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INFLUENCE OF UNDERGROUND MINING ACTIVITIES ON THE TOPOGRAPHIC SURFACE, CASE STUDY OF NUI BEO COAL MINE (VIETNAM)

Purpose. Coal mining activities by underground mining method will disrupt the equilibrium of the surrounding rock mass. In underground mining, determining the influence zone of exploiting the longwall on the topographic surface is extremely important. Through analyzing the displacement and deformation of the rock mass when exploiting the longwall 21103 in Seam 11 at Nui Beo Coal Mine, the influence is to be determined of exploiting this longwall on the topographic surface in order to forecast the boundary of the influence zone that may affect the surface works, ensuring the safety of such works.

Methodology. To achieve the research results, actual field survey methods, data analysis and numerical modeling methods are used in this article.

Findings. Analysis of the results from the numerical model determined that the total height of the collapsed and cracked area when exploiting the longwall 21103 in Seam 11 is about 85 m. The subsidence to the ground is about 10 cm from the center of the subsidence area. The analysis results from the numerical model also show that the roof collapse angle is 69°, thereby determining the area of influence on the topographic surface in the range of 55 m. Results on the cross-sections show that the boundary of the influence of mining on the topographic surface is the closest section 6–6, which is about 12 m. The stability time of the collapsed rock mass is determined to be about 5 months.

Originality. On the basis of UDEC (Universal Distinct Element Code) software, the authors have developed a simulation model for the mining process of the longwall 21103 in Seam 11. Analysis of the results from the model has shown the state of displacement and deformation of the surrounding rock mass. In this study, the numerical modeling method is applied to simulate the displacement of the longwall, which is consistent with the actual production of the underground mine. This enabled the authors to assess and identify the affected area with the required degree of reliability.

Practical value. The research results of the paper are used as a basis for implementation in actual production at Nui Beo Coal Mine. On the basis of the analysis of the surrounding rock mass displacements and deformations, when exploiting the longwall 21103 in Seam 11 at Nui Beo Coal Mine, the affected boundary of the topographic surface has been determined. At the same time, the stability time of the collapsed rock mass is also calculated. So, this is also the basis for Nui Beo Coal Mine to plan construction works on the site outside the determined affected areas to ensure the safety of such works.

Keywords: *underground mining, displacement and deformation, topographic surface, Nui Beo Coal Mine*

Introduction. It is well known that underground coal mining usually causes serious damage to underground structures and topographic surface buildings. One of the most important manifestations of underground mining activities is its potential influence on the initiation and reactivation of slope movements [1, 2]. The degree of impact of exploiting the longwall on the topographic surface depends on many different factors [3]. The factors of geological conditions include the thickness of alluvium, the depth of mining compared to the ground, the mechanical parameters of the rock mass, the hydrogeological characteristics. There are also technological factors such as mining method, support plan of the longwall, mining height, top coal recovery height and mine pressure control method.

Nui Beo Coal Mine has begun to convert from an open-pit mine to an underground mine according to the coal industry development plan approved by the Prime Minister [4]. Currently, the mine has operated stably and maintains a capacity of 1.5 million tons/year. To meet the annual capacity, the Nui Beo Coal Mine has added Seam 11 to the mining plan. Seam 11 can be exploited with many different longwalls, of which the longwall 21103 in Seam 11 has been prepared and ready to be exploited (according to Nui Beo Coal Mine production plan, 2021). According to the survey, this longwall has the closest distance to the topographic surface where the households are living. The exploitation of the longwall in Seam 11 will cause displacement and deformation zones in the surrounding rock mass, and at the same time form a new stress state. In this new stress state, the rock mass is completely destabilized and affects the surrounding rock mass and topographic surface, and at the same time, may adversely affect the households [5, 6]. The assessment and determination of the boundary of influence of the displacement and deformation zones when exploiting the longwall 21103 in Seam 11 on the topographic surface at Nui Beo Coal Mine is required in order to ensure the safety of the topographic surface works and safety in mining. Therefore, this study is necessary for the reality of the Nui Beo Coal Mine.

In the world and in the country, there have been studies to determine the influence of mining on topographic surface works [7]. On that basis, solutions are proposed to minimize the impact of displacement and deformation caused by mining activities. Case studies are based on numerical modeling methods to calculate and predict the degree of roof collapse [8, 9], and calculate the pressure on support by analytic method [10, 11], studies on the influence of mining on surface subsidence [12, 13], studies to determine the displacement and deformation areas of roof when exploiting the longwall [14–16]. The studies calculate the pressure for the longwalls in complex geological conditions [17–19].

It can be seen that, there have been many studies related to the determination of surface subsidence, displacement and deformation of roof when exploiting the longwall. However, the above studies have not mentioned development models to forecast and determine the influence of boundary and collapse angle of roof on the topographic surface when exploiting the longwall near residential households. Therefore, in this study, the authors developed a simulation model of the mining process of the longwall 21103 in Seam 11 at Nui Beo Coal Mine, observed and determined the boundary of influence on the topographic surface. This is also the basis for evaluating, analyzing and identifying the boundary that affects the topographic surface when exploiting this longwall, which is also an important problem for Nui Beo Coal Mine in implementing and ensuring mining safety.

Research Methods. ***Research method basis***. On the basis of information on geological conditions, stratigraphic columns of boreholes were collected, development a numerical model based on UDEC software. From there the results from the model were analyzed to determine the research results. The specific steps are as follows:

1. Collecting geological documents.
2. Developing models based on UDEC software.
3. Analyzing the model results to determine the boundary of influence on the topographic surface when exploiting the longwall in Seam 11 at Nui Beo Coal Mine.
4. Analyzing the model results to determine the fracture angle of the roof, the level of subsidence of the topographic surface.
5. Determining the stabilization time of collapsed rock mass.

Features of geological conditions in the study side. The stratigraphy of the study side consists of siltstone, claystone, and solid sandstone. However, in some places the roof has soft thin layers of claystone and coal clay forming a false roof, which collapses along with the coal mining process. The results of the mechanical analysis of the samples are shown in Table 1. The stratigraphic column of Seam 11 at Nui Beo Coal Mine is shown in Fig. 1.

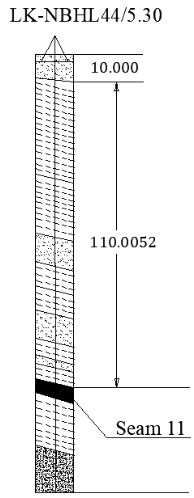

Fig. 1. LK-NBHL44/5.30 borehole stratigraphic column in Seam 11 at Nui Beo Coal Mine

Study side. The longwall 21103 belongs to Seam 11 at Nui Beo Coal Mine, mining depth is from –130 level. After Nui Beo Coal Mine was opened up by a pair of shafts according to

Table 1

Analytical results of the roof and floor rock of Seam 11

Rock unit	Value	Compression resistance strength σ_n (kG/cm^2)	Tensile strength σ_k (kG/cm^2)	Internal friction angle (degrees)	Cohesive force C	Specific weight γ (g/cm^3)
Siltstone (Immediate roof)	Max	1412.87	121.79	34°50’	449	3.15
	Min	171	16.3	31°53’	61	2.68
	Medium	565.85	57.16	32°24’	191.59	2.35
Gravelstone (Main roof)	Max	2652.83	197.34	35°20’	890.00	2.77
	Min	150.4	11.40	33°06’	139.00	2.53
	Medium	1218.01	106.26	34°45’	474.52	2.62
Sandstone (Main roof)	Max	3132	500	35°00’	563.0	2.93
	Min	148.83	6.06	22°30’	117.0	2.33
	Medium	979.68	86.37	33°44’	324.06	2.65
Siltstone (Main roof)	Max	1385	123	34°50’	376	2.77
	Min	182	16.1	30°15’	66	2.53
	Medium	668.53	56.19	32°25’	193.2	2.65
Claystone (Main roof)	Max	962.80	62.9	32°01’	108.0	3.15
	Min	150.40	11.4	30°54’	51.0	2.22
	Medium	345.81	32.80	31°42’	63.73	2.64
Gravelstone (Immediate floor)	Max	1536.91	139.19	35°00’	460.00	2.65
	Min	800.13	77.71	33°56'	244.00	2.56
	Medium	1198.45	107.24	34°22’	361.00	2.60
Sandstone (Immediate floor)	Max	2811.42	238.00	35°35’	900.00	2.79
	Min	127.00	42.00	31°45’	138.00	2.52
	Medium	1061.93	102.37	34°16’	347.26	2.66
Siltstone (Immediate floor)	Max	1092	78.67	36°15’	324	2.86
	Min	201.6	25.5	32°02’	69	2.54
	Medium	522.41	44.16	32°44’	132	2.67
Claystone (Immediate floor)	Max	1987.00	76.50	33°54'	116.00	2.76
	Min	103.00	22.30	29°30’	43.00	2.44
	Medium	460.18	34.66	31°49'	71.14	2.60

the plan of Vietnam Coal and Mineral Industries Group, the longwall 21103 was also prepared and ready for exploitation. The preparation plan of the longwall is shown in Fig. 2.

Mining technology, operation scheme, economic and technical indices of the longwall.

+ *Basic parameters of longwall 21103.*

- average thickness of seam: 5.1 m;
- average slope angle: 5°;
- extraction height: 2.6 m;
- thickness of top coal recovery: 2.5 m;
- the length of the longwall in the dip direction: 84 m;
- the length of the longwall in the strike direction: 80 m.

+ *Mining technology.*

Mining technology applied in the longwall 21103 is a mechanized mining technology to recover top coal, cut coal by shearer, support by shield, transport coal by scraper conveyors and control mine pressure by caving method. Some of the basic equipment used in a specific longwall is shown in Table 2.

+ *Operation scheme*.

The production tasks in the longwall face 21103 are organized and performed in cycles. A cycle of three web cuts is completed within three shifts, equivalent to the face moving progress of 1.89 m per day. A web cut includes the following stages: cutting face and moving supports with an advance rate of 0.63 m, recovering top coal and ventilation drifts. The inspection and maintenance of equipment are carried out at the top of each shift, including maintenance, repair, and replacement of spare parts if necessary for shearer, roof supports, scraper conveyors, electrical equipment and emulsifier pump

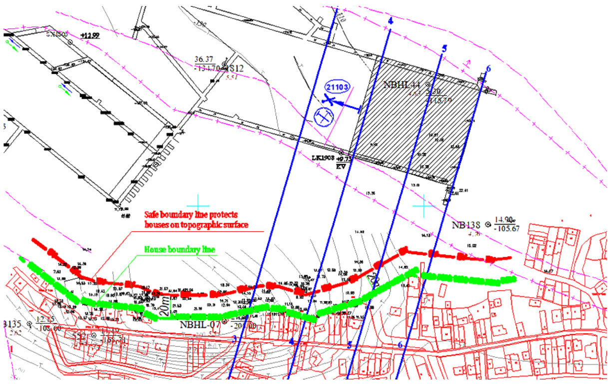

Fig. 2. Location of the longwall 21103 in Seam 11 at Nui Beo Coal Mine

Table 2

The equipment is mainly used at the longwall 21103 in Seam 11 at Nui Beo Coal Mine

No.	Equipment	Type	Amount	Note
1	Shearer	MG160/391-WD	01	26.5 tons
2	Shield	ZF4400/17/28	50	16 tons
3	Shield	ZFG4800/18/30	06	18.5 tons
4	Scraper conveyors	SGZ630/264	02	–
5	Crusher	PCM110	01	–
6	Conveying Machine	SZZ730/132	01	–
7	Belt conveyor	DSJ100/63/2*75	01	–
8	Emulsifying pumping station	BRW315/31.5	01	–
9	Mist station	BPW315/10	01	–

systems, dust filter system, power supply system, water supply system, methane warning system, and pressure test of supports. The number of workers in the face is arranged depending on the specific work of each shift.

+ *Economic and technical indices.*

After researching and establishing an operation scheme for longwall 21103 in Seam 11 at Nui Beo Coal Mine, which is exploited by mechanized technology, with the above equipment combination, the main economic-technical indices are calculated. They are shown in Table 3.

Building a numerical model. Based on the geological conditions and approved mining design of the longwall 21103 in Seam 11 at Nui Beo Coal Mine, a simulation model of the studied area has been built with dimensions of 300 m length, 156 m wide, including many layers of rock and coal. Extraction height: 2.6 m. Thickness of top coal recovery: 2.5 m. The simulation model is shown in Fig. 3.

Results and discussion. ***Analysis of numerical modeling results to determine the collapse step of the roof and the total height of the collapsed and cracked area when exploiting the longwall 21103 in Seam 11.*** Analysis of the modeling results shows that when the longwall moved in the strike direction of 18 m, the immediate roof began to delaminate, and cracks began to appear. With the longwall cut of 28 m in the strike direction, the immediate roof began to collapse into the voids, more and more cracks appeared with increasing density. With the longwall cut of 38 m in the strike direction, the immediate roof was almost completely collapsed, the main roof moved to the caving area, increasing the movement of rock mass, the crack systems had a thickness of about 1.5–2.0 m. Fig. 4 shows a model of the process of forming cracks with the longwall cut of 38 m in the strike direction.

With the longwall cut of 46 m in the strike direction, the immediate roof was completely collapsed, the main roof moved to the caving area, increasing the movement of rock mass, the crack system continued to grow strongly, with a thickness of about 1.5–2.0 m. Fig. 5 shows a model of the process of forming cracks with the longwall cut of 46 m in the strike direction.

Table 3

Economic and technical indices of the longwall 21103

No.	Indices	Unit	Amount
1	Average thickness of coal seam	m	5.1
2	Average slope angle of coal seam	độ	5
3	The length of the longwall in the strike direction	m	80
4	Extraction height	m	2.6
5	Top coal recovery height	m	2.5
6	Average length in dip direction	m	84
7	Volumetric weight of coal	ton/m^3	1.64
8	Extraction coefficient	–	0.95
9	Top coal recovery coefficient	–	0.85
10	The number of shifts per day	shift	3
11	Coal output of one face cut (1 shift)	ton	405
12	The number of web cuts per day	web	3
13	Cycle completion coefficient	–	1
14	Coal output of a day	ton	2430
15	Coal output of a month	ton	60750
16	Capacity of longwall face	ton/year	619,650
17	The number of workers per day	worker	72
18	Direct labor productivity	ton/labor	33.75

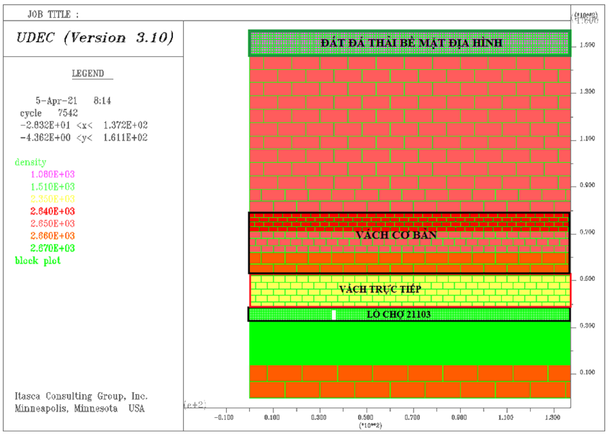

Fig. 3. Simulation of the mining area at the longwall 21103 in Seam 11 by UDEC 2D-3.1 software

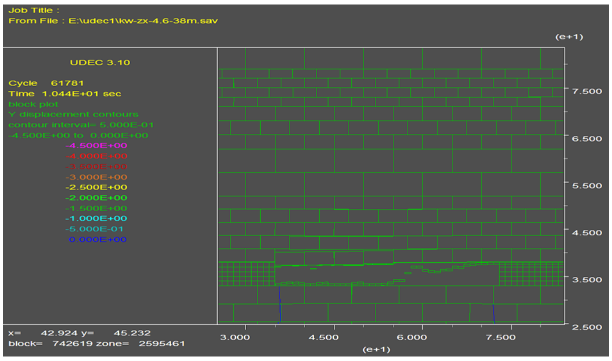

Fig. 4. Process of forming cracks with the longwall cut of 38 m in the strike direction

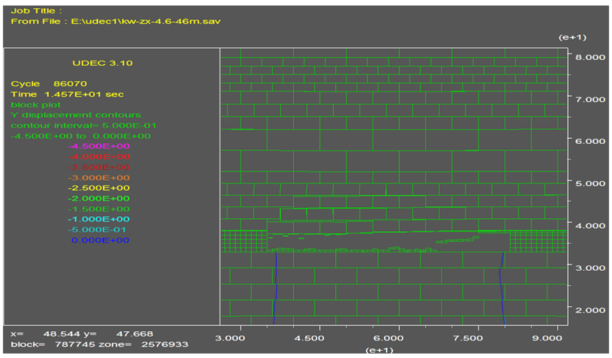

Fig. 5. Process of forming cracks with the longwall cut of 46 m in the strike direction

Fig. 6 shows that there was a great change from the roof with the longwall cut of 68 m in the strike direction, the main roof collapsed clearly, the system of cracks developed strongly. When the longwall continued to be cut of 80 m in the strike direction, the collapsed rock mass began to stabilize. Fig. 7 shows that the total height of the collapsed and cracked area of the roof when exploiting the longwall 21103 in Seam 11 is about 85 m.

Analysis of numerical modeling results to determine the fracture angle of the roof at longwall 21103 in Seam 11 and determine the boundary of influence of displacement and deformation on cross-sections of topographic surface.

+ *Analysis of numerical modeling results to determine the fracture angle of the roof.*

According to the results of the model, the displacement range of the roof in the longwall 21103, corresponding to the fracture angle is about 69 degrees. This result is shown in Fig. 8 below.

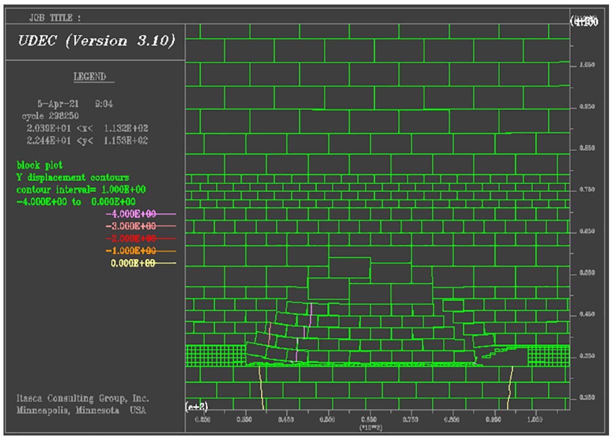

Fig. 6. Process of forming cracks with the longwall cut of 68 m in the strike direction

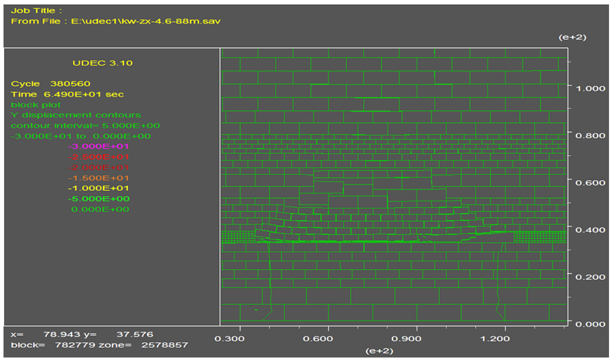

Fig. 7. Process of forming cracks with the longwall cut of 80 m in the strike direction

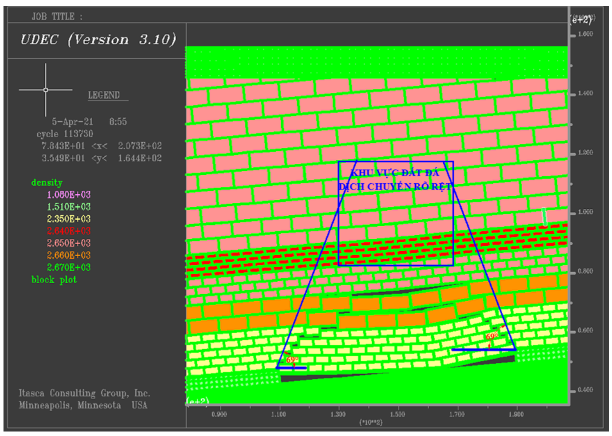

Fig. 8. Fracture process of roof in the longwall 21103 in Seam 11 at Nui Beo Coal Mine

+ *Determining the boundary of influence of displacement and deformation area caused by exploiting the longwall 21103 on the respective cross-sections.*

As shown in Fig. 2, the mining area of longwall 21103, this area is adjacent to the residential boundary. In order to determine the influence of the displacement caused by mining activities in the longwall 21103 on the topographic surface corresponding to the fracture angle of 69 degrees, in Fig. 2, sections 3–3; 4–4; 5–5 and 6–6 are shown; we continue to bring the fracture angle of 69 degrees to each of those sections, thereby determining the boundary of its influence. This result is shown in Figs. 9 to 12 as follows.

Figs. 9 to 12 show that, when exploiting the longwall 21103 in Seam 11 at Nui Beo Coal Mine, the total height of the col-

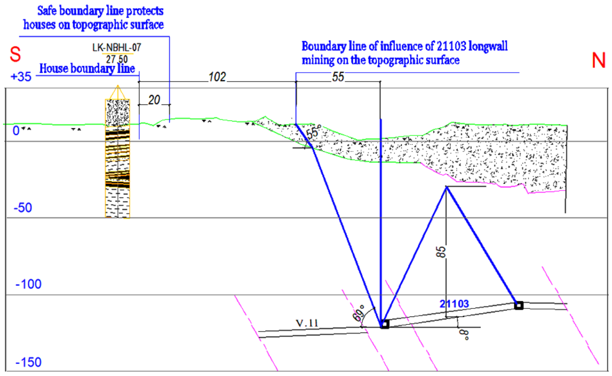

Fig. 9. Boundary of influence of displacement and deformation caused by exploiting the longwall 21103 on the cross-sections 3–3

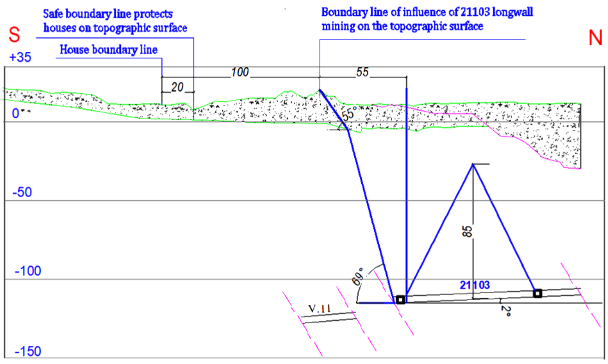

Fig. 10. Boundary of influence of displacement and deformation caused by exploiting the longwall 21103 on the cross-sections 4–4

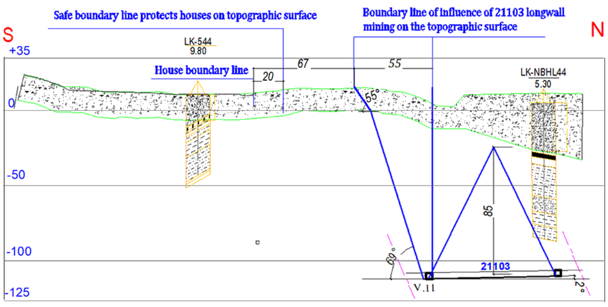

Fig. 11. Boundary of influence of displacement and deformation caused by exploiting the longwall 21103 on the cross-sections 5–5

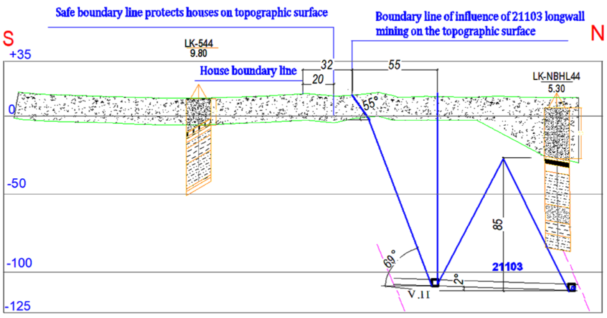

Fig. 12. Boundary of influence of displacement and deformation caused by exploiting the longwall 21103 on the cross-sections 6–6

lapsed and cracked area is 85 m, the fracture angle is 69 degrees. On the basis of the corresponding cross-sections, the area of influence (influence boundary) of this longwall exploitation on the topographic surface is 55 m. The cross-sections also show that this influence boundary will gradually move closer to the safe protection boundary of the residential area and the boundary of the house on the ground. Section 6–6 shows the closest distance of 12 m, while the furthest distance of 82 m is shown in section 3–3. The results are shown in Table 4.

Analysis of numerical modeling results to determine surface subsidence caused by exploiting the longwall 21103. The results of model analysis show that the depth of surface subsidence when exploiting the longwall 21103 is about 10 cm (the greatest subsidence depth is at the center of the displacement basin of the rock mass). The process of surface subsidence of the rock mass when exploiting the longwall 21103 is shown in Fig. 13.

Calculating the end time of the impact of the displacement on the topographic surface. The time of displacement and deformation is calculated from the beginning to the end of exploiting the longwall, and at the same time, the collapsed rock mass has completely stabilized. According to the National Regulation TCVN 10673:2015 on Mine Surveying (point 12.1.1.11) [20], the time to be considered as the end of the displacement process is when the total subsidence in 06 months does not exceed 10 % of maximum subsidence, but not more than

Table 4

Results of determining the boundary of influence of exploiting the longwall 21103 in Seam 11 at Nui Beo Coal Mine on cross-sections

Section (Figure)	Total height of the collapsed and cracked area (m)	Fracture angle of roof (degree)	The boundary of influence of mining (m)	Distance from the boundary of influence of mining to the residential safety boundary (m)	Distance from mining influence boundary to residential house boundary (m)
3–3 (9)	85	69	55	82	102
4–4 (10)	85	69	55	80	100
5–5 (11)	85	69	55	47	67
6–6 (12)	85	69	55	12	32

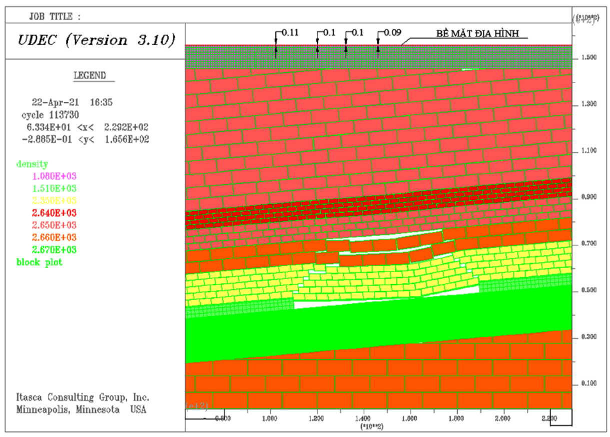

Fig. 13. Process of surface subsidence of the rock mass when exploiting the longwall 21103

30 mm. The time of topographic surface displacement when exploiting the longwall is determined by the formula

$$T - k_T \cdot \frac{H}{c}(\text{ctg}\,\delta_o + \text{ctg}\,\psi_3), \qquad (1)$$

where H is average mining depth, m; C is the average speed of the longwall, m/month; k_T is the coefficient depending on the average speed of the longwall (C) and the average mining depth (H), determined according to Table 5.

The results of calculating the displacement time of the longwall 21103 in Seam 11 at Nui Beo Coal Mine are shown in Table 6.

The calculation results in Table 6 show that the time to end the displacement when exploiting the longwall 21103 in Seam 11 at Nui Beo Coal Mine is about 4.58 months, this result is rounded to 5 months.

Conclusions.

1. The total height of the vertical collapse and cracking area is within the allowable safety limit. According to the analysis results from numerical modeling, the total height of the vertical collapse and fracture zone is about 85 m, which means that the maximum limit of the fracture zone is about 50 m from the topographic surface.

2. The influence of displacement and deformation is within the allowable limit. The influence of displacement and deformation on the ground when exploiting the longwall 21103 in Seam 11 is shown through the fracture angle of the rock mass during the collapse. The results of model analysis show that the fracture angle of the rock mass is 69 degrees. When determining displacement and deformation on some cross-sections, it is shown that the affected areas are outside the safety protection boundary of residential areas and allowable boundary of households on the topographic surface. At section 6–6 (Fig. 12), the affected area of displacement and deformation when exploiting the longwall 21103 is the closest to the safety protection boundary and the residential boundary (Table 4).

3. Surface subsidence is within the allowable limit calculated from 55 m onwards (outside the affected area of exploiting the longwall 21103 in Seam 11). The depth of surface subsidence when exploiting the longwall 21103 is about 10 cm (the greatest subsidence depth is at the center of the rock displacement basin). The subsidence depth decreases gradually as further away from the center of the displacement basin, the permissible subsidence is outside the affected area of exploiting the longwall 21103 in Seam 11, i.e. from 55 m onwards.

4. The end time of displacement and deformation effects is about 5 months. The calculation results of the end time of the effects of displacement and deformation when exploiting the 21103 in Seam 11 is 4.58 months (rounded to 5 months), shown in Table 6.

Nui Beo Coal Joint Stock Company – Vinacomin needs to manage the area within the boundary of the influence of displacement and deformation when exploiting the longwall 21103, not allowing the construction of works close to the safe boundary of the longwall has ended mining. The Company continues observation at some locations closest to the longwall (safety boundary) to monitor displacement and deformation.

Acknowledgements. *The authors would like to thank Nui Beo Coal Joint Stock Company for creating favorable conditions during the field survey and providing data to complete this study.*

Table 5

Table for looking up coefficients k_T

Average speed of the longwall C, m/month	Average mining depth H, m		
	Up to 100	Up to 300	≥ 500
20	1.5	1.2	1.1
60	1.8	1.5	1.3
Up to 150	2.0	1.5	1.5

Table 6

Results of calculation of displacement effect time

No.	Longwall	Average speed of the longwall C, m/month	Average mining depth H, m	Coefficients k_T	displacement effect time (month)
1	21103	47.25	123	1.5	4.58

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Вплив підземних гірничих робіт на топографічну поверхню на прикладі вугільної шахти Нуі Бео (В’єтнам)

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Мета. Видобуток вугілля підземним способом порушує рівновагу масиву, що оточує виробку. При підземних гірничих роботах дуже важливо визначити зону впливу процесу експлуатації лави на топографічну поверхню. Шляхом аналізу зміщення й деформації масиву гірських порід при розробці лави 21103 у пласті 11 вугільної шахти Нуі Бео визначити вплив експлуатації цієї лави на топографічну поверхню з метою прогнозування межі зони впливу, що може впливати на поверхневі роботи, забезпечуючи безпеку таких робіт.

Методика. Для досягнення результатів дослідження в роботі використовуються методи реальних польових досліджень, аналіз даних і методи чисельного моделювання.

Результати. Аналіз результатів чисельної моделі дозволив визначити, що загальна висота зони обвалення та тріщин при відпрацюванні лави 21103 пласта 11 становить близько 85 м. Просідання грунту становить близько 10 см відносно центру області просідання. Результати аналізу чисельної моделі також показують, що кут обвалення покрівлі становить 69°, що визначає зону впливу на топографічну поверхню в діапазоні 55 м. Результати відносно поперечних перерізів показали, що межею впливу гірських робіт на топографічну поверхню є найближча ділянка 6–6 протяжністю близько 12 м. Визначено, що час стійкості порушеного масиву гірських порід становить близько 5 місяців.

Наукова новизна. На основі програми UDEC (Універсальний унікальний код елемента) авторами розроблена імітаційна модель процесу відпрацювання лави 21103 пласта 11. Аналіз результатів моделі показав зміщений і деформований стан вміщуючого масиву гірських порід. Для імітації зміщення лави у цьому дослідженні застосовується метод чисельного моделювання, що відповідає фактичному видобутку підземної копальні. Це дозволило авторам оцінити й визначити зону впливу з необхідним ступенем достовірності.

Практична значимість. Результати дослідження даної роботи використовуються як основа для впровадження в реальне виробництво на вугільній шахті Нуі Бео. На підставі аналізу зсувів і деформацій вміщуючого масиву гірських порід при відпрацюванні лави 21103 пласта 11 вугільної шахти Нуі Бео визначається межа топографічної поверхні, що піддається впливу. При цьому також розраховується час стійкості порушеного масиву гірських порід. Таким чином, це також є підставою для вугільної шахти Nui Beo Coal Mine планувати будівельні роботи на території за межами зон впливу, що були визначені для забезпечення безпеки таких робіт.

Ключові слова: *підземний видобуток, зміщення й деформація, топографічна поверхня, вугільна шахта Нуі Бео*

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