DOI: 10.25515/PMI.2017.4.412

UDC 622.272: 502.65

DETERMINATION OF PARAMETERS OF THE UNDERGROUND INCLINED COAL SEAM MINING IN QUANG NINH BASIN UNDER PROTECTED OBJECTS ON THE SURFACE

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Based on analysis of mining and geological conditions of natural occurrence of coal seams at Quang Ninh basin it has been determined that more than 37 % of deposit reserves are located under the protected surface objects. To justify the possible variants of technological schemes for development of these coal seams situated under protected surface objects there has been a methodology for evaluation of displacement parameters of undermined layer during underground mining operations. The article shows the possibility to perform calculations for this methodology that originally were developed for coal deposits in Russia and to use calculated coefficients for Bulanashskoe deposit (Ural), because its mining and geological conditions of natural occurrence for coal seams are similar to the conditions of occurrence at Quang Ninh basin. It also presents the research results for possibility to apply the development systems to mine the reserves located under protected surface objects using the technological schemes with roof control, with complete caving, full backfilling and pillar roof support. It has been identified that with a system of roof support using complete caving the deformation of surface exceed the critical values required for preservation of surface objects. In case of using the development technology with full backfilling there have been defined a minimal admissible coefficient of backfilling, as well as requirements to filling materials. For coal deposit mining technology using the method of pillar roof support there have been defined parameters for pillars and chambers, identified maximum admissible extraction ratio ensuring protection and safety of objects located on the surface. It also presents the algorithm for selection of technological mining scheme for development of coal seams of Quang Ninh basin.

***Key words*:** Quang Ninh basin, coal seam, underground working, displacement, protected objects, technological scheme

***How to cite this article*:** Le Van Hau. Determination of Parameters of the Underground Inclined Coal Seam Mining in Quang Ninh Basin Under Protected Objects on the Surface. Zapiski Gornogo instituta. 2017. Vol. 226, p. 412-419. DOI: 10.125515/PMI.2017.4.412

Introduction. The Quang Ninh coal basin is the largest in Vietnam, it covers an area of 6.1 thousand km^2, total resources located up to a depth of 800 m are 3.6 billion tons. In accordance with the plans for Vietnam coal industry development in 2018-2020 this basin will no longer be developed with open pit mining methods, most of the cuts will be closed. According to the Vietnam Institute of Mining Science and Technology, coal reserves under the protected facilities in the Quang Ninh basin amount to 663.4 million tons, including 284.8 million tons in the reservoirs currently being developed in the basin jointly by underground and open mining methods. Protected surface objects are, as a rule, urban buildings and structures, while conducting mining operations under these objects it is obligatory to provide both safe underground coal mining and functioning of ground facilities [6].

The solutions of tasks ensuring the efficiency of underground mining of seams, taking into account the conservation of objects on the earth's surface, are covered in works of S.G.Avershin, A.A.Borisov, V.I.Borsch-Komponitsa, V.N.Gusev, S.N.Zelentsov, V.N.Gusev, V.P.Zubov, M.A.Iofis, O.V.Kovaleva, A.B.Makarov, V.M.Shik, M.G.Gustafin, V.P.Zemisev, A.S.Yagunov, S.P.Penga et al. [1, 2, 4, 11, 12, 16, 18, 20].

Research methods. There are industry normative documents that allow to determine the displacement parameters and assess the stability of objects on the surface using different technologies for development of seams in Russian coal basins [9, 13]. At the same time, direct use of the Russian Federation normative methods for calculating the shearing parameters for various mining technologies for conditions of the Quang Ninh basin is impossible in connection with the specific geological and mining conditions. Thus, the justification of the parameters of underground inclined coal seam mining in Quang Ninh basin, which ensure the economic efficiency of coal mining while preserving the objects on the surface, is an urgent scientific task, the solution of which is of great importance for the coal industry in Vietnam.

In order to justify the parameters of the underground mining technology for the inclined coal seams of the Quang Ninh basin, which ensure the economic efficiency of coal mining while preserving the objects on the surface, in 2011-2016 a complex of studies was carried out. They were designed to find solutions of the following main tasks:

DOI: 10.25515/PMI.2017.4.412

• analysis and evaluation of the world's experience and best practices in the field of underground mining of inclined seams under protected objects on the earth's surface;

• selection of a technique for estimating the displacement parameters of undermined rock mass using different technological schemes for development of inclined seams under conditions of the Quang Ninh basin;

• development of variants of technological schemes for underground mining of inclined seams with ensuring the safety of surface objects;

• estimation of influence of development of inclined coal seams technological conditions on the displacement parameters of undermined rock mass in the mines of the Quang Ninh basin;

• justification of the parameters of underground coal mining technology at the mines of the Quang Ninh basin, which ensure the efficiency of coal mining and the preservation of objects on the surface.

Research results and their discussion. The evaluation of the surface objects safety was determined from the results of a comparison of the displacement parameters of undermined rock mass with their limiting values for the protected objects. Within the zone affected by undermined space there was identified a specific hazardous zone. To determine the boundaries of the hazardous zone on the Russian deposits, the following values of deformations of the earth's surface are accepted: slope $i = 4 \cdot 10^{-3}$; curvature $k = 0.2 \cdot 10^{-3}$ 1/m; tension $\varepsilon = 2 \cdot 10^{-3}$ (with an average interval of 15-20 m).

In 2011, the staff of the Vietnam Institute of Mining Science and Technology carried out observations of the surface displacement at several mines in the Quang Ninh basin, including the Nam mau mine. The Nam mau Mine is located in the cultural and tourist area of Yen Tu, a large part of the deposit reserves is located under protected surface objects. The mine is worked on a layer 7 with an average thickness of 2.0 m, with an angle of incidence from 25 to 30°, lying at a depth of 180 to 220 m, with an overburden thickness of 10 m. The development of the deposit is carried out using a long wall mining method along the strike. Bringing of coal in a 80-meter-long face is carried out with the help of drilling and blasting operations, fixing the bottomhole area with single prop support, and roof control is done by complete caving. The length of the working area along the strike is 160 m.

The data obtained from field observations on the Nam mau mine, which determine the displacement parameters, were subsequently used to conduct numerical studies of the process of rock mass deformation and its different development techniques.

To determine the displacement parameters, the software complex «Massiv» was developed at the Saint-Petersburg Mining University, which implemented the normative for the Russian mines methodology described in the Rules for the Protection of Structures from the Harmful Influence of Underground Mining [13]. The possibility of using the technique is justified by comparing the mining and geological conditions of workings of seams at the mines of the Bulanashskoe deposit (the Urals) and the Quang Ninh basin. The conditions of bedding and the displacement parameters of the subsoil layer for the basin of the Quang Ninh and the Bulanashskoe deposit practically coincide (the difference is not more than 20 %). To take into account the specifics of the conditions of the Quang Ninh basin, a safety factor of 1.2 was introduced as a result of calculations using the empirical coefficients of the Bulanashskoe field.

To ensure the safety of surface objects we have studied the technology of mining with backfilling of mined space. The aim of the research was to determine the minimum possible filling factor of the mined space, which ensures the protection of surface objects [5]. The calculation results together with hazardous values from the point of view of surface objects safety are shown in Fig.1. The hazardous and maximum values are the following: for slopes $i = 4.87 \cdot 10^{-3}$, curvature $k = 0.5 \cdot 10^{-3}$ and tension $\varepsilon = 3.15 \cdot 10^{-3}$. As can be seen from Fig.1, in a number of cases the calculated values exceeded the hazardous values of the displacement parameters.

The world's best practices in the underground development of coal seams with backfilling of mined space shows that the filling factor of the worked-out space can reach 0.8-0.95 (depending on the method of backfilling) [3, 8, 14, 15, 17, 19]. To ensure the safety of surface structures of Nam mau mine, the calculation factor for the mined space is 0.8. The calculated parameters of earth sur-

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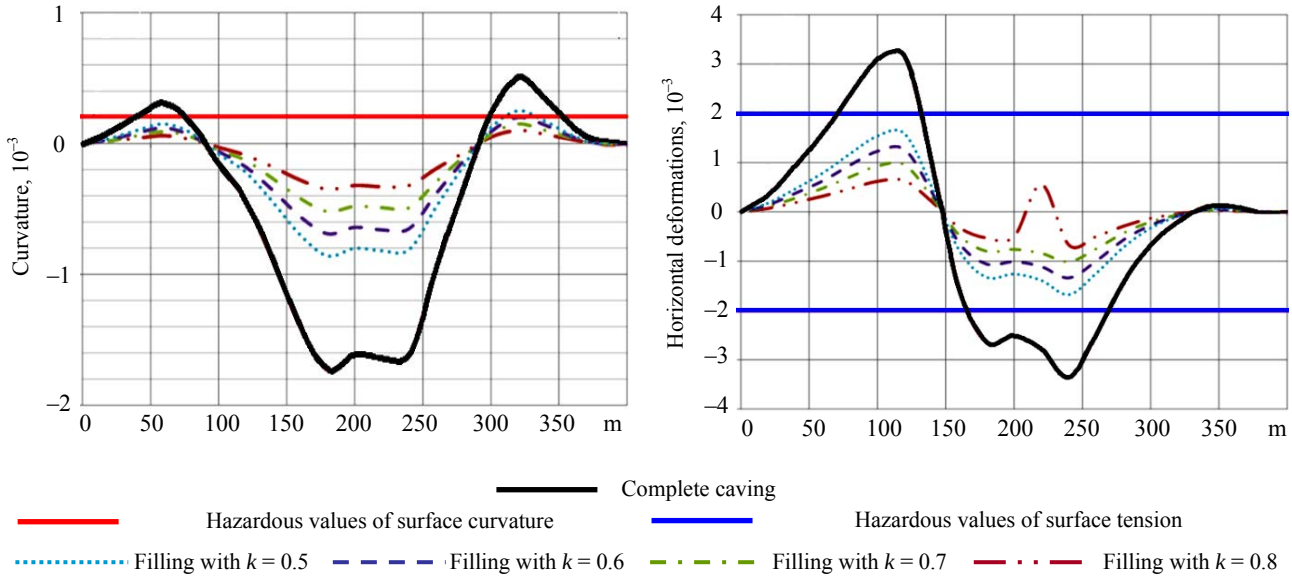

Fig.1. Surface displacement parameters at Nam mau mine

face displacement with the use of full backfilling of the mined space with a filling factor of 0.8 are significantly lower than hazardous values, which indicates provision of the safety of surface structures and the possibility of developing coal reserves under the protected surface objects.

Further numerical studies have shown that the displacement values that are safe for surface objects under conditions of the Nam mau mine are provided with a filling ratio for the mined space exceeding 0.7. At lower values of the coefficient, the curvature of the earth's surface in the work area exceeds the maximum permissible values (Fig.1). Thus, the established limit values of the filling factor allow us to determine a set of technological schemes for working out the formation with full or partial backfilling, ensuring the safety of surface objects.

The carried out researches of influence of the type of filling material on the displacement parameters showed that the filling material should provide a deformation modulus of at least 30 MPa (Fig.2). These requirements are fully consistent with the parameters of qualitied waste rock of this mine. This material is incombustible, after the appropriate preparation of the rock in the crushing and screening plants, the required granulometric composition, strength and modulus of deformation up to 600 MPa are provided.

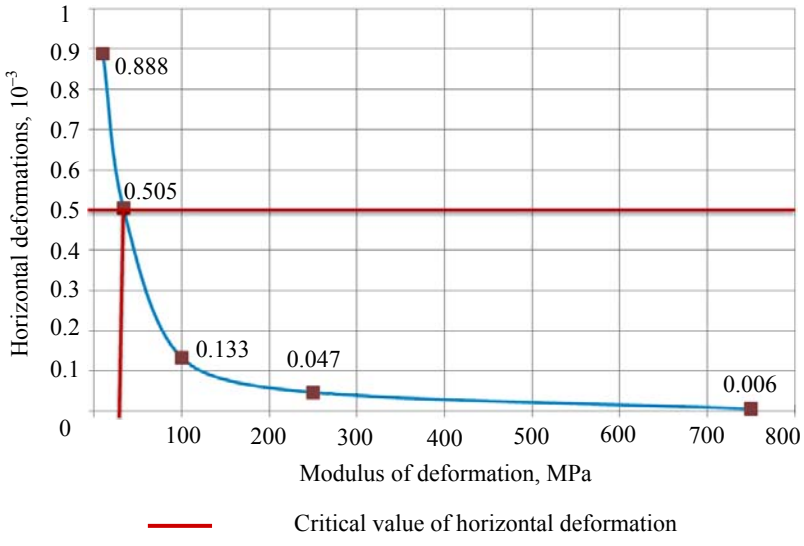

Fig.2. Determination of deformation modulus of backfilling material

As an alternative to the technological schemes of development of seams with backfilling of mined space, the possibility of using development systems with short longwall faces was considered. The version of layout of minefield at Nui Beo is shown in Fig.3. The development of a formation section 11 by longitudinal and transverse chambers with the leaving inter-chamber and barrier pillars was considered. It is planned to use a set of equipment, including a heading machine, equipped with a device for mounting an anchor support, or a separate anchor-mounting machine, as well as self-propelled wagons.

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Fig.3. Layout of Nui Beo mine section developed with short longwall faces

The parameters of the chambers and the pillars were calculated according to the methodology outlined in the methodological guidelines for choosing the geomechanical parameters of the coal bed technology mining using short longwall faces [10]. Three variants of the technological scheme, differing in the ratio of the width of working sections D, the width of the chambers A, as well as the barrier *X* and the inter-chamber *x* pillars, were considered for assessing the impact of the development of the formation by short longwall faces on the surface (Table 1).

The width of the chambers and the width of the working sections are accepted on the basis of the analysis of the experience of working out layers with short longwall faces, the dimensions of the inter-chamber and barrier *X* pillars are determined by calculations. A finite element model consisting of 35,000 elements was developed, the results of calculations (for example, horizontal deformations for working sections with width $D = 120$ m) are shown in Fig.4. As calculations have shown, the integrity of the surface is ensured for the whole range of working sections widths considered.

Table 1

Parameters of chambers and pillars

Parameter	Type of technological scheme		
	First	Second	Third
D, m	80	120	200
A, m	6	9	6
X, m	42	45	51
x, m	7	8	7
Coal loss, %	58	43	44

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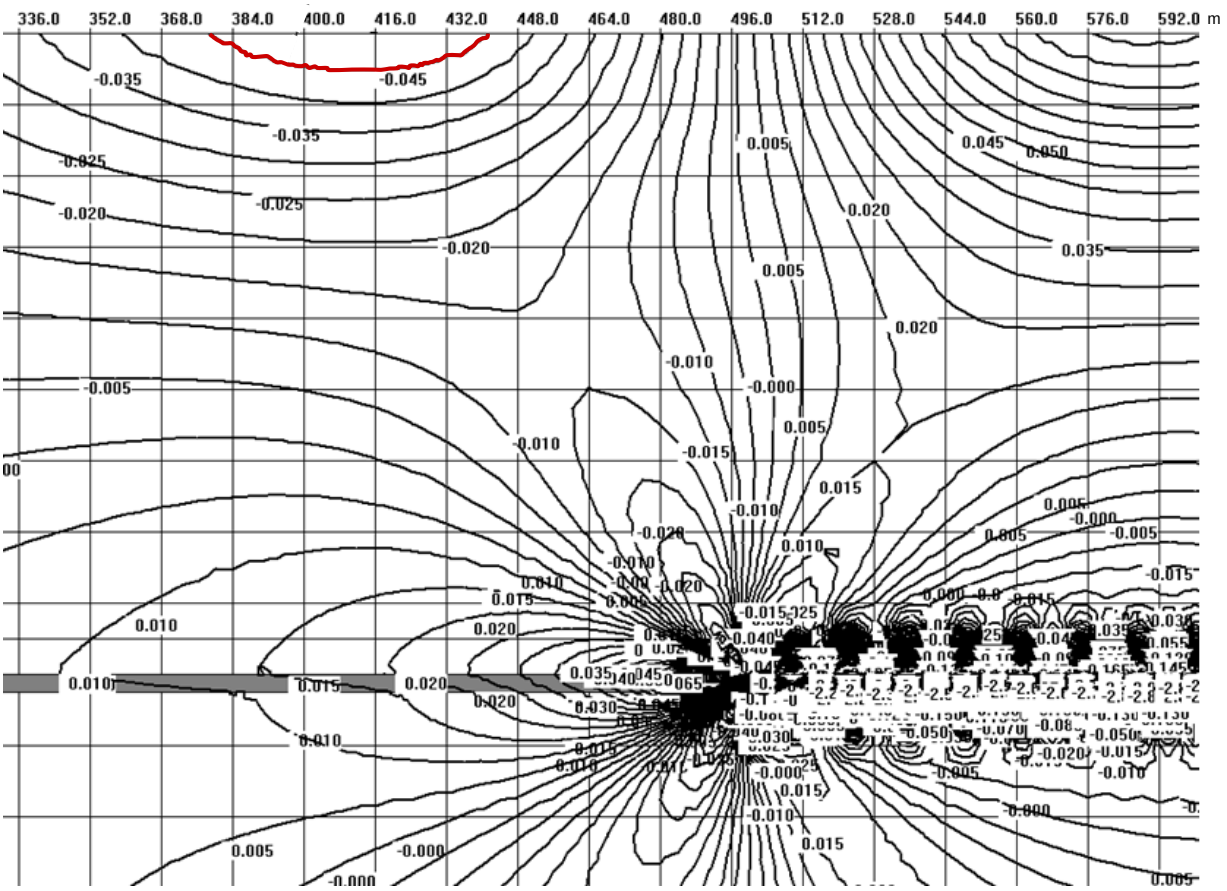

Fig.4. Horizontal deformations (relative, normalized to 1000)

To determine the limit value of coal extraction completeness, when deposit is being developed with short longwall faces, the calculations were carried out for a situation involving partial extraction of barrier pillars. As studies have shown, the maximum permissible level of horizontal deformation of the surface is achieved when chain inter-chamber pillars are extracted with stopes of 7 m width developed at every 6 m, which corresponds to a recovery factor of 0.6. Thus, the minimum level of coal loss, at which the preservation of objects on the surface is ensured, will be 40 %.

The method for controlling roof and parameters of technological schemes for development of inclined seams in the basin of Quang Ninh under protected objects is proposed to be chosen on the basis of minimization of the amount of costs for developing the working sections and damage from losses of coal left in the pillars, under condition of preserving the surface objects. For this purpose, a corresponding algorithm was developed (Fig.5).

Technological schemes for development of inclined seams of the basin with the roof control, complete caving, full backfilling and pillar support have been considered (Table 2).

Table 2

Characteristics of technological schemes

Technology requirements	Roof control method		
	Complete caving	Full backfilling	Pillar support
Economic efficiency	+	–	+
Preservation of surface objects	–	+	+
Minimal coal losses	+	+	–

The economic efficiency can be estimated by the level of loads on the longwall faces, as well as the cost of development of C_{dev} in comparison with the market value of extracted in the process of coal mining P_{coal} [7]. In connection with the lack of detailed data on the costs of development of seams at the Vietnamese mines, data on similar fa-

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cilities in the mines of Russia were used for comparative evaluation. Since the market price of coal varies widely, the estimations can be made on the basis of loads of longwall faces and the cost of their development. The greatest value of loads on longwall face is provided with the use of technological schemes with complete caving, the smallest is during full backfilling; the lowest costs – when working with roof control, pillar support, the largest – with full backfilling of the mined space.

Preservation of objects on the surface is a mandatory requirement for the technology used. The possibility of destroying the objects was estimated on the basis of the calculation of the parameters of surface displacement using various technological schemes P_i and comparing them with the critical values of P_{cr}.

Minimal losses of coal are ensured when developing with complete caving or full backfilling, the maximum – in case of pillar support. The damage from losses at the same time depends on the market value of the reserves left in non-recoverable stocks.

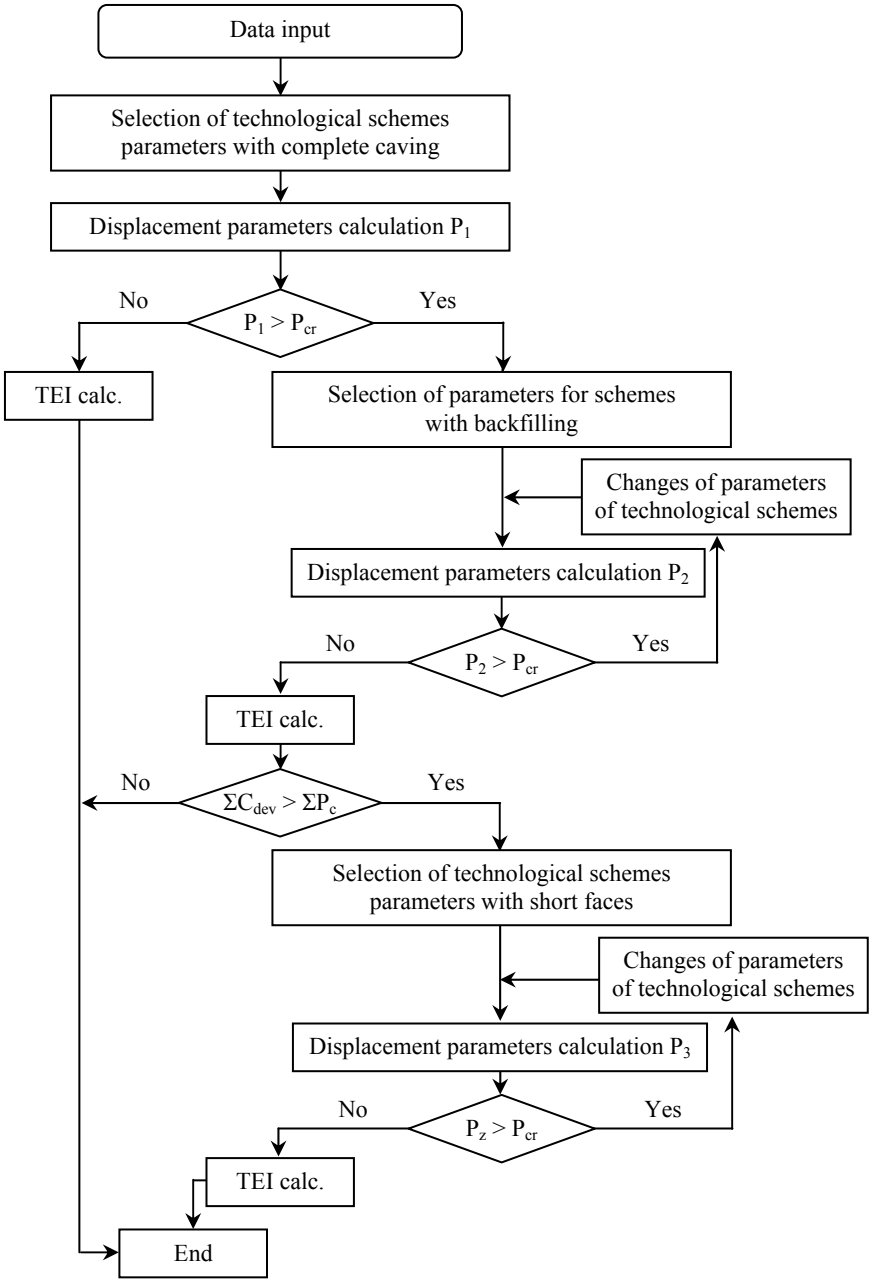

Fig.5. Algorythm for selection of technological schemes for development of inclined seans under protected objects, TEI – technical-economic indicators; C_{dev} – development costs; P_c – Coal price

In accordance with the algorithm (Fig.5), the choice of technological schemes and their parameters for the development of inclined seams of the Quang Ninh basin under protected objects the technological schemes for working out seams with longwall faces using coal face mechanized heading systems and roof control with complete caving has been chosen for initial consideration. Then the parameters of the expected surface displacements P_1 and their comparison with the critical values for a given type of objects P_{cr} are estimated. If the failure is not expected, then the calculation of technical and economic performance indicators is carried out and this scheme is adopted for implementation, as it provides lower costs compared to schemes using backfilling method and lower expenses compared to schemes with leaving the support pillars as hence coal losses.

The scheme with a full backfilling is selected on the basis of comparing the cost of mining with the market value of recoverable reserves. If the costs exceed the value of the reserves, then the development will be unprofitable and one should proceed to the consideration of schemes with pillar roof support, i.e. application of short longwall face development systems.

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Technological schemes of short longwall face development systems with pillar roof support ensure the lowest operational costs, high productivity at the highest coal losses in pillars in comparison with schemes with complete caving and full backfilling variants.

The calculation of the displacement parameters for systems with complete caving for the conditions of the Quang Ninh basin showed that in case of their implementation it is impossible to provide the stability of objects on the surface. The displacement parameters exceed the critical values in the seam 11 when it is being developed not even at full capacity.

The experience with the application of technological schemes in Vietnam with the full backfilling of the worked-out space showed that, with the surface objects preserved, the cost of mining exceeded the market value of recoverable reserves, i.e. from an economic point of view, the scheme turned out to be unprofitable. Thus, at the existing level of prices for energy coal, the most effective schemes are pillar roof support, providing loads of up to 2000 tons per day with operational losses of at least 40 percent.

Conclusions

1. The largest Vietnamese coal basin Quang Ninh has over 37 % of mineral resources reserves (over 280 million tons) are located under buildings, structures, cultural objects, quarries and other protected surface objects, this fact excludes application of development systems using schemes with longwall faces with complete caving.

2. The evaluation of expected surface displacements during underground mining of coal seams of Quang Ninh basin can be carried out according to normative standards and methodology developed for Russian mines, these guidelines are published in Rules of Protection of structures from Harmful influence of underground mining, they can be used as analogue deposit from experience of developing Russian deposit Bulanashskoe with introduction of a safety factor of 1.2.

3. The application of development systems with full backfilling of mined out space enables to ensure the safety of objects located on the surface with a filling factor not less than 0.7, which can be achieved while using longwall face mechanized heading systems with backfilling pattern.

4. As materials for backfilling there can be used rocks mined at this deposit if they are processed to the condition of having deformation modulus of the filled rock mass not less than 30 MPa.

5. Development system with short longwall faces and leaving inter-chamber and barrier pillars provides safety of protected objects located of the surface, the best performance indicators being achieved with a width of working section of 200 m and width of chambers of 6 m.

6. As a criterion for selection of technological schemes for development systems in case of inclined coal seams located under protected surface objects we have proposed to use the minimal development costs and costs related to coal loss due to the material being left in support pillars.

7. The methodological guidelines for selection of coal seam development systems technology have been worked out, the guidelines provide efficiency of mining operations and safety of objects located on the surface.

8. The carried out comparative assessment of development systems with complete backfilling and systems with short longwall faces under conditions of coal mines of Quang Ninh basin has shown that despite the increase of extraction ration the expenses for full backfilling of mined out space system exceed the damage from additional losses of reserves when using development systems with shirt longwall faces.

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The paper was accepted for publication on 20 March, 2017.