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The influence of rock mass disturbance on surface subsidence in urban areas

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Wpływ zruszenia górotworu na obniżenia powierzchni terenu zurbanizowanego

Abstract

This paper presents an analysis of the parameters of surface deformation prediction theory carried out for a hard coal mine in the Upper Silesian Coal Basin. Two areas of the coal mine were used as the subject of this analysis – in these areas, underground mining with roof caving was carried out in similar geological conditions for various numbers of seams, and consequently, for various rock mass disturbance rates. In order to estimate the parameters of the surface deformation prediction theory, i.e. the exploitation coefficient and the angle of the main range of influences, geodesic measurements of subsidence along the observation lines were used. The study shows that rock mass disturbance affects the values of the Knothe theory parameters and the values of the surface deformation indicators. In the case of a larger number of selected seams, the determined value of the exploitation coefficient was larger than the determined value in the case of a less disturbed rock mass. Assuming inappropriate parameters for surface subsidence prediction may cause unexpected damage to surface objects.

Keywords: mining, intensity of exploitation, surface deformation, subsidence prediction

Streszczenie

W artykule przedstawiono analizę parametrów teorii prognozowania deformacji powierzchni terenu, którą wykonano dla jednej z kopalń węgla kamiennego w Górnośląskim Zagłębiu Węglowym. Analizie poddano dwa rejony kopalni, dla których w zbliżonych warunkach geologicznych prowadzono eksploatację z zawałem stropu dla różnej liczby pokładów, a więc różnego zruszenia górotworu. W celu oceny wartości parametrów teorii prognozowania, czyli współczynnika eksploatacji oraz kąta zasięgu wpływów głównych, posłużono się pomiarami geodezyjnymi obniżeń na liniach obserwacyjnych. Na podstawie przeprowadzonych badań stwierdzono, że zruszenie górotworu wpływa na wartości parametrów teorii Knothego, a więc i wartości wskaźników deformacji powierzchni terenu. Przy większej liczbie wybranych pokładów uzyskano większą wartość współczynnika eksploatacji niż przy mniejszym zruszeniu górotworu. Przyjęcie niewłaściwych parametrów do prognozy może powodować, że zakładane uszkodzenia w obiektach znajdujących się na powierzchni terenu będą inne niż oczekiwane.

Słowa kluczowe: górnictwo, intensywność eksploatacji, deformacje powierzchni, prognozowanie obniżeń

1. Introduction

Underground mining is consistently accompanied with the phenomenon of rock mass disturbance. It is assumed that the fracture of the rock mass occurs as a result of the movement of rocks into the excavated void. The disturbed rock mass remains in a state of relative balance, whereas the range and intensity of fracture depends upon the rock structure and overburden loading. The influence of rock mass disturbance on surface subsidence may be estimated using the parameter values of the surface deformation prediction theory.

The Knothe theory is most frequently used in the prediction of mining-induced surface deformation [1, 8, 15]. Crucial parameters of the influence function include the exploitation coefficient a, the angle of the main influences range β and the perimeter A_1. In addition, the depth of exploitation H and the thickness of the coal seam g are also essential.

The exploitation coefficient a is determined using the relationship between the largest possible subsidence forming at the bottom of the complete or incomplete trough and the average thickness of the excavated coal seam. Its value is dependent upon the method of exploitation, the method of post-mining void liquidation and the ratio of the seam excavation. The exploitation coefficient can be determined on the basis of the mining conditions in the flat section of the trough. The largest surface subsidence occurs during underground mining with roof caving in which the most frequently assumed value is $a = 0.7–0.8$. Numerous research studies show that the value may increase in rock mass affected by previous exploitation [5, 15].

The angle of the main influences range β is determined using the relationship between the depth of exploitation and the radius of the main influences range r; its value is most frequently determined by matching the trough obtained on the basis of the geodesic measurements to the theoretical trough. This allows the determination of the radius of the range r, and as a result, also the angle β. The value of the angle β is normally assumed to be in the range of 60–65° and depends upon such geological and mining factors as the method of backfilling of the excavated voids, the depth of a particular seam, the thickness of the strata overburden above the Carboniferous layers, or the disturbance of the analysed rock mass.

The perimeter A_1 is another parameter utilised for the prediction of surface deformation indices. The perimeter determines the movement of the profile of the subsidence trough in the direction of the goaf and describes the asymmetry of the profile of the subsidence trough.

The accuracy of the surface deformation prediction largely depends upon the credibility of the assumed parameters of the theoretical model, i.e. the exploitation coefficient and the angle of the main influences range. For mining with roof caving, the following values of the parameters are most frequently assumed for the surface deformation prediction: $a = 0.8$ and $\mathrm{tg}\beta = 2.0$. As numerous earlier research studies show, the values of the theory parameters generally depend upon the factors affected by geological and mining conditions [2, 6–11, 13, 14].

Nowadays, as a result of multi-seam mining exploitation at continually increasing depths, the obtained results often fail to represent the complete subsidence troughs; therefore, only occasionally is it possible to determine the theory values in a traditional way. In such cases, the determination of the parameters of the influences should be carried out with the application of specialist software [1, 3, 4, 12].

The paper presents the results of a study on the influence of rock mass disturbance on the value of the exploitation coefficient *a* and the angle of the main influences range β, which were determined using the TGB1 software. In fact, the analysed surface is a typical urban area – the precision of determining the above-mentioned parameters is of crucial importance [1, 12].

2. Research results in the areas subject to observations

The hard coal deposit in the area embraced by the observation study possesses an industrial value down to a depth of approx. 1,000 m. The following strata can be differentiated in the geological structure of the analysed area: the Quaternary (the Holocene, the Pleistocene), the Tertiary (the Miocene) and the Carboniferous strata (the 'Orzeskie' and 'Rudzkie' layers).

The Quaternary strata in the analysed area consists of alluvial sand, sand with gravel, and silty clay transforming into silt. The Tertiary strata deposited immediately above the Carboniferous layers consists of loam, claystone with small interlayers of silty sand and silt. These interlayers have varied thicknesses, depending upon the varied morphology of the terrain surface.

The Carboniferous rocks are mostly represented by siltstone, siltstone with sand inclusions and sandstone; however, the coal deposits are grouped as the 'Orzeskie' layers.

The study embraced two areas of the same coal mine in the Upper Silesian Coal Basin in the first area, three seams were subject to exploitation, whereas in the second area, the exploitation was executed in as many as eight seams. In both analysed areas, the mining was executed using the longwall system with roof caving.

In the areas subject to the study, the prevailing part of the terrain was an urban area with one- or two-storey buildings, mostly grouped along the transport roads, creating a rather loose and dispersed village-like settlement. In addition, dense and multi-storey settlements appear in the area, which is typical for the residential areas of a large city. In the analysed areas, there are also public buildings and industrial plants.

Area 1

In the period between November 2011 and September 2016, eight longwall panels situated in three coal seams (362/1, 401/1 and 404/1) were exploited in the analysed area. The average thickness of the excavated panels ranged between 1.90 m and 4.20 m, whereas the average depth of exploitation ranged between 900 m and 1,000 m.

Figure 1 presents the distribution and shape of particular longwall panels along with the positioning of the measurement line.

Measurements along observation line XVII are regularly carried out once a year. The subsidence of measurement line XVII in particular points ranged from 0.10 m (in the points 19–24) to 0.90 m (in the part closer to the end of the line, i.e. points 35–37) (Fig. 2). In 2015, the bottom of the trough was formed. While analysing the subsidence of particular points in time, it can be seen that the significant subsidence began to occur in the end of 2014 and its development is still in progress in all the points.

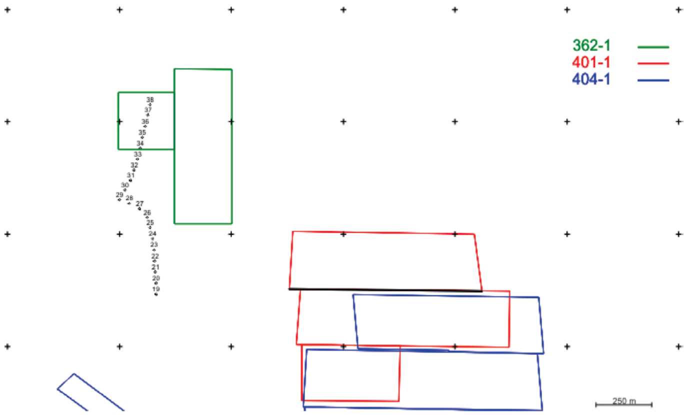

Fig. 1. Distribution and shape of exploitation in the period 2011-11-25 to 2016-09-14 in the area of line XVII

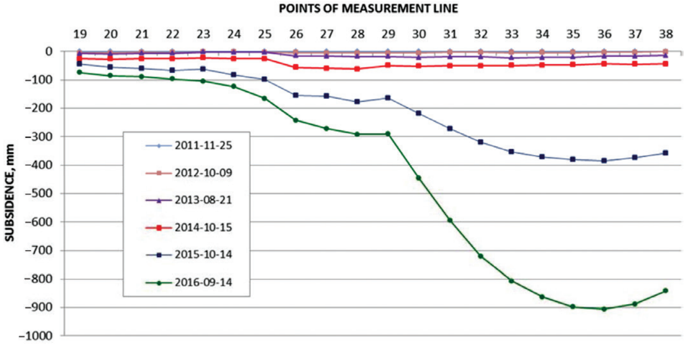

Fig. 2. Subsidence trough in observation line XVII

On the basis of the deformation analysis in line XVII, the parameters of the surface subsidence prediction theory have been determined (Table 1).

Table 1. Parameters of the Knothe theory for line XVII in the period 2011-11-25 to 2016-09-14

Parameters		**Values**
parameters of prediction theory	a	0.70
	A_1	0.150
	tgβ	1.97
coefficient of correlation	r	0.987
standard deviation [mm]	σ	36.8
variability index [%]	M_w	4.1
maximal subsidence [m]	w_{max}	0.91

The obtained values can be considered as typical for rock mass either undisturbed by earlier exploitation or slightly disturbed. The comparison of the subsidence measured in line XVII in the selected period of time with the subsidence calculated according to the Knothe theory is presented in Fig. 3.

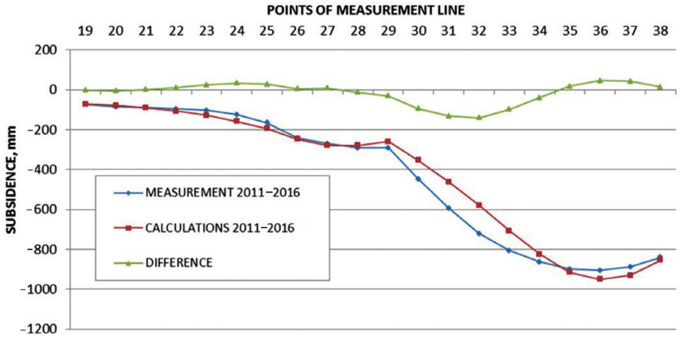

Fig. 3. Matching the measured subsidence with the calculated subsidence along line XVII in the period 2011-11-25 to 2016-09-14

Area 2

In the analysed area, eight coal seams (340/2, 346/1, 347/1, 355/1, 356/1, 357/1, 360-1, 361) were mined out with roof caving from April 1986 to March 2016 at depths ranging from 464 m to 961 m. The average thickness of the total 60 excavated longwall panels ranged between 1.3 m and 2.6 m.

It should be pointed out here that the exploitation was executed directly below the middle part of the observation line. The distribution and shape of particular panels and the positioning of the measurement line in the analysed area is presented in Fig. 4. The measurements along line XI have been conducted at a frequency of once per year since April 1986.

Fig. 4. Distribution and shape of exploitation in the period April 1986–March 2016 in the area of line XI

The subsidence in measurement line XI at particular points changed in the range from approx. 0.15 m on the edges of the line to 4.29 m at the point H 23.0 (Fig. 5). Therefore, a classical incomplete subsidence trough was created – this was close to being symmetrical in its middle part. Insignificant and homogeneous rates of subsidence at the end points of the line with values of approx. 0.15 m clearly indicate a lack of serious exploitation impact.

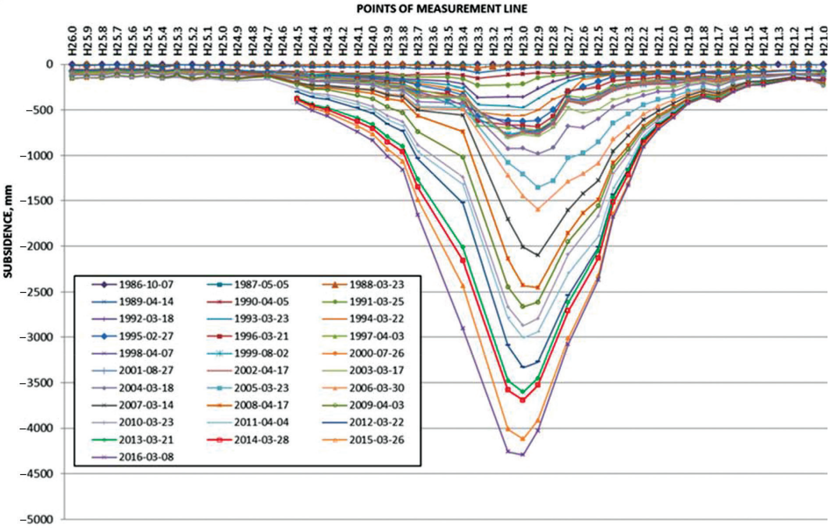

Fig. 5. Subsidence trough along observation line XI

The determined parameters on observation line XI in the analysed period are presented in Table 2. The obtained values indicate that the increased number of excavated longwall panels, especially immediately below the measurement line, causes an increase in the values of the surface subsidence and, as a result, the theory parameters also reach values higher than those which are typical.

Table 2. Parameters of the Knothe theory for line XI in the period April 1986–March 2016

Parameters		Values
parameters of prediction theory	a	0.91
	A_1	0.144
	$\mathrm{tg}\beta$	2.15
coefficient of correlation	r	0.986
standard deviation [mm]	σ	221.5
variability index [%]	M_w	4.9
maximal subsidence [m]	$w_{\max}$	4.49

A comparison of the subsidence measured along line XI in the selected period of time (April 1986–March 2016) with the subsidence calculated theoretically is presented in Fig. 6.

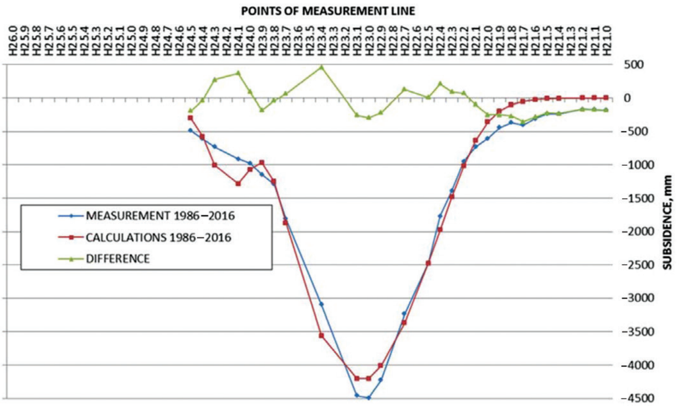

Fig. 6. Matching the measured subsidence with the calculated subsidence along line XI in the period April 1986–March 2016

3. Analysis of results

The parameter values of the function of influences, i.e. the exploitation coefficient *a* and the angle of the main influences range tgβ, were obtained from the calculations. The analysis of the results indicates that the rock mass disturbance affects the values of surface deformation, as well as the volume of mining damage. Depending on the assumed values of the prediction theory parameters, the differences in determining the values of surface subsidence in both selected areas can be presented in the form of an isoline.

Area 1

The values of surface subsidence in the first selected area were determined for the commonly assumed prediction parameters ($a = 0.80$, tgβ = 2.0), as well as for the parameters $a = 0.70$ and tgβ = 1.97 determined in geodesic measurements in observation line XVII. Fig. 7 and Fig. 8 present the isolines of surface subsidence determined for both variants of the assumed prediction parameters.

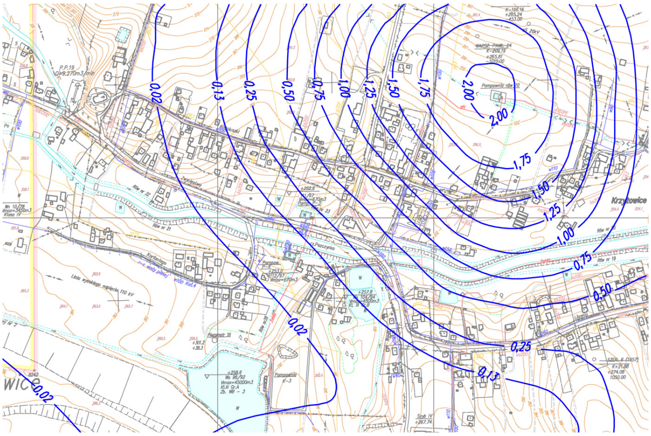

Fig. 7. Subsidence with the standard theory parameters $a = 0.80$ tgβ = 2.0

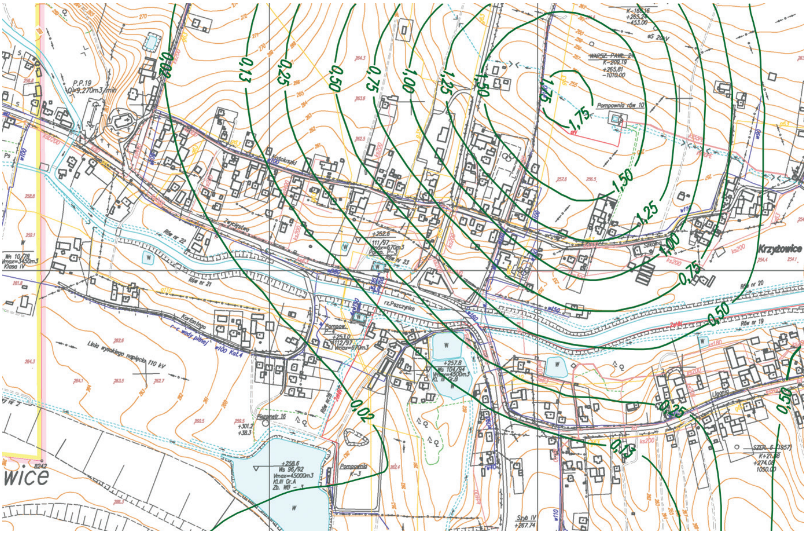

Fig. 8. Subsidence with the theory parameters *a* = 0.70 tgβ = 1.97 obtained from the geodesic measurements along line XVII

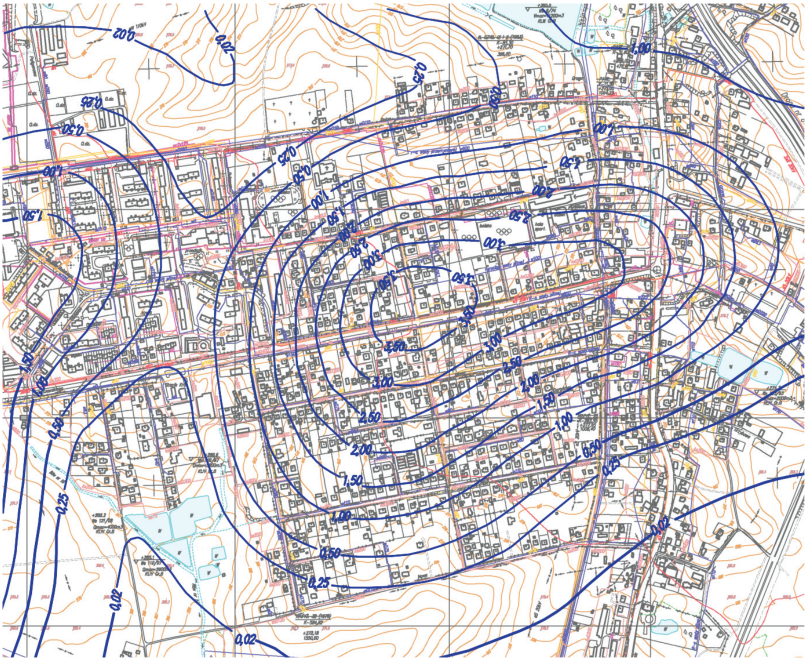

Fig. 9. Subsidence with the standard theory parameters *a* = 0.80 tgβ = 2.0

The deformation prediction, utilising the determined values of the parameters (i.e. *a* = 0.7 and tgβ = 1.97), results in obtaining maximum real values of the urban area subsidence that are smaller by 0.25 m. In the case of only slightly disturbed rock mass, the values of surface subsidence are smaller than the values obtained with the use of the commonly assumed parameter values (i.e. *a* = 0.8 and tgβ = 0.2).

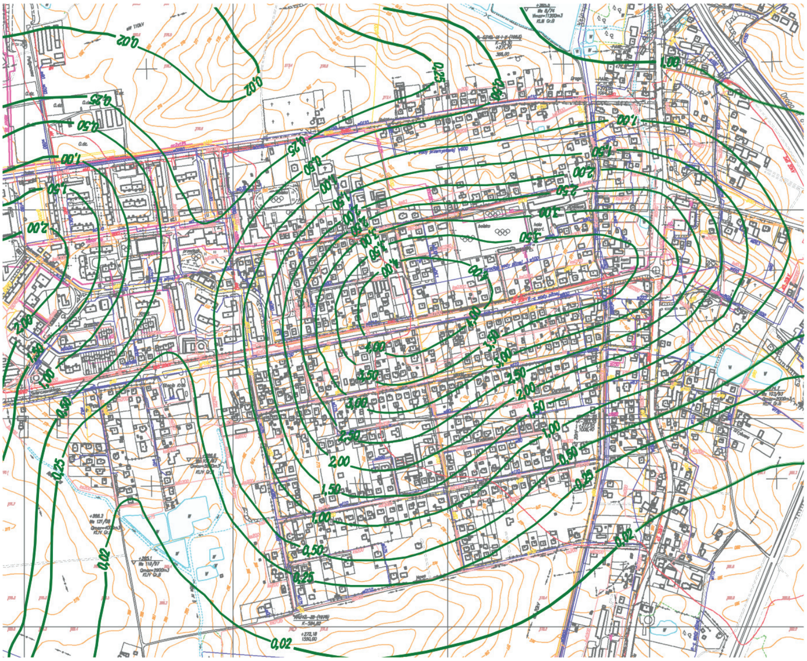

Fig. 10. Subsidence with the theory parameters *a* = 0.90 tgβ = 2.15 obtained from the geodesic measurements along line XI

Area 2

In the second selected area, the comparison embraced the values of the surface subsidence determined with the parameters commonly assumed for the prediction (*a* = 0.80 tgβ = 2.0) (Fig. 9), as well as for the parameters *a* and tgβ determined from the geodesic measurements along observation line XI. Figures 9 and 10 present the isolines of surface subsidence determined for both variants of the prediction parameters.

In the rock mass disturbed by multiple exploitation, the values of the prediction theory parameters determined from the measurements along the observation line were *a* = 0.90 and tgβ = 2.15. The comparison of the real subsidence with the subsidence expected from the prediction using the theory parameters (*a* = 0.80 and tgβ = 2.0) shows that in the selected area, the target subsidence was more than 0.5 m larger than expected in the analysed period of time. In the rock mass disturbed with by mining exploitation, the parameters *a* and tgβ have larger than standard values – this results in larger surface subsidence. The Knothe theory, commonly applied in the estimation of the impact of mining, refers to the predicting surface deformation and its consequences, hence the obtained results because of crucial practical importance due to the urban character of the area analysed in this study.

The prediction of surface subsidence induced by multi-seam mining exploitation requires particular calculations. In such calculations, the shape and dimensions of the mining field, as well as the exploitation coefficient and the angle of the main influences range, are essential. The present study shows that the values of the theory parameters should be assumed also in relation to the degree of rock mass disturbance.

In order to determine the optimal conditions for mining activities in urban areas, it is crucial to evaluate the state of each building existing in the premises of the designed mining exploitation. Such an evaluation should particularly embrace the state of damage in the building, the building construction, the general technical condition of the building related to its technical wear (including earlier mining damage), the predicted values and types of surface deformation of the terrain and the existing protection against mining damage.

Assuming proper values of the prediction theory parameters for predicting surface subsidence is a crucial factor in determining the real values of surface deformation. Such an approach facilitates the adequate and precise determination of the influence of mining on terrain surface and building objects and, at the same time, helps to prevent or limit some negative consequences of mining activity to the natural environment and urban areas.

4. Conclusions

1. The study on the exploitation coefficient *a* and the angle of the main influences range tgβ has been carried out for two areas of a selected coal mine. The analysed cases are characteristic of similar geological conditions and exploitation systems (underground mining with roof caving). They differ, however, in relation to the rock mass disturbance resulting from a different number of excavated coal seams.
2. In the surface deformation prediction, the value of parameters *a* and tgβ should be adopted on the basis of matching the theoretical curve of subsidence with the curve of the subsidence obtained from the geodesic measurements. The values of the exploitation coefficient and the angle of the main influences range increase along with the increase of rock mass disturbance.
3. Assuming the equivalent values of the exploitation coefficient and the angle of the main influences range facilitates the determination of surface subsidence; it also allows the prediction of the potential damage of the selected buildings and planning of the range of renovation works or preventive measures.

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