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ASSESSING THE IMPACT OF UNDERGROUND WORKING (TUNNELING) IN THE II SECTION OF SEAM 14 ON SURFACE CONSTRUCTION WORKS AT HA LAM COAL MINE (VIETNAM)

Purpose. Tunneling in the ground changes the initial equilibrium stress state of the rock, which is also the cause of displacement and deformation of the surrounding rock mass. To determine the impact of tunneling on surface construction works in order to ensure the safety of surface works by analyzing the displacements and deformations of the rock mass during tunneling in the II section of Seam 14 at Ha Lam Coal Mine.

Methodology. To achieve the research results, actual field survey methods, data analysis and numerical modeling, as well as combined blasting vibration methods are used.

Findings. After analyzing the numerical modeling results, an area has been identified in the II section of Seam 14 of the Ha Lam Coal Mine that affects the surface construction works and is located within a radius of about 20 m from the portal of two inclined shafts. The results of blasting vibrations are calculated on the basis of the passport of blasting operations in tunnels. Thus, the affected area has been identified within a radius of 30.5 m. However, at a distance of 30.5 m, surface construction works are not in the area of influence.

Originality. On the basis of FLAC software, the authors have developed a simulation model for tunneling, thereby analyzing and describing the best state of deformation and displacement of the surrounding rock mass. In this study, a numerical modeling method is applied to simulate the driving order for each tunnel, which is consistent with the actual production of underground mines. Based on the passport of drilling and blasting operations in tunnels, the authors calculated the impact of blasting vibrations on surface construction works. After that, the authors assessed and identified the affected area with the required degree of reliability.

Practical value. The research results are used as a basis for implementation in actual production at Ha Lam Coal Mine. On the basis of analysis of the surrounding rock mass displacements and deformations, when tunneling in the II section of Seam 14 at Ha Lam Coal Mine, the affected area of the surface construction works has been determined. This is also the basis for Ha Lam Coal Mine when planning construction works on the site outside the determined affected areas to ensure the safety of such works.

Keywords: *tunnels, surface construction works, displacement, deformation, Ha Lam Coal Mine*

Introduction. When digging a system of tunnels for mining minerals, cavities are formed in the ground [1–3]. The degree of impact of digging the system of underground tunnels for mining minerals on surface construction works depends on many different factors [4, 5]. The factors of geological conditions, such as the thickness of alluvium, the depth of tunnels relative to the surface, the mechanical parameters of the rock mass, and hydrogeological characteristics. Technological factors such as the rock breaking method, the type of structure to support the tunnels, the tunnel cross-sectional dimensions, and density of tunnels in the rock mass.

A system of underground tunnels was dug in the II section of Seam 14 of the Ha Lam Coal Mine, including a pair of inclined shafts of +30 to –300 levels and two crosscuts at –150, –300 levels. Above the surface of this system of tunnels, construction works are carried out. The construction of this pair of inclined shafts and crosscuts destroys the primary stress state in the rock mass, causing the formation of a new stress state in the surrounding rock mass. In this new stress state, the rock mass may stabilize or destabilize or, in other words, may cause the dug cavity deformation. Assessing the impact of displacements on surface construction activities, while digging these tunnels, is important to ensure the safety of these surface operations. Therefore, this study is necessary for the reality of the Ha Lam Coal Mine.

In the world and in the country, a lot of research has been carried out to ensure the safety of surface operations during digging of tunnels. The case studies are based on numerical modeling methods to calculate and predict the subsidence level [6, 7], to calculate pressure on tunnels [8, 9], to study the impact of mining on surface operations [10, 11], as well as equivalent material models to assess the impact of mining operations [12, 13]. In the course of the research, models of tunnels in deep coal mines and tunnels dug in soft rock have been developed, as well as pressure has been calculated for tunnels in difficult mining-geological conditions [14–16]. Some other studies are mainly based on models developed for tunnels dug in urban areas to determine surface deformation values [17–19].

It can be seen that the above studies do not mention models developed to predict and determine the displacements and deformations of rock areas in digging of each tunnel, which could assess its impact on surface operations. Therefore, in this study, the authors have developed a simulation model of the process of digging the tunnels in the II section of Seam 14 with simultaneous control and determination of the displacements and deformations of the rock mass. This is also the basis for evaluating, analyzing and identifying the area influencing the II section of Seam 14 at the Ha Lam Coal Mine.

Research Methods. ***Location of the studied area.*** The II section of Seam 14 belongs to the Ha Lam Coal Mine, Ha Lam ward, Ha Long city, Quang Ninh province, Vietnam. The boundaries of the area location in coordinates are as follows: X = 19,600–19,800; Y = 408,300–408,700. The studied area is mainly a highland area. The terrain surface elevation is from 120 to 130 m. The terrain slope is from 15 to 45 degrees, gradually increasing to the North.

A pair of inclined shafts of +30 to –300 levels and the crosscuts at –150, –300 levels was dug.

In seams of coal, siltstone, sandstone, gravel and pebbles, a pair of inclined shafts and the crosscuts were dug at –150, –300 levels in the II section of Seam 14 of +30 to –300 levels, with a cross-section of 15.8 m^2. The tunnels are supported by SCP-27 steel and solid concrete. The diagram of a pair of inclined shafts of +30 to –300 levels and the crosscuts at –150, –300 levels is shown in Fig. 1.

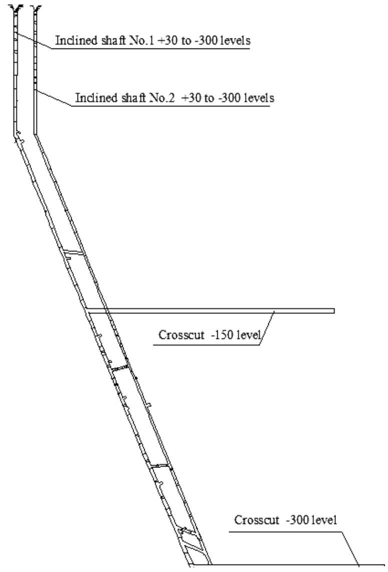

Fig. 1. Diagram of a pair of inclined shafts of +30 *to* –300 *levels and the crosscuts at* –150, –300 *levels* [20]

Table 1

Basic parameters of rocks occurring in the mine [21]

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	Max	2104	179	38	800	3.25
	Min	110	1.22	16	34.5	2.02
	Medium	613	61	32.35	189	2.65
Sandstone	Max	3132	500	38	950	3.07
	Min	113	26.9	18.3	39	2.16
	Medium	1188	105	33.56	366	2.63
Gravel stone	Max	3733	199	38	1000	2.86
	Min	148	34	22.30	118	1.79
	Medium	1413	110	33.51	375	2.60
Claystone	Max	1043	103	35.3	315	2.86
	Min	87	17	21	11.6	1.79
	Medium	350	32	29.57	92	2.6

Peculiarities of geological conditions. The stratigraphy in the II section of Seam 14 includes coal deposits and alluvium. Within the exploration boundaries, the average thickness is from 335 to 400 m, including layers of cobblestone, gravel, claystone, and interbedding of coal seams. The basic parameters of some rocks occurring in the mine are shown in Table 1.

Research method basis. Currently, there are many methods used to predict and calculate the displacements and deformations of a rock mass when digging the tunnels. This study uses a numerical modeling method based on FLAC3D software, combined with a calculation of blasting vibrations to determine the area of impact during digging the tunnels. This software allows modeling the geomechanical transformation processes in a rock mass, paying attention to technological processes. The process of calculating and modeling is conducted using user-controlled commands. The steps are as follows:

1. Building a numerical model to simulate the process of digging inclined shaft No. 1.
2. Building a numerical model to simulate the process of digging inclined shafts No. 1 and 2.
3. Building a numerical model to simulate the process of digging inclined shafts No. 1, 2 and a crosscut at –150 level.
4. Building a numerical model to simulate the process of digging inclined shafts No. 1, 2 and the crosscuts at –150, –300 levels.
5. Analyzing results of numerical modeling.
6. Calculating the impact of blasting vibrations.
7. Comparing and determining the area affected.

Building a numerical model. Based on the geological conditions and tunneling process performed in the II section of Seam 14 of the Ha Lam coal mine, a simulation model of the studied area has been built with dimensions of 450 m high, 700 m wide, including many layers of rock and coal. A pair of inclined shafts has been dug of +30 to –300 levels and two crosscuts at –150, –300 levels. The simulation model is shown in Fig. 2.

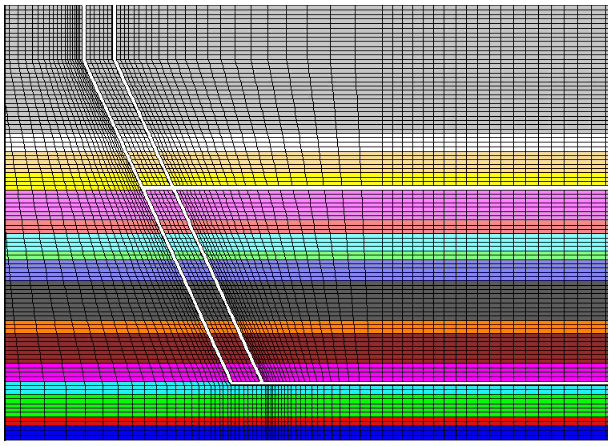

Fig. 2. Simulation model of the process of digging the tunnels in the II section of Seam 14 of the Ha Lam Coal Mine

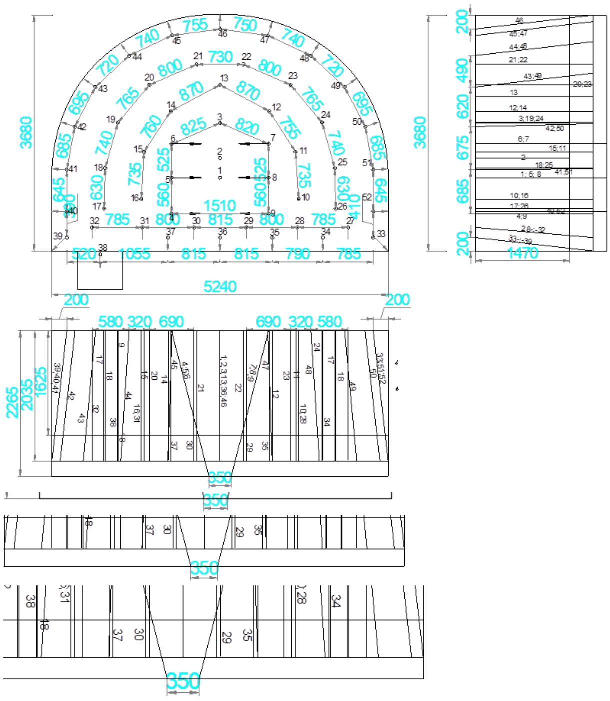

Fig. 3. Passport of drilling and blasting operations in rocks enclosing a pair of inclined shafts and crosscuts [22]

Based on the documents, the order of digging a pair of inclined shafts and the crosscuts are as follows: firstly, an inclined shaft No. 1 from +30 to –300 level is dug, then an inclined shaft No. 2 from +30 to –300 level is dug. Then, the crosscut at - 150 level is dug and finally a crosscut at –300 level is dug.

Impact of blasting vibration. The delayed blasting method has been used to dig a pair of inclined shafts and the crosscuts. Passport of drilling and blasting operations is shown in Fig. 3.

The safe distance allowed for blasting vibration is determined according to the guidelines in the regulation of the Ministry of Industry and Trade at QCVN 2008/BCT, appendix D, page 76, as follows [23].

$$R_c = K_c \alpha^3 \sqrt{Q}, \qquad (1)$$

where R_c – safe distance, m; K_c – coefficient dependable on the soil properties of the protected work, Table 3.3 in the QCVN 2008/BCT regulation; α – coefficient dependable on blasting impact index n, (Table 3.4 in the QCVN 2008/BCT regulation); Q – total amount of explosives per detonation, kg.

Results and discussion. ***Analysis of numerical modeling results when digging an inclined shaft No.1.*** Horizontal displacements and deformations are shown in Fig. 4.

From the numerical modeling results shown in Fig. 4, it can be seen that after digging the inclined shaft No. 1, the process of displacements and deformations in the horizontal rock mass occurs around the inclined shaft No. 1 and the surface area around the gateway.

At the location of gateway of the inclined shaft No. 1, displacements and deformations of the rock mass occur with the maximum value of horizontal deformations at this position, which is 2.6 cm. At the position of more than 20 m from gateway, the maximum value is 2 cm. In general, the value of rock mass deformations on a horizontal surface, as indicated above, will not have an impact on surface operations.

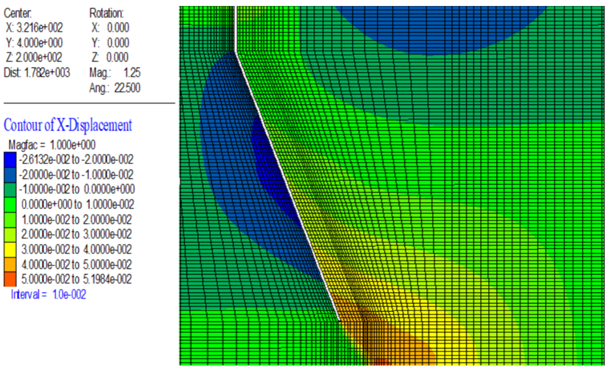

Fig. 4. Horizontal rock mass deformations after digging an inclined shaft No. 1

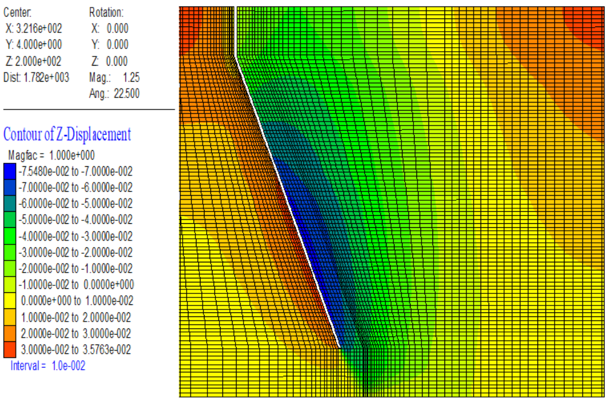

Fig. 5. Vertical rock mass deformations after digging an inclined shaft No. 1

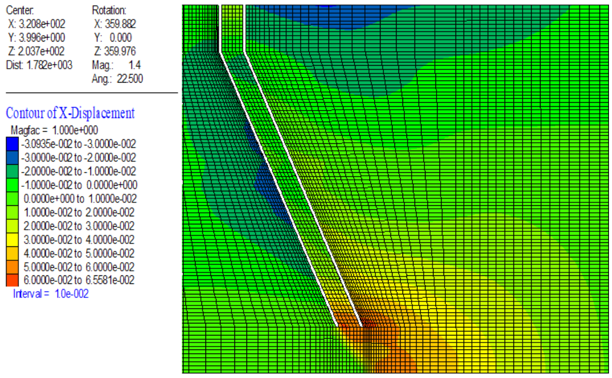

Fig. 6. Horizontal rock mass deformations after digging a pair of inclined shafts No. 1 and 2

Vertical displacements and deformations are shown in Fig. 5.

From the numerical modeling results shown in Fig. 5, it can be seen that deformation movement occurs at the location of gateway of inclined shaft No. 1. The largest value of vertical deformations at this location is 3.6 cm. At the position of more than 20 m from the gateway, the maximum value is 3 cm.

Analysis of numerical modeling results when digging a pair of inclined shafts No. 1 and 2. Horizontal displacements and deformations are shown in Fig. 6.

From the numerical modeling results shown in Fig. 6, it can be seen that after digging a pair of inclined shafts No. 1 and 2, the horizontal deformations and displacements of rocks continue to develop around a pair of inclined shafts and the surface area around the gateway.

At the location of gateway, the rock mass deformation movement still occurs most strongly and the largest value of horizontal deformations at this position is 3.09 cm. At the position of more than 20 m from gateway, the maximum value is 2.4 cm.

Vertical displacements and deformations are shown in Fig. 7.

From the numerical modeling results shown in Fig. 7, it can be seen that after digging a pair of inclined shafts No. 1 and 2, the vertical rock mass deformations develop and expand around the inclined shafts and surface area around the gateway.

At the location of gateway of a pair of inclined shafts, the maximum value of vertical deformations is about 5 cm. At the location of more than 20 m from gateway of a pair of inclined shafts, the maximum deformation value is 3.2 cm.

Analysis of numerical modeling results when digging a pair of inclined shafts No. 1, No. 2 and a crosscut at –150 level.

Horizontal displacements and deformations are shown in Fig. 8.

From the numerical modeling results shown in Fig. 8, it can be seen that after digging a pair of inclined shafts and a

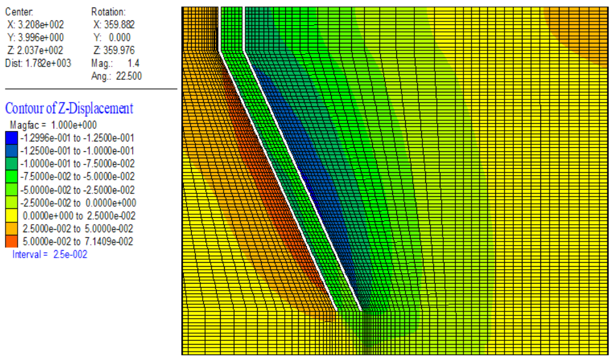

Fig. 7. Vertical rock mass deformations after digging a pair of inclined shafts No.1 and 2

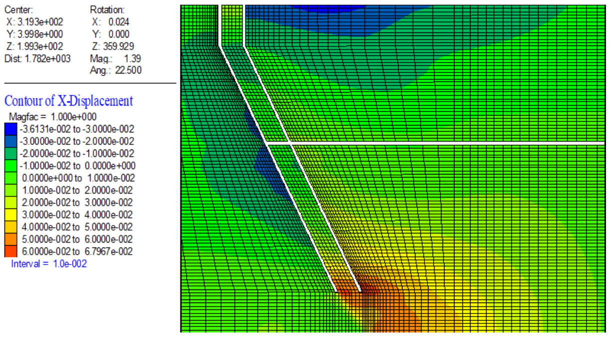

Fig. 8. Horizontal rock mass deformations after digging a pair of inclined shafts and a crosscut at –150 level

crosscut at –150 level, the horizontal rock mass deformations occur at the crosscut and continue to develop around a pair of inclined shafts, especially in the area of intersection between a pair of inclined shafts and a crosscut at –150 level. In the surface area around the gateway, the deformation continues to develop, but it is not clear and its value is small.

At the location of gateway of inclined shafts, the values of displacements and deformations change insignificantly and the horizontal deformation value at this location increases by 0.5 cm compared to that before digging a crosscut at –150 level. At the position of more than 20 m from the gateway, the maximum value is 2.5 cm.

Vertical displacements and deformations are shown in Fig. 9.

From the numerical modeling results shown in Fig. 8, it can be seen that at the location of gateway of inclined shafts, the values of displacements and deformations change insignificantly. The value of vertical deformations at this location increases by 0.1 cm compared to that before digging the crosscut at –150 level. At the location of more than 20 m from the gateway, the maximum value is 2.6 cm.

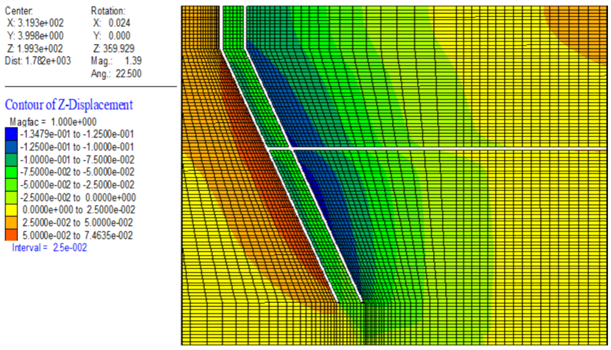

Fig. 9. Vertical rock mass deformations after digging a pair of inclined shafts and a crosscut at –150 level

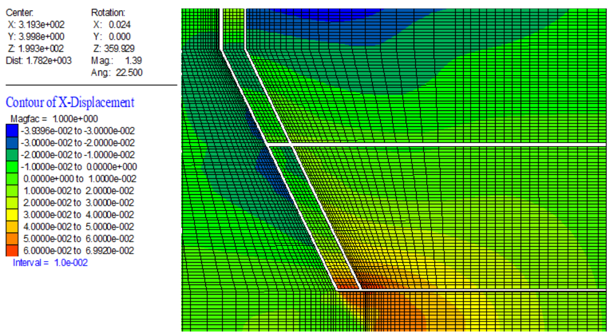

Fig. 10. Horizontal rock mass deformations after digging a pair of inclined shafts and the crosscuts at –150, –300 levels

Analysis of numerical modeling results when digging a pair of inclined shafts No. 1, No. 2 and the crosscuts at –150, –300 levels. Horizontal displacements and deformations are shown in Fig. 10.

From the numerical modeling results shown in Fig. 10, it can be seen that after digging a pair of inclined shafts and the crosscuts at –150, –300 levels, the process of rock mass horizontal deformations occurs at –300 level of the crosscut and continues to develop around the area of intersection between a pair of inclined shafts and a crosscut at –300 level. The surface area around the gateway of a pair of inclined shafts is no longer affected by digging operations at –300 level.

Vertical displacements and deformation are shown in Fig. 11.

From the numerical modeling results shown in Fig. 11, it can be seen that at the location of gateway of a pair of inclined shafts, there is no change in vertical deformations. In the area of intersection between a pair of inclined shafts and a crosscut at –300 level, the largest vertical deformation value is about 10 cm.

Results of calculating the impact of blasting vibrations. The results of calculating the impact of blasting vibrations according to the above formula (1) are shown in Table 2. Table 2 also presents the coefficients dependable on the soil properties of the protected work for raw rock, destroyed rock and crushed stone. Therefore, the corresponding K_c is found in the QCVN 2008/BCT regulation. The coefficient depends on the blasting impact index $n = 1.2$. The maximum amount of explosives per one detonation is $Q = 14.95$ kg.

Table 2 shows that in the case of a delayed blasting in rocks with a maximum amount of explosive per one detonation, the safe distance on the surface in the II section of Seam 14 at the Ha Lam Coal Mine is $R_c = 30.5$ m.

Conclusions. Digging a pair of inclined shafts of +30 to –300 levels and the crosscuts at –150, –300 levels affects the rock mass stability on the surface within a radius of 20 m from the gateway of a pair of inclined shafts.

On the topographic surface, outside the radius of 20 m from the gateway of a pair of inclined shafts, it is completely unaffected by digging a pair of inclined shafts of +30 to –300 levels and the crosscuts at –150, –300 levels. Time affects the rock layer stability on the surface only for the first time when digging the gateway and collar of a pair of in-

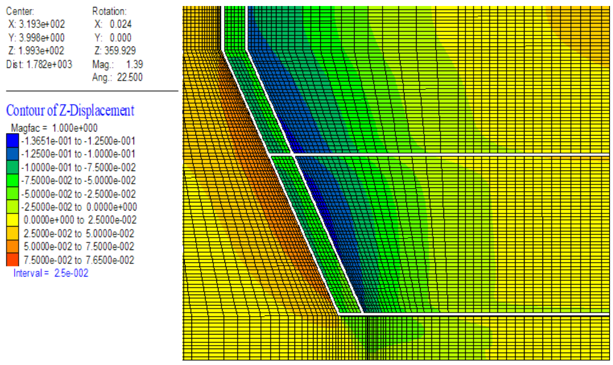

Fig. 11. Vertical rock mass deformations after digging a pair of inclined shafts and the crosscuts at –150, –300 levels

Table 2

Results of calculating the safe distance in case of a delayed blasting when digging tunnels in the rocks

No	K_c	α	Q, kg	R_c, m
1	3	1,2	14,95	12,9
2	5	1,2	14,95	21,6
3	7	1,2	14,95	30,5

clined shafts (this time is about 01 month). After setting an anti-fixing structure, deformation stabilizes and will not develop further.

Based on the regulation of the Ministry of Industry and Trade QCVN 2008/BCT, the impact distance from the place of blasting to the constructions on the surface has been calculated under condition of differential blasting with a range of 30.5 m when digging in the rock.

When combining the following methods: numerical modeling method, drilling and blasting method, it has been revealed that the largest impact area is assessed using the method of blasting concussion. That is, the maximum impact area from the position of the gateway of a pair of inclined shafts to surface operations is within 30.5 m and beyond 30.5 m. Thus, it will not effect surface operations.

After construction and setting anti-fixing structure for the gateway and collar in a pair of inclined shafts (more than one month), by this time the blasting position is at a distance of about 60 m from the gateway and collar in a pair of inclined shafts. The speed of digging a pair of inclined shafts is 60 m/month. Therefore, it is possible to conduct construction operations on the surface in the area of less than 30.5 m to serve the operation of a pair of inclined shafts and other related works.

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Оцінка впливу підземних виробок (тунельних виробок) II ділянки пласта 14 на наземні будівельні роботи на вугільній шахті Ха Лам (В'єтнам)

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Мета. Прокладання тунельних виробок у землі змінює початковий рівноважний напружений стан гірської породи, що також є причиною переміщення й деформації навколишнього масиву гірських порід. Встановити вплив прокладання тунельних виробок на поверхневі будівельні роботи з метою забезпечення безпеки поверхневих робіт шляхом аналізу зсувів і деформацій гірського масиву під час прокладання тунельних виробок II ділянки пласта 14 на вугільній шахті Ха Лам.

Методика. Для досягнення результатів дослідження використовуються фактичні методи польових досліджень, аналізу даних і чисельного моделювання, а також комбіновані методи щодо вибухових вібрацій.

Результати. Після аналізу результатів чисельного моделювання визначена ділянка, що впливає на поверхневі будівельні роботи II ділянки пласта 14 вугільної шахти Ха Лам, яка розташована в радіусі близько 20 м від входу двох похилих стовбурів. Результати вибухових вібрацій розраховуються на підставі паспорта підривних робіт у тунелях. Таким чином, територія ураження виявлена в радіусі 30,5 м. Проте на відстані 30,5 м наземні будівельні роботи не знаходяться в зоні впливу.

Наукова новизна. На основі програмного забезпечення FLAC автори розробили імітаційну модель для прокладання тунельних виробок, таким чином аналізуючи та описуючи найкращий стан деформації та зміщення навколишнього масиву породи. У цьому дослідженні метод чисельного моделювання застосовано для моделювання порядку проходження кожного тунелю, що узгоджується з фактичним виробництвом підземних шахт. На підставі паспорта буропідривних робіт у тунельних виробках розраховано вплив вибухових коливань на поверхневі будівельні роботи. Після цього автори оцінили й визначили уражену ділянку з необхідним ступенем достовірності.

Практична значимість. Результати дослідження використовуються як основа для впровадження у фактичне виробництво на вугільній шахті Ха Лам. На підставі аналізу зсувів і деформацій навколишнього гірського масиву, при прокладанні тунельних виробок II секції пласта 14 вугільної шахти Ха Лам, визначена зона впливу на поверхневі будівельні роботи. Це також є основою для вугільної шахти Ха Лам при плануванні будівельних робіт на майданчику за межами визначених уражених зон, щоб забезпечити безпеку таких робіт.

Ключові слова: *тунелі, поверхневі будівельні роботи, переміщення, деформації, вугільна шахта Ха Лам*

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