THE COMPARISON OF IDENTIFICATION METHODS OF W.BUDRYK - S.KNOTHE THEORY PARAMETER “c” ON THE PRACTICAL EXAMPLE

SROVNÁNÍ IDENTIFIKAČNÍCH METOD PODLE W.BUDRYK - S.KNOTHE – TEORIE PARAMETRU “c” V PRAXI

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Abstract

This work presents practical example of identification of subsidence rate coefficient “c”, which is used in the W.Budryk-S.Knothe theory for description of post-mining transient deformation state of rock mass and land surface. The determination of the “c” parameter has been performed on the basis of surveys results, according to the traditional methods, as well as methodology proposed by author of this paper, involving the simultaneous determination of the parameter values in both: space and time coordinates. For determination purposes, the author’s own software was used. The presented example bases on the survey’s results from the area of one of Upper Silesia Basin hard coal mine. Obtained results point that proposed methodology seems to be a promising way of obtaining optimal value of the “c” parameter.

Abstrakt

Tato práce představuje praktický příklad stanovení koeficientu, který udává míru poklesu v poklesové kotlině a je označen symbolem „c“. Používá se v teorii W. Budryka a S. Knothe k popisu stavu přechodné deformace po dobývce pro horninový masiv a zemský povrch. Určení koeficientu „c“ bylo stanoveno na bázi výsledků sledování, které se týkaly tradičních metod stejně tak jako metodologie navržené autorem této práce, což zahrnuje současně simultánní stanovení obou parametrů tj. prostoru i časových souřadnic. Za účelem dosažení cíle byl použit autorův vlastní software. Předložený příklad vychází z výsledků sledování oblasti jednoho antracitového dolu z hornoslezské pánve. Získané výsledky naznačují, že navržená metodologie může představovat slibnou cestu jak získat optimální hodnotu koeficientu „c“.

Keywords

underground mining influences, geometric-integral theories, identification of parameters, transient deformation state

Klíčová slova

vliv podzemního dobývání, geometricko-integrální teorie, identifikace parametrů, přechodná deformace stavu

1 Introduction

In Polish hard coal mining industry, for prediction of surface subsidence changes over time (transient subsidence), the solution worked out by S.Knothe (Knothe, 1953b) is used most frequently. It bases on the assumption, that for a given point, the subsidence rate is proportional to the difference between final (asymptotic) value of subsidence w_k and momentary (transient) value w (t) in a given time t:

$$\frac{dw}{dt} = c \times \left(w_k - w(t)\right), \qquad (1)$$

where w_k = asymptotic value of subsidence due to extraction led up to time *t*. It should be calculated by using solution of W.Budryk-S.Knothe for asymptotic state (Knothe, 1953a).

w(t) = the value of transient subsidence at the time *t*;

c = the coefficient of subsidence rate;

The general solution of (1) for w(t) is :

$$w(t) = \int_0^t f(\lambda \times v) \times v d\lambda - e^{-ct} \int_0^t f(\lambda \times v) \times v \times e^{c\lambda} d\lambda, \qquad (2)$$

where v = is the extraction advance rate.

To meet the appropriate quality of prognoses of underground mining influences on the rock mass and land surface with using geometric-integral theories, one must possess the proper values of parameters to be taken into calculations.

The distribution of post-mining deformations of rock mass and land surface depends on many factors, thus proper method of parameters determination has an important impact on the prediction quality. The most appropriate way of evaluating them is their identification on the basis of geodetic measurements. Procedure for determining the values of parameters for geometric-integral theories should be performed according to the following rules:

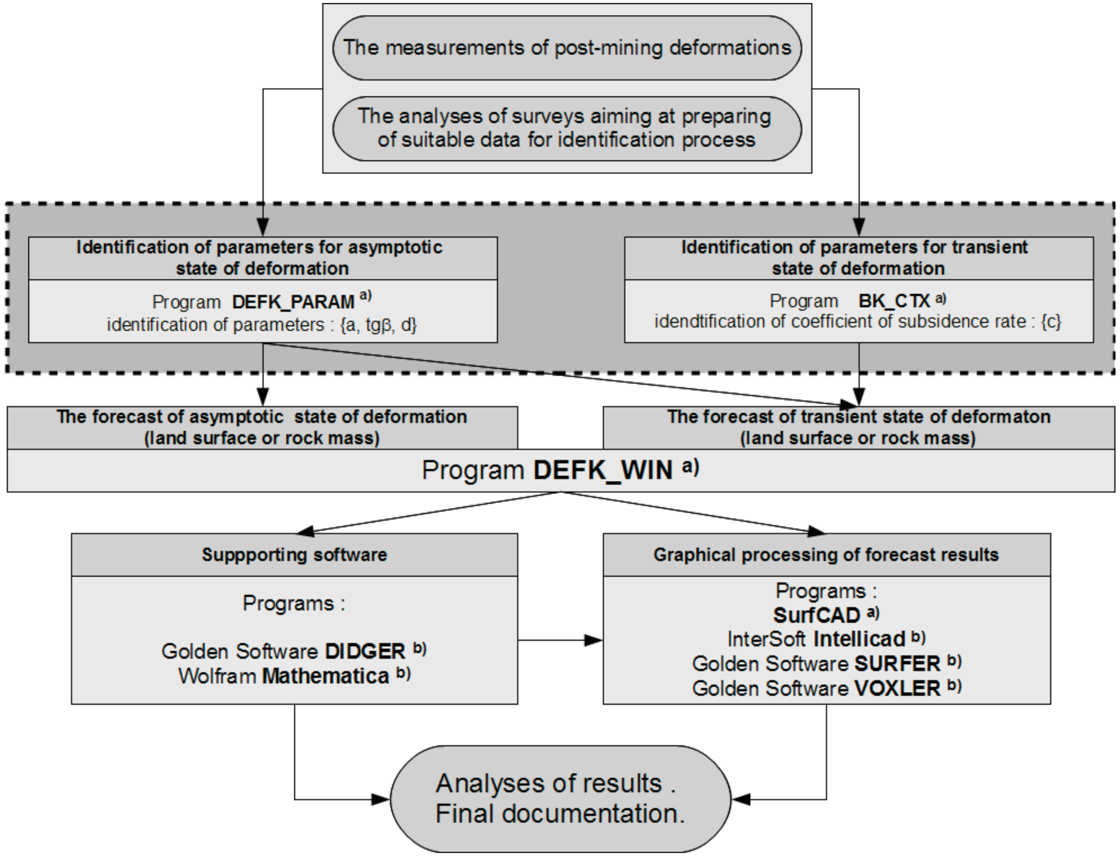

Fig.1 The general stages of works connected with forecasting of post-mining deformations in relation to discussed software system a) own software; b) commercially available software.

- The values of parameters should be determined on the basis of relevant results of surveys, conducted earlier in the area for which the forecast is being developed.
- If there is a lack of measurements from the area of interest, one should use the results from neighbouring region or area with similar geological structure.
- If there are no suitable survey results, the corresponding empirical formulas may be employed.

Originally, for parameters determination, simple analytical or graphical methods were used, where the basic requirement, which allowed use of surveys results for this task was, that extraction should be of so called "infinite half-plane" shape (Knothe, 1984). This means that recorded subsidence along the observing line should present the influence of a single extraction edge, preferably situated perpendicularly to the line. At a time, when the mining extraction was carried out at shallow depths, this condition was relatively easy to meet. Today, when the extraction is led usually at great depths, it is virtually impossible to satisfy this condition. Thus, all simplified methods of parameters identification do not work today.

So, it became necessary to use programmatic tools for this purpose, where it is possible to take into account the shape of extraction field. It should be noted here, that despite of the significant development of software tools for parameters identification, still apply the same basic principles of the selection of appropriate measurements results for the proper performance of this task (Ścigała, 2008; Strzałkowski, 2010).

In the Department of Geomechanics, Underground Construction and Surface Protection Management at the Faculty of Mining and Geology, Silesian University of Technology, a complete software system has been worked out to perform a variety of calculations related to the prediction of post-mining rock mass and land surface deformations. This system is being built by the author of this article for several years. Its scope is associated with the implementation of various stages of works related to the forecast. These stages are presented in Figure 1, along with the software names. In this figure, a rectangle outlined with dashed line indicates the part of system used for parameters identification. The general description of predictive part of the system is presented in (Ścigała, 2005).

2 The methods of parameter “c” identification

The coefficient of subsidence rate “*c*” can be determined in several ways (Ścigała, 2009) - see fig.2:

1. By using simplified graphical method that employs the course of subsidence over time for a single point. Today this method is obsolete, so it has not been presented in this paper.
2. Methods that base on the iterative algorithms:

2a. *Identification made on the basis of the subsidence course over time for each observing point.*

As an effect, one obtains as many “*c*” values as observing points analyzed. In this case space coordinates (point locations) are “fixed” - the identification is performed over time coordinate $\{t\}$.

2b. *Identification made on the basis of transient subsidence troughs from every measured profile.*

As an effect one obtains as many "c" values as subsidence troughs analyzed. In this case time is "fixed" – the identification is led over space coordinates {x,y}.

2c. *The simultaneous identification made over space and time coordinates {x, y, t}.*

In this case all the transient subsidence troughs are considered at once – as an effect the only one, "average" value of parameter "c" is obtained. This way is the most natural from prediction point of view - in prognoses we use one, constant value of "c".

In this paper, a practical example of using these methods and comparison of their results has been shown. The parameter "*c*" has been determined on the basis of the survey results taken from one of Upper Silesian Basin coal mines. For determination purposes, the author's own software was used, as presented in Fig.1. More detailed information about the software is presented in (Ścigała, 2013).

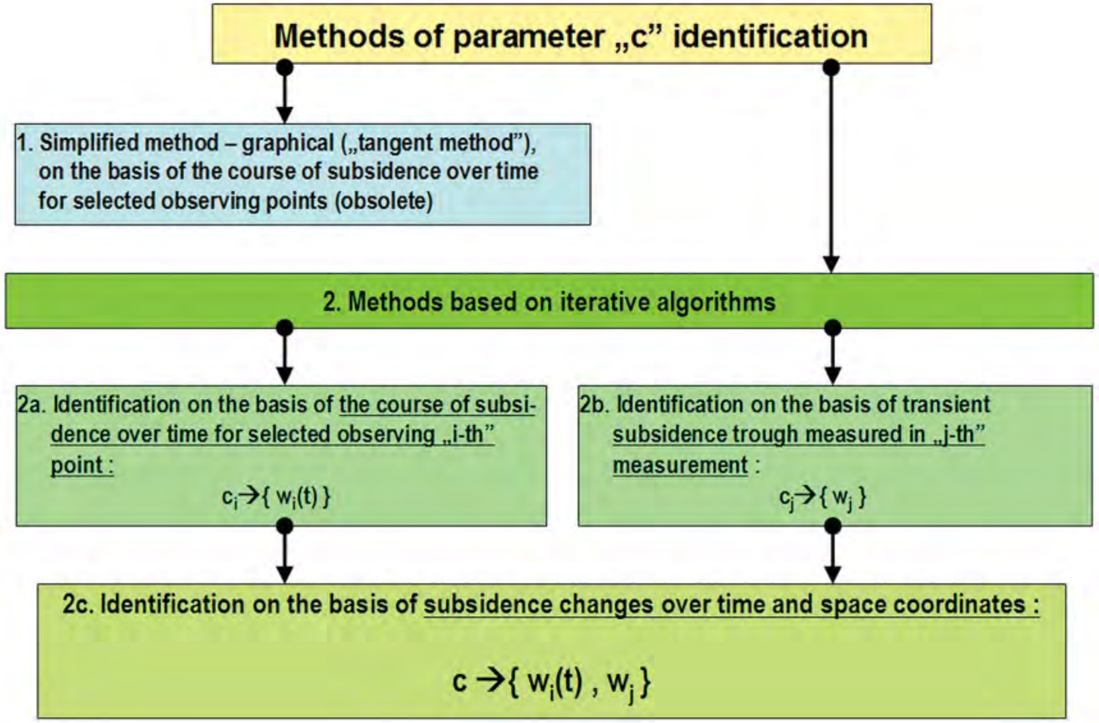

Fig.2 The methods of parameter "c" identification

3 Identification of parameter "c" value for one of Polish coal mine conditions

In the considered area, surveys were led on two observing lines located above extraction of several long walls, as shown in fig.3. For this paper purposes, measurements from line located perpendicular to the extraction advance has been used (in fig.3 marked with thick red line). Two long walls were extracted directly under the line (in fig.3 marked with green colour). The extraction was led with caving at the average depth of 310 m. The thickness of extracted deposit was equal to 3.3 m. There was earlier extraction led north to the considered area within the period of 2001-2004. First longwall started in November 2005 and was finished in the end of December 2006. The second one was extracted from March 2007 to January 2008.

The considered observing line consists of 24 points with average distance 25 m. Total line length is about 560 m. Measurements were led from November 2005 to September 2009, with various time interval, from 2 months up to 11 months. The most frequent time interval was 3 months. Totally, 12 measurement actions were performed. The last analyzed measurement was done in September 2009. In fig. 4 the measured subsidence troughs profiles are presented, as well as the courses of subsidence over time for every point.

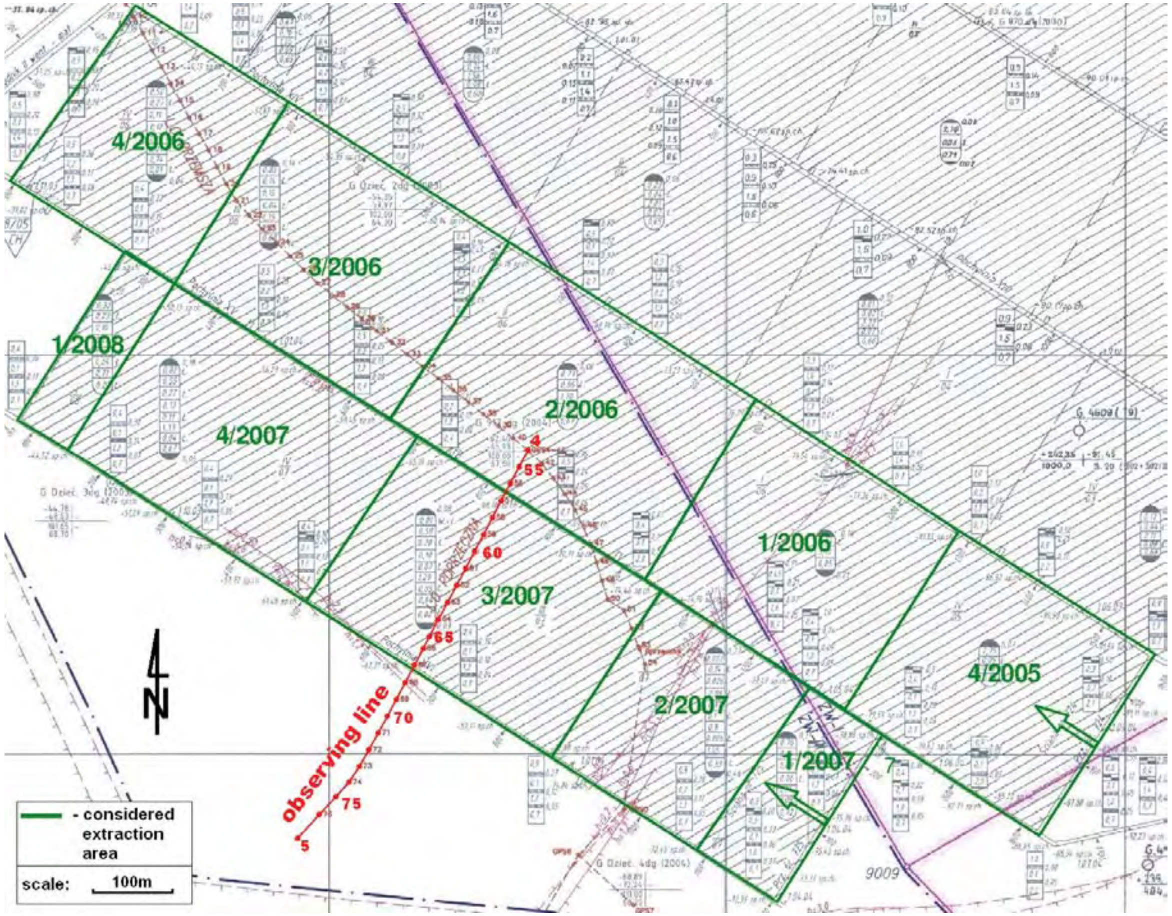

Fig.3 The location of extraction in relation to observing line

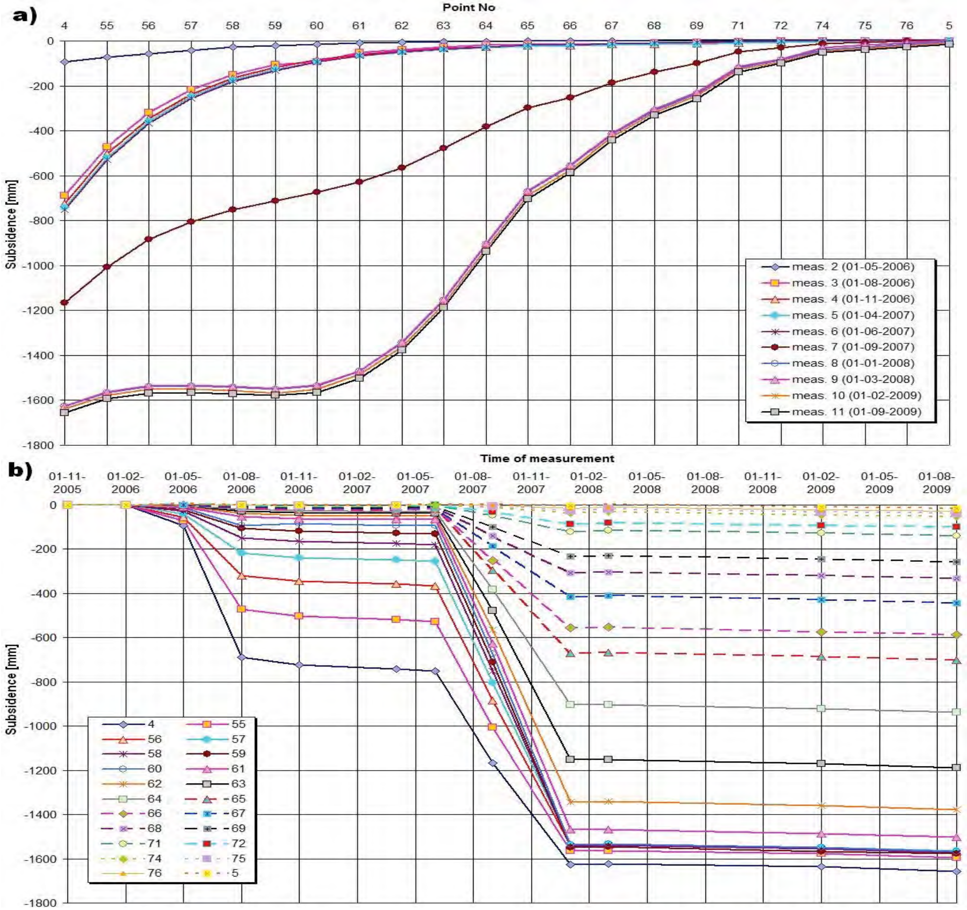

Fig.4 Measured subsidence trough profiles (a) and the course of subsidence over time for every observing point (b)

With using mentioned above software, parameters were determined, starting from the parameters describing the asymptotic trough profile. Following values have been obtained: coefficient of roof control: $a=0.51$, parameter describing the influence range: $tg\beta = 1.5$ (β - the angle of main influence range), extraction boundary: $d=50$ m.

Then, the parameter "*c*" was determined, firstly using traditional methods 2a and 2b, and then using proposed method 2c. In all calculations, determined earlier values of a, $tg\beta$ and d were used as constants. The resulting values are presented in table 1. What can be seen from the "*c*" values presented in table 1, that there is a quite great dispersion of its value, no matter if it has been identified on the basis of method 2a or 2b. As it was mentioned earlier, for prediction one has to have a single value. So there is necessary to use some kind of "averaging", usually with arithmetic mean. But the question arises: should all observing points (for method 2a) or all measurements (for method 2b) be taken for averaging, taking into account the quality of every survey?

The answer seems to be not as clear as one might expect. For example, in method 2a, if one tries to identify the value of "*c*" from the observing point, which is located relatively far from the edge of extraction (close to the distance of influence range), the distribution of subsidence over time shows very small values, close to the measurements error. So it is hard to say, which observing points may be taken for calculation of average value of "*c*" parameter.

Proposed by the author method 2c is free from such problems, because we use the whole measurement results set with the subsidence variability over the space and time coordinates. As an effect we obtain a single value, which is somewhat "automatically" averaged in the sense of least square method. And because of that, it seems to be the most accurate way for obtaining "*c*" values for the prediction purposes.

One thing more is necessary to mention here. Another question arises: how average values of "*c*" obtained form methods 2a and 2b compare to results from method 2c? In this case, as it is presented in table 1, as well as other research results, one can state that these values are different very often.

Table 1 The juxta-position of the "c" parameter values obtained by its identification with using all considered methods

Method 2a Identification on the basis of the subsidence course over time for each observing point.	**Method 2b** Identification on the basis of transient subsidence troughs from every measured profile	**Method 2c** Simultaneous identification over space and time coordinates {x,y,t}.

Method 2a

Point No	„c" value [1/day]	Percentage error [%]
4	0.005	12.4
55	0.004	13.6
56	0.005	15.0
57	0.007	14.9
58	0.012	12.9
59	0.024	9.6
60	0.054	5.9
61	0.067	3.9
62	0.072	2.7
63	0.069	1.2
64	0.061	3.7
65	0.056	7.8
66	0.061	7.1
67	0.064	4.5
68	0.084	4.9
Average value :	**0.043**	

Method 2b

Survey No	Date of measurement	„c" value [1/day]	Percentage error [%]
2	V.2006	0.071	5.6
3	VIII.2006	0.008	6.7
4	XI.2006	0.004	6.3
5	IV.2007	0.002	6.1
6	VI.2007	0.002	5.9
7	IX.2007	0.044	8.7
8	I.2008	0.029	2.9
9	III.2008	0.019	2.9
10	II.2009	0.009	2.9
Average value :		**0.021**	

Method 2c

"c" value : 0.014 [1/day]

Percentage error : 9.0%

4 Conclusions

Summing up presented in the paper material, one can draw the following conclusions:

- The presently used identification methods for the subsidence rate coefficient "*c*" assume its determination either on the basis of the course of subsidence over time for single observing points (2a), or on the basis of measured transient troughs profiles (2b). In both cases, this results in obtaining different values of "*c*" for each case.
- Performed today predictions of transient deformation state with using the W.Budryk-S.Knothe theory require the use of a one, constant value of parameter "*c*". With different values of "*c*" obtained in the identification process by using methods 2a and 2b, it is necessary to get for predictions the only single value - usually the arithmetic mean is used. One could ask here if such procedure is correct.
- A solution to this problem may be the proposed method 2c, which allows to obtain a single, optimal (in terms of the least squares method) value of the parameter "*c*", determined on the basis of the measured space-time distribution of subsidence.

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