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# APPLICATION OF NUMERICAL OPTIMIZATION METHOD FOR IDENTIFICATION OF PARAMETERS UTILIZED IN FORECASTING OF UNDERGROUND MINING EFFECTS ON GROUND SURFACE

APLIKACE NUMERICKÝCH OPTIMALIZAČNÍCH METOD PRO URČOVÁNÍ PARAMETRŮ POUŽITÝCH PŘI PROGNÓZNÍCH VÝPOČTECH VLIVU PODZEMNÍHO DOBÝVÁNÍ NA ZEMSKÝ POVRCH

**Abstract**

Compatibility of predicted parameters of ground surface deformations (subsidences) after underground mining with measurement results depends in a fundamential extent on values of theoretical parameters applied for prediction of such parameters. By the presented work some possibilities of employing PC for purposes of identification of such parameters based on surveying measurements are presented.

**Abstrakt**

Přesnost prognózy vlivu poddolování povrchu je ve velké míře závislá na hodnotách parametrů použitých při numerických výpočtech. V práci jsou uvedeny možnosti využití osobních počítačů pro jejich stanovení na základě výsledků geodetických měření deformací povrchu.

**Key words:** undergroung mining, subsidence, prediction, parameter.

## Introduction

Underground mining extraction leads generally to deformations of ground surface, regardless of conditions of extraction. By irregular nature of subsidence arising of other effects of deformation is caused such as inclinations, curvatures, horizontal displacements and strains [1]. They play the most significant role in damaging of objects located on the surface in mining areas. Because of that, every decision about underground extraction in urbanized areas has to be preceded by prognosis of mining extraction influences on ground surface. Special calculation procedures are applied for this purpose in different countries.

In Poland, the Budryk–Knothe theory enjoys the greatest popularity and widespread application. Based on predicted values of deformation effects the decision-making should take into consideration possibilities and consequences of advancing of the considered extraction project. Thus the basis should be provided for activities aimed at developing methods of how to secure objects that are menaced by mining extraction.

The quality of prediction made on the basis of this theory is closely connected with values of parameters accepted for calculations. Therefore, the ability of determining proper values of such parameters is very important. They depend on geological and mining conditions of extraction and they are rather stable for given areas. There are several ways for obtaining them – the most accurate one is the method that applies results of surveying measurements performed in the considered area. The results of such measurements shall reflect deformations caused by earlier extraction in considered area.

An example of using numerical method for obtaining values of the above mentioned parameters has been presented below.

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## The basis of Budryk - Knothe theory

Let us assume a situation as it is indicated in Fig. 1. In the considered model [2], final values of subsidence at point A(s,t) located on ground surface are determined by the equation:

$$w(s,t) = -\frac{a \cdot g}{r^2} \iint_P f(x-s, y-t)\, dP \qquad (1)$$

Where:

*f*(*x* - *s*,*y* - *t*) – so-called „influence function”:

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

*g* - thickness of coal seam,
*s, t* - coordinates of point *A* in Cartesian coordinate system,
*x,y* - coordinates of elementary extraction field *dP*,
*P* - the extracted area of coal seam.

Parameters:
*a* - coeficient of roof control. Average value of its changes within range of 0.15 to 0.85 depending on the way of roof controll,
*r* - main influences range.

The parameter *r* can be substituted by parameter $tg\beta$ – they both are tied up with the equation: $tg\beta=H/r$, where *H* – the depth of extraction. In Upper Silesian Coal Basin its value varies from 1.5 to 3.0 in different areas.

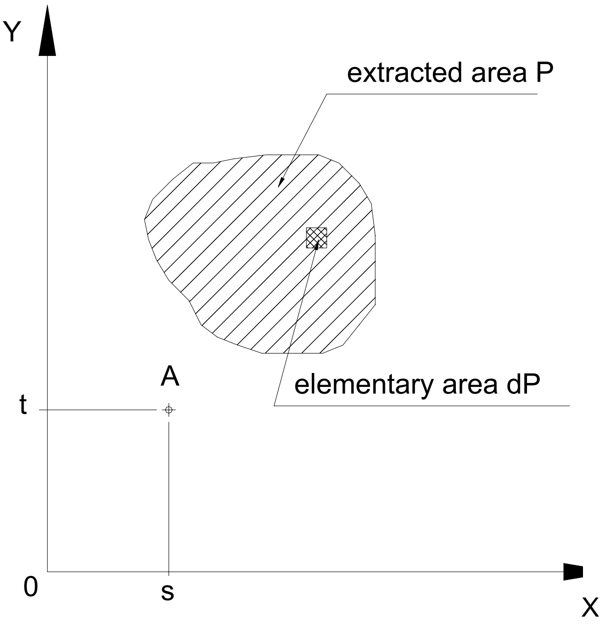


*Fig.1. The scheme for calculation*

The deformation indices that mainly decide on the hazard degree for buildings and other objects located on the ground surface are: inclination *T* and horizontal strain *ε*. In Knothe theory they are calculated as derivatives from subsidence by the following equations:

$$T_x = \frac{\partial w}{\partial x}, T_y = \frac{\partial w}{\partial y} \qquad (3)$$

$$\varepsilon_x = B \cdot \frac{\partial^2 w}{\partial x^2}, \varepsilon_y = B \cdot \frac{\partial^2 w}{\partial x^2} \qquad (4)$$

Where $B$ is another main parameter of Budryk-Knothe theory [2] – by it the values of horizontal displacement and strain are determined.

As it can be seen on the basis of formulae 1-4 the values of parameters accepted for calculations play a key role in predicted distribution of deformation effects on land surface.

It has been shown in Fig. 2 and Fig. 3, where this distribution is represented in form of subsidence shape and horizontal strain contour line maps. In Fig. 2 the distribution of these deformation effects is indicated, with values of parameters: $a$ = 0.7, $B$ = 0.32$r$, $tg\beta$ = 1.5. In Fig. 3 the same is indicated with values: $a$ = 0.7, $B$ = 0.32$r$, $tg\beta$ = 2.5.

In the first case a virtual object named ***K*** has been influenced by underground extraction – in area of its location there is a zone of subsidence and strain, in the second one it is outside of this area.

Thus it can see, that properly determined values of parameters plays the key role in forecasting process.

## The computer program for calculation the values of parameters based on measurement results

In order to determine considered parameters, which are based on measurement results, a computer program has been elaborated. The program has been written in programm's language - Fortran and it is designed for PC computers. It has been elaborated for any shape of mining field. The determination of parameters: [*a, r, d*] is based on measured subsidence. In both cases, the objective function is a result of the application of the least square method. To determine the minimum of the objective function, Powell's algorithm was chosen (used in [3], too), because of its accuracy and speed of calculations. Calculations are made for a given accuracy and a given variation range of the optimized parameters.

Optimization method consists of two stages. In the first one, starting from point $x^k$, there are ($n+1$) minimization steps in directions $d^1, d^2, \ldots, d^n$ and they are finally repeated in direction $d^1$. As a result of such minimization steps, the points: $x^1, x^2, \ldots x^k_n, x^k_{n+1}$ are reached. Point $x^k_{n+1}$ being a result of repeated minimization in $d^1$ direction is used for next approximation $x^{k+1}$. After finishing of first stage, the basic stop criteria are tested:

$$\left\| x^{k+1} - x^k \right\| \le \omega \,, \qquad (5)$$

where: ω – accuracy of calculations.

The second stage starts with determining of new directions of optimization by using certain rules. The new directions are tested for linear independence. If they are dependent, a renovation of algorithm is made.

Minimized function results obtained by the least square method:

$$F = \sum_{i=1}^{n} (w_{meas.i} - w_{cal.i})^2 = \min \,, \qquad (6)$$

where:

$w_{meas.\,i}$ – measured subsidence at point „*i*",

$w_{cal.\,i}$ – subsidence calculated at point „*i*", its value depends on values of parameters of Knothe model: [*a, r*] or [*a, r, d*],

$n$ – number of measuring points.

In Fig. 4 an example of graphical comparison of the measured – $w_{meas}$ and the calculated values of subsidence is presented. There are two theoretical curves – first one - $w_{cal}$ obtained by using Knothe theory with employing only parameters [*a, r*], and the second one - $w_{cald}$ obtained by employing parameters [*a,r,d*].

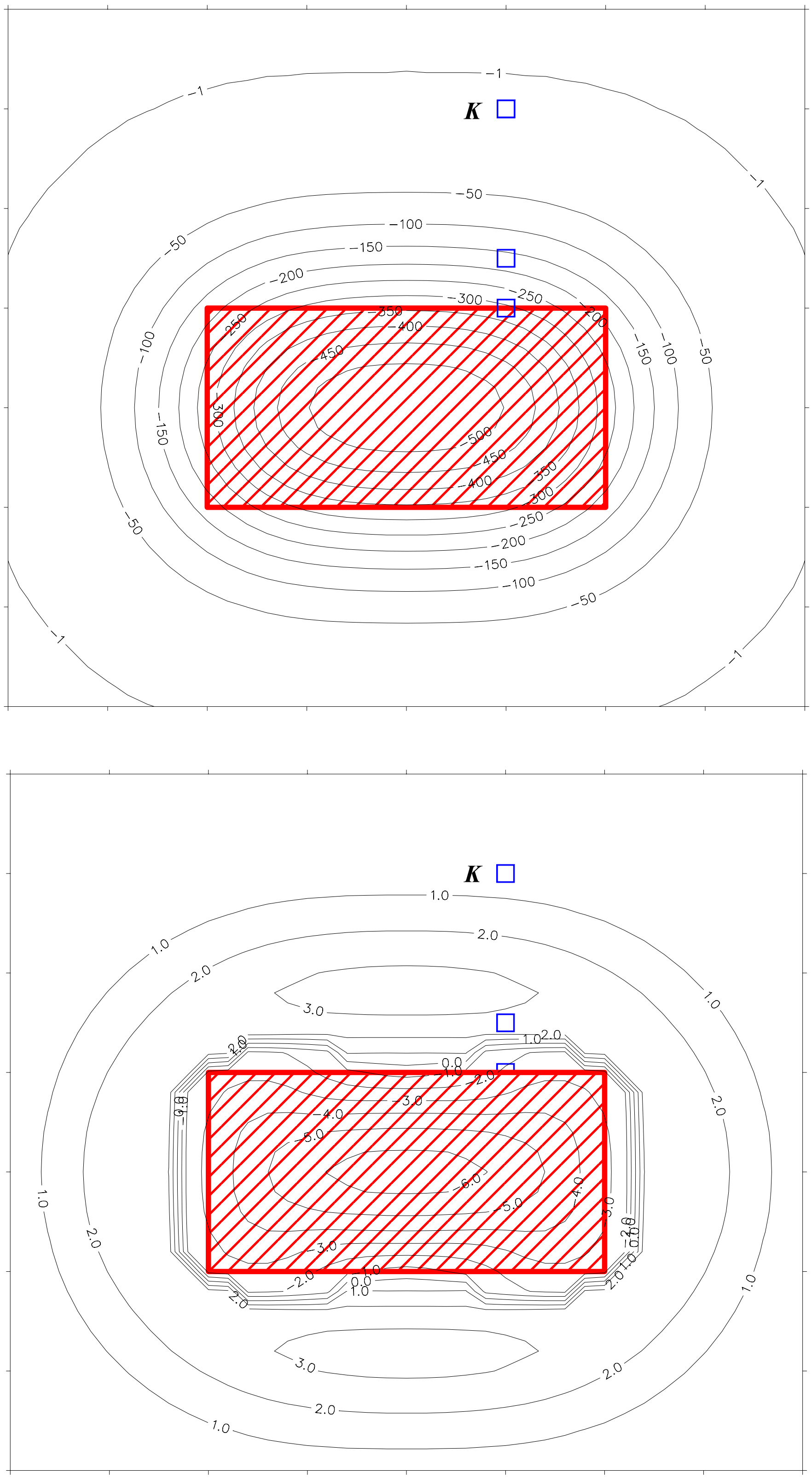


*Fig. 2. An example of distribution of subsidence (a) and horizontal strain (b) caused by underground extraction. Calculation made by using Knothe theory with parameters: a = 0.7, B = 0.32r, tgβ = 1.5*

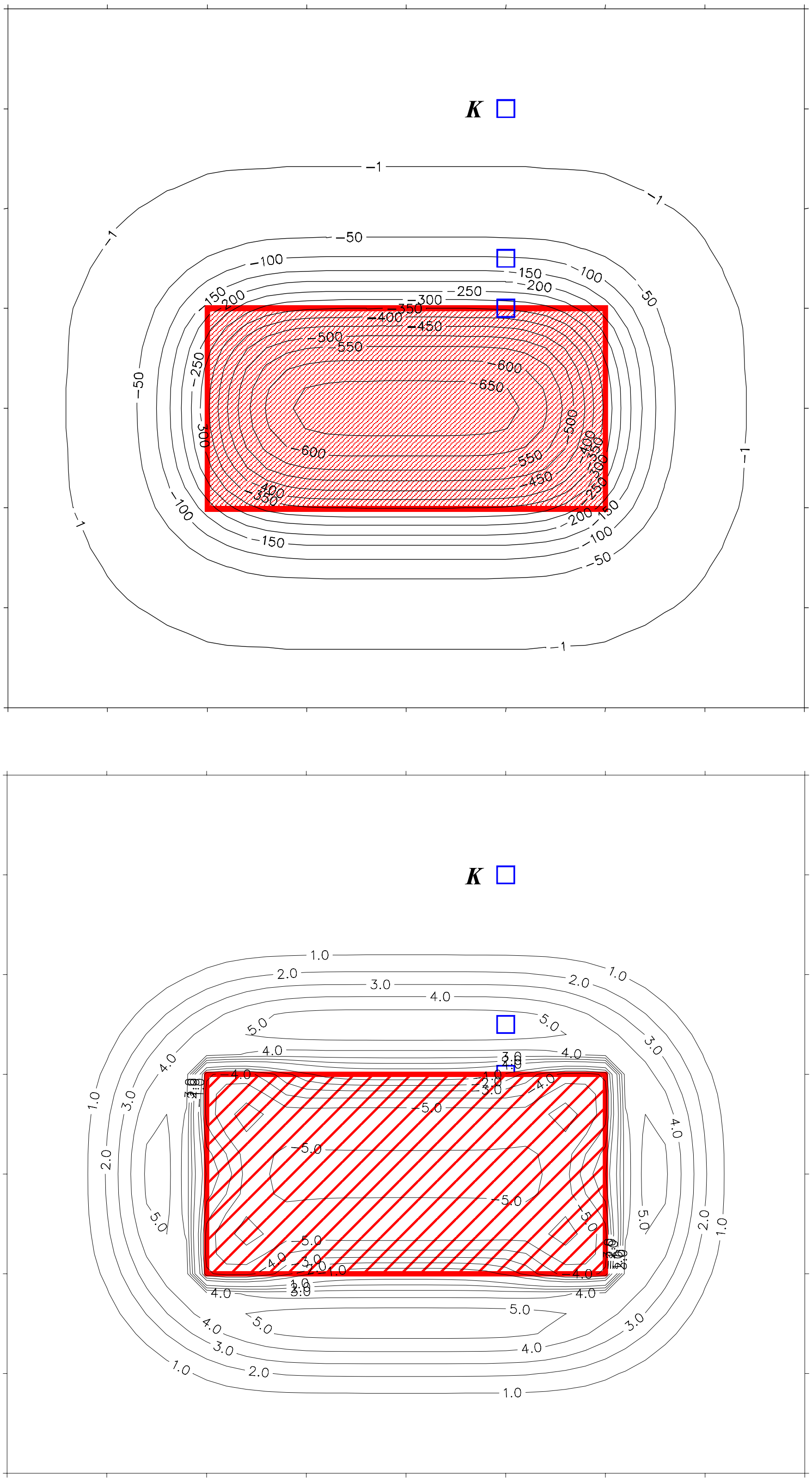


*Fig.3. An example of distribution of subsidence (a) and horizontal strain (b) caused by underground extraction. Calculation made by using Knothe theory with parameters: a = 0.7, B = 0.32r, tgβ = 2.5*

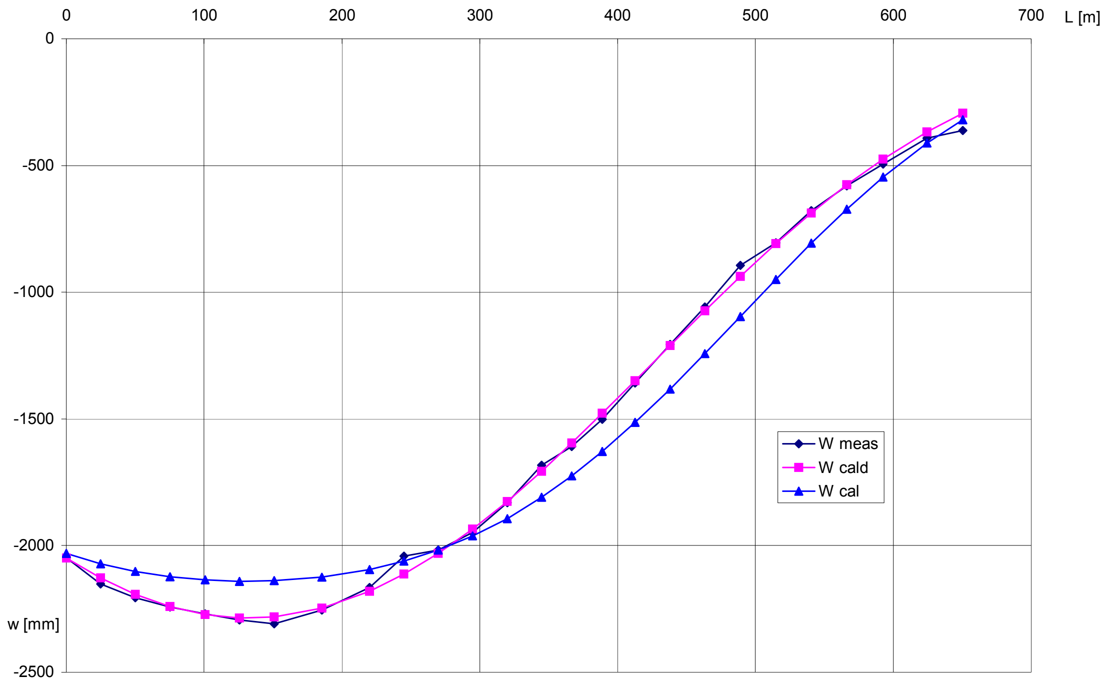


*Fig. 4. The diagrams of subsidence*

## Conclusion

Properly prepared evaluation of possibilities of advancing of underground mininig extraction below urbanized areas has to based on analysis of predicted values of deformation effects. There are several factors that influence the quality of prediction. The most important one is proper determination of parameter values used in model by which deformation of ground surface will be described. In the presented example as a model of description the Knothe theory has been used. This theory enjoys the greatest popularity in Polish mining industry.

The values of parameters are characteristic for given areas and they should be determined on basis of results of surveying measurements. These results should present a state of deformation that took place in surface ground after preceding underground extraction advanced directly below this area or nearby.

The algorithm for determination of the values according to Knothe theory has been elaborated by the autor, as well as the sofware for PCs. In this software, Powell algorithm has been employed for minimization of function (6).

The presented procedures have been wide used in Polish mining industry for evaluation of hazard degree for buildings located in mining areas.

## References


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## Resumé

Přesnost prognózy vlivu podzemního dobývání ovlivňuje hlavně použití správných hodnot parametrů výpočtu, které jsou určeny hornicko-geologickými poměry. V případě teorie W. Budryka – S. Knotheho se hodnoty parametrů nejlépe stanovují na základě geodetických měření. Nastavení těchto parametrů je vhodné provádět s pomocí počítačového programu.

V práci je popsán vlastní počítačový program, jehož algoritmus je založen na metodě nejmenších čtverců. K minimalizaci funkce je použit Powellův algoritmus. V práci jsou také uvedeny příklady výsledků činnosti programu.

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