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EFFICIENCY AND SEISMIC SAFETY OF CONSTRUCTING UNDERGROUND STRUCTURES IN COMPLEX ROCK MASSES

Purpose. To develop new resource-saving method of underground construction and evaluate how effective it is, to set thresholds for safe seismic ground vibrations which accompany explosions during breaking in mine workings.

Methodology. The work used method of analysing mining and geological conditions of workings, field surveys of rock conditions in face, experiments are conducted on rock samples taken from blasting sites, more detailed data are obtained on rock properties, type and direction of development of crack systems along the workings cross-section by funneling method and approved research methods in accordance with current State Standards.

Findings. Research has been carried out to determine main features of physical and mechanical properties of rocks, fracture and tectonic structure of rock mass and development of fracture systems. According to the results of ejection funnel parameters, the anisotropy coefficient was calculated, and according to data on identification of crack systems and their density, fracture coefficient was calculated. The experimental data obtained were used to adjust rational distances between contour boreholes and along the entire cross-section of working face. Based on corrected drilling and blasting operations (DBO), experimental explosions were carried out in workings. It was established that the borehole utilisation rate (BUR) was 0.95–0.97, uniformity of rock mass crushing was achieved, and explosive material consumption was reduced by 10–15 %. Instrumental measurements of explosion impact in workings proved seismic ground vibrations at protected facilities amounted to 0.4 cm/s with a duration of 0.05 s, which did not exceed the State Standard.

Originality. Optimal DBO parameters are substantiated based on changes in numerical parameters of anisotropy and fracture coefficient, as well as radius of fracture zone along the cross-section of working face. The idea of forming a shielding zone along the contour of workings with explosive charges having an elongated symmetrical cut was confirmed and technically implemented.

Practical value. Laboratory and field research results are fundamental for designing borehole layouts along workings and refer to major initial data used to justify design parameters of blasting chart.

Keywords: *blasthole, explosion, blasthole charge, face, rock, fracture*

Introduction. Construction works of underground structures and large cross-sectional workings (railway and subway tunnels in cities, mine workings in deep mines and mines), especially in difficult mining and geological conditions, require improvement of existing resource-saving technological solutions and development of new ones for the construction of underground structures, destruction, and processing of minerals with underground work cycles.

Construction of underground structures, such as tunnels and other large cross-sectional excavations, is often carried out both in weak rocks (clay-retaining soils of low strength) and in massive solid rocks of complex structure, which are constructed using explosive energy. Such rocks differ from structurally homogeneous rock masses by anisotropy of physical and mechanical properties, presence of both vertical and horizontal systems of cracks of different intensity with alternating areas of highly fractured and almost monolithic strong rocks. Structure of these rocks significantly complicates transfer of explosion energy to massif being destroyed by interaction of extended explosive charges (borehole and downhole) and processes of rocks crushing intensity control by explosion with predicted seismic effect.

These problems can reduce efficiency in construction of underground structures (tunnels, large section mine workings) in areas with developed infrastructure (civil and industrial facilities) located in protected zones without use of new technical solutions developed based on results of theoretical and experimental studies to substantiate their rational parameters and serve as a basis for their implementation in practice.

Literature review. Studies on increasing efficiency in using explosive energy from blasting of blasting charges in mining operations consisted mainly of large-scale theoretical and experimental studies with subsequent implementation in practice. This is due to significant labour-intensive process of mine workings in massifs of strong stressed rocks. So, domestic scientists: Mindeli E., Demediuk G., Berishvili G. (1971) and foreign scientists: Wagner C., Diederichs M., Kaiser P., Eberhardt E. (2004) and others have conducted a number of studies, both in laboratory [1] and in industrial conditions, to study mechanism of solid media destruction by explosion energy in a stress-strain state [2] and to model these processes by discrete and finite element methods [3]. These studies allowed us to develop new highly efficient technical solutions for implementation in practice.

They found [2] that high stresses are concentrated at great depths in rock masses that are in an equi-component stress state with one free surface, when sinking mine workings, on surface of face, leading to their brittle fracture under dynamic (explosive) loading. Depending on a load’s nature, brittle fracture of solid media and rock masses can be divided into two main categories, including spalling and deformation detachment. Spalling or sloughing is a result of visible tensile failure under high compressive stresses. While detachment at workings in hard rock masses is naturally brittle, it contributes to releasing large volumes of rock mass, which is common in crystalline rocks and in conditions where fractured rock has one free surface and is in a high intensity stress state.

According to practical experience [1], during construction of two parallel tunnels of large cross-section, one of which served as an experimental section, it was sinking according to the newly developed parameters of drilling and blasting operations using a new design of the explosive charge, and another – according to basic drilling and blasting parameters. Both tunnels were driven perpendicular to sub-horizontal rock stresses. During tunnelling, seismometric monitoring was carried out to detect the effects of explosive charges along the cross-section of workings. The analysis of seismic data of rock mass vibrations during tunnelling in the conventional way showed that the seismic instability zone moves ahead of the face along the excavation to a depth of 4.0 m. At the same time, explosion in neighbouring tunnel contributed to weakening of rocks in that zone by penetration of gaseous detona-

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tion products (GDP) into natural cracks with subsequent weakening of their bonds. The high strain gradients around part of rock mass blown away by explosion were due to seismic velocity propagation relative to tunnel face position.

Also, we should focus on results of industrial tests with new designs of prismatic cutters, namely: with a charge placed in advance borehole, which performs the final destruction of rocks with subsequent ejection to face separation [4], as well as a cutter with uncharged boreholes in the centre [5]. Rocks are blasted off when sinking mine workings in hard rocks of complex structure using emulsion explosives (EE) [6] by intensifying technological processes with the use of high-performance charging equipment, methods for sinking mine workings using charge designs with a cumulative effect [7]. Application of this technology will ensure high-quality sinking with further advancement of at least 3.0–3.5 m per cycle and increase the sinking rate to 50–70 m/month.

Special approach is required when conducting contour blasting in construction of underground structures for protected facilities. So, according to Y. Epimakhov, et al. (1993), it was established that use of contour blasting method in sinking underground mine workings leads to increased technical requirements for accuracy of contouring and quality of newly formed surface along the workings contour, indicators of which (contour formation of extended network of cracks and rock overburden along the design contour of workings) are determined by accuracy of blasting chart. However, in production conditions, parameters of blasting chart are usually implemented with significant deviations of actual parameters from calculated ones, which is caused by instrumental and methodological errors of surveying measurements when transferring axis of workings to face, type and characteristics of used mining equipment, physical, mechanical and structural features of rocks, as well as organisational reasons that lead to significant violations of contour blasting technology with subsequent seismic impact on protected facilities.

One of the ways to prevent technological disruptions is to comply with drilling regulations and prevent deviations of calculated values for contour holes placement parameters from the normative values with appropriate tolerances. Therefore, authors of [8] assessed a degree of rock mass disturbance in contact with mine workings contour under different methods and schemes of blasting [9]. Experimental explosions showed that when sinking mine workings of large cross-section (respectively, from 17 to 24 m^2) during contour detonation of emulsion explosive charges in cartridges using considered methods and schemes of contour detonation with formation of branched network cracks to a considerable depth from mine workings contour. Their greatest manifestation was noted in drifts adjacent to driven face, which is associated with the interaction of a group of blasting charges and redistribution of stresses near face during drilling. According to results analysis, contour blasting technology using emulsion explosives in cartridges is preferred by mining companies worldwide. However, as noted by Mosinets V. N., Tseitlin Y. I. and other authors, a special function in this technology of underground structures construction in protected areas with developed infrastructure is assigned to controlling intensity of seismic and shock air waves propagation during industrial explosions in mine workings [10] and mining blocks of mines [11]. Moreover, the explosion's useful effect in rock destruction can be increased in various ways, in particular, by adjusting explosive specific energy by using a new design of a borehole charge with a different cross-sectional shape from traditional ones [12]. Such a design is a charge with a longitudinal symmetrical cut along the length of charge cavity.

Stockwell (2010) and other researchers have proved that use of notched explosive charge design in blasting operations contributes to efficient transfer of explosion energy to rock masses being destroyed, reduction of stabs and canopies on tunnel (mine workings) surface during crack propagation in process of underground structures construction. Moreover, application of this method will ensure uniformity of rock crushing and improvement of mining efficiency in difficult mining and geological conditions.

Furthermore, implementation of developed method (Kutter, et al. 1971, Fournet, et al. 1982) during tunnelling operations in difficult mining and geological conditions by unloading the rock mass under the action of rock cutting will contribute to redistribution of stresses around working area under tensile stresses of rock mass. Therefore, further testing and implementation of the developed method of seismic impact reduction during drifting of a working face in massifs of a complex rock structure using the proposed design of explosive charge with symmetrical longitudinal incision in blast cavities will contribute to efficiency and seismic safety of blasting operations in the field of initial static load and is important for science and practice.

Research work is performed in accordance with complex program of National Academy of Sciences of Ukraine on development of nuclear energy "Development of scientific bases and improvement of methods and means of increasing efficiency and safety of mining operations in uranium ore mining" (No. GR 0117U004231), according to research work "Scientific and technical support of engineering and survey works on experimental sections of the transfer tunnel of Dnipro subway" under the contract No. 939 between JSC "LIMAK INSAAT SANAY ve TIDZHARET A. S." and "Institute of Geotehnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine" and agreement on scientific and technical cooperation between "Institute of Geotehnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine" and "Dnipro University of Technology".

Purpose. To develop a new resource-saving method for construction of underground facilities to evaluate efficiency and set thresholds for safe seismic ground vibrations accompanied by explosions in workings at protected facilities during rock stripping.

Objectives, methods, presentation of research results and discussion. Effective method for controlling seismic impact of an explosion and reducing level of impact on surface objects of civil and industrial facilities is shielding of blast wave seismic vibrations by forming a shielding zone along contour of workings under construction.

According to the results of theoretical and experimental studies, charges with an acute-angled cut along length of borehole (hole) will contribute to effective destruction of complex rock structures and optimise blasting chart when sinking large-section workings (tunnels) with improvement and seismic safety of protected facilities.

For this purpose, we have developed a new method for reducing seismic impact of an explosion when sinking workings in massifs of complex rock structure, based on consideration of physical and mechanical properties of rock mass, structure and fracture, which are determining factors of influence on nature of seismic oscillations propagation in different directions from explosion site.

Distillation tunnels of Dnipro subway under construction were chosen as an object for implementation of developed method of reducing seismic impact of an explosion during sinking workings in massifs of complex rock structure. Main idea is to define a zone of rocks with different physical and mechanical properties of rock massif section in working face.

Geological exploration wells with a diameter of 75–100 mm are drilled in marked areas in cross-section of workings with NKR-100M drilling rig, and cores are taken using a core sampler, for example, EZY-MARKTM. Samples are prepared from selected exploration cores in lab conditions and studies are carried out to clarify data on rock properties, type and direction of fracture systems development. Then, in these areas, boreholes are drilled to a depth equal to half length of borehole, charged with cartridge industrial explosives and detonated. Based on resulting ejection funnels, the anisotropy coefficient is calculated from the following equation $K = a/b$, where a and b are large and small axes of fracture crater, according to blasting charts in these zones (distance between holes in a row and between rows of holes) are adjusted.

Also, crack systems are identified, and density is considered when calculating average fracture coefficient according to the following expression

$$K_{cr.\ aver.} = (K_{cr.1} + K_{cr.2} + K \cdot K_{cr.3})/3,$$

where $K_{cr.1}$ $K_{cr.2}$ and $K_{cr.3}$ are intensities of microcracking in horizontal plane, respectively.

Justification of distance between contour boreholes considering fracture coefficient and anisotropy of physical and mechanical properties of rocks.

According to the results, markings are made on the face and drilled along entire cross-section of workings.

Next, symmetrical longitudinal cuts are made in the contour borehole along its length in direction of working contour at acute angle to a depth equal to

$$h = (1.2\text{–}1.3)d_{bh},$$

where h is a depth of the longitudinal cut; d_{bh} – the diameter of the borehole. The distance between them is

$$a = (1.5\text{–}2.0)R_{cr},$$

where a is a distance between contour charges; R_{cr} – the radius of fracture formation

$$R_{cr} = (5\text{–}7)d_{hol}.$$

Then, in prepared boreholes, explosive charges of solid construction are formed along entire cross-section of workings, and in contour boreholes – sectional charges of two interconnected explosive cartridges, which are located along axis, which passes through the centres of these charges parallel to contour of workings and perpendicular to principal stress tensor and maximum flow of explosive energy in direction of destructive medium. In addition, in contour boreholes, the gap between rock mass and explosive charge is filled with a damping layer made of inert material, such as salt, wood flour, rubber or foam balls.

Next, initiators are installed in prepared explosive charges, borehole mouths are sealed with packing, charges are switched to network and detonated with a slowdown starting with contour charges to form a shielding zone along the workings contour from an extensive network of radial cracks, and lastly, face, breakaway and auxiliary charges with a slowdown starting from 60 ms.

Experimental results of developed blasting chart in conditions of Dnipro subway overrun tunnels under construction in rock mass of complex structure. To correct the existing technological blasting charts and develop new ones, it is necessary to obtain comprehensive data on physical and mechanical properties and structural features of rocks in subway tunnel workings. For this purpose, periodic monitoring was carried out by taking rock samples along an entire cross-section of left overhaul tunnel (LOT, shaft 11) at the level of 1 m from bottom of workings and 1.5 m from tunnel axis and in face of right overhaul tunnel (ROT, shaft 14) and according to tectonics on the left side of tunnel (2 m from face at height $H = 2.5$ m). Samples were made from the collected samples and tested for physical and mechanical properties in accordance with the current DSTU. The test results are presented in Table 1.

Analysis of data showed that rocks (LOT face, *11th* shaft) are anisotropic in their physical and mechanical properties and consist of granites, plagiogranites, pinkish-black, pinkish, with particles of grey-green, fine-medium grained, folded (layers are flattened into folds and microscopic folds), quartzed, with cracks of different directions crossing them, cemented with

Table 1

Physical and mechanical properties of rock samples collected in Dnipro subway overhaul tunnels

No. of samples	Lithological difference	Sampling location	Samples density $\rho \cdot 10^{-3}$, kg/m^3	Compressive strength σ_{cs}, MPa	Young's modulus of elasticity E, MPa	Poisson's ratio, μ
Shaft No. 11, PK 132 + 96.6 m						
1	weathered granite	right part near the face roof $H = 4.5$ m	1.88	4.9	4,900	0.2
2	leuco-crag granite	right side of the face $H = 2$ m	2.53	50.8–109.9	20,000	0.39
3	granite leuco pegmatoid	central part of the face $H = 2$ m	2.6	59.8–211.0	46,000/ 40,200	0.41/ 0.38
4	Quenched rock	left part of the face $H = 1$ m	2.59	89.8–110.3	20,500	0.34
5	Granodiorite, plagiogranite	left side of the face $H = 1.5$ m	2.55	93.4–154.5	20,000	0.39
6	weathered diorite, kaolin	right side of the face (1 m from axis) $H = 1$ m	2.56	117.2	4,000	0.22
7	granodiorite, diorite	right side of the face (2 m from axis) $H = 1.5$ m	2.50	127.3–161.8	40,000	0.41
Shaft No. 14.						
8	contact of granite with diorite (large crystals of granite)	left side wall	2.63	120.6	36,100/ 35,500	0.37/ 0.36
9	contact of granite with diorite (grey-green)	left side wall	2.74	140.8	38,900/ 36,100	0.36/ 0.35
10	granite with large grains	centre of the face	2.61	138.8	38,300/ 34,400	0.37/ 0.36
11	granite with fine grains	face support + 1 m from the face	2.56	137.1	36,700/ 33,400	0.38/ 0.36
12	granite with pinkish feldspar	right side wall	2.63	119.8	29,600/ 26,700	0.35/ 0.33

secondary quartz, pyrite inclusions, which have undergone chloritisation and are located in weathered massif zone with strength $f = 5–7–8–12–14$. In ROT (*14*th shaft), the rocks are granites and plagiogranites with a developed system of different crack directions, cemented by secondary quartz, with inclusions of pyrite and granite with strength $f = 8–12–14$.

Considering physical and mechanical properties of strong anisotropic rock massif and developed method for reducing seismic impact of explosion during large cross-sectional excavations (subway tunnels), new technological blasting chart for Dnipro subway were developed. Fig. 1 shows a schematic of blasting chart and in Table 2 there are parameters of hole charges and the sequence of their detonation.

The developed blasting chart (Fig. 1) differs from the basic one in that a shielding zone is formed in the contour of working to reduce seismic impact of explosion by drilling holes with a diameter not less than a double diameter of industrial explosive charge (70–80 mm) to depth of entry with symmetrical acute-angled cuts along the hole length, placing two sections of a double charge in these cuts and detonating them first, followed by other borehole charges with a delay along a cross-section of workings. Moreover, the distance between adjacent contour holes was increased to 0.7 m instead of 0.60 m compared to the basic blasting chart. Such charges in contour boreholes made it possible to reduce the number of charges used to form workings by 10 pieces, which accordingly reduces weight of explosives by 10 kg (Anemix-P) and energy of explosives transformed into destructive medium.

Other boreholes along the cross-section of workings are drilled with a diameter of 43 mm using AtlasCopco and Epiroc drilling and rock-cutting complexes. The marking and drilling of boreholes along workings are carried out using a computer module, a laser device with software that contains parameters and a graphic image of blasting chart.

Experimental explosions to test the developed technological blasting chart were carried out in conditions of LOT, shaft No. 11 (15.06.2017, 04.07.2017) and ROT of shaft No. 14 (20.07.2017) of Dnipro subway under construction, the appearance of which is shown in Fig. 2.

First, sectional charges were detonated in contour holes, and then solid structure charges in face, baffle and auxiliary holes using a live round of Anemix P32/250 emulsion explosive and UNS-ShK-20-40 initiator according to calculated deceleration blasting chart data for each group of charges. Appearance of distillation tunnel face before blasting and after rock destruction is shown in Figs. 3, *a, b*.

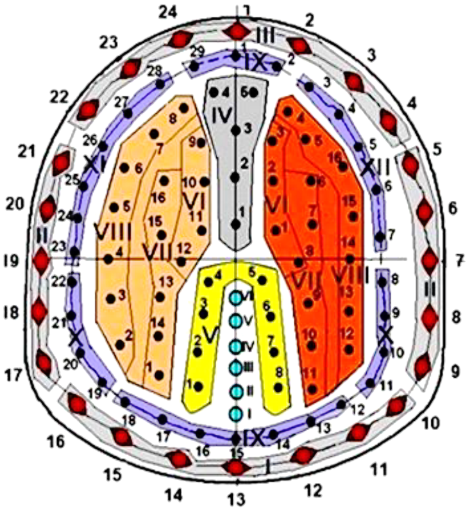


Fig. 1. Scheme of explosive charges location in working face and sequence of detonation

Criteria for assessing blasting results are borehole utilisation factor (BUF), quality of rock blasted away, and distance of spread in working face.

Rock quality of rock blasted in the face is determined by average piece using the U-CARFnet [13] and WipFrag [14] methods using software WipFrag©Win Version 2.6. Processing results of grain size distribution data are presented in form of distribution curve, histogram and grain size data by class (in %), which are presented in the table (Fig. 4).

Experimental blasting results during construction of subway runway tunnels showed:

- face advancement during the blasting cycle was 1.65–1.7 m (BUF = 0.97–0.98);
- no refusals and visible “glasses” were detected because of blasting, no overburden was found along the tunnel contour, but a slight oversize yield was noted in LOT, shaft 11 and ROT, shaft 14.

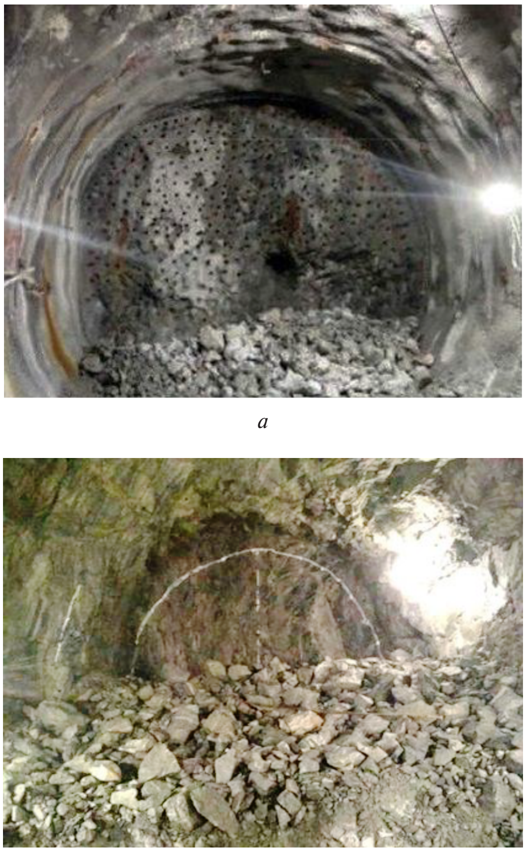
Moreover, seismic effects of explosions in Dnipro subway overrun tunnels at protected facilities were assessed using de-

Table 2

Parameters of explosive charges and detonation sequence

No. of borehole blasting sequence	Naming boreholes	Slowdown interval, ms	Number of boreholes, pcs.	Borehole depth, m	No. of boreholes in group	Charge weight Anemix – P, kg	
						in the borehole	in the group
I	Floor	20	7	1.6	10, 11, 12, 13, 14, 15, 16	1.0	7.0
II	Wall	40	10	1.6	5, 6, 7, 8, 9, 17, 18, 19, 20, 21	1.0	10.0
III	Roof	60	7	1.6	22, 23, 24, 1, 2, 3, 4	1.0	7.0
IV	Cut	200	5	1.8	1, 2, 3, 4, 5;	1.0	5.0
V	Cut	250	8	1.8	1, 2, 3, 4, 5, 6, 7, 8	1.0	8.0
VI	Stoping	300	8	1.6	1, 2, 3, 8, 9, 10, 11, 12	0.75	6.0
VII	Stoping	500	10	1.6	6, 7, 9, 10, 11, 15, 16, 13, 14	0.75	7.5
VIII	Stoping	800	14	1.6	2, 3, 4, 5, 6, 7, 8; 4, 5, 16, 15, 14, 13, 12	0.75	10.5
IX	Contour	1,000	10	1.6	1, 2,12, 13, 14, 15, 16, 17, 18, 29	0.75	7.5
X	Contour	3,000	8	1.6	8, 9, 10, 11, 19, 20, 21, 22	0.75	6.0
XI	Contour	5,000	6	1.6	23, 24, 25, 26, 27, 28	0.75	4.5
XII	Contour	7,000	5	1.6	3, 4, 5, 6, 7	0.75	3.75
	Total:		98				82.75

Fig. 2. Appearance and equipment of the distillation tunnel for Dnipro subway



a

b

Fig. 3. Exterior view of Dnipro subway tunnel junction face before and after rock blasting:

a – before explosion; b – after explosion

veloped recommendations. Seismic impact of explosions was assessed with involvement of the Centre for Blasting Problems of "Dnipro University of Technology" together with "Institute of Geotehnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine" by measuring seismic vibrations using a Blast Mate III seismograph (serial number BA 12183), a microphone and two three-axis geophones ISEE No. BG 11138, and pressure at the shock air wave front using a ZET Lab 048-E seismic station with a three-component accelerometer BC1313. Each of them was placed on the earth's surface at three points in areas of protected objects (along D. Yavornytskoho Avenue in the central part of Dnipro city).

During blasting rocks in distillation tunnels, seismic ground vibrations and amplitude-frequency characteristics were recorded and processed using ZETLab Seismo and Blast Ware Rev 8.12 software. The results obtained were used to assess seismic vibrations in comparison with reference vibrations for similar rock masses in accordance with the current maximum permissible standards and State Standards [15–17].

The results showed that total duration of seismic ground vibrations during blasting operations was 7.5 s. Maximum ground vibrations during blasting operations at measurement points are slightly higher than the permissible 0.4 cm/s, but duration is not significant and generally less than 0.05 s. These vibrations are high-frequency in nature, while the general background of seismic vibrations also has high-frequency vibrations, and they exceed 50 Hz. While at a distance from explosion epicentre, namely at a point 35 m in direction of tunnelling and at point 20 m near residential buildings and structures perpendicular to tunnel, seismic vibrations are within the limits of permissible II points according to MSK-64 scale. Seismic ground vibrations intensity decreases with distance from the explosion epicentre and at more than 35 m, seismic ground vibrations are commensurate with those caused by passage of city tram.

Reducing seismic impact on protected facilities under such blasting conditions is ensured by adjusting total mass of explosives per explosion. This can be achieved by increasing deceleration intervals between borehole charges in groups and design.

Conclusions. The results of experimental explosions during construction of Dnipro subway overrun tunnels showed the following:

1. The face retreat during the blasting cycle was 1.65–1.7 m (BUF = 0.97–0.98), no failures and visible "glasses", no rock overruns along tunnel contour were detected, but a slight oversize yield was noted in LOT, 11 shaft and ROT, 14 shaft.
2. During blasting operations, according to the developed recommendations, it was found that seismic vibrations of the ground are of high-frequency, and with 35 m from explosion epicentre decay. At the same time, general background of registered vibrations at points did not exceed permissible limit of II points according to MSK-64 scale and DSTU 4704.2008 with their total duration not exceeding 7.5 s, which did not pose a threat to buildings in Dnipro, which are in satisfactory condition and under protection.
3. Implementation of the proposed charge design will facilitate concentration and further transfer of explosive energy towards design fracture plane, which is directed perpendicular to normal component of principal tensile stress tensor in compression wave with concentration at tip of notch (pilot crack initiation). The effect will prevent the formation and propagation of crack in opposite direction with reduced destruction of opposite walls of borehole (well) that do not have a notch.
4. Implementation and introduction of methods to reduce the seismic impact of an explosion when sinking a mine in massifs of complex rock structure will contribute to formation of a shielding zone along the contour of mine with a change in conditions of explosion energy transfer from explosive charge to rock mass, which will help to reduce risk of damage to mine walls, and, as a result, reduce amplitude of seismic vibrations on protected objects, as well as forming multigradient and

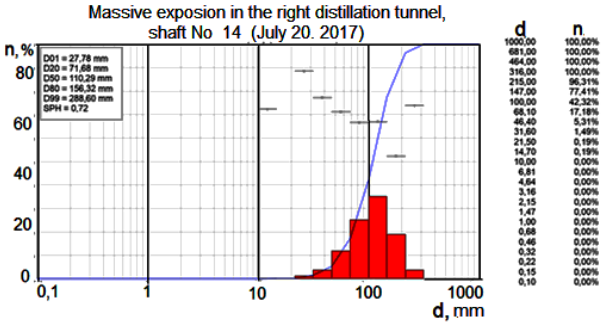


Fig. 4. Granulometric composition of rock mass in the face of Dnipro subway distillation tunnel destroyed by an explosion

multidirectional stress fields, which will contribute to uniform rock crushing.

Industrial tests demonstrate that implementation of proposed technology for construction of different technological facilities in complex rock masses will ensure efficiency and seismic safety of their construction in areas with developed infrastructure.

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Ефективність і сейсмічна безпека будівництва підземних споруд у масиві складної будови

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Мета. Розробити новий ресурсозберігаючий спосіб будівництва підземних споруд і виконати оцінку його ефективності та встановити поріг безпечних сейсмічних коливань ґрунту, що супроводжують вибухи під час відбійки гірських порід у виробці.

Методика. У роботі використані методи аналізу гірничо-геологічних умов проходки виробок, натурних обстежень стану порід у вибої, проведені експерименти на зразках порід, узятих із місць проведення вибухових робіт, отримані уточнюючі данні щодо властивостей порід, типу й напрямку розвитку систем тріщин по перерізу виробки методом воронкоутворення, апробовані методики згідно із діючими Держстандартами.

Результати. На основі виконаних досліджень отримані дані основних ознак анізотропії фізико-механічних властивостей гірських порід, тріщинно-тектонічної будови масиву й розвитку систем тріщин. За отриманими параметрами воронок викиду розраховано коефіцієнт анізотропії, а за даними ідентифікації систем тріщин та їх густини – коефіцієнт тріщинуватості. На підставі отриманих експериментальних даних виконане коригування раціональної відстані між контурними шпурами та по всьому перерізу виробки. За коригованими параметрами буропідривних робіт (БПР) проведені експериментальні вибухи у виробках. Встановлено, що коефіцієнт використання шпурів склав 0,95–0,97, досягнута рівномірність дроблення відбитої гірничої маси, витрати вибухових матеріалів зменшені на 10–15 %. Шляхом інструментального виміру дії вибуху у виробці доведено, що сейсмічні коливання ґрунту на об'єктах, які знаходяться під охороною, становили 0,4 см/с за їх тривалості 0,05 с, що не перевищило норми національного стандарту.

Наукова новизна. Полягає в обґрунтуванні раціональних параметрів БПР з урахуванням змін отриманих числових параметрів коефіцієнту анізотропії та тріщинуватості, радіусу зони тріщиноутворювання по перерізу виробки. Підтверджена й технічно реалізована ідея формування по контуру виробки екрануючої зони зарядами вибухових речовин із подовженим симетричним надрізом.

Практична значимість. Зазначені результати лабораторних і промислових досліджень є базовими для проєктування схем розташування шпурів по перерізу виробки та належать до основних вихідних даних, що застосовуються при обґрунтуванні конструктивних параметрів паспортів буропідривних робіт.

Ключові слова: *шпур, вибух, шпуровий заряд, вибій, гірнича порода, тріщинуватість*

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