SOFTWARE SYSTEM FOR IDENTIFICATION OF PARAMETERS NEEDED FOR FORECAST OF DEFORMATIONS CAUSED BY UNDERGROUND EXTRACTION

SOFWAROVÝ SYSTÉM IDENTIFIKACE PARAMETRŮ POTŘEBNÝCH PRO PŘEDPOVĚĎ DEFORMACÍ VYVOLANÝCH PODZEMNÍ DOBÝVKOU

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Abstract

In this work, a system of two specialized computer programs necessary in forecasting of post–mining deformations has been presented. They have been designed for parameters determination of W.Budryk–S.Knothe theory. These parameters have different values in a given mining – geological conditions. So it is necessary to determine their values for forecasting purposes in considered coal mine area on the basis of the survey results. Presented system serves for identification of parameters describing asymptotic state of deformation (coefficient of roof control “a”, parameter “tgβ” and extraction boundary “d”), as well as transient deformations (coefficient of subsidence rate “c”).

Abstrakt

V této práci je uveden systém dvou specializovaných výpočetních programů, které jsou potřebné pro předpověď deformací spojených s ukončením hornické dobývky. Byly přizpůsobeny pro parametry determinace podle teorie W.Budryka a S.Knothe. Parametry nabývají různých hodnot podle konkrétních hornicko-geologických podmínek. Takže je třeba stanovit jejich hodnoty za účelem odhadu pro danou uhelnou oblast na základě kontrolních měření. Předložený systém slouží pro identifikaci parametrů, které popisují asymptotický stav deformace (koeficient kontroly pokryvu “a”, parametr “tgβ”, hranice dobývaného prostoru “d”) stejně dobře jako přechodové deformace (koeficient velikosti poklesu “c”).

Keywords

underground mining influences, geometric–integral theories, identification of parameters

Klíčová slova

vlivy podzemního dobývání, geometricko-integrální teorie, identifikace parametrů

1 Introduction

The quality of prognoses of underground mining influences on the rock mass and land surface performed with using geometric–integral theories is closely tied with values of their parameters taken for calculations. The best way of evaluating them is identification on the basis of geodetic measurements. At the times, when extraction was led at shallow depths, a simple analytical or graphical methods were employed – these methods can be used in cases, where recorded subsidence along the observing line presents itself the influence of a single extraction edge, preferably situated perpendicularly to the line. Today, when extraction is led usually at great depths (in some Polish hard coal mines the present depth of extraction is more than 1000 m), it is nearly impossible to satisfy this condition. Thus, all simple methods of parameters identification are not suitable for 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 in relation to its depth. Presently in Poland several software solutions in this field is functioning. This paper presents such software worked out by author of this paper. It can be used for determination of parameters of W.Budryk–S.Knothe theory (Knothe 1953). Below, there is a short description of this theory presented, then the principles of parameters determination, the basic characteristic of software and finally the example of its usage is shown.

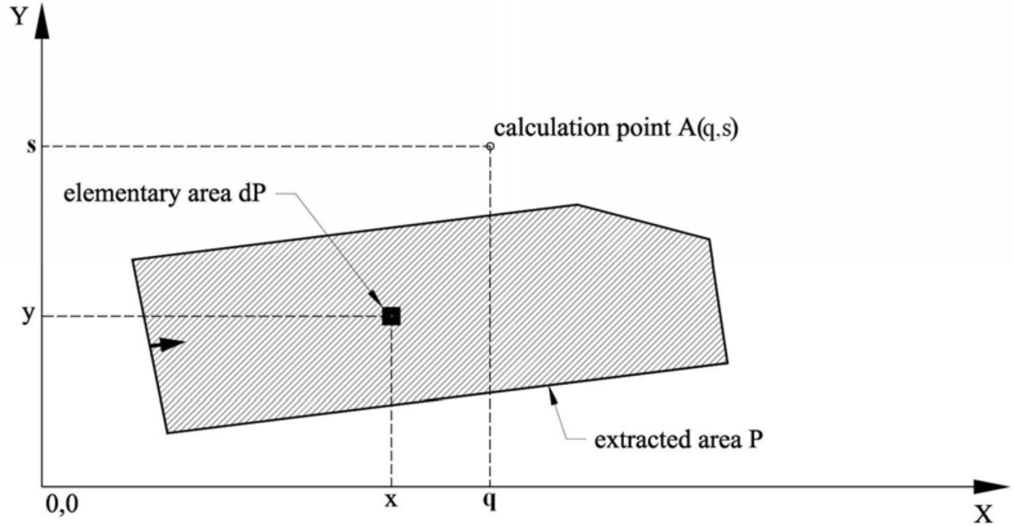

Fig.1. The sketch illustrating calculation of subsidence according to formula (2)

2 The principles of W.Budryk–S.Knothe theory

2.1Asymptotic state of deformation

Influences of elementary underground extraction area ***dP*** (fig.1) can be described by using so–called influence function. It is a special kind of function, which integral calculated over extracted seam area is a measure of asymptotic (final) subsidence for given point at the land surface:

$$f(x-q, y-s) = \frac{w_{\max}}{r^2} \times \exp\left\{\frac{-\pi \times \left[(x-q)^2 + (y-s)^2\right]}{r^2}\right\} \qquad (1)$$

For chosen point A (q, s), the subsidence ***w (q, s)*** one can calculate as:

$$w(q,s) = -\frac{a \cdot g}{r^2} \times \iint\limits_P f(x-q, y-s)\, dP \qquad (2)$$

where: g – thickness of coal seam;

a – coefficient of roof control;

q, s – coordinates of point A in a Cartesian coordinate system;

x, y – coordinates of elementary extraction field dP;

P – the extracted area of coal seams;

r – the main influences range.

Terrain tilt ***T*** is defined as first derivative of subsidence with respect to given direction: $T_x = \frac{\partial w}{\partial x},\ T_y = \frac{\partial w}{\partial y}$. Vertical curvature ***K*** is defined as second derivative of subsidence with respect to given direction: $K_x \cong \frac{\partial^2 w}{\partial x^2},\ K_y \cong \frac{\partial^2 w}{\partial y^2}$. Horizontal displacement ***u*** is proportional to the tilt : $u_x = -B\frac{\partial w}{\partial x}, u_y = -B\frac{\partial w}{\partial y}$. Horizontal strain ε is defined as first derivative of horizontal displacement with respect to given direction: $\varepsilon_x = \frac{\partial u}{\partial x}, \varepsilon_y = \frac{\partial u}{\partial y}$.

2.2 Transient state of deformation

For description of surface subsidence changes over time (so called “transient subsidence”), S.Knothe made an assumption, that for given point, the rate of its subsidence is proportional to the difference between final value of subsidence w_k and momentary (transient) value $w(t)$ (in given time t) :

$$\frac{dw}{dt} = c \times \left(w_k - w(t)\right) \qquad (3)$$

where: w_k – asymptotic value of subsidence due to extraction led up to time “t”;

$w(t)$ – the value of transient subsidence at time “t”;

c – coefficient of the subsidence rate.

Assuming that $w_k = const.$ (extraction is done with “one step” – $e_{xtraction} \rightarrow 0$) and $w(0) = 0$ we get simple solution:

$$w(t) = w_k \times (1 - e^{-ct}) \qquad (4)$$

This solution suffers considerable inconsistency: subsidence process should start with maximum speed, which is not true – in practice, the final value of subsidence $\boldsymbol{w_k}$ changes over time: $\boldsymbol{w_k \neq const.}$, due to lasting coal face advance: $\boldsymbol{w_k \rightarrow w_k(t)}$. This fact considerably complicates the solution of equation (3):

$$w(t) = \int_0^t f(\lambda \times v) \times v \, d\lambda - e^{-ct} \times \int_0^t f(\lambda \times v) \times v \times e^{c\lambda} d\lambda. \qquad (5)$$

For practical reasons it is convenient to assume, that the extracted field is divided into small elementary fields. So, it may be assumed that the extraction time for each field is close to zero. Taking this into account, the condition: $\boldsymbol{w_k(t)=const.}$ is fulfilled. In this case, we can use solution (4) and, for i–th elementary field, extracted at time $\boldsymbol{\tau_i}$, we have elementary subsidence $\boldsymbol{w(\tau_i)}$ “generated”:

$$w(\tau_i) = w_{ki} \times \left(1 - e^{-c(t-\tau_i)}\right), \qquad (6)$$

where: $\boldsymbol{w_{ki}}$– asymptotic value of subsidence due to extraction of i–th elementary field.

Summing up all the “elementary subsidence” calculated by using (6), we get good approximation of the solution (5) :

$$w(t) = \sum_{i=1}^{K} w(\tau_i), \qquad (7)$$

where : ***K***– total number of elementary extraction fields.

2.3 Parameters

There are two sets of parameters, what can be seen from the formulae presented above: first one is connected with description of asymptotic state of deformation, and second one consists of parameters describing transient state (in case of W.Budryk–S.Knothe theory there is only one parameter in this set). Below one can find a short descriptive summary of these parameters.

For forecasting of ***asymptotic state*** of deformation is necessary to determine the values of:

a – coefficient of roof control;

r – the main influences range. It is closely tied with alternative parameter $\boldsymbol{tg\beta}$ by simple equation: $\boldsymbol{tg\beta=H/r}$ where ***H*** is the depth of extraction;

d – so called “extraction boundary”;

B – parameter of horizontal influences.

Additionally, for description of ***transient*** state of deformation we use:

c – coefficient of subsidence rate (often called “time factor”).

The complete set of parameters {a, tgβ, r, d, c}, accepted for prognoses, should be determined on the basis of surveys from considered forecast area, however parameter ***B*** in Upper Silesia Basin is usually taken as constant value : ***B=0.32r***.

2.4 The rules of parameters identification

Certain general principles of parameters identification exist. They can be described in the following manner (Ścigała 2008, Strzałkowski 2010):

(1) The values of parameters should be determined on the basis of surveys from the area of interest (area of deformation forecast);
(2) If (1) can't be fulfilled, one should use survey results from the neighbouring area or area with similar mining–geological conditions;
(3) If (1) and (2) can't be fulfilled, it is possible to use some empirical formulae available for given area.

The selection of the measurement results suitable for parameters describing asymptotic trough, should be subject to the following rules:

- the subsidence trough should present asymptotic state of deformation;
- the extraction range which caused the asymptotic trough should be unequivocally determined;
- the extraction field should have large enough area in relation to its depth;
- there should be no other factors disturbing the subsidence trough profile (e.g. rock mass drainage, activation of old shallow workings);
- the surveys should cover the whole deformation process.

For determination of parameter ***c***, describing transient state of deformation, some important remarks must be pointed:

- One should have in possession survey results that reflect the advance of subsidence trough in relation to coal face advance;
- There is essential to establish proper relations between date of given survey and location of extraction front (face edge) at this date for every survey action;
- One should have in possession parameters describing asymptotic state of deformation : ***{a, tgβ, d}*** They must be used in determination of parameter ***c*** as constant over time;
- With considered software it is possible to analyze several coal faces influences (older software was usually limited to one extraction field);
- The **c** parameter can be determined in 3 ways :
    - from each measured transient subsidence trough. As an effect one obtain as many ***c*** values as subsidence troughs analyzed. In this case time is "fixed" – the identification is led in space coordinates {x,y}.
    - from each observing point. As an effect one obtain as many ***c*** values as observing points analyzed. In this case space coordinates are "fixed" – the identification is led along time coordinate {t}.
    - simultaneously in space and time coordinates {x,y,t} (Ścigała 2009). 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 forecasting point of view – in prognoses we use one, constant value of ***c***.

3 Short description of the software

Presented in the paper two programs are part of whole software system, which consists of author's own and commercial programs. This system serve in the Department of Geomechanics, Underground Construction and Surface Protection Management at the Faculty of Mining and Geology, Silesian University of Technology, to perform a variety of calculations related to the prediction of post–mining rock mass and land surface deformations (Ścigała 2005, 2008). The central part of the system is a relational database that contains data

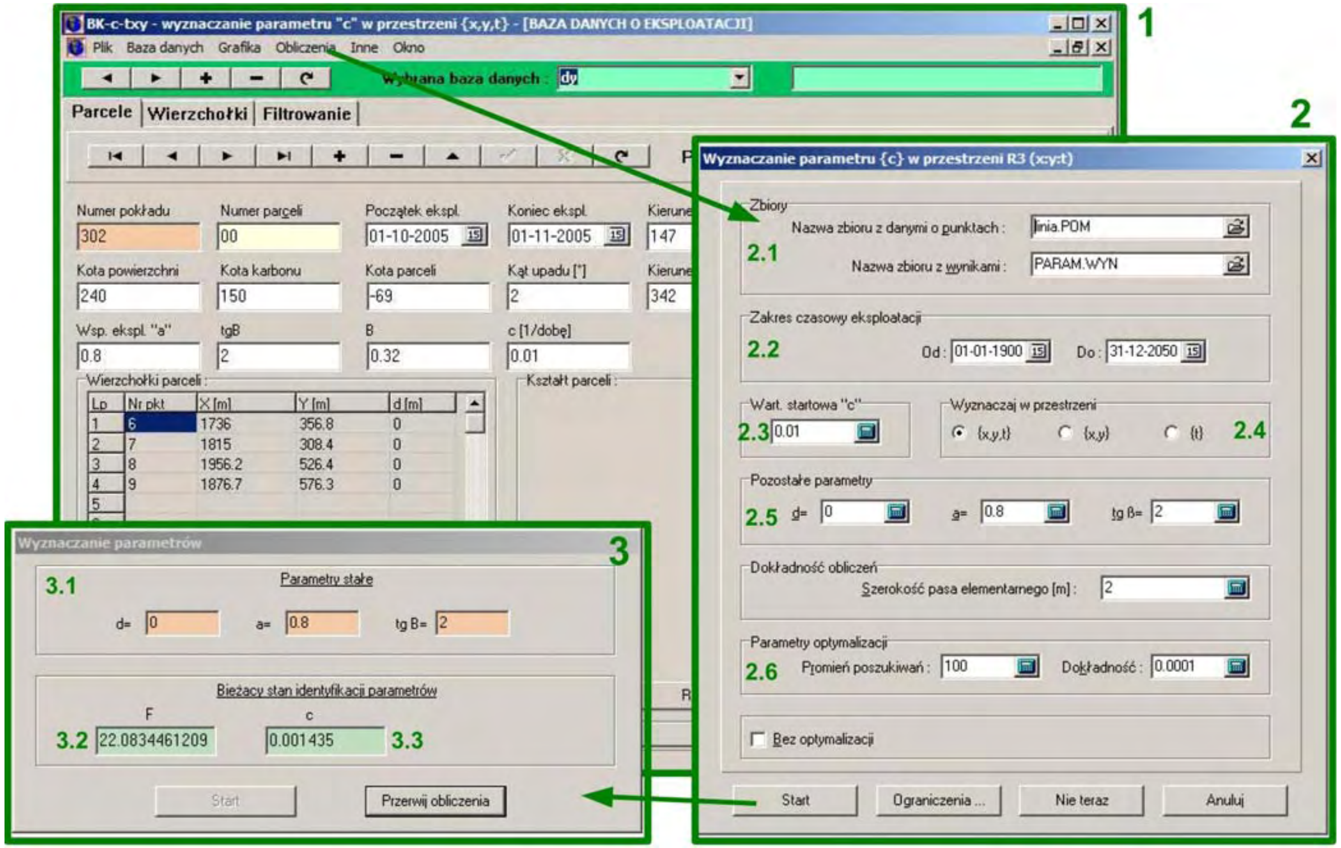

Fig.2. Main windows of program BK_CTX connected with parameter c identification process

1 - Main application window with database contents
2 - Specification of data necessary for identification
2.1 - input & output file names
2.2 - extraction time range specification
2.3 - starting value of parameter ***c***
2.4 - modes of determination process
2.5 - definition of values of parameters $\{d,a,tg\beta\}$, describing asymptotic trough
2.6 - parameters of Hooke-Jeeves method
3 - Information window displayed during identification process
3.1 - information on used values of parameters $\{d,a,tg\beta\}$
3.2 - the value of objective function ***F*** for current iteration
3.2 - the value of parameter ***c*** for current iteration

concerning the extraction fields: finished and planned. Within the database, one can create any number of so–called "project accounts", each of which can hold any number of extraction fields of any geometry. All computing programs share this database, which greatly facilitates the use of the information recorded in one place. The database can be conveniently viewed, edited, and filtered, to select an appropriate range of extracted fields necessary to given computational task. The discussed here programs are:

- DEFK_PARAM – for identification of parameters describing asymptotic subsidence trough in W.Budryk–S.Knothe theory;
- BK_CTX – for identification of "time factor" ***c***.

The user interface for both programs is identical, due to their functioning in the environment of the Windows operating system, as well as author's intention to facilitate the operation of all programs in the package. Obvious differences exist in terms of content, associated with a variety of tasks for which these programs were developed. The main application window is shown in the background of Figure 2. Its main task is to manage the extraction database. In fig.2 there are two windows shown in the foreground. These are, for example purpose, the windows that serve for determination of parameter ***c***, in program BK_CTX. Very similar set of windows is used of course in program DEFK_PARAM, with some differences connected with other parameters set determination. Below on the right, there is short description of main controls used in these windows.

The identification process in these programs bases on the optimization task, with the objective function ***F*** built by using the least square method. In the most general case, the ***F*** function may be written as :

$$min\{F(\Omega)\} = min\left\{\sum_{j=1}^{M}\sum_{i=1}^{N}\left(W_{i,j}^{mes} - W_{i,j}^{mod}\right)^2\right\}, \qquad (8)$$

where: ***N*** – the number of observing points;
M – the number of used measurement cycles;
i – the point counter;
j – the measurements counter;
$W_{i,j}^{mes}$ – measured subsidence at point "i", for measurement time of cycle "j";
$W_{i,j}^{mod}$ – calculated (modelled) subsidence at point "i", for measurement time of cycle "j";
Ω – the set of parameters to be optimized : $\Omega \rightarrow \{a, tg\beta, d\}$ for asymptotic state or : $\Omega \rightarrow \{c\}$ for transient state.

In case of asymptotic parameters determination or in traditional methods of ***c*** determination, there is assumption made : $M=0$.

4 The example of parameters identification

For an example of software utilization purposes, the survey results from former "Czeczott" coal mine were taken into consideration. There was extraction led in the coal seam 207 with longwall system. The length of the longwall was about 250 m, the height 2.7 m. The average depth of extraction was 500 m. The seam inclination was about 6°, the rate of face advance: 1.5–5 m/day.

The survey results from two observing lines were analysed aiming at parameters determination. For analysis purposes, 8 measurement actions (cycles) were chosen. The last of analysed measurement actions presents profile of asymptotic trough. Fig.3 shows the location of analysed lines against extracted field. Apart from that, the location of extraction edge is marked at the moment of successive measurement actions, when transient subsidence troughs were measured. The number if measurement is shown close to bottom edge of extraction.

At the first stage of analysis, the parameters for asymptotic state of deformation were determined on the basic of asymptotic trough

profile measured at the measurement No 8 separately for each observing line. For this task the program DEFK_PARAM was used. The following average values were obtained: $\boldsymbol{a=0.64}$, $\boldsymbol{tg\beta=2.12}$, $\boldsymbol{d=62\ m}$.

The second stage concerned the identification of parameter $\boldsymbol{c}$. Having information about time and spatial changes of active extraction edge, as well as measured changes in profiles of subsidence troughs, the parameter $\boldsymbol{c}$ was determined using the BK_CTX software. For this task,

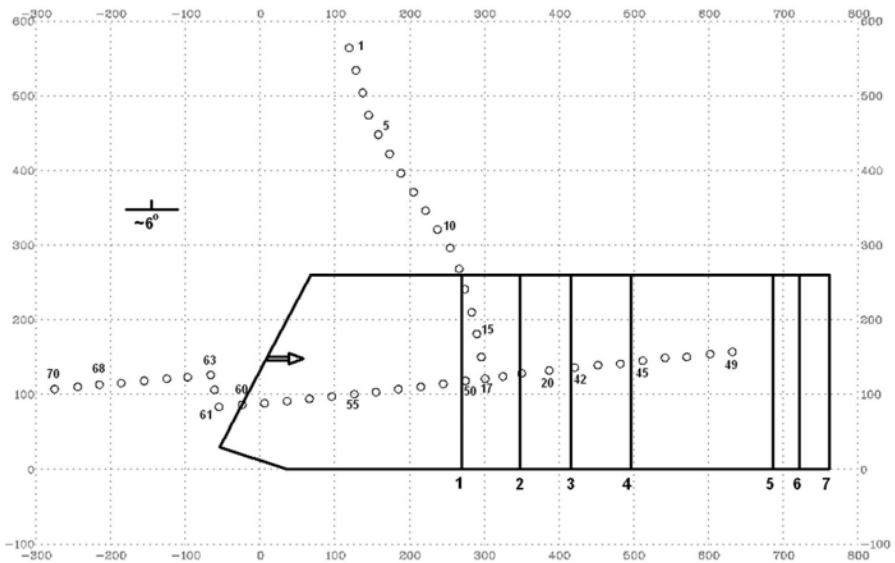

Fig.3. The location of analysed observing lines against extracted field

Tab.1 The juxtaposition of the c parameter values obtained by its independent identification for every measuring action

Measuring action	Measurement date	Obtained value of c [1/day]	Percentage error M [%]
1	12-10-1993	0.006	7.26%
2	28-10-1993	0.011	4.10%
3	13-11-1993	0.017	4.39%
4	02-12-1993	0.019	4.95%
5	06-01-1994	0.025	4.35%
6	22-01-1994	0.023	4.58%
7	12-02-1994	0.020	5.02%

Tab.2 The summary of the c parameter identification in (x,y,t} space

Determined value of c: c=0.019 [1/day]		
Measuring action	Measurement date	Percentage error M [%]
1	12-10-1993	59.91%
2	28-10-1993	20.70%
3	13-11-1993	6.34%
4	02-12-1993	4.97%
5	06-01-1994	6.65%
6	22-01-1994	5.54%
7	12-02-1994	5.03%

parameters obtained from asymptotic trough were used as constant values. The identification was performed twice : first in traditional way – on the basis of each transient subsidence trough profile. In this

procedure, for each considered measurement action, different values of ***c*** were obtained. Secondly – using author's proposal (Ścigała 2009) – by taking all measured points, across the time and spatial coordinates (see fig.1). In this case the only one value of ***c*** was obtained – this presents real "averaged" value due to using simultaneously the courses of subsidence along spatial and time coordinates. Table 1 presents the results of calculations of ***c*** values for each transient subsidence trough, table 2 – the results of using second method.

In the tables presented above, the percentage error was calculated as follows :

$$M_{\%} = \frac{\delta}{D_{\max}} \times 100\% , \qquad (9)$$

where :

$$\delta = \sqrt{\frac{SUMVV}{M*N-1}}, \quad SUMVV = \sum_{j=1}^{M}\sum_{i=1}^{N}\left(W_{i,j}^{mes} - W_{i,j}^{\mathrm{mod}}\right)^2, \quad D_{\max} = \max\left\{ \left|W_{i,j}^{mes}\right|, \; i = 1,2,..,N, \; j = 1,2,...,M \right\}.$$

5 Summaries

The description of two specialized computer programs used for identification of W.Budryk – S.Knothe theory parameters has been presented in this paper. They are the components of a complete system for forecasting of underground extraction influences on the rock mass and land surface, which was built by the author of this work. The results obtained by using these programs are necessary for the forecast, concerning calculations of prognosed values of deformation indices due to planned underground extraction. Advanced calculation options of programs DEFK_PARAM and BK_CTX allow to determine in a comprehensive way the optimal set of parameters, on the basis of surveys results. It contributes to improving the quality of predictions made by using such values of parameters.

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