AGH Journal of Mining and Geoengineering • Vol. 36 • No. 1 • 2012

*Tadeusz Majcherczyk *, Zbigniew Niedbalski *, Katarzyna Kryzia **

CHANGES TO THE RANGE OF EXPLOITATION IMPACT WHEN MINING THE NEXT COAL DEPOSIT ON THE BASIS OF GEODETIC MEASUREMENTS

1. Introduction

The impact of mining exploitation on deformations of the rock mass and land surface is a complex issue and depends on many factors. The most important of them are variable geological and mining conditions. For the assessment of the impact of underground exploitation on land surface, various models have been created using the parameters of the deforming rock mass which are determined. Forecasts created are all the more so necessary, the more the land surface is urbanised [3, 6]. Conformance of the forecasts to the later factual status provides information about their effectiveness, and principally allows for undertaking relevant measures aimed at protection of near-surface or underground facilities against negative effects of exploitation or minimisation of these results. In conditions relating to Polish coal mines, the theory by Budryk-Knothe is of major usefulness for forecasting the indices of surface deformations [5, 9, 10]. Nevertheless, its application requires the adoption of relevant theory parameters, such as angle of the range of main impact or the exploitation factor. In the case of the angle of the main impact range, its value is adopted depending on geological and geo-mechanical conditions, whereas the exploitation factor – on the basis of roof management method. Average values stated in the literature, however, often deviate from the actual values determined in geodetic measurements [7]. Reasons for such a state of affairs is the multi-layer exploitation and unknown geological distortions.

Exploitation of further seams situated below will result in the occurrence of summary deformations on the land surface [7]. Considering the fact that in most areas of Polish

* AGH University of Science and Technology, Faculty of Mining and Geoengineering, Department of Geomechanics, Civil Engineering and Geotechnics, Kraków.

mines exploitation was carried out in more than one seam, the adopted parameters of the theory may be subject to changes, even within one batch or exploitation block in a particular mining area.

In the article, the analysis involves the results of geodetic measurements considering the impact of exploitation of seam 357/1, and next of seam 360/1. The situation analysed is interesting, as the measurement line is half the length over the mined plots, and half over the undisturbed soil. Furthermore, the line direction is approximate to the perpendicular towards the exploitation edges. Another factor impacting on the analysis of this case is the fact that there is no simultaneous overlapping of impacts of extraction of two seams. The article specifies the estimated values of the range angle of main impacts, and the exploitation factor for two seams separately.

2. Characteristic of study area

In the area covered with geodetic observations, a hard coal seam has an industrial value up to the depth of approx. 1000 m. In the geological structure of the region discussed, there are three strata: Quaternary (Holocene, Pleistocene), Tertiary (Miocene) and Carbon (Orzesze and Ruda strata).

Quaternary strata in the region are shaped as alluvial sand, sand with grit and silt loam turning into dust, with total thickness of 23.8–51.0 m.

Tertiary strata placed directly on Carbon are principally represented by clay, shale clay with some overlays of silt sand and dust. Such layers have variable thicknesses conditioned by the differences in land morphology. To the south from the seams analysed, at the distance of 350 m, thickness of Tertiary strata amounts to approx. 225 m, whereas in the region of the beginning of the observation line — to the east from the mined seams — approx. 500 m.

Carbon formations are principally clay shales, as well as sandy shales and sands, whereas coal seams are in the Orzesze strata.

In the region analysed, there are two faults: Krzyżowicki I and Krzyżowicki II, oriented NW-SE. Both faults are towards NE, and fault sizes amount to 35 m and 15 m, respectively. To the north of Krzyżowicki faults, there is a tectonically distorted zone, formed by two major faults crossing at an angle close to right angle. Border Fault 1 runs from NW to SE, and is oriented towards NW at the height of 105–130 m (Fig. 1). The fault crosses Border Fault 2 running from NE to SW, with fault height of 30 m towards NW. Apart from border faults, there are a number of minor faults with the height not exceeding the usual 2–3 m.

In the region analysed, exploitation took place from the mid-1980s, and involved seams 346/1, 347/1, 352/1, 356/1 and the analysed seams 357/1 and 360/1 (Fig. 1). Seam 357/1 was exploited as first, starting from the first quarter of 2000 to the third quarter of 2004. The seam with an exploitation thickness of 1.95–2.25 m was located at the depth amounting to from 782 to 897 m. In seam 360/1, the exploitation was commenced in the first quarter of 2004 and it lasted until the fourth quarter of 2007. The seam, with a thickness of 1.65–1.98 m remained at the depth of from 843 to 951 m. Both seams analysed were exploited using four walls, and roof collapse system. The scheme of geological-mining situation together with measurement line of the length of approx. 450 m (21 measurement points with average intervals between the points amounting to 20–23 m) is presented in Figure 1.

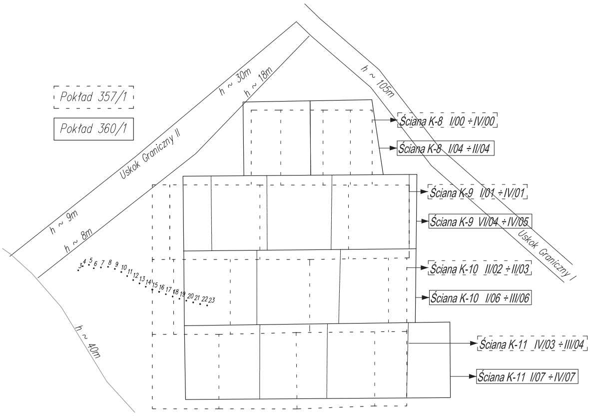

Fig. 1. Distribution of exploitation plots and measurement line

3. Characteristics of geodetic measurement results

Within geodetic measurements, at the analysed observation line, a height measurement was performed using the geometric levelling method, side length measurement and angle measurement. Geodetic measurements were performed regularly three or four times per year throughout the period of ten years.

The analysis of the course of the impact of the exploitation for each of the seams was made separately due to a lack of simultaneous impact on the measurement line on the part of effects of subsequent exploitations. Results from geodetic measurements allow for describing the course of continuous surface deformations caused by mining exploitations of the two seams analysed in the specific time and space.

The impact of the exploitation of seam 357/1 on subsidence of the land surface has been presented in Figure 2. Measurement results covered the period from 1.09.2000 to 22.07.2004. The above period was selected due to a lack of impact of prior exploitation onto the measurement line points. This is testified to by a minimal growth of subsidence in the initial two measurement periods. In the case of the final period, no impact of the exploitation was observed on the measurement line, and moreover, some measurement points were damaged on the turn of 2004 and 2005, and it became necessary to stabilise them again.

The exploitation of seam 357/1 resulted in maximum subsidence on the measurement line amounting to 1.70 m, whereas over the exploitation edge the subsidence it amounted to 0.58 m. Subsidence at the beginning of the observation line, namely over the undisturbed ground, at the distance of approx. 200 m from the edge amounted to 0.14 m. Similarly as at

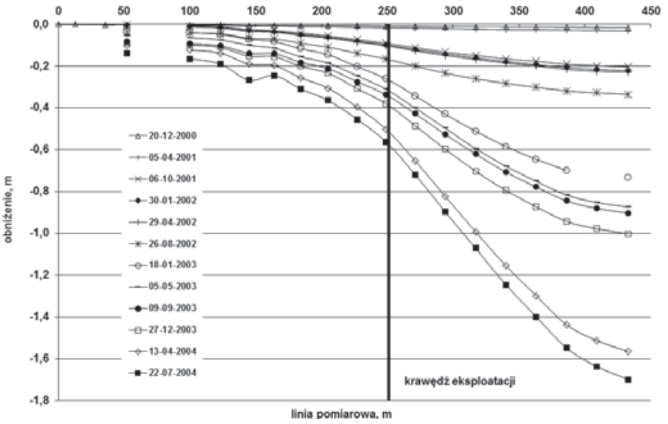

Fig. 2. Subsidence of points on the measurement line in the period 1.09.2000–22.07.2004 exploitation of seam 357/1

the beginning of the measurement line, also at its end one can clearly see extinction of subsidences. Also extreme points of the line in its end section, and near the beginning, are within the zone of exploitation impact, which does not mean that other than at these points, there were no increased subsidences. Growth to subsidences in particular measurement periods indicate revelation of major impacts on the surface within 3-4 months from exploitation of a particular part of the seam.

Exploitation of seam 360/1 resulted in maximum subsidence on the measurement line amounting to 1.145 m (Fig. 3). As one can observe, only the three final points of the observation line remain over the seam mined. Over the exploitation edge, subsidence amounted to 0.84 m, while at the beginning of the observation line, namely over the undisturbed ground at the distance of approx. 350 m from the edge, subsidence it amounted to 0.10 m. Clear stabilisation of changes to the location of the measurement points has been observed since 20 September 2007, as until the end of the measurements analysed, namely until 16 November 2009, subsidence was recorded across the entire measurement line, so regardless of the location of the points against the plots mined, within the limits of 0.07–0.09 m.

Measurements carried out as regards distance between surface benchmarks, namely changes to the length of the observation line, have also allowed for determining the changing horizontal deformations on the surface. Furthermore, based on subsidence difference, land surface slant was determined. In the case of seam 357/1, maximum value of the slant amounted to approx. 8 mm/m and was located at the line section between 280–320 m, namely over the plot mined. This corresponds to average distances from the exploitation edge of approx. 50 m (Fig. 4). A similar distance from the edge was also recorded for the zero value of horizontal deformations, as it occurred at the observation line at 310 m, namely at a distance of 60 m from the exploitation edge. Maximum values of deformations amounted to approx. 4.5 mm/m and remained at the distance of approx. 60–70 m from the zero value of deformation. A deformation value for the point at approx. 140 m of the measurement line was neglected due to possible measurement error.

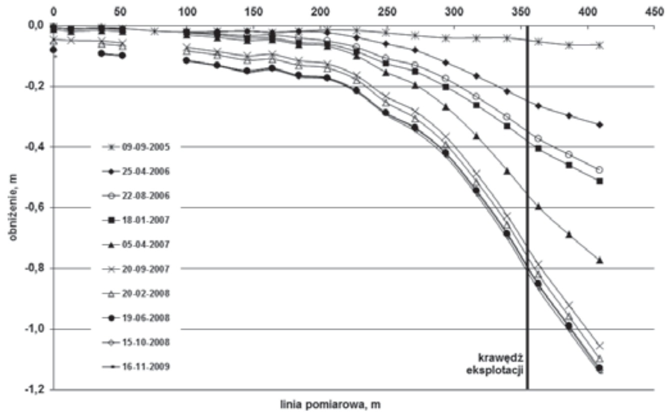

Fig. 3. Subsidence of points on the measurement line in the period
18.05.2005 to 16.11.2009 — exploitation of seam 360/1

It may, therefore, be stated that the location of the maximum value of the slant and zero value of deformation are very close. At the same time, this indicates the presence of the exploitation edge. The value conforms to the Budryk-Knothe theory, inflection of the edge part of the basin's profile has shifted when compared to the exploitation edge by the value expressed by the equation (1):

$$p = \frac{\sqrt{H}}{0.1 \cdot H} \tag{1}$$

where: H — exploitation depth.

In the example analysed, as regards exploitation of seam 357/1, the shift value of inflection amounts to p = 28.3–79.9 m.

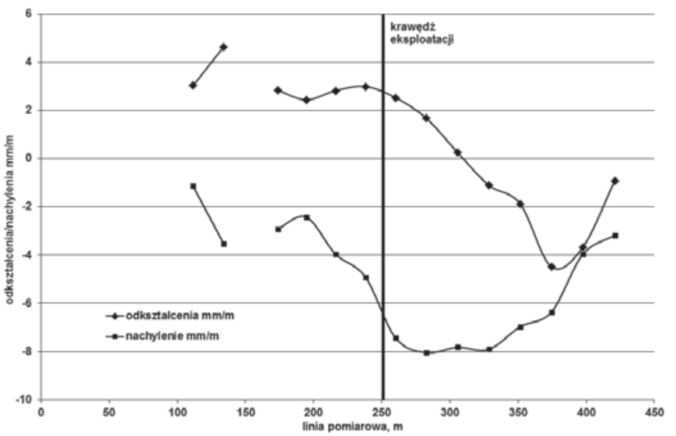

Fig. 4. Values of deformation factors in the period
1.09.2000–22.07.2004 – exploitation of seam 357/1

The analysis of horizontal deformations and slants performed for seam 360/1 points to a slightly different nature of the changes to the values set. The location of the exploitation edge in seam 360/1 as compared to the measurement line has been presented in Figure 5. The slant adopts a maximum value of approx. 7 mm/m, whereas horizontal deformation — approx. 3.5 mm/m. What is very interesting, however, is the location of the characteristic points in diagrams of the factors discussed, as the maximum value of the slant almost overlaps with the zero value of horizontal deformation, and their location is almost identical as is the location of the exploitation edge.

If it is assumed that the location of the basin's inflection occurs at the point of zero values of horizontal deformations, namely at 362.5 m of the observation line length, then the exploitation edge only amounts to p = 7.5 m. This value differs from value with equation (1) and does not fall within the aforementioned range for seam 360/1, which amounts to p = 29.63–87.8 m.

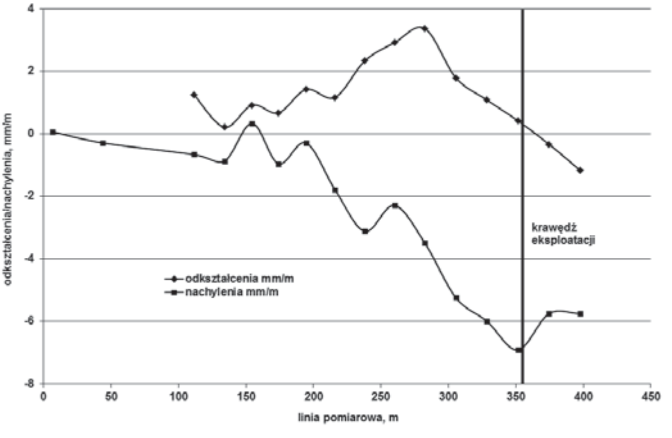

Fig. 5. Values of deformation factors in the period 18.05.2005 to 16.11.2009 — exploitation of seam 360/1

The information above points to a different nature of disclosure of exploitation impact on the land surface from two consecutively mined seams. This principally refers to the range of exploitation, therefore principally to the major impact range angle.

4. Specification of the parameters of the Budryk-Knothe theory

For the purpose of performing a correct forecast of land surface deformation factors before commencing the exploitation, it is necessary to adopt appropriate parameters of the Budryk-Knothe theory [4]. Fundamental parameters include the major impact range angle and the exploitation factor. The essence of these parameters principally results from practical needs, particularly in the urbanised area where the exploitation is planned [2]. In the example analysed, the aforementioned parameters will be estimated on the basis of the available data. Due to the fact that the measurement line is of the length that did not ensure obtaining full subsidence basin, the exploitation factor and the major impact range angle will be determined using indirect methods using the dependencies from the Budryk-Knothe theory.

4.1. Seam 357/1

The values of the exploitation factor for seam 357/1 were determined on the basis of the location against the measurement line of the exploitation edge and the location of zero value of horizontal deformation. Due to the fact that the diagram of changes according to land surface subsidence as a result of the exploitation of seam 357/1 it does not contain maximum values of subsidences (Fig. 2), they were determined as follows:

— value of subsidences of the land surface over the exploitation edge of seam 357/1, which falls at the length of 251 m from the beginning of the observation line, according to the Budryk-Knothe theory, amounts to 0.5 w_{max1}, which after reading from diagram (Fig. 2) yields subsidence value of 0.58 m; on this basis, the value of maximum subsidence must be determined as w_{max1} = 1.16 m, due to the fact that the maximum measured value was much higher, for further analyses, the maximum value of subsidence was adopted directly from the diagram, namely w_{max1} = 1.70 m,

— zero value of deflection falls at the point being at 311 m from the beginning of the observation line (Fig. 4), therefore, reading from the land setting diagram (Fig. 2) the value of subsidence at this point, the result is 0.5 w_{max2} = 1.04 m; maximum subsidence will then amount to w_{max2} = 2.08 m.

On the basis of the above analysis, one may state that maximum setting must occur within the range of w_{max} = 1.70–2.08 m. According to the Budryk-Knothe theory, exploitation factor a is defined as the ratio of the greatest subsidence of a full basin or over-full basin to average thickness of the seam exploited. Exploitation factor is calculated as follows:

$$a = \frac{w_{\text{max}}}{g} \tag{2}$$

where:

w_{max} — the greatest subsidence of the basin,
g — average thickness of the seam exploited.

The value of the exploitation factor a principally depends on the method of eliminating the post-mining voids, and further on the geological conditions. It is most frequently defined for a particular region on the basis of geodetic observation on the land surface [8]. It is assumed that the greatest subsidence occurs upon an exploitation with roof collapse, for which a = 0.7–0.9. In the case of significantly disturbed rock mass due to prior exploitation with roof collapse, the value may increase, and can even be greater than one [5, 10]. Such a situation may occur principally as a result of multi-layer exploitation with roof collapse, which is related, as a consequence, to reactivation of old gunis.

For seam 357/1, where the exploitation thickness remained within the range of from 1.95 m to 2.25 m, exploitation factor a was determined using maximum subsidences (w_{max1} = 1.70 m) and location of zero value of horizontal deformations (w_{max2} = 2.08 m).

Comparison of thickness values (1.95 and 2.25 m), and maximum subsidences, can serve for setting two ranges of the exploitation factor. Value of the exploitation factor for wmax1 will amount to a_1 = 0.75–0.87 — on average $a_{1śr}$ = 0.81, whereas for w_{max2} it will be equal to a_2 = 0.92–1.06 — on average $a_{2ŚR}$ = 0.99.

Further on, main impact range radius r can be set. For this purpose, the slant diagram was used (Fig. 4), which indicates maximum value T_{max} = 7.8 mm/m. Assuming that maximum value slant is calculated as follows:

$$T_{max} = \frac{w_{max}}{r} \tag{3}$$

where:

w_{max} — the greatest subsidence of the basin,
r — major impact range.

Value r can be determine for:

— w_{max1} = 1.70 m, major impact range radius will amount to r_1 = 218.0 m
— w_{max2} = 2.08 m, major impact range radius will amount to r_2 = 266.7 m

Due to the above, the main impact range for seam 357/1 can be estimated at the level of 218–267 m.

Table 1. Calculation of parameters of the Budryk-Knothe theory for seam 357/1 for seam thickness g = 1.95–2.25 m

Determination method							
Maximum value from subsidence diagram				**Value set from the slant and horizontal deformation**			
Max. subsidence w_{max1}, m	Exploitation factor a_1		Major impact range r_1, m	Max. subsidence w_{max2}, m	Exploitation factor a_2		Major impact range r_2, m
	min/max	average			min/max	average	
1.70	0.75	0.81	218.0	2.08	0.92	0.99	266.7
	0.87				1.06		

4.2. Seam 360/1

Analogically as in the case of seam 357/1, also for seam 360/1, the values of the exploitation factor were determined, using the subsidence diagram for seam 360/1. Calculations were also performed in two variants, namely: using the location of the exploitation edge against the measurement line and the location of zero value of horizontal deformation:

— value of subsidences of the land surface over the exploitation edge of seam 360/1, which falls at the length of 355 m from the beginning of the observation line, according to the Budryk-Knothe theory, amounts to 0.5 w_{max1}, which after reading from diagram (Fig. 3) yields subsidence value of 0.82 m; on this basis, the value of maximum subsidence must be determined as w_{max1} = 1.64 m,

— zero value of deflection falls at the point located at 362.5 m from the beginning of the observation line (Fig. 5), therefore, reading from the land setting diagram (Fig. 3) the value of subsidence at this point, the result is 0.5 w_{max2} = 0.87 m; maximum subsidence will then amount to w_{max2} = 1.74 m.

Seam 360/1 was exploited in the area of thickness from 1.65 m to 1.98 m, therefore the value of exploitation factor a will be set using the thickness range and the range of maximum subsidences, namely w_{max1} = 1.64 m (set on the basis of exploitation edge location) and w_{max2} = 1.74 m (set on the basis of location of zero value of horizontal deformations).

Using the data obtained, the exploitation factor will be as follows for:

- w_{max1} = 1.64 m, exploitation factor a_1 = 0.83–0.99 – on average $a_{1śr}$ = 0.91,
- w_{max2} = 1.74 m, exploitation factor a_2 = 0.88–1.05 – on average $a_{2śr}$ = 0.97.

Using the dependence (3) and maximum slant value T_{max} =7.22 mm/m, which occurred on the surface under the impact of exploitation of seam 360/1, main impact range radius was obtained for:

- w_{max1} = 1.64 m, major impact range radius will amount to r_1 = 227.0 m,
- w_{max2} = 1.74 m, major impact range radius will amount to r_2 = 241.0 m.

Due to the above, the main impact range for seam 360/1 can be estimated at the level of 227–241 m. This is, therefore, a lower value than for the seam located above, namely 357/1.

Table 2. Calculation of parameters of the Budryk-Knothe theory for seam 360/1 for seam thickness g = 1.65–1.98 m

Determination method							
Maximum value from subsidence diagram				**Value set from the slant and horizontal deformation**			
Max. subsidence w_{max1}, m	Exploitation factor a_1 min/max	Exploitation factor a_1 average	Major impact range r_1, m	Max. subsidence w_{max2}, m	Exploitation factor a_2 min/max	Exploitation factor a_2 average	Major impact range r_2, m
1.64	0.83	0.91	227.0	1.74	0.88	0.97	241.0
	0.99				1.05		

The aforementioned dependencies of the major impact range have been presented graphically in Figure 6. For seam 357/1, the major impact range determined on the basis of the subsidence diagram (continuous line) falls at 36 m from the beginning of the measurement line, while the range is set from the slant and horizontal deformation (dashed line) falls 11 m further, namely at 47 m. The values correspond to the major impact range angle of β_1 = 74.74° and β_2 = 71.54°, respectively.

For seam 360/1, the major impact range determined on the basis of the subsidence diagram falls at 130 m from the beginning of the measurement line, while the range is set from the slant and horizontal deformation and falls 6.5 m earlier, namely at 123 m from the beginning of the measurement line. The major impact range angle amounts then to β_1 = 75.50° and β_2 = 74.65°, respectively.

Therefore, one can observe that at a distance of 102 m between the edges of the seams exploited and the depth difference amounting to on average 79 m, with the exploitation of the next seam located below, the calculated major impact range angle is greater, namely: $\beta_{\text{min } 360/1}$ = 74.65° than for the previously exploited seam $\beta_{\text{min } 357/1}$ = 71.54°.

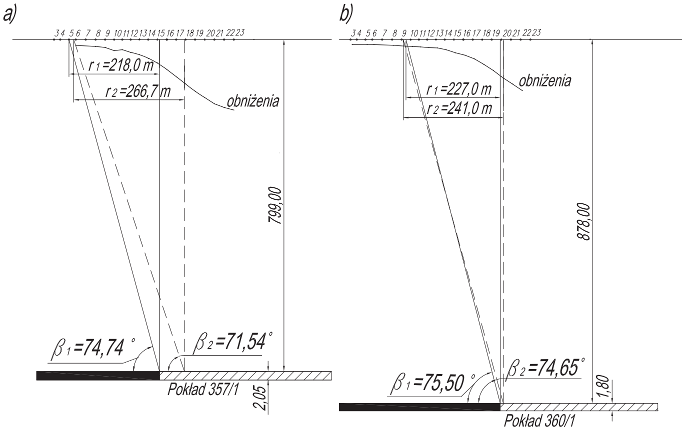

Fig. 6. Major impact range: seam 357/1, b) seam 360/1

Considering measurement results of the subsidences, it must however be stated that in the case of land surface setting recorded during exploitation of seam 360/1, vertical shifts occurred at a distance much greater from the edge than it would result from the calculations. subsidences as a result of exploitation of seam 360/1 reach the beginning of the observation line, and amount to 0.12 m. The same value occurs at 52 m of the measurement line, whereas the subsidence gradually grows. It can therefore be, assumed that in the case of seam 360/1, the major impact range reaches the point of the measurement line at 52 m, which corresponds to the distance from exploitation edge of approx. 320 m. Due to the above, for seam 360/1, the value of the major impact range angle will amount to 70°, whereas the impact range will be closed to the one observed in seam 357/1. Such a situation is possible due to development of the shift surface caused by exploitation of seam 357/1 and the seams situated above.

5. Summary

Forecasting of land deformation due to underground mining exploitation requires the knowledge of local values of the parameters characterising the rock mass over the exploitation site, and the method of the elimination of the post-mining void. On the basis of measurements on the observation line covering the incomplete subsidence basin, a certain tendency of changes to the rock mass parameters was determined accompanying the exploitation of consecutive seam. The results, however, allowed for determining the angle of mining impact range and the exploitation factor. The analysis involved the impact of land surface deformation as a result of exploitation using the roof collapse system for seams 357/1 and 360/1. Deformation size was analysed for each seam separately due to lack of simultaneous impact on the measurement line. Major impact on the land surface is revealed in the period of the next 3–4 months after the end of exploitation. In consecutive months, the value of such impact is already small. On the basis of the analysis performed, the following conclusions can be drawn:

1) The exploitation of seam 357/1 as consecutive in a particular batch, depending on the adopted calculation method, caused subsidence of the land surface corresponding to the exploitation factor of 0.81–0.99, namely on average by 0.90. Exploitation of the consecutive seam was the cause of subsidences characterised with the exploitation factor value of 0.91–0.99, namely, on average 0.95. This indicates high distortion of the rock mass with prior exploitation.
2) The impact range radius, calculated on the basis of maximum values of the slant and location of zero values of horizontal deformations, indicates that for the seam situated higher, namely 357/1, the major impact range angle amounts to 71.54–74.54°. For seam 360/1, the calculated major impact range angle amounted to 74.65–75.50°. The analysis of subsidences and land slant during the mining of seam 360/1, however, indicates that the exploitation range is greater, and corresponds to the major impact range angle of 70°. This may testify to the development in the rock mass of a shift surface comprising the seams exploited above.
3) The analysis is based on current measurement results and forms a basis for verification of the generally applied parameters of the Budryk-Knothe theory, namely exploitation factor for the system with roof collapse $a = 0.8$, and parameter tg$\beta = 2.0$ [1, 2]. Exploitation at increasing depths and in rock mass subject to the impact of many exploitations causes a significant growth to the exploitation factor. Decrease or increase in the major impact range angle is rather related to local mining and geological conditions.

REFERENCES

[1] Białek J.: *Uwagi o sporządzaniu prognoz ciągłych deformacji terenu górniczego*, II konferencja naukowo-szkoleniowa: Bezpieczeństwo i ochrona obiektów budowlanych na terenach górniczych, Katowice–Ustroń Zawodzie, 2008, p. 33–45.

[2] Białek J., Mielimąka R.: *Próba weryfikacji parametrów teorii prognozowania wpływów eksploatacji na teren górniczy*, Zeszyty Naukowe Politechniki Śląskiej, seria Górnictwo z. 250, 2001, p. 69–79.

[3] Florkowska L.: *Land Subsidence Due to Mining Operations in Disturbed Rock Mass, on the Example of Ruda Śląska (Poland)*, Archives of Mining Sciences, Vol. 55, 2010.

[4] Hejmanowski R.: *Prognozowanie deformacji górotworu i powierzchni terenu na bazie uogólnionej teorii Knothego dla złóż surowców stałych, ciekłych i gazowych*, Wydawnictwo IGSMiE PAN, Kraków 2001.

[5] Knothe S.: *Prognozowanie wpływów eksploatacji górniczej*. Wydawnictwo „Śląsk", 1984.

[6] Kowalski A., Jędrzejec E.: *Ocena wpływów dokonanej eksploatacji i sporządzanie prognoz deformacji powierzchni terenu dla ochrony obiektów budowlanych*. Miesięcznik WUG nr 8/2008, p. 14–18.

[7] Kwiatek J.: *Ochrona obiektów budowlanych na terenach górniczych*. Wydawnictwo GIG, 1998, p. 163–173.

[8] Ostrowski J., Piskorz-Joniec M.: *Wyznaczanie wartości parametrów modelu Knothego na podstawie wyników pomiarów obniżeń z wykorzystaniem zmodyfikowanej metody graficznej*. Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie, nr 11(195)/2010, p. 3–7.

[9] Popiołek E.: *Ochrona terenów górniczych*. Wydawnictwa AGH, Kraków 2009.

[10] Zych J., Kruczkowski M.: *Porównanie prognozy deformacji powierzchni z wynikami pomiarów*. Zeszyty Naukowe Politechniki Śląskiej, seria Górnictwo z. 286, 2008, p. 181–190.