2. CONTROLS AND ELEMENTS OF DEFORMATION PROCESS DUE TO SHALLOW MINING

The main factors controlling the deformations over old, shallow workings comprise technological, geotechnical, and environmental variables:

1. Size of mine workings
   a) Vertical distance to the surface
   b) Shape
   c) Dimensions
2. Mining conditions
   a) Technology of exploitation (linked with 1 and 4c)
   b) Filling method
   c) Other mining activities eg.: firing, drainage, etc.
3. Characteristics of the rock massif
   a) Homogeneity
   b) Mechanical properties
   c) Degree of consolidation
   d) Hydrogeological properties (permeability, water storage capacity, etc.)
   e) Presence of man-made cavities
4. Stability of external conditions
   a) Variability of loading (vibration, etc.)
   b) Water recharge
   c) Mining activity in the bed-rock
5. Time
   a) Time from the termination of extraction
   b) Time of changes in external conditions
   c) Rate (speed) of extraction

The phenomenon of rock massif deformation in effect of shallow mining, according to the theory of pressure arch (Sałustowicz, 1953) and the subsequent model by Janusz & Jarosz (1976) (Fig. 3) may be described as follows:

- Above the mine working (a primary void) the pressure arch, and a zone of distressed rocks in shape of an ellipsoid are formed. Height of the zone is controlled by the size of the working, and physical-mechanical rock properties.
- Rock material situated within the arch is fractured, then cracked and eventually falls into the working, forming the caving zone (collapse).
- Over the caving zone a secondary, self-supported pressure arch is formed; the maximal tensile stress, equal to the tensile strength of the rocks is observed at the top of the arch; rock material (debris) filling the mine working has bigger volume compared to the primary rock volume.
- Between the arch and the caving zone a secondary void is formed,

- Accordingly to the development of primary void (mine working) the height of pressure arch the range of caving zone is increasing. The volume ratio of secondary void to the primary void decreases,
- At a certain width of the primary void, a right value of loosening, and sufficient thickness of consolidated rock above the working, the process of the secondary void "self-filling" is observed. The collapse zone reaches its maximal vertical size.
- The zone of fracturing is produced in every case over the caving zone. If the height of the fracturing zone is bigger than thickness of consolidated rock above the working – the secondary void appears in the roof of the latter one. This leads to the downward movement of the rocks of the overburden, and formation of discontinuous deformation of the ground surface.

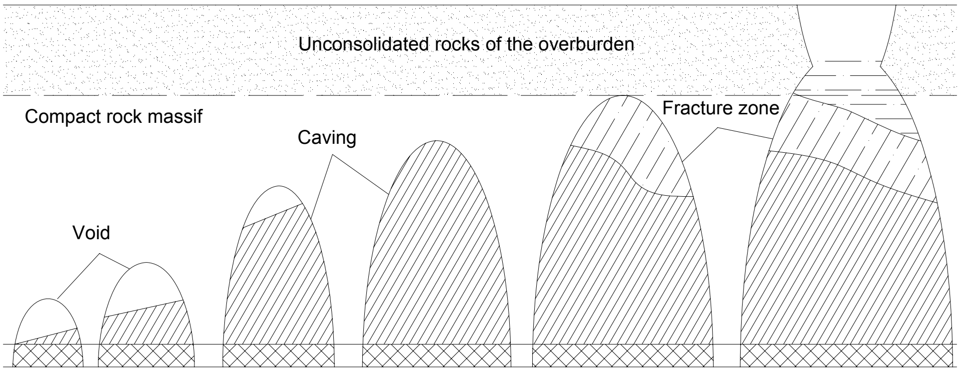

Fig. 3. Expansion of free space over an extending mine working after Janusz & Jarosz (1976)

The model assumes that the ground over the caving is divided into two layers: compact massif and a loose rocks of its overburden. Tensile strength of the both layers is much lower than their compressive strength.

3. MODELS OF DISCONTINUOUS DEFORMATIONS

Most of the recent theories and solutions underline the role of variables defining the space and size of old workings. Formation of a heading causes a change of stress and effort, leading to exceess of the strength limits. In effect a dynamic zone of fissured rocks, susceptible to deconsolidation process, is formed. Within the zone of deconsolidation the bulk density of rocks is altered. Fissured zones, and deconsolidation of rocks is caused by concentration of tensile and shearing stress. An example of the stress pattern after Rummel (1971) is presented in the Fig. 4.

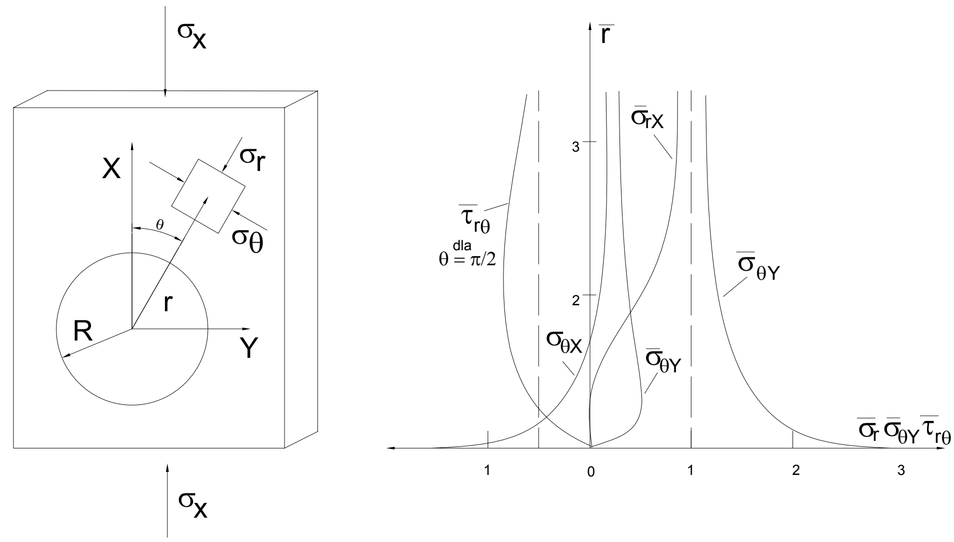

Fig. 4. Stress pattern in a rock massif around a spherical cave; after Rummel, 1971

Presented model bases on the assumption that $\sigma_y=0$; r, θ are polar coordinates, and:

$\bar{r} = \frac{r}{R}$ is the dimensionless radial distance,

$\bar{\sigma}_r = \frac{\sigma_r}{\sigma_x}$ stands for the dimensionless normal stress (radial),

$\bar{\sigma}_\theta = \frac{\sigma_{r\theta}}{\sigma_x}$ is the dimensionless normal stress (circumferential), and

$\bar{\tau} = \frac{\tau_{r\theta}}{\sigma_x}$ is the dimensionless tangential stress, shearing.

Two models of deformation processes due to shallow mining, leading to surface damage seem to be the most useful in the conditions of the USCB. The first model elaborated by Sachs (1987 vide Goszcz et al., 1991) allows assessment of the character and size of a sinkhole, formed on the surface, over an inclined, worked out part of rock massif – Fig. 5.

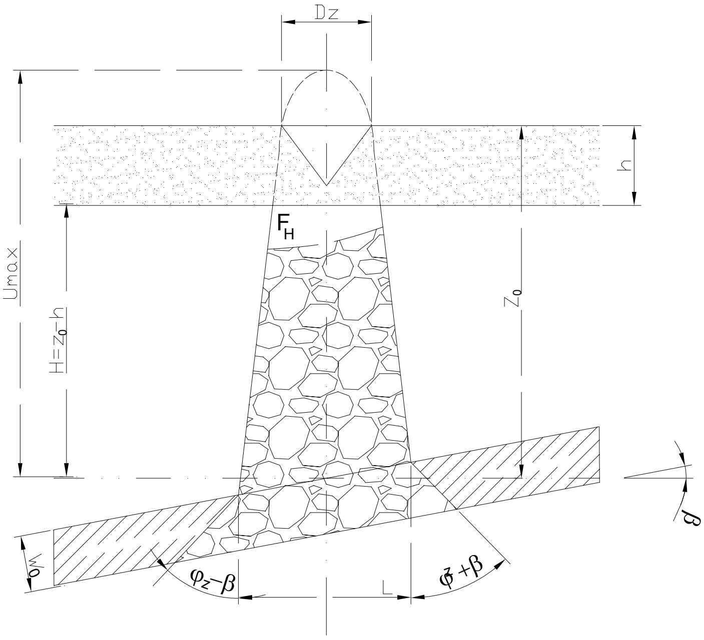

Fig. 5. Model of a sinkhole formation process over an inclined, worked out part of rock massif; after Sachs, 1987 vide Goszcz et al., 1991.
Explanations Dz- diameter of the sinkhole, H –thickness of the rock massif above the working, z_0 – depth of the roof of the working, h - thickness of unconsolidated overburden, F_H – size of the roofside cavity, U_{max} – maximal displacement of cavity, β - seam dip angle, φ_z – internal friction angle of debris material inside the caving, w_0 – height of the cavity, L- length of the cavity at the roof of the seam

According to the described model the maximal height of the cavity is defined after the following formula:

$$U_{\max} = \frac{3w_0}{2(k-1)}\left[1 + \frac{w_0}{L}ctg(\varphi_z - \beta) + \frac{w_0}{L}ctg(\varphi_z + \beta)\right]$$

and the diameter – D_z, and the depth – G_z of a sink-hole are:

$$D_z = \sqrt{\frac{Lw_0}{tg\varphi}\left(1 - \frac{z_0 - h}{U_{\max}}\right)^{3/2}}\ ,\ G_z = \sqrt{Lw_0 tg\varphi\left(1 - \frac{z_0 - h}{U_{\max}}\right)^{3/2}}\ .$$

The second model formulated by Chudek (eg. 2002), describing the collapse (caving) zone and the fracture zone over a mine working is presented in the Fig. 6.

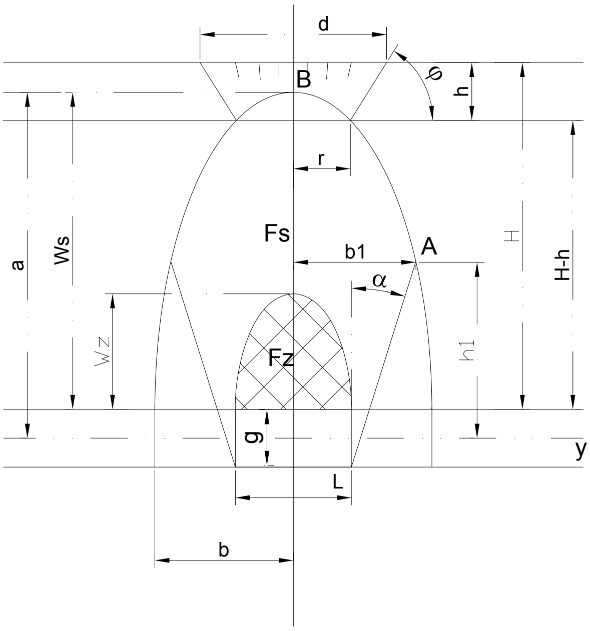

Fig. 6. Model of a collapse zone and zone of fracture over a worked out part of rock massif; after Chudek, (2002). Explanations: Dz – diameter of the sinkhole, h – thickness of unconsolidated overburden, r – sinkhole radius at the roof of the rock massif, Fz – sectional area of the caving zone over the mine working, Fs – sectional area of the fracture zone over the mine working, α – angle between the slip plane and the axis of the principal stress, H – depth of the roof of the working, H-h – thickness of the rock massif above the working, w_s – height of the fracture zone, w_z – maximal height of the caving zone, L – width of the working, g – height of the working

Maximal height of the fracture zone follows the equation:

$$w_s = \pm M \sqrt{\frac{(L + g\ tg\alpha)^2\,(M^2\,tg^2\alpha + 1)}{4(1 - M^2\,tg^2\alpha)}}\ ,$$

where M – proportion between semi-axes of the fracture zone.

For practical applications the condition of a discontinuous deformation was defined by Chudek (2002), on the basis of statistical analysis of several hundreds of sink-holes, in the following form:

$$w_z \geq H - h\ .$$

Probability of sink-holes appearance is possible to be assessed also on the basis of stochastic models. These models allow classification of areas into categories relevant to the size and depth and aerial density of sinkholes (eg. Chudek, 2002).

4. CONCLUSIONS

The mentioned deterministic and statistical models, are efficient in forecasting surface deformations within the areas of simple geological setting. Despite the capacities of the mentioned methods their results become uncertain, when the geology is more complex. Each case of such an area needs then to be solved individually by means of modern techniques eg. microgravimetry. However there are numerous examples where classification of endangered grounds is possible to be performed only on the basis of data including archival geological records (Fig. 7) or land development plans. The latter ones, if possible, contemporary to the old mining activity.

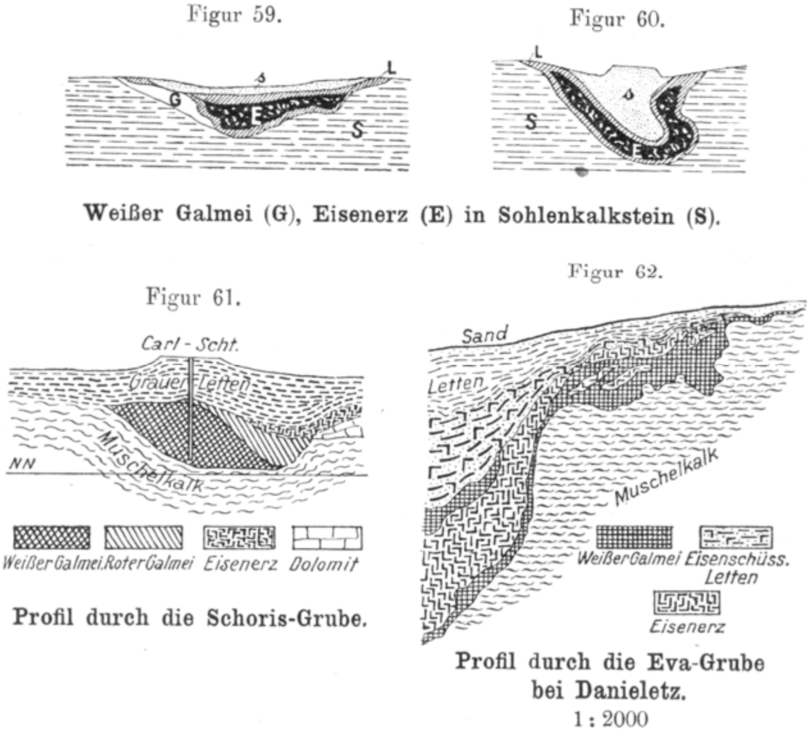

Fig. 7. Geological cross-sections of shallow Zn-Pb ore-bodies of the Bytom - Tarnowskie Góry region (from Berg et al., 1913). Explanations: Eisenerz – oxide iron ore, Sohlenkalkstein - Basal Limestone, Grauer Letten- grayish clay, Eisenschüss Letten – iron-bearing clay

Recently the problems of discontinuous deformations within the area under consideration are properly and reliably recognized. However regions of their occurrence were catalogued for the most part of the USCB, and methods of their forecasting were elaborated at the precision level allowing their usage in practice, the problem of wide application of the methods in development planning remains still open. Moreover the techniques of prevention against sudden deformation, and degraded land reclamation need to be constantly developed.

REFERENCES

1. Berg G., Beyschlag F., Ebeling F., Jentzsch A., Kaunhowen F., Krusch P., Michael R., 1913: *Beiträge zur Geologie Ostdeutschlands. Band I.: Der Bergbau im Osten des Königreichs Preussen.* Berlin.
2. Chudek M., 2002: *Geomechanika z podstawami ochrony środowiska górniczego I powierzchni terenu.* Wyd. Politechniki Śląskiej. Gliwice.
3. Goszcz A., Surowiec Z., Kotyrba A., Foryś T., 1991: *Feasibility of assessing surface hazards due to shallow lying cavities and also methods for their combating. (in Polish).* Prace GIG. Nr 763. Katowice.
4. Janusz W., Jarosz A., 1976: *Nieciągłe deformacje powierzchni wywołane płytką podziemną eksploatacją górniczą.* Mat. Konf. Naukowo-Technicznej: Budownictwo na terenach górniczych o dużych deformacjach powierzchni. Komisja Ochrony Terenów Górniczych PAN Oddział Katowice.
5. Rummel F., 1971: *Uniaxial compression tests on right angular rock specimens with central holes.* Rock Fracture Proceeding of the International Symposium on Rock Mechnics. Nancy 4-6th October 1971. Vol.2. pp. 90-100.
6. Sałustowicz A., 1965: *Zarys mechaniki górotworu*. Wyd. Śląsk. Katowice
7. Strzałkowski P. Szafulera K., Koźmiński K., 2006: *The hazard to building caused by discontinuous deformations. (in Polish)*. Zesz. Nauk. Pol. Śl. Series: Mining. Vol. 271, pp. 139-148.

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

No. 3 2009

ROCK POROSITY DETERMINATION IN THE HISTORICAL MONUMENTS PRESERVATION

Małgorzata LABUS
Silesian University of Technology

Since ancient times people have used natural stone materials for building purposes. The need of safeguarding historical sites and cultural heritage provoke considering the precise technical characterization of building stones and their changes in weathering processes. In the paper there were listed detailed petrographical analysis used for assessing the quality and durability of the stone material The porosity properties are detected by means of a range of methods, divided into two groups: direct (including thin section microscopy and scanning electron microscopy), which allow direct documentation and measuring of pore space; and indirect (including mercury porosimetry or nitrogen sorption method), which enable calculating the porosity data from the measuring results. Precise knowledge of porosity characteristics, like total porosity, pore sizes, pore size distribution and pore surface is essential for: stone characterization, modeling of transportation processes, assessment of stone durability, interpretation and prediction of the weathering behavior of natural stones, quantification and rating of stone deterioration and evaluation of effectiveness of stone treatments. Basing on the literature digest and own experience, some examples of the stone porosity characteristic application was presented. The variety of natural stones used as construction material, the complicated nature of weathering processes and complex porosity properties determine implication of different analytical methods for stone examination. The most popular method is mercury porosimetry, but it is worth to remember that a reliable characterization of porosity properties can be guaranteed by application of different analytical procedures.

1. INTRODUCTION

Stone elements are used for building purposes more and more frequently, especially in public, monumnetal objects. Stone materials are also needed for the reconstruction of a great number of ancient, historical buildings made of natural materials. During restoration often occurs a need for replacement of stone elements, mainly when dealing with weathering-sensitive historical building stones, eg. calcareous sandstones, soft limestones, etc. The most