THE USE OF DELAYED AND IMMEDIATE INFLUENCES MODEL IN PREDICTIONS OF TRANSIENT DEFORMATION STATE

WYKORZYSTANIE MODELU WPŁYWÓW OPÓŹNIONYCH I NATYCHMIASTOWYCH W PROGNOZACH NIEUSTALONEGO STANU DEFORMACJI

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Abstract

Predictions of continuous surface deformations caused by underground mining are important part of hazard assessment to building constructions located in mining areas. Present practical experiences show, that changes of post-mining deformation state over time occur faster at the surface level in the relation to the position of working extraction edge. Survey results show, that after stopping of extraction, subsidence rate slows down relatively quickly, in several days. There is a question, if we are able to model such phenomenon by using traditional prediction methods, especially Budryk-Knothe theory. So, some remarks concerning transient deformation state prediction have been pointed in the paper. Two theoretical models have been shown, that may be used in predictions of transient deformation state by using the Budryk-Knothe theory: so called „delayed” and „immediate” influences models, with connection to different prediction alternatives.

Streszczenie

Předpovědi týkající se deformací souvislých ploch způsobených hlubinnou těžbou jsou významnou součástí posouzení nebezpečí, které může vznikat při výstabě konstrukcí umístěných v oblastech těžby. Současná praxe ukazuje, že dochází k rychlejším změnám potěžebního deformačního stavu - zejména pak na povrchové úrovni v závislosti na poloze pracovní těžby. Výsledky průzkumu ukazují, že po ukončení těžby se rychlost propadání půdy zpomaluje poměrně rychle - v řádech několika dní. Je tedy otázkou, zda jsme schopni realizovat takový to jev pomocí tradičních předpovědních metod, zejména pak podle Budryk - Knotheovy teorie. Některé poznámky týkající se předpovědi přechodných deformací stavu byly také zdůrazněny v tisku. Dva teorické modely byly prezentovány tak, že mohou být použity k předpovídání přechodné deformace stavu s využitím teorie Budryk - Knothe: to znamená modely takzvaného"zpoždění" a "okamžitého" vlivu s návazností na další alternativy předpovědi.

Keywords

underground mining influences, geometric-integral theories, transient deformation state

Słowa kluczowe

oddziaływanie podziemnej eksploatacji, teorie geometryczno - całkowe, nieustalony stan deformacji

1 Introduction

Geodetic surveys performed with great frequency (sometimes even daily) show that changes of extraction rate, as well as weekend stoppages/starts of extraction, cause quick unfavorable effects on the surface - the rate of subsidence slows down or accelerates in one-two days after stopping/starting the extraction.

One of the conditions of efficient protection against mining damages is to work out accurate predictions of land surface deformations. In recent years, a number of new proposals in Poland have been worked out for description of transient deformation state. One can mention solutions proposed by J.Białek (1991), B.Drzęźla (1993), J.Kwiatek (1998), P.Strzałkowski (1998). But still the Budryk-Knothe theory dominates in Polish hard coal mining industry (Knothe, 1953 a, b). So it is necessary to answer the question, how this solution meets the aforementioned findings in this field.

Some theoretical and practical considerations have been presented in the paper, aiming at estimation of Budryk-Knothe theory accuracy for transient deformation state, in relation to increased face advance speed as well as weekends face stoppage. Two basic models of time-related behavior have been presented - so called: „delayed" and „immediate" influences models.

Apart from above described problem, there still exists another practical issue, namely connected with taking into account estimation of time-extreme values of deformation indices that change together with spatial development of extraction. The last part of this paper shows an example of different possible prediction results obtained with different models employed into Budryk-Knothe theory.

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

$$\frac{dw}{dt} = c \cdot \left(w_k(t) - w(t) \right) \tag{1}$$

where:

- $w_k(t)$ - final (asymptotic) value of subsidence at time „*t*",
- $w_t(t)$ - the value of transient subsidence at time „*t*",
- ***c*** - coefficient of subsidence rate („time factor").

Due to extraction front development, final value of subsidence changes over time: $w_k(t) \neq const$. This considerably complicates the solution of equation (1), which gives (Fig. 1a):

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

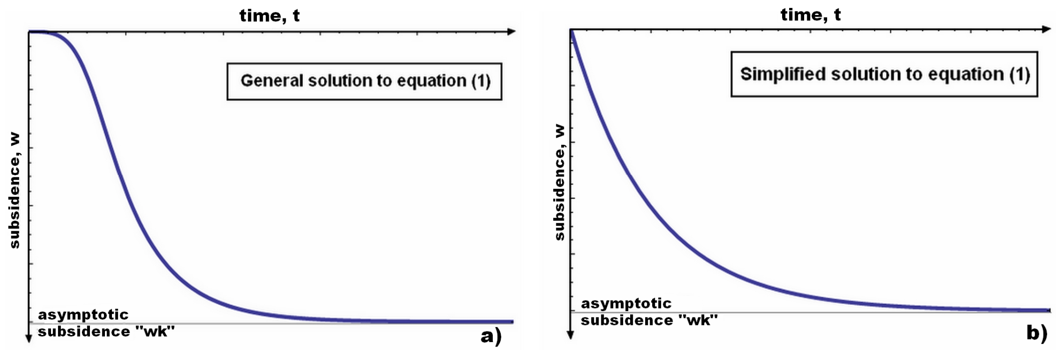


Fig. 1 Subsidence over time according to equation (1) - left and (2) -right

Thus, for practical reasons it is convenient to assume, that the extracted field has a relatively small area. Accordingly, it may be assumed that the time of such extraction is close to zero. Taking this into account, the condition is fulfilled: $\boldsymbol{w_k(t) = const = w_k}$. Such assumption greatly simplifies the solution of the equation (1), which, provided that the initial condition is fulfilled ($\boldsymbol{t=0 \Rightarrow w_t(t)=0}$), is expressed as follows (Fig. 1b):

$$w(t) = w_k \cdot (1 - e^{-ct}) \tag{3}$$

For practical purposes, the equation (3) - so called „time function", may be used, provided that discrete model for simulation of longwall advance is employed: the extraction area is divided into elementary stripes (Fig.2), of which may be assumed as extracted instantaneously. Taking this into account, an elementary transient subsidence is calculated for every strip independently. In the next step, the total transient subsidence $\boldsymbol{w(t)}$ is determined by summing up the values of elementary subsidence calculated for particular stripes and for a given time period - Fig. 3.

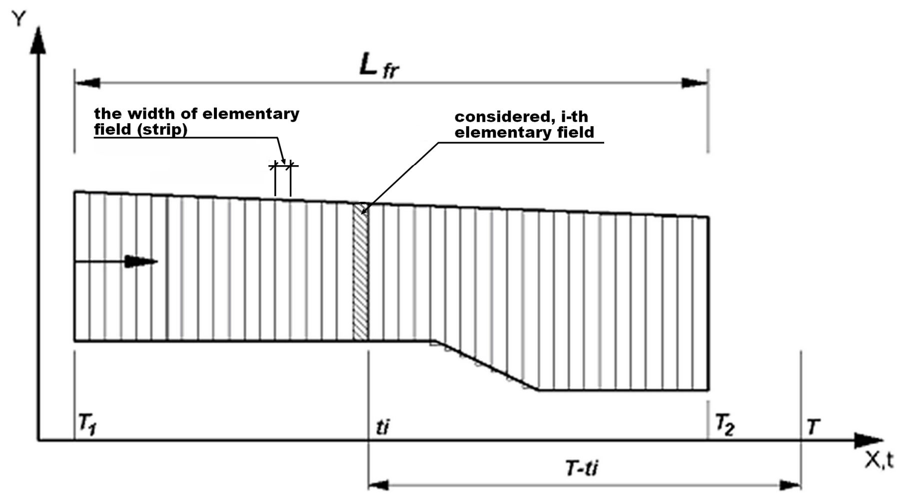


Fig. 2 Discretization of extraction field

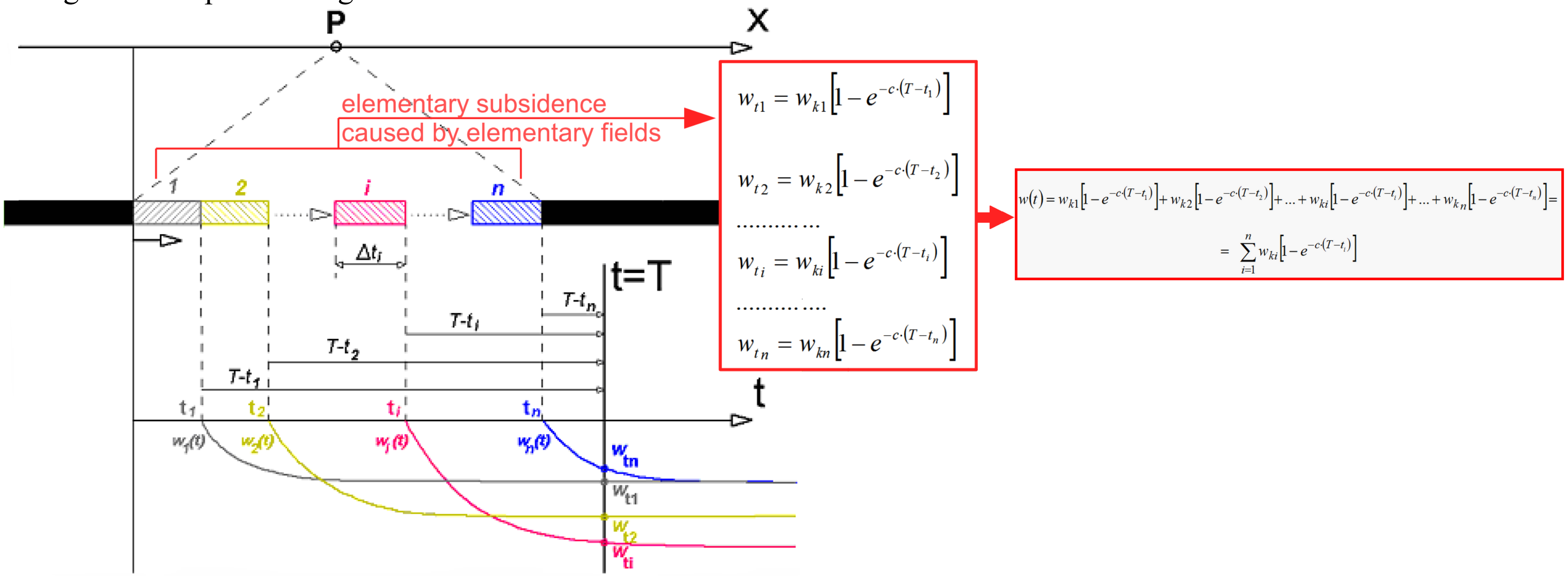


Fig. 3 The sketch of discrete calculation model

The concept of immediate and delayed influences

Considering predictions of deformation indices with taking into account time-space changes of extraction front position, it is necessary to keep in mind, that there are two possible ways of including longwall advance influence (Fig. 4):

1. Taking into account delay of influences arising at the surface with some time shift in relation to elementary extraction step (Fig. 4 upper-left) - so called „***delayed influences model***”. This attitude refers to classical Knothe solution (2) or (3) with certain value of „*c*” parameter taken for calculation purposes.
2. Assuming that 100% influences from elementary extraction field arise the surface instantaneously (without any delay - Fig. 4 upper-right) - so called „***immediate influences model***”. From theoretical point of view it means that „*c*” value goes to infinity.

The above case 1 is more „physically” related to real rock mass reaction to underground extraction, but predictions of surface deformation state in this case have limited amount of safety factor. More safe from the surface building objects protection point of view is to perform the prediction according to case 2. Especially that last several years of experiences show that subsidence trough „travels” through the rock mass much quicker than it was suggested in the past.

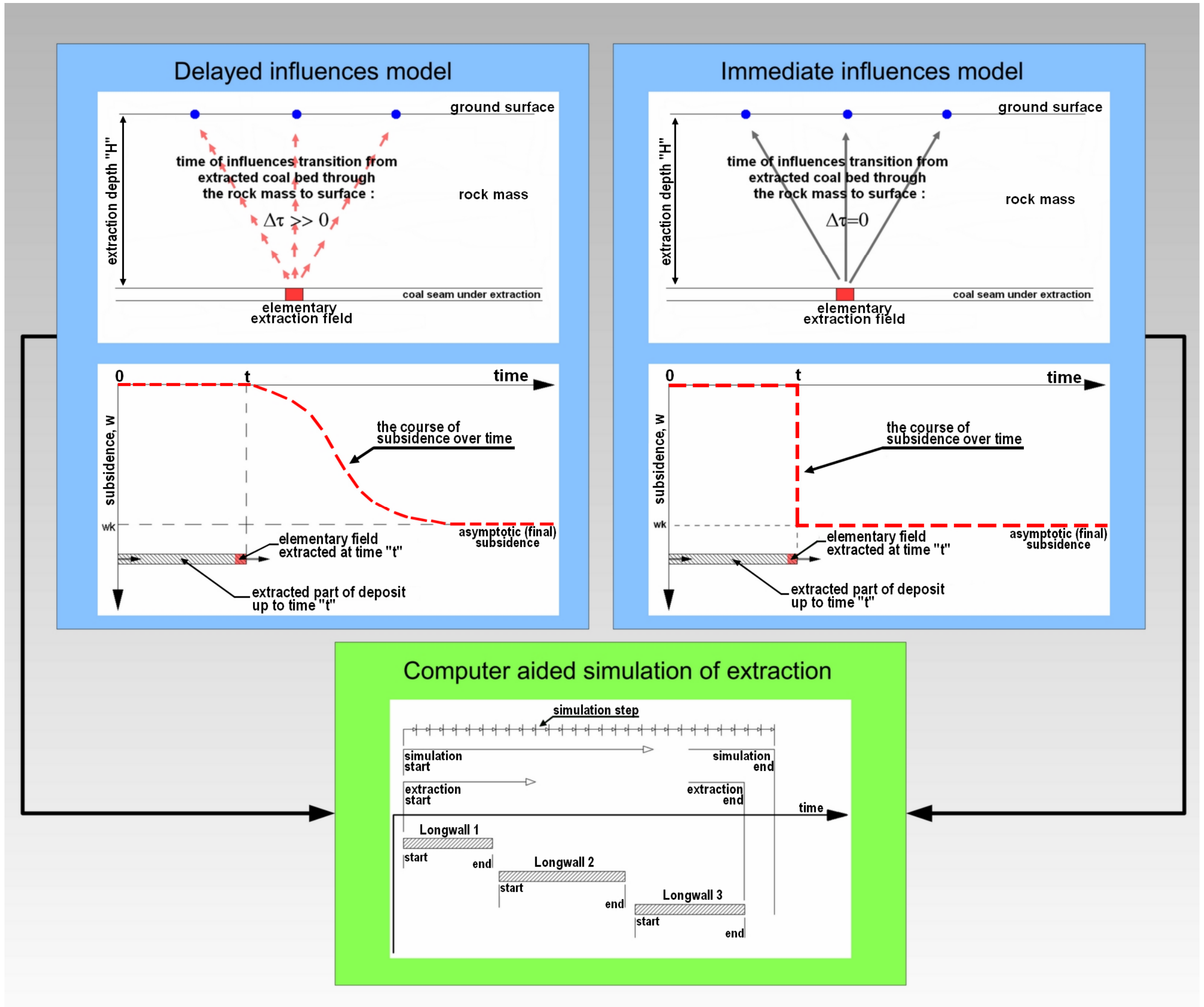


Fig. 4 The concept of delayed and immediate influences model used in computer aided simulation of extraction

Having the software capable to simulate the extraction advance in time-space coordinates, one is able not only to evaluate the certain deformation state related to given geometry of extraction, but to find time - extreme values of deformation indices. It is especially important for predictions of horizontal strain, which values may be as twice of those for final state, for some stages of extraction development.

2 Theoretical example showing problems with prediction of weekend extraction breaks influence on the subsidence process

For the exemplary calculations purposes, an extraction field was virtually located at the depth of 500 m, with face length of 250 m, the height of 2.0 m and the speed of face advance 10 m/day. It was assumed that the extraction takes place 5 day per week, with Saturday-Sunday break. 5 weeks of extraction was taken into consideration. During the simulation, resulting subsidence was registered at point „***A***", located at the land surface directly above the centre of extraction field. The calculations were performed for:

- delayed model, with different values of parameter „***c***",
- immediate influence model ($c \to \infty$).

As a result, the courses of subsidence over time have been obtained for every considered value of parameter „***c***" - see figure 5.

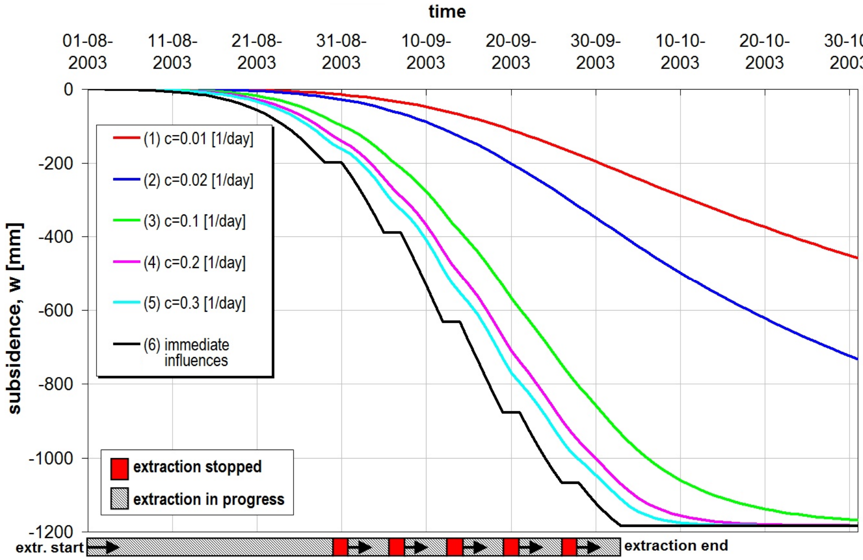


Fig. 5 Subsidence over time modelled by using Budryk-Knothe theory. The theoretical case of 5-week extraction led with weekend breaks.

Basic conclusion is, that one cannot observe the disturbances in subsidence course over time due to weekend face stoppage. With used values of parameter c<10 [1/year], it is impossible to predict the changes in subsidence rate that really occur on the surface after face stoppage. As it comes from the analyses of geodetic measurements presented by other authors (Sroka, 1999; Kanciruk et al., 2002), it is unequivocal, that in case of face stoppage, the surface subsidence rate considerably decreases, with a small time delay in relation to the extraction stoppage. One can determine this delay as equal to maximum several days. Analyzing subsidence courses presented above for higher values of „***c***" it is clear, that this approach doesn't allow to describe accurately actual course of subsidence over time.

3 Practical example

Example comes from the mining area of one of Upper Silesian Basin coal mine. On the basis of measured distribution of subsidence over time ***w(t)*** for survey point No 1 shown below in Fig. 6, the values of parameter „***c***" were identified by using dedicated software (Ścigała, 2008) with least square method as the minimization criterion. Then, using obtained values of „***c***", theoretical distribution of w(t) was compared with measured one. Presented results show, that despite of general good agreement between theoretical and measured course of subsidence over time, there are no possibilities to describe the disturbances in subsidence process caused by face stoppage. Greater „***c***" values cause that theoretical curve of subsidence over time is steeper and final values of subsidence are reached earlier, which does not correspond with surveys.

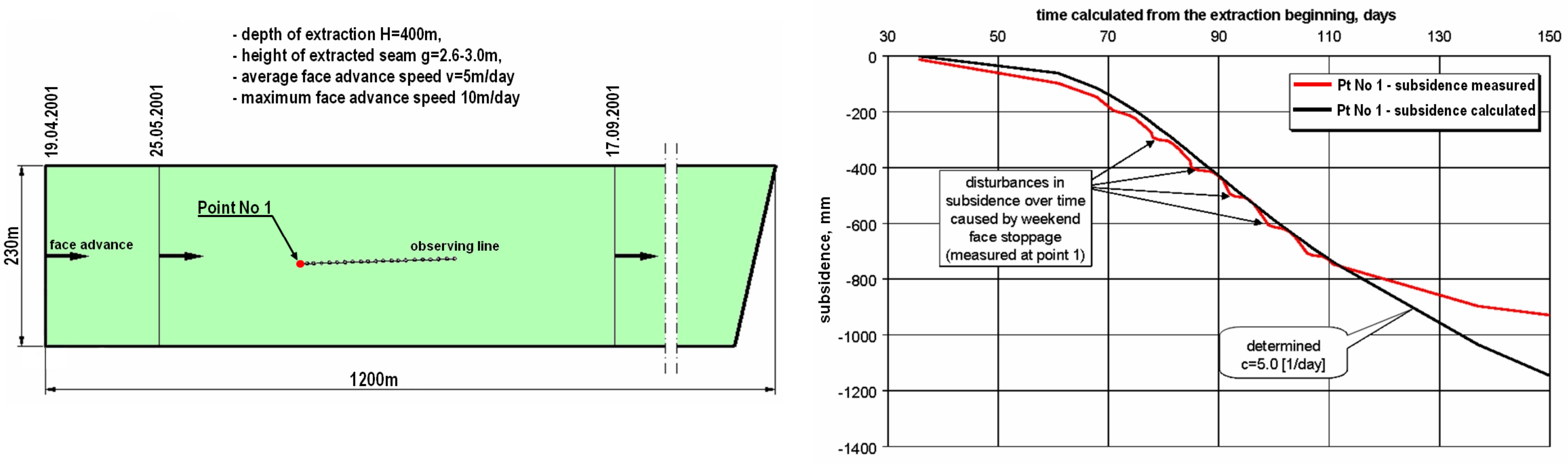


Fig. 6 The sketch of performed extraction (left) and the measured course of subsidence over time for considered observing point No 1 (right).

4 Exemplary distributions of horizontal strain „ε" obtained with different prediction assumptions

Another important issue connected with predictions of underground mining influences on the land surface goes from analyses of its spatial distribution in relation to extracted field geometry. Problem especially relates to forecasting of horizontal strain, tilt and vertical curvature. Spatial distribution of such deformation indices may have greater magnitude during longwall advance development, than in its final (asymptotic) stage. Especially in the starting stage of extraction, there is additional amount of deformations as an effect of interaction between extraction edges being in close mutual distance. In figure 8, there are exemplary maps presented of horizontal strain spatial distribution obtained with different prediction models described above.

What is necessary to mention here is, that prediction performed for final (asymptotic) state of deformation shows lower maximum values of strain - figure 8a, than those performed with computer aided simulation of extraction, which takes into account spatial development

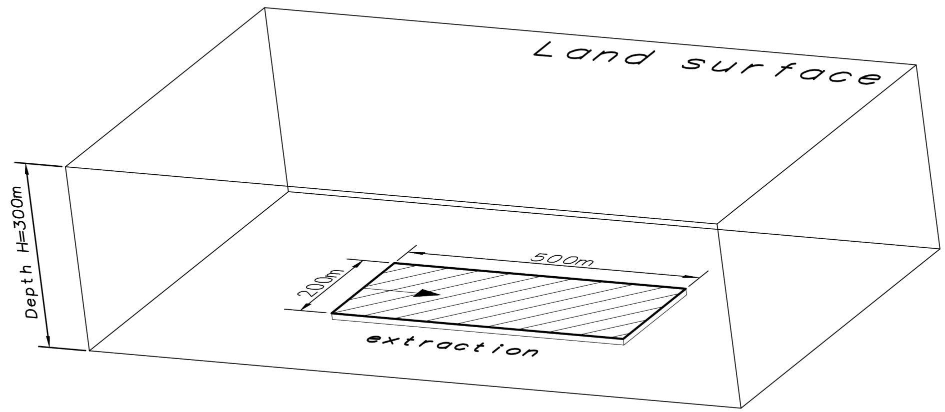
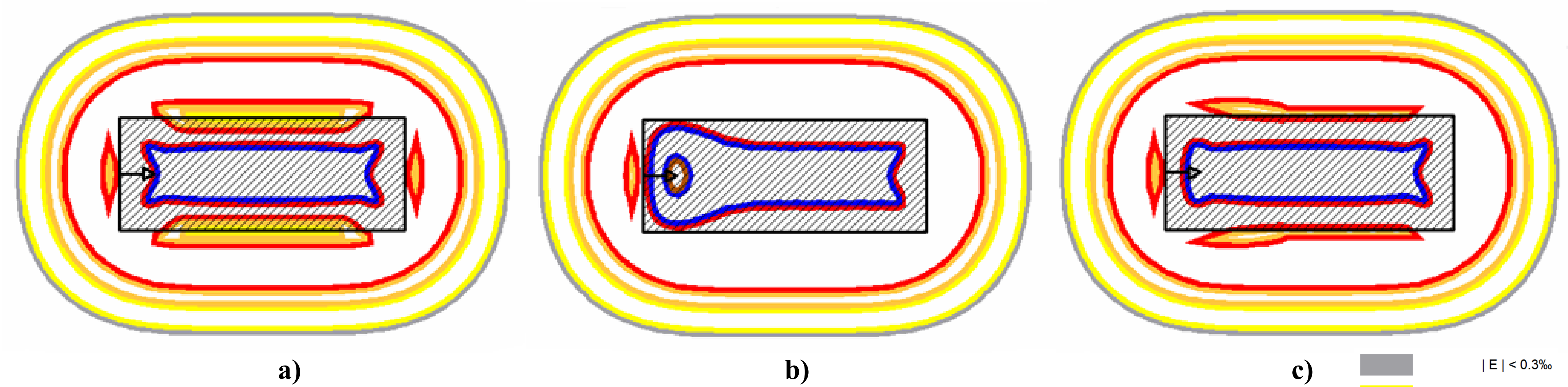


Fig. 7 The sketch of extraction defined for exemplary prediction of extreme horizontal strain.

of extraction - figures 8b and 8c. The prediction was worked out by using DEFK-Win software (Ścigała, 2008) with the following assumptions (see figure 7):

- extraction field dimensions (advance × length): 500 m x 200 m (in figure 8 - hatched area),
- direction of advance: East,
- depth of extraction: H = 300 m
- thickness of extracted seam: g = 2 m,
- parameters of Budryk-Knothe theory: a = 0.8, tgβ = 2.0, B = 032r, r = H / tgβ



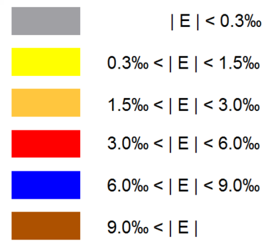


Fig. 8 Maps of predicted horizontal strain distribution obtained with different prediction assumptions:
a) asymptotic state of deformation,
b) time-extreme deformations obtained for <u>immediate</u> influences model (with c→∞),
c) time-extreme deformations obtained for <u>delayed</u> influences model (with c=7 [1/year]).

5 Conclusions

Summing up presented material one may draw the following conclusions:

1. There are problems in predictions of transient subsidence by using geometric-integral theories (e.g. Budryk-Knothe) in situations, when extraction is stopped for several days. In this case, land subsidence rate decreases relatively fast. This phenomenon cannot be described properly by using such models. One can try to improve the quality of prediction of subsidence over time by altering „time function" given here by formula (3).

2. Prediction of asymptotic (final) state of deformation is not sufficient enough, especially for estimating horizontal strain, vertical curvature and tilt. During the extraction development there is transition of subsidence trough following the advancing front, which causes different spatial distribution of mentioned deformation indices. Problem especially applies to horizontal strain - it may be situations when its values are twice as for asymptotic state. So predictions should be performed in such way, that time - spatial development of extraction is to be taken into account. To ensure this, computer aided simulation of extraction development should be used in predictions.

References

BIAŁEK J. *Opis nieustalonej fazy obniżeń terenu górniczego z uwzględnieniem asymetrii wpływów końcowych*. Zeszyty Naukowe Pol. Śl. Górnictwo nr 1106. Gliwice, Poland, 1991 (in Polish).

CHUDEK M. *Geomechanika z podstawami ochrony środowiska górniczego i powierzchni terenu*. Wydawnictwo Politechniki Śląskiej. Gliwice, Poland, 2002 (in Polish).

DRZĘŹLA B. *Niektóre poglądy w zakresie kinematyki niecki osiadania i nowy model geometryczny*. Szkoła Eksploatacji Podziemnej. Kraków-Ustroń, Poland, 1993 (in Polish).

KNOTHE, S. *Równanie profilu ostatecznie wykształconej niecki osiadania*. Archiwum Górnictwa i Hutnictwa, Vol. 1, No. l. Kraków, Poland, 1953a (in Polish).

KNOTHE, S. *Wpływ czasu na kształtowanie się niecki osiadania*. Archiwum Górnictwa i Hutnictwa, Vol. No. 1. Kraków, Poland, 1953b (in Polish).

KANCIRUK A., ROGOWSKA J., STANISŁAWSKI L., POPIOŁEK E., OSTROWSKI J. *Badania skutków ujawniania się przerw eksploatacyjnych na powierzchni z wykorzystaniem pomiarów tensometrycznych i geodezyjnych*. XXV Zimowa Szkoła Mechaniki Górotworu. Kraków, Poland, 2002 (in Polish).

KWIATEK J. *O reologicznych aspektach zagrożenia obiektów budowlanych na terenach górniczych*. Prace naukowe GIG, nr 827. Katowice, Poland, 1998 (in Polish).

SROKA A. *Dynamika eksploatacji górniczej z punktu widzenia szkód górniczych*. Instytut Gospodarki Surowcami Mineralnymi i Energią PAN. Kraków, Poland, 1999 (in Polish).

STRZAŁKOWSKI P. *Model nieustalonych przemieszczeń pionowych górotworu w obszarze objętym oddziaływaniem eksploatacji górniczej*. Zeszyty Naukowe Pol. Śl. s. Górnictwo z. 237. Gliwice, Poland, 1998 (in Polish).

ŚCIGAŁA, R. *Komputerowe wspomaganie prognozowania deformacji górotworu i powierzchni wywołanych podziemną eksploatacją górniczą*. Wydawnictwo Politechniki Śląskiej. Gliwice, Poland, 2008 (in Polish).

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