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DIVERGENCY VERIFICATION OF PREDICTED VALUES AND MONITORED DEFORMATION INDICATORS IN SPECIFIC CONDITION OF THONG NHAT UNDERGROUND COAL MINE (VIET NAM)

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Keywords: Knothe time function, subsidence prediction, monitoring data, Thong Nhat coal mine

Abstract

During the last several years, the problem of mining damage on the Quang Ninh coalfield has become more and more serious. Some methods of prediction theories have been applied including the Budryk-Knothe's infection function one. This article presents the analysis and comparison of predicted result and monitored subsidence indicators for case study of Thong Nhat underground coal mine (Viet Nam) in the light of S. Knothe time function.

WERYFIKACJA ROZBIEŻNOŚCI WARTOŚCI PROGNOZOWANYCH I MONITOROWANYCH WSKAŹNIKÓW DEFORMACJI W WARUNKACH PODZIEMNEJ KOPALNI WĘGLA THONG NHAT (WIETNAM)

Słowa kluczowe: Funkcja czasu Knothego, prognozowanie obniżeń, monitoring geodezyjny, kopalnia węgla kamiennego Thong Nhat.

Streszczenie

W ciągu ostatnich lat problemy szkód poeksploatacyjnych na terenie górniczym Quang Ninh stają się coraz poważniejsze. W artykule zastosowano pewne metody prognozowania wpływów eksploatacji w tym funkcję wpływów Budryka-Knothego. Na przykładzie podziemnej kopalni węgla Thong Nhat (Wietnam) przeanalizowano wyniki i dokonano porównania wartości wskaźników deformacji zaprognozowanych i uzyskanych z pomiarów terenowych w świetle funkcji czasu według teorii S. Knothego.

1. INTRODUCTION

In Vietnam, mining industry is one of the important part of national economy. The mineral industry has indeed been steadily increasing over the years. Besides evident benefits, the mining activities causes many environmental problems including mining damage. Subsidence and its related deformations are inevitable consequences of underground mining, bringing about changes to surface landforms, ground and surface water, and damage to constructions on surface as well in underground mines. It is recorded many serious incidents due to underground mining in Quang Ninh coalfield. For example, a fan station at 142 m level was damaged required of costly repair in the Mao Khe coal mine in 2000 year; 110 Kv electricity line destroyed, and cracks in houses's walls around Mong Duong coal mine, etc. The prediction of the mining subsidence is an important task of the mine surveyors, it enables to repair the mining damages efficiently and has a positive impact on the economic results of mining. Thus, the preliminary aim of mine surveyors is to estimate the impact of underground mining on the surface of mines. They started to measure the subsidence of points on the mine surface in order to be able to control the subsidence process and to reduce the damages caused by the underground excavation activity (Kratzsch, 2012).

In Quang Ninh coal basin, field observation have demonstrated that the deformations start occurring with some delay, increasing with time and attaining maximum value with the passing of time. Maximum subsidence velocity often monitored in the second year after excavation implementation, even though in some mines, maximum subsidence velocity have been monitored in the first months after excavation, in other cases, from the third even the fourth year. For properly monitoring of surface deformation, apart from registration, necessary is to check the earlier prediction. Subject of article is to show the comparison of the predicted values and montoired deformation indicators carried out on the area of Thong Nhat underground mine.

The various principal methods of predicting mining subsidence can be grouped as Empirically derived relationships, Profile functions, Influence functions, Analytical models and physical models (Reddish & Whittaker, 2012). Each method has its own advantages and disadvantages as well as conditions for individual applications.

However, empirical prediction methods have high reliability because they are built based on a large number of field measurements. Profile functions are based on a curve fitting procedure that uses a mathematical function to match the measured subsidence profile. When this mathematical function is established by use of actual field data then it can be used for the future prediction of surface subsidence in the mining area (Reddish and Whittaker, 2012).

2. DETERMINING THE PARAMETERS OF KNOTHE TIME FUNCTION

Ones describe surface point subsidences by an Knothe time function as follow (Hejmanowski 2001):

$$\mathrm{W}(t_i) = \mathrm{W}_0(1 - e^{-ct_i}) \tag{1}$$

where, W_0 is total value of subsidence at t time, c is time coefficient, t_i is time of i^{th} cycle monitoring from the first cycle. It can be seen that when $t = \infty$ then $W_\infty = W_0 = W_{\max}$. It is clear given concrete values for W_k and c we can predict η_{ti} for any surface point.

The values of W_k and c can be determined based on observated point subsidence. If the number of observation cycles is greater than or equal 2, the parameters W_0 and c can be determined by the least square principle. The error equation of observations can be written as follows:

$$V_i = \mathrm{W}_0(1 - e^{-ct_i}) - \mathrm{W} \tag{2}$$

If the subsidence values are observed with the same accuracy, the parameters W_0 and c are solved with the condition of least square [VV] = min. The approximate value of W_0 is assigned by subsidence value of the last cycle, and the approximate value of c (c_0) is assigned by 0.1.

The equation of error (2) expanded by linear transformation is expressed as (Chinh, 1997):

$$V_i = A_i.d\eta + B_i.dc - L_i \tag{3}$$

where,

$$\begin{aligned} A_i &= (1 - e^{-c_0 t_i}) \\ B_i &= \mathrm{W}_0 t_i e^{-c_0 t_i} \\ L_i &= \mathrm{W}_{t_i} - \mathrm{W}_0(1 - e^{-c_0 t_i}) \end{aligned} \tag{4}$$

The error equation (3) can be expressed by matrix form as below:

$$V = A.X - L \tag{5}$$

where,

$$V = \begin{bmatrix} V_1 \\ V_2 \\ \ldots \\ V_n \end{bmatrix} \quad A = \begin{bmatrix} A_1 \; B_1 \\ A_2 \; B_2 \\ \ldots \; \ldots \\ A_n \; B_n \end{bmatrix} \quad X = \begin{bmatrix} dw \\ dc \end{bmatrix} \quad L = \begin{bmatrix} L_1 \\ L_2 \\ \ldots \\ L_n \end{bmatrix} \tag{6}$$

The system of normal equations as follow:

$$A^T AX = A^T L \tag{7}$$

Solving the system of normal equations obtained vector X, the best probability values of W and c are calculated as below:

$$W = W_0 + d_w$$
$$c = c_0 + d_c \qquad (8)$$

The parameters W_0 and c show the rule of subsidence process, the subsidence of points at the time $t_k = t_n + \Delta t$ can be predicted (t_n is the time at the last monitoring cycle). Subsidence value at t_k is computed as follow:

$$W_{t_k} = W_k(1 - e^{-ct_k}) \qquad (9)$$

After determining the parameters of the subsidence point prediction model, replacing these parameter in equation (2) to predict the subsidence of the point in the next cycle, then compare them with the actual monitoring values. The relevance of points subsidence prediction model over time is evaluated by the Root mean square error (RMS) between the predicted results and the monitored values:

The accuracy of prediction model is assessed by Root Mean Square Error

$$\text{RMS} = \sqrt{\tfrac{1}{n}\sum\nolimits_{i-1}^{n}(W_{t_k} - W_{t_k}^{p})^2} \qquad (10)$$

where,

$W_{t_k}^p$ is subsidence value of point i from Knothe time function at t_k;

W_{t_k} is subsidence experimental value of point i t_k.

3. CASE STUDY

The experimental data is collected on Lo Tri area (Thong Nhat mine) from 5 observation lines. Lines A, B and C are established along the dip direction and lines T and P in the strike direction. Each line includes 20 to 40 mornitoring points with spant distance of about 10 m to 40 m. 8 measurement cycles were carried out on the network using level instrument Ni 030. The period of two successive cycles is approximately 3 months. Precision of measuremet is satisfied with Vietnam National Specifications on mine surveying (Ministry of Information & Communications, 2013).

To verify the Knothe function in underground mining condition of Thong Nhat coal mine, all subsidence data in 9 cycles of 26 points belong o T lines are used (table 1) (Truc, 1991), from which the W_k and c were calculated. Subsidence profile of T lines over time is displayed in fig. 1.

Table 1. The data of subsidence measurement
Tabela 1. Dane obserwowanych obniżeń

Unit: millimeter

Point ID	Distance	Period of time (month)								
		0	3	6	9	12	15	18	21	24
T1	0	0	0	–17	–25	–32	–45	–53	–66	–70
T2	34	0	–5	–23	–28	–38	–51	–69	–73	–80
T3	62	0	–7	–25	–29	–39	–50	–73	–85	–91
T4	105	0	–11	–27	–39	–48	–53	–78	–95	–120
T5	133	0	–17	–59	–78	–77	–87	–115	–155	–175
T6	154	0	–31	–70	–102	–117	–135	–165	–210	–230
T7	177	0	–45	–85	–159	–183	–199	–231	–287	–307
T8	190	0	–54	–90	–150	–194	–212	–249	–310	–350
T9	206	0	–86	–157	–286	–356	–396	–431	–527	–585
T10	232	0	–134	–217	–445	–501	–555	–597	–705	–815
T11	250	0	–197	–351	–588	–753	–791	–832	–980	–1046
T12	263	0	–215	–362	–629	–844	–956	–1015	–1142	–1206

Table 1. Cont. Unit: millimeter

Point ID	Distance	Period of time (month)								
		0	3	6	9	12	15	18	21	24
T13	279	0	–183	–335	–651	–893	–1062	–1154	–1301	–1365
T14	291	0	–189	–289	–596	–810	–990	–1108	–1286	–1339
T15	307	0	–201	–289	–495	–757	–934	–1102	–1262	–1311
T16	341	0	–254	–352	–551	–795	–956	–1139	–1269	–1326
T17	350	0	–220	–350	–493	–688	–888	–1071	–1179	–1268
T18	373	0	–197	–274	–441	–627	–798	–934	–1081	–1116
T19	390	0	–93	–175	–302	–471	–643	–776	–887	–923
T20	401	0	–61	–113	–204	–370	–454	–522	–594	–639
T21	418	0	–38	–86	–142	–185	–243	–306	–366	–398
T22	438	0	–42	–50	–80	–117	–159	–221	–287	–311
T23	458	0	–11	–18	–31	–40	–85	–113	–157	–170
T24	481	0	–3	–28	–41	–62	–84	–117	–148	–155
T25	509	0	0	–9	–12	–14	–19	–30	–36	–45
T26	542	0	0	–3	–6	–7	–8	–11	–14	–19

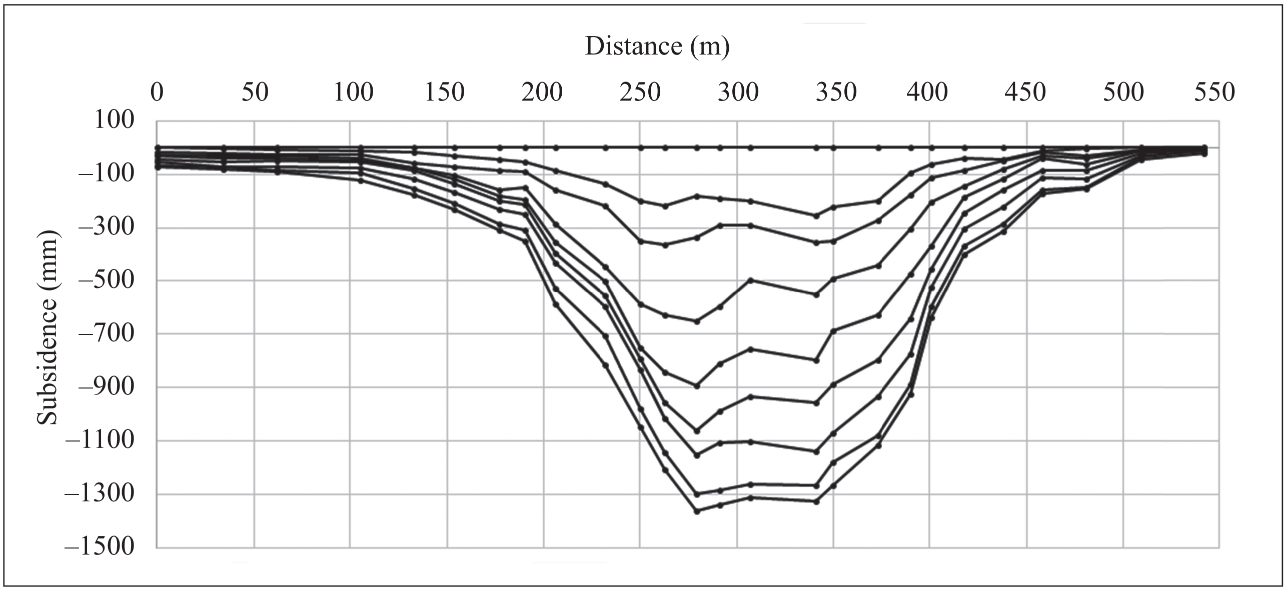

Fig. 1. Subsidence trough profile over time of "T" line.
Rys. 1. Zmiana profilu niecki obniżeniowej w czasie dla linii obserwacyjnej „T"

4. RESULTS AND DISCUSSION

Measured data subsidence of 6 first cycle (from 0 month to month 15 month) of all points on the line T are used to build subsidence models over time of points. Using the algorithm as introduced in section 2 to determine the parameters and W_k and c for all 26 points. Applying the calculated parameters to Equation (1) and recalculate the subsidence of all points in the first 6 cycles. The difference between actual subsidence and calculated subsidence from models of the points in each cycle are shown in Table 2. The accuracy of the prediction model are presented by RMS of each point. The obtained values of parameters W_k and c with its Root Mean Square Error (RMS) for each point in line T are set in Table 3.

Table 2. The difference between the predicted and the measured subsidence
Tabela 2. Różnice między prognozowanymi i obserwowanymi wartościami obniżeń

Point ID	The difference between the predicted and the measured subsidence over 6 cycles											
	0	3	6	9	12	15	Point ID	0	3	6	9	12	15
T1	–4	–1	3	0	1	–3	**T14**	31	–12	–7	–7	24	–32
T2	–7	2	4	3	–5	0	**T15**	–3	39	–10	–3	–12	–35
T3	–13	–2	4	12	12	26	**T16**	–35	28	0	18	–17	–24
T4	–12	–8	–1	10	2	2	**T17**	–70	26	34	8	–27	–9
T5	–28	–20	7	20	14	–7	**T18**	–26	19	15	–1	–3	–36
T6	–23	–15	5	18	14	–8	**T19**	3	38	17	–19	–29	–28
T7	–9	–23	1	23	21	–11	**T20**	16	40	–24	–17	–5	–5
T8	–18	–16	–7	21	23	–4	**T21**	–16	–7	11	10	0	–11
T9	–13	–29	–8	23	45	–6	**T22**	–11	0	7	11	–3	–19
T10	–2	–68	–1	37	65	10	**T23**	–2	4	16	–4	–4	–15
T11	–16	–23	–29	43	77	–19	**T24**	–6	3	4	5	–4	–11
T12	1	–2	–25	3	45	–8	**T25**	–4	–2	2	3	–1	0
T13	30	–1	–20	–16	28	–13	**T26**	–1	–2	0	1	1	1

Table 3. Results of Knothe time function parameters computation
Tabela 3. Wyniki obliczeń parametrów funkcji Knothe

Point ID	W_k	c	RMS (mm)	Point ID	W_k	c	RMS (mm)
T1	–170,112	0,026	2	**T14**	–1835,903	0,064	70
T2	–154,074	0,036	4	**T15**	–2091,093	0,049	75
T3	75,981	–0,050	22	**T16**	–1829,486	0,063	92
T4	596,753	–0,008	8	**T17**	–1903,559	0,053	84
T5	–355,841	0,030	17	**T18**	–1723,568	0,052	73
T6	–351,788	0,047	17	**T19**	–2026,631	0,031	42
T7	–370,240	0,076	22	**T20**	–1167,714	0,039	29
T8	–512,498	0,050	24	**T21**	–1056,621	0,023	16
T9	–692,918	0,077	39	**T22**	746,417	–0,017	18
T10	–876,402	0,094	63	**T23**	104,982	–0,048	10
T11	–1076,981	0,124	80	**T24**	929,670	–0,008	6
T12	–1330,386	0,106	79	**T25**	47,414	–0,032	2
T13	–1663,839	0,083	67	**T26**	25,070	–0,026	1

Using these models in order to predict the subsidence of 26 above points at the 7th and 8th cycles (18th month and 24th month). The results of predicted subsidence are shown in table 4. Compare them to the measured data, there are 17 points have the difference lesser or equal to 10 mm. The largest and smallest difference are –61 mm at point T10 and 0 mm at point T2, equivalent to 7,5% and 0% of measured subsidence value. Thus it can be concluded that the results calculated from Knothe time function closer to actual observations. Some points measured subsidence values and its corresponding predicted values by Knothe time function are shown in Fig. 2.

The RMS values in Table 3 show that the deviations between prediction and reality of the points in the center of subsidence trough are greater than the point located at the edge side. Distribution curve error of the point shown in Figure 4.

Table 4. Results of subsidence prediction
Tabela 4. Wyniki prognozowanych obniżeń

Unit: millimeter

Point ID	18 months			21 months		
	Mea	Pre	Difference	Mea	Pre	Difference
T1	–66	–63	–3	–70	–71	1
T2	–73	–73	0	–80	–81	1
T3	–85	–111	26	–91	–141	50
T4	–95	–97	2	–120	–115	–5
T5	–155	–148	–7	–175	–166	–9
T6	–210	–202	–8	–230	–222	–8
T7	–287	–276	–11	–307	–295	–12
T8	–310	–306	–4	–350	–335	–15
T9	–527	–521	–6	–585	–557	–28
T10	–705	–715	10	–815	–754	–61
T11	–980	–961	–19	–1046	–997	–49
T12	–1142	–1134	–8	–1206	–1188	–18
T13	–1301	–1288	–13	–1365	–1370	5
T14	–1286	–1254	–32	–1339	–1356	17
T15	–1262	–1227	–35	–1311	–1345	34
T16	–1269	–1245	–24	–1326	–1346	20
T17	–1179	–1170	–9	–1268	–1278	10
T18	–1081	–1045	–36	–1116	–1142	26
T19	–887	–859	–28	–923	–962	39
T20	–594	–589	–5	–639	–653	14
T21	–366	–355	–11	–398	–402	4
T22	–287	–268	–19	–311	–322	11
T23	–157	–142	–15	–170	–180	10
T24	–148	–137	–11	–155	–162	7
T25	–36	–36	0	–45	–45	0
T26	–14	–15	1	–19	–18	–1

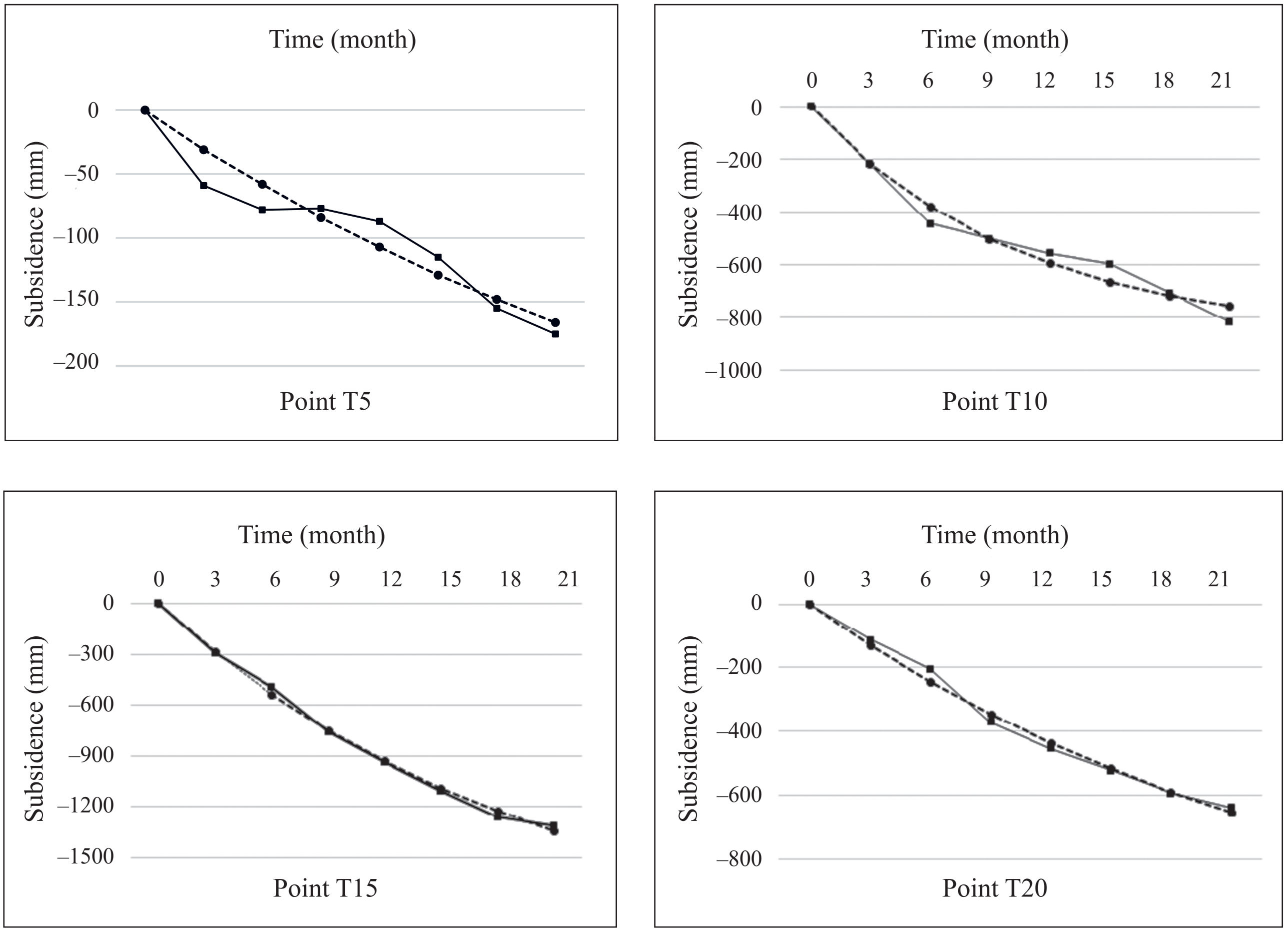

Fig. 3. Comparison of subsidence values of points obtained by empirical measurements and by Knothe time function.
Rys. 3. Porównanie wartości obniżeń punktów uzyskanych z pomiaru oraz obliczonych z wykorzystaniem funkcji czasu według Knothego.

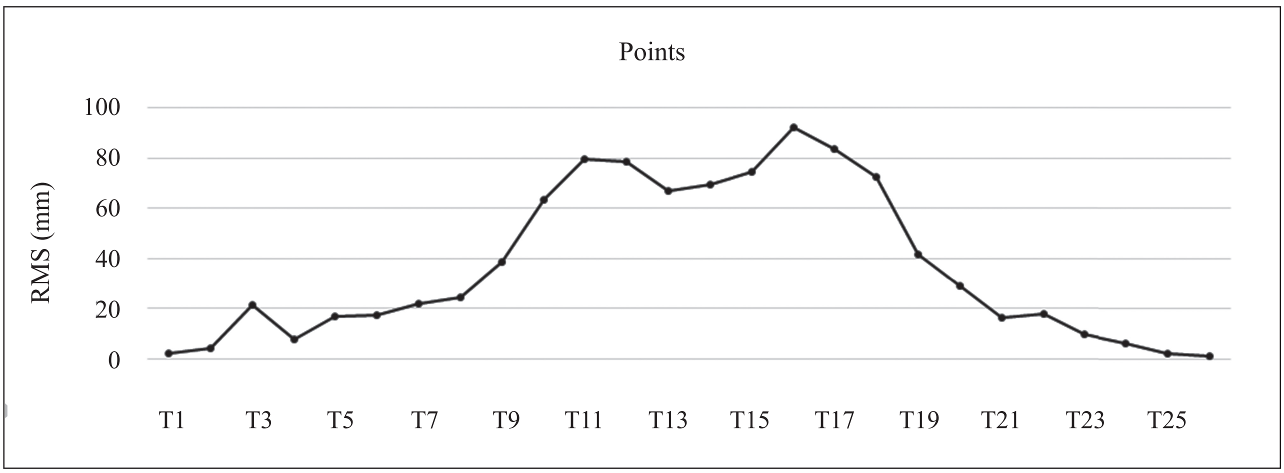

Fig. 4. Diagram of pridicted subsidence errors over time
Rys. 4. Wykres rozkładu błędów prognozowanych obniżeń z czasem

5. CONCLUSIONS

Underground coal mining of Quang Ninh coalfield in general and Thong Nhat coal mine in particular causes ecological problems especially the problem about mining damage has aroused the widespread interest.

The applicability of Knothe time function for the prediction of surface subsidence was first checked in various monitoring points of Thong Nhat coal mine. The small deviations between the predicted and the measured values show high reliability of method.

Apart from accuracy of parameters determination, the biases are caused by the particularity of geology and mining technology conditional.

Analyzed differences between subsidence indicators on the monitoring lines and predicted values have showed the characteristics of normal distribution.

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