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Identification of theoretical parameters used to forecast impact of underground mining on one coal seam performed on the basis of a geodetic survey

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Abstract. The paper is a case-study of ground surface subsidence induced by a short-term mining exploitation of hard coal. Budryk-Knothe's prediction theory is commonly used in Poland as a technique for prediction of the subsidence-related deformation of ground surface. The presented issue is related to assumptions about the value of the theory parameters in short-term forecasts on the impact of mining on the surface. Incorrectly selected values can significantly influence the quality of deformation forecasts.
The calculations presented in the article were made for the area where the exploitation of one coal seam lasted for few years. At the same time, deformations of the surface were observed by means of geodetic measurements. Parametric calculations were made for the increasing range of mining operations.

1. Introduction

Underground mining causes a number of changes in the environment due to exploitation of the deposits. The main changes include continuous surface deformation occurring in the form of the subsidence troughs. Forecasting these changes involves calculations of deformation indices based on the designs from the Budryk-Knothe's theory [1, 2] and, at a further stage, the values obtained in such way are used to categorize those mining areas, which in turn is crucial to assess the impact of exploitation on the surface. The quality of the forecast depends primarily on the values of the parameters that are used in the theoretical formulas. Parameter values should be based on the values obtained from surveying observations, which increase the reliability of the calculations.

Criteria that determine whether parameters can be identified are primarily: the termination of rock mass movements in the analyzed region and the lack of indirect influences (reactivation of abandoned workings, dehydration). In the case of exploitation conducted at a great depth, the impact of a single longwall panel on the surface may be small and only during exploitation of subsequent fields gives the opportunity to determine the parameters based on the theory.

As presented in the example given in this article, in order to identify those parameters, the subsidence trough measurements were used. They comprised data from several longwall panels exploited in one seam, in the rock mass untouched by earlier operations, for two different positions of longwall panels.

Issues related to identification of the parameters of the Budryk-Knothe's theory were previously discussed extensively in the literature on the subject [3, 4, 5, 6, 7, 8, 9, 10, 11, 12] and this article supplements the previous research.

2. Geological and mining conditions in the analyzed region

2.1. Geological structure

The rock mass in the area of interest is built of quaternary, tertiary and upper carboniferous formations.

Quaternary formations with a thickness of about 55 m include sands, gravels, clays, and silts.

Tertiary layers with a thickness of about 45 m are made of gray clays.

Upper Carboniferous structures in the analyzed area include the Orzesze layers with a clear dominance of claystones and mudstones over a few layers of fine-grained sandstones.

2.2. Tectonics

Carboniferous formations fall northwards at an angle of up to 40^o, whereas the angle of dip decreases with the depth.

In the south, the analyzed region borders with a fault zone with a vertical throw of about 80 m in the SW-NE direction.

2.3. The scope of mining exploitation

Mining exploitation was conducted in one seam of the Orzesze layers with a cave-in of the roof. It was the first mining operation in the analyzed area. Table (table 1) presents a brief characteristic of selected longwall panels, while figures (figure 1 and figure 2) showing two different positions of longwall panels for which the parameters of the theory were determined.

Table 1. Characteristics of excavated longwall panels.

Longwall panel	Coal seam thickness g [m]	Mean depth exploitation range H [m]	Exploitation time frame [years]
1a	1,0	455	1983-84
3	1,0	485	1984-85
5a	1,0	535	1985-87
5c	1,2	550	1986-88
5d	1,3	570	1988

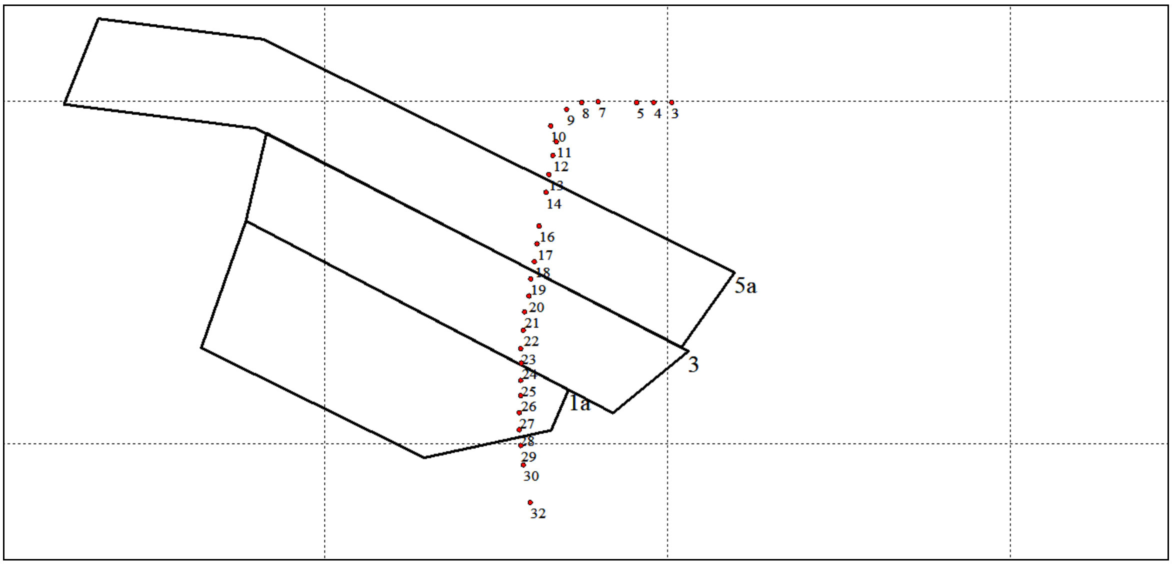

Figure 1. Excavated longwall panels and location of observation stations – first period.

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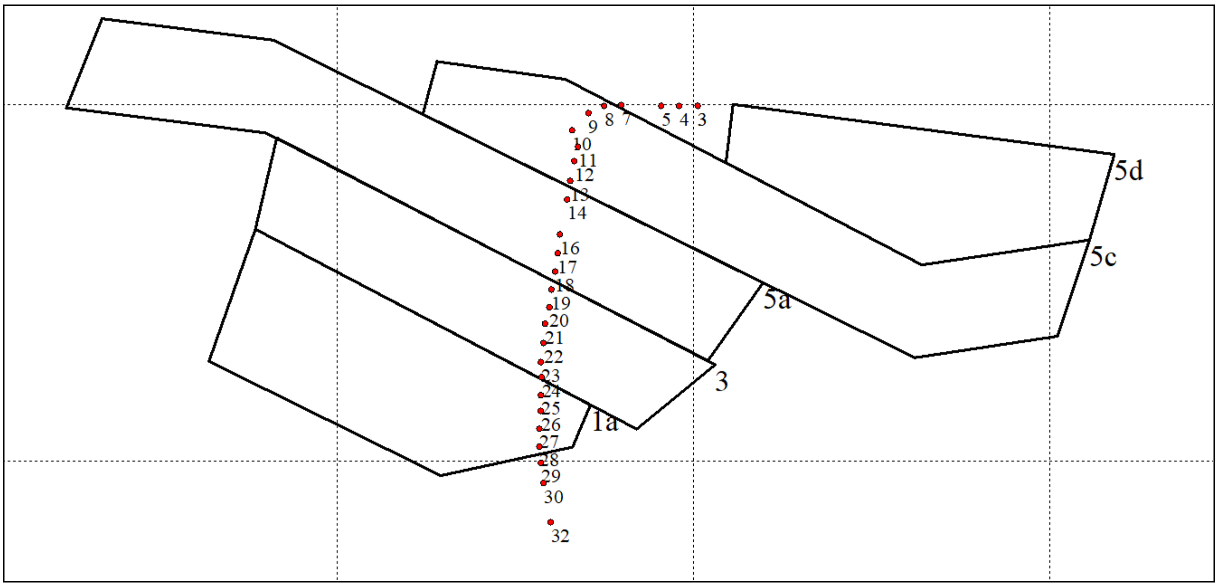

Figure 2. Excavated longwall panels and location of observation stations – second period

2.4. Geodetic surveys

Geodetic surveys on the measuring line were performed on the surface, the location of which is shown in figures 1 and 2. The initial measurements were made before the first rock movements were revealed. Measured profile of subsidence trough is shown in figure 3. The graph demonstrates that subsidence in the measuring line is from about from -0.05 m to -0.07 m in the boundary zone of the subsidence trough to about -0.64 m in the maximum subsidence zone.

Based on them, a plot of subsidence of measurement points over time was made, as shown for chosen observation points in figure 4.

Two periods of motion decrease have been identified, based on the analysis of subsidence points in time and the range of current exploitation:

- first period (figure 3 and figure 4) – exploitation of longwall panels 1a, 3, 5a (figure 1);
- second period (figure 3 and figure 4) – exploitation of longwall panels 1a, 3, 5a, 5c, 5d (figure 2).

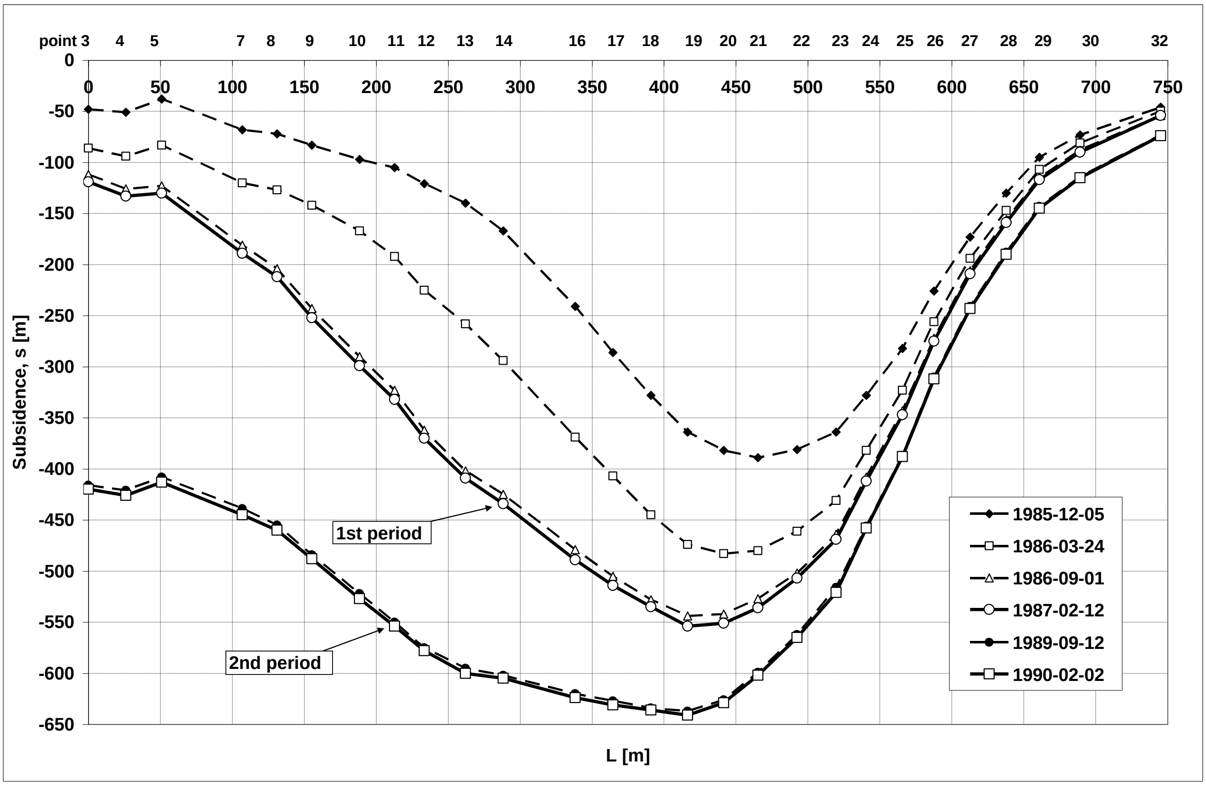

Figure 3. Subsidence monitoring results over longwall panels 1a – 5d.

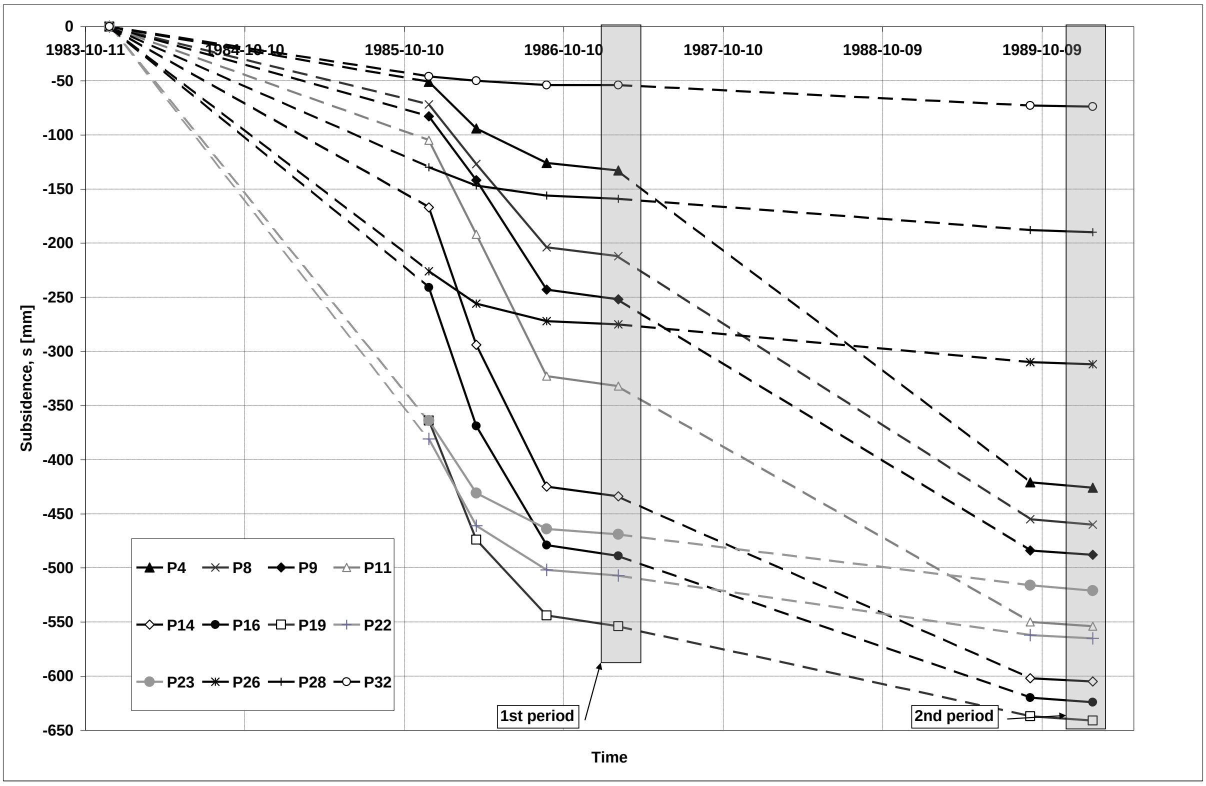

Figure 4. Time-subsidence curve of chosen observation points.

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3. Identification of parameters of the Budryk-Knothe's forecasting theory

The Budryk-Knothe's theory of predicting influences on the rock mass and surface [1, 2] it is based on the normal distribution of influences. Formula (1) for subsidence in the case of a two-dimensional displacement is as follows:

$$w(s,t) = \iint_P \frac{w_{max}}{r^2} e^{\frac{-\pi}{r^2}\left[(x-p)^2+(y-q)^2\right]} dP \tag{1}$$

where:
$s_{max} = ag$ – maximum subsidence, [m].
a – coefficient of roof control,
g – mean thickness of the exploited coal seam, [m],
p, q – point coordinates, [m],
P – the area of extraction (exploitation) panel,
r – influence dispersion radius, [m],
x, y – exploitation element coordinates, [m].

Identification of the parameter values of the geometric integral theory was carried out with the use of the software developed by R. Ścigała [9, 10, 13]. In the given program, the least-squares method was used to find the minimum of the objective function (2):

$$F = \sum_{i=1}^{n} \left(s_{meas\ i} - s_{theor\ i}\right)^2 \tag{2}$$

where:
n – number of points observing line,
$s_{meas\ i}$ – subsidence measured at i-th point,
$s_{theor\ i}$ – subsidence calculated for i-th point by using considered theoretical model.

The minimum of the objective function is sought numerically with the use of the Hooke-Jeeves method.

The goodness of fit of a subsidence trough calculated theoretically to the values obtained from the measurements is expressed with two quantities:

- average error of single observation $M = \sqrt{\frac{\sum_{i=1}^{n}\left(s_{meas\ i} - s_{theor\ i}\right)^2}{n-1}}$,
- percentage error $M\% = \frac{M}{max(|s_{meas}|)} 100$,

where:
$max(|s_{meas}|)$ – absolute value of the maximum measured subsidence.

4. Results of parameter identification

The Budryk-Knothe's prediction theory parameters were identified for the assumed scope of operation and the results of geodetic measurements. The calculation results for all the cases considered are shown in table (table 2), while figure 5 illustrates the subsidence obtained from the measurements as well as the value calculated theoretically for the determined parameter values.

Table 2. Values of the Budryk-Knothe's prediction theory parameters for analyzed cases.

Parameters	First Period	Second period
Coefficient of roof control *a*	0,629	0,632
tanβ parameter	1,767	1,871
Average error of single observation *M* [mm]	14,41	26,07
Percentage error *M%* [%]	2,60	4,07

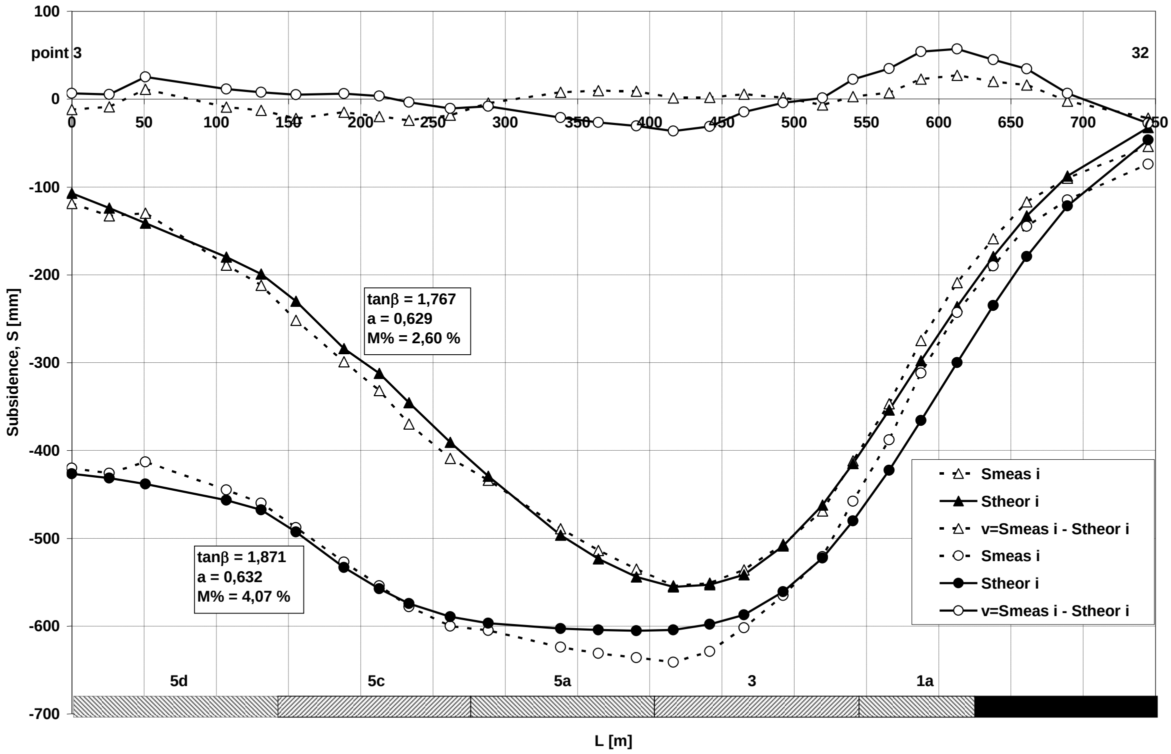

Figure 5. Comparison of measured subsidence *Smeas i* with subsidence predictions *Stheor i* obtained from Budryk-Knothe's influence function using calculated values of parameters (first and second period).

As a result of the performed calculations, it can be concluded that a high goodness of fit of theoretical troughs to those measured has been obtained, as evidenced by the values of the average percentage error. In both cases the values of subsidence coefficients can be considered a constant, while the value of the tanβ parameter increases for the second calculation period. The small value of the tanβ parameter confirms that no fracture of the rock mass was caused by the previous operations.

5. Summary

The article presents the results of the identification of the Budryk-Knothe's theory parameter values for a several-year long mining exploitation of one seam. The results of the study show possible changes in the values of parameters describing the final state of deformation, which may result from a fracture of the rock mass caused by exploitation, with a cave-in of the roof layers in subsequent longwall panels. It may be noticed that changes in the tan*β* parameter values for the two operational stages are small (change by approx. 0.1), and the value of the roof control coefficient may be considered constant.

The presented analysis indicates the need for further research in other regions of the Upper Silesian Coal Basin. It may give the opportunity to make more accurate predictions of the impact of mining operations on the surface.

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