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IMPROVING ROCK CLASSIFICATION IN TERMS OF EXPLOSIVITY

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ABSTRACT

Purpose. To improve rock classification in terms of explosivity relying upon the detailed analysis of characteristics of rating classifications available in the Russian Federation and in the world.

Methods. Complex approach has been applied involving comparison of sizes of particle-size fractions determined in terms of both national and the world standards; information gathering and processing as for the available classifications intended to identify difficulties of rock explosivity; compilation of comparative systematic of classifications or methods being considered.

Findings. Both national and the world rock classifications in terms of explosivity have been considered. While comparing national classifications as for the difficulties of rock mass failure (i.e. explosivity), a comparative table has been compiled where the most popular rock classifications are compared. Analysis of the world practices, concerning compilation of rock classifications in terms of explosivity, has shown that their approaches differ from Russian ones slightly. In the first instance, they are empiric dependences being calculated for each rock mass type separately in any single case. It has been determined that geomechanical classification of D. Lobshir (MRMR) is the most popular and rating world system to evaluate rock explosivity. It has been demonstrated that while compiling such classifications, foreign scientific writers put an emphasis on physical and mechanical indices of rocks (i.e. density, fissility, compression strength, tensile strength etc.) as well as on mine engineering ones (i.e. line of the least resistance, well diameter and depth, stope height etc.) which determines essential reliability of calculation of drilling-and-blasting parameters.

Originality. The research is the first stage of the development of the unified transition classification from Russian explosivity scales to the comparable world methodic practices as for rock mass explosivity.

Practical implications. To perform rapid transition from one explosivity classification to the other. The findings are recommended to be used while projecting drilling and blasting operations in the context of any types of minerals and in the context of academic activity.

Keywords: *rock explosivity, classification, rating, explosion, granulometric size composition, explosives*

1. INTRODUCTION

Perfection of drilling-and-blasting operations is one of the tendencies to improve the efficiency of a deposit mining. Technical and economic performance of a block extraction may vary significantly depending upon the correctness of drilling-and-blasting parameter calculation. At large mining enterprises, expenditures, connected with drilling-and-blasting, are high percentage of total mining cost. In this connection, perfection of drilling-and-blasting method is one of the key problems in the set of tasks intended to improve the efficiency of a deposit development (Tangaev, 1978; Lowrie, 2002; Vokhmin, Kurchin, Kirsanov, Shigin, & Shigina, 2017).

Accurate definition of rock explosivity effects considerably many subsequent parameters. Well diameter, and well spacing and arrangement is one of such basic technological blasting parameters determining a degree of rock fragmentation, capacity of drilling machinery, LHD machines as well as general technical and economic performance concerning drilling-and-blasting operations together with the whole cycle of mineral mining and processing (Shevyrev & Savko, 2012; Afum & Temeng, 2015; Kanchibotla et al., 2015).

Analysis of papers, aimed at drilling-and-blasting study, has helped conclude that there is no shared vision among experts as for the numerous problems concerning calculation of technological parameters of blasting opera-

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tions (i.e. spacing between wells, calculation of a charge mass etc.) (Mikhlin & Zhupiev, 1997; Ak & Konuk, 2008; Hosseini & Baghikhani, 2013; Singh et al., 2016).

A charge parameter calculation may rely upon the two basic principles: consideration of an explosive capacity per meter of a well or amount of rock, blasted by means of a charge.

Analysis of more than 40 mining enterprises (Hustrulid, 1999; Thornton, Sprott, & Brunton, 2005; Rout & Parida, 2007; Aarsen, Milne, & Erickson, 2012), has shown that in Russian mines, average diameter range of wells, used to develop open pit, is 89 – 269 mm; it is 93 – 409 mm abroad. Feasibility analysis to select reasonable well diameter, carried out for different enterprises, has demonstrated that in the context of open pits where annual output capacity is 3 – 10 mln m^3, 250 mm blast wells are the most effective for medium-hard rocks $f = 10 – 14$ (according to a scale by M.M. Protodiakonov) and 200 mm blast wells are the most effective for softer rocks. As for the large open pits (i.e. more than 10 mln cubic meters), wells with more than 270 mm diameter are more expedient for hard rocks (Rajmeny, Shrimali, Shekhawat, & Joshi, 2012; Choudhary, 2013; Kitaly, 2013).

Methods to determine basic parameters of drilling-and-blasting operations, represented in papers (Wesley, 1999; Nobel, 2010; Rock breakage and blast design…, 2012; Roberts, 2013), are widely used at foreign enterprises.

Forecasting of broken rock fragmentation is another important condition of successful rock mass breaking (Cunningham, 1987; Kuznetsov, 2010; Rozhdestvenskiy, 2012). That depends on the fact that explosivity, determined incorrectly, may deteriorate significantly quality of an explosion; thus, higher yield of oversize fraction is possible resulting inevitably in extra expenditures connected with secondary fragmentation, hoisting etc.

In turn, analysis of the available techniques to determine fragmentation of the broken rock mass has shown that there is no common scientifically grounded approach for the parameter determination (Bondarenko, Maksymova, & Koval, 2013; Vokhmin et al., 2018). As a rule, the techniques do not take into consideration interaction of following factors: physical and mechanical characteristics of rock mass; a type of an explosive being applied; diameter of a charge; design of a charge; priming area; length of a charge and size of undercharge; length of tamping and its quality; and interaction of charges blasted simultaneously (Kulatilake, Qiong, Hudaverdi, & Kuzu, 2010; Shapurin & Vasilchuk, 2012; Bakhtavar, Khoshrou, & Badroddin, 2015). The above can explain instability of blasting parameters, low efficiency, and, as a result, high yield of oversized materials.

Hence, being initial link in the process of blasting planning, rock explosivity influences directly each subsequent technological operation, which makes it possible to conclude that such a research is of a timely character.

2. METHODOLOGY

2.1. Description

Since in the process of open pit mining substantial share of cost falls on drilling-and-blasting, the taken blasting parameters should be identical to rock resistance being determined mainly by the two factors – rock hardness and fissility (Cherniaiev, 2017). Otherwise, results will be worsened either due to the high yield of oversize or due to excessive secondary rock fragmentation with its throwing about a berm. To follow the identity it is required to rely upon adequate evaluation of rock explosivity while drilling-and-blasting planning.

Taking into account certain assumption, the available evaluation approaches can be divided into the two groups:

1. Direct approaches taking into consideration the geological factors effecting shattering.
2. Indirect approaches relying upon the elastic wave propagation velocity or upon a value of specific power intensity of blast well drilling recorded by gauges.

The indirect approaches did not become popular. Their use was limited by certain experiments. Considerable labour intensity and ambiguous interpretation of the obtained results, and, what is the most important, the information, concerning explosion, is obtained during drilling limiting time for drilling-and-blasting planning as well as possibility to manoeuvre their parameters (Tangaev, 1978; Khomenko, Kononenko, & Myronova, 2013).

2.2. Algorithm

Analysis of the available direct methods to evaluate rock explosivity within the rock mass has shown lack of a common approach, and has made it possible to demonstrate a number of disadvantages as for their implementation.

First, very often only one of the basic factors (i.e. either fissility or rock hardness) is taken into consideration; moreover, the former is preferred (Kutuzov, Lemesh, Lemesh, & Pluzhnikov, 1979). On the one hand, it can be explained by the fact that fissility is really dominates; on the other hand, its parameters are evaluated more easily, faster, and more precisely than hardness of rocks within formation. Nevertheless, any of the factors neglecting cannot result in the determination of optimal blasting parameters (Chernai, Sobolev, Chernai, Ilyushin, & Dlugashek, 2003; Sobolev & Usherenko, 2006).

Second, standard scale of rock fissility by a Joint Commission for blasting operations (Vremennaya klassifikatsiya gornykh porod…, 1968), including five categories distinguished with 0.5 m interval, is too approximate. A scale by B.N. Kutuzov (Kutuzov, Lemesh, Lemesh, & Pluzhnikov, 1979) is more acceptable since according to which ten categories with 0.15 – 0.30 m are distinguished. Moreover, related categories are quite contrasting in terms of explosivity. In addition, each deposit is individual from the viewpoint of fissility progress nature and distribution of the different-size natural blocks within rock mass.

Third, researchers usually develop classification of deposit rocks in terms of explosivity ignoring geometrization of open-pit field in terms of rock explosivity of separate blocks. Such an approach results in the fact that drilling-and-blasting planning of each block to be blasted should involve separation of areas of rocks, belonging to different explosivity classes, in accordance with the classification being used. It means differential evaluation of fissility degree as well as rock hardness being connected with extra labour input and reducing time for the explosive block planning.

A number of different rock explosivity classifications are available.

A problem to develop comparative classification is to widen and systemize knowledge of mining engineers about problems concerning rock explosivity used while drilling-and-blasting planning at the modern national and foreign mining enterprises; and identification of the key principles of interaction between various input parameters and the final rock characteristic (i.e. category/class/group).

3. RESULTS AND DISCUSSION

3.1. Soil and rock classification

According to the Russian classification (GOST 25100-2011, 2013), soils are any rocks, grounds, convergences, and technogenic formations being considered as multicomponent dynamic systems as well as a part of geological environment and analyzed depending upon engineering and economic human activities. Operative control of surface drilling and blasting is performed involving physical and mechanical soil characteristics.

In the Russian Federation, soil classification, depending upon the results of a probe drilling of a meter of a borehole by means of average-weight borehammers, is the most popular technique (SNiP IV-2-82, 1984), making it possible to determine a group when certain mandatory requirements are met. Currently, (Vremennaya klassifikatsiya gornykh porod…, 1968; ENiR Sbornik E2, 1986) are the updated versions of the SNiP (construction norms & regulations).

Denominations of large-block, coarse-grained, and sandy soils in terms of ISO 14688-2:2004. Standards are determined on the basis of their particle size, and fractionating degree of a curve factor being identified according to a cumulative curve of their granulometric composition. Table 1 explains correspondence of different soil fractions in (GOST 25100-2011, 2013; ISO 14688-2:2004, 2004; ASTM D 2487-2000, 2000) Standards.

Table 1. Comparison of sizes of granulometric fractions determined according to (GOST 25100-2011, 2013; ISO 14688-2:2004, 2004; ASTM D 2487-2000, 2000) Standards

Particle size, mm	GOST 25100-2011		ISO 14688-2:2004		ASTM D 2487-2000	
800.000	Boulders, blocks	Coarse	Large boulders		Boulders	
630.000		Medium				
400.000			Boulders			
300.000		Fine				
200.000					Cobbles	
100.000	Alluvium, broken rock	Coarse	Cobbles			
76.200		Medium				
63.000					Gravel	Coarse
60.000		Fine	Coarse gravel			
40.000						
20.000						
19.000			Medium gravel			
10.000						Fine
6.300	Alluvium, granitic subsoil	Coarse				
4.750			Fine gravel			
4.000					Sand	Coarse
2.000		Fine				
0.630	Sand	Coarse	Sand	Coarse	Sand	Medium
0.500				Medium		
0.425		Medium				
0.250						Fine
0.200		Fine				
0.100				Fine		
0.075		Powdery				
0.063					Silt	
0.050			Silt	Coarse		
0.020	Dust					
0.0063				Medium		
0.005				Fine		
0.002						
<0.002	Clay		Clay		Clay	

To revaluate shares of certain fractions, being determined in terms of various Standards, and to identify fractioning degree as well as curve coefficient, cumulative curve of granulometric composition is developed (Fig. 1) basing on which further revaluations are performed in terms of the required Standard (Table 1). To classify large-block, coarse-grained, and sandy soils in terms of ASTMD 2478-2000 Standard, fraction content is calculated according to following boundary particle sizes: 300, 76.2, 19, 4.75, 0.425 and 0.075 mm; 630, 200, 63, 20, 6.3, 0.63, 0.2 and 0.063 mm according to ISO 14688-2:2004 Standard; and 800, 400, 200, 100, 60, 40, 20, 10, 4, 0.5, 0.25, 0.1 and 0.05 mm according to the Russian classification in terms of GOST 25100-2011 d_{60}, d_{30} and d_{10} parameters are determined to calculate a degree of fractioning degree as well as a curve coefficient.

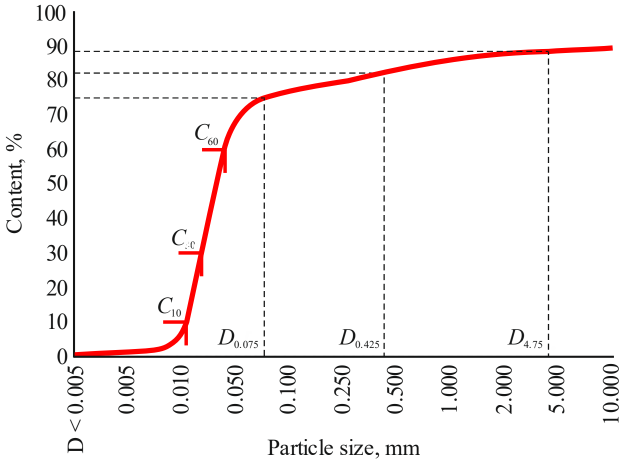

Figure 1. Cumulative curve of granulometric composition (GOST 25100-2011, 2013)

Currently, rock hardness classification by Professor M.M. Protodiakonov is the most popular in the Russian Federation and the CIS countries (Avdeev, Baron, Gurov, & Kantor, 1986; Trubetskoy, Artem'yev, & Ruban, 2014).

While developing the scale, M.M. Protodiakonov introduced a notion of rock hardness. To compare with the accepted notion of a material strength, being evaluated in terms of one type of its stress state (for instance, compressive strength, tensile strength, torsion strength etc.), the hardness notion makes it possible to correlate rocks in terms of failure efforts and mineability. He believed that the parameter could evaluate aggregate of stresses, taking place during rock failure, to be comparable while blasting.

3.2. Soil classification in terms of explosivity

Rock explosivity is rock resistance to failure under the action of a shot of an explosive. Basic criteria to distinguish rocks on categories are as follows: specific consumption of an explosive, being determined with the help of experimental explosions and called specific powder factor, and quantity of energy of an explosive in terms of J/m^3, i.e. specific energy consumption of an explosive, required to form a square explosion crater in 1 m borehole with 40 mm diameter located at 45° to a horizontal free surface.

The classification is characterized by the number of a reference explosive in terms of kg/m^3 (i.e. specific consumption of the reference explosive).

Currently, there are a number of different explosivity classifications taking into account various factors. Below you can find brief description of some of them.

V.V. Rzhevski recommends to determine rock explosivity through a reference specific consumption of an explosive (q_e) depending upon fissility taken into consideration by $k_T = 1.2l_{av} + 0.2$ coefficient where l_{av} is average size of a parting, m. The explosivity classification relies upon determination of specific consumption of a certain explosive under the standard blasting conditions. In this context, rock should be broken down into the pieces of certain sizes. Variety of rock masses in terms of their explosivity has been divided into ten categories (Onika, Stasevich, & Kovalèva, 2016).

Soiuzvzryvprom rock explosivity classification has been developed on the basis of generalization of long-term data concerning a design specific consumption of an explosive (for ammonite #6 ZhV) while blasting in different rocks (Onika, Stasevich, & Kovalèva, 2016).

Interbranch rock explosivity classification, proposed by B.N. Kutuzov and V.F. Pluzhnikov, is also based upon a value of a design specific consumption of an explosive; however, it involves scientifically grounded interval of explosive consumption variation in terms of categories. Rock category is identified according to a value of an explosive specific consumption being calculated basing upon average separate size within rock mass d_o (m), hardness ratio f, and rock density when size of a standard piece is 100 cm, charge diameter is 250 mm, and explosion heat is 4190 kJ/kg.

Table 2 explains the basic Russian classifications used by mining enterprises of the Russian Federation and the CIS countries to plan drilling-and-blasting operations.

Table 3 demonstrates basic techniques to determine rock mass explosivity according to the dependences developed by different scientists (Fraenkel, 1954; Hino, 1959; Sassa & Ito, 1974; Heinen & Dimock, 1976; Borquez, 1981; Laubscher & Jacubec, 2000; Kaushik & Phalguni, 2003).

Below you can find a review of research intended to determine rock explosivity, and specific consumption of an explosive with the use of rock parameters.

In his scientific work (Hino, 1959; Kaushik & Phalguni, 2003), K. Hino has assumed that explosivity (called as Blasting Coefficient, BC in short) is rock compressive strength-tensile strength ratio.

G.V. Borquez (Fraenkel, 1954; Kaushik & Phalguni, 2003) has determined explosivity coefficient (K_V) from Pierce equation to calculate load with the use of RQD index, corrected by a coefficient of variation. The coefficient of variation takes into consideration bonding strength depending upon their hermeticity and a filling type.

K.H. Fraenkel has proposed empiric dependence between charge height and charge diameter, well depth, peak load, and explosivity (Sassa & Ito, 1974; Kaushik & Phalguni, 2003).

A method to determine rock mass explosivity by K. Sassa and I. Ito (Heinen & Dimock, 1976) relies upon the use of rock breakage field index. Further, using regressive analysis of mechanical characteristics of rocks, measured in a laboratory environment, and analysis of fissure frequency within a site of blasting operations, the authors have developed rock breakage laboratory index.

R.H. Heinen and R.R. Dimock (Kaushik & Phalguni, 2003) have proposed a technique to describe rock mass explosivity basing upon practices of a copper mine development in Nevada, the USA. The researches link average specific consumption of an explosive to a velocity of seismic propagation within rock mass. As a result of their observations, the authors have recognized that specific consumption of an explosive is higher, the higher velocity of blast propagates within rock mass is.

Table 2. Comparison of the Russian classifications of rock explosivity in terms of various data

Soils and rocks	Rock categories in terms of failure complexity (blastability)					
	Rock hardness classification by M.M. Protodiakonov)	Classification in terms of explosion complexity (according to G.P. Demidiuk)	Uniform rock classification in terms of drillability	Classification in terms of failure complexity (according to V.V. Rzhevski)	Classification in terms of failure complexity (according to V.K. Rubtsov)	Blastability classification of AURI of non-ferrous metals
The hardest, dense, and viscous quartzites and basalts. Other rocks being exceptionally hard.	I (20)	VI	XVIII-XX	V	V	VIII-X
Very hard granite rocks. Quartzitic porphyry, very hard granite and hornstone. Quartzites being less hard than the abovementioned quartzites. The hardest sandstones and limestones.	II (15)	V	XVI-XVII		IV	VII
Dense granite and granite rocks. Very hard sandstones and limestones. Quartz ore veins. Hard glutenite. Very hard iron ores.	III (10)	IV	XIII-XV	IV	III	VI
Hard limestones. Soft granite. Hard sandstones. Hard marble. Dolomith. Pyrite.	IIIa (8)	III	XII	III		
Ordinary sandstone. Iron ores.	IV (6)		XI			IV
Sandy shales. Shaly siltstone.	IVa (5)		X		II	III
Hard argillaceous shale. Soft sandstone and limestone; soft glutenite.	V (4)	II	IX	II		
Various soft shales, dense clay.	Va (3)		VII-VIII			II
Soft shale. Very soft limestone, cretaceous, salt rock, and plaster stone. Frozen soil, anthracite. Standard clay. Broken-down sandstone, coherent alluvium and grit, stony ground.	VI (2)	I	V-VI	I		I
Crushed-rock ground. Broken-down shale, packed alluvium and crushed rock, hard coal. Batt.	VIa (1.5)		V			
Dense clay, soft coal, solid cap rock – clayey soil.	VII (1)		III-IV		I	
Light sandy clay, loess, coarse sand.	VIIa (0.8)		II			
Vegetable soil, lignum fossil, light loam, green sand.	VIII (0.6)		I			
Slide sand, fine gravel, fill-up ground, mined coal.	IX (0.5)					
Soft ground, marshy ground, running loess, other running soils.	X (0.3)					

In terms of copper deposit Bougainville, Ashby has developed empirical correlation to describe specific consumption of an explosive required for qualitative blast (Kaushik & Phalguni, 2003). According to Ashby, specific consumption of an explosive with ANFO can be determined using a graph or an expression derived by him. The design value of frequency of fissure origination function is represented by a blast density and effective friction angle being strength of the structured rock mass.

R. Praylet calculated compressive strength of rock using penetration norm, traction mass, rotation velocity, and diameter. While applying cubic equation, he determined LLR as a function from:

1. Bench height.
2. Detonation velocity.
3. Undercharge value.
4. Rock compressive strength.
5. Components depending upon loading facilities.

The advantage of R. Praylet system is that it helps calculate well drilling network depending upon foregone parameters exclusive of breaking strength which should be determined according to drilling results (Kaushik & Phalguni, 2003). Thus, several trial blasts are required.

B.R. Rakishev (Kaushik & Phalguni, 2003) analyzed explosivity (i.e. blast resistance) depending on rock density (kg/m^3), longitudinal wave velocity (m/c), Poisson's ratio, elasticity modulus (kN/m^2), rock compressive strength and rock tensile strength (kN/m^2), average size of a piece, and a coefficient characterizing properties of fissure filling as well as their opening degree. He determined critical breaking velocity with the use of the abovementioned parameters and then classified explosivity through five categories corresponding to different values of critical breaking velocity.

According to JKMRC theory (Kaushik & Phalguni, 2003), rocks are classified in terms of their effect on the blasting efficiency. A team of authors has analyzed impact elasticity for coal fractures taking into account the following.

Table 3. Determination of rock mass explosivity according to the techniques by foreign researchers

Author(s) and year	Formula (if any)	Characteristic feature
Fraenkel, 1954 (Fraenkel, 1954)	$h \cdot d^2 = \dfrac{(50 \cdot V_{\max})^{3.3}}{S^{3.3} \cdot H \cdot d^{\frac{2}{3}}}$	Interaction between a charge and ability to be broken down
Hino, 1959 (Hino, 1959)	$BC = \dfrac{CS}{TS}$	Specific consumption of an explosive-explosivity ratio
Hansen, 1968 (Kaushik & Phalguni, 2003)	$Q = B^2 \left\{0.0236 \cdot \left(\dfrac{h}{B} + 1.5\right) + 0.1984 \cdot C \cdot \left(\dfrac{h}{B} + 1.5\right)\right\}$	Total charge-rock ratio
Sassa & Ito, 1970 (Sassa & Ito, 1974)		RBFI and RBLI have been determined by means of regressive analysis
Heinen & Dimock, 1976 (Sassa & Ito, 1974)		Specific consumption of an explosive correlates with seismic velocity
Ashby, 1977 (Kaushik & Phalguni, 2003)	$PF = \dfrac{0.56 \cdot \tan(f+i)}{\sqrt[3]{fracture / meter}}$, kg/m^3	Specific consumption of an explosive ANFO is determined according to failure frequency
Langefors, 1978 (Kaushik & Phalguni, 2003)		Specific consumption of an explosive-rock constant ratio has been identified
Praillet, 1980 (Kaushik & Phalguni, 2003)		Charge density depends upon input parameters
Borquez, 1981 (Borquez, 1981)	$K_v = a + b + \ln(ERQD)$	Coefficient of bonding strength variation is applied
Leighton, 1982 (Kaushik & Phalguni, 2003)	$\ln(CE) = \dfrac{RQI - 25.000}{7.2000}$	RQI-specific consumption of explosive ratio
Lilly, 1986 (Kaushik & Phalguni, 2003)	$BI = 0.5 \cdot (RMD + JPS + JPO + SGI + H)$	Specific consumption of an explosive-explosivity ratio
Ghose, 1988 (Kaushik & Phalguni, 2003)	$BI = (DR + DSR + PLR + JPO + AF1 + AF2)$	Specific consumption of an explosive belongs to the indicated explosivity
Jimeno, 1989 (Kaushik & Phalguni, 2003)	$CE\left(kg\ of\ ANFO / m^3\right) = 1.124 \cdot e^{-0.5727 Lp}$	Specific consumption of an explosive-drilling factor ratio
Gupta, 1990 (Kaushik & Phalguni, 2003)	$Charge\ Factor = 0.278 \cdot B^{-0.407} \cdot F^{0.62}$	Specific consumption of an explosive-rock hardness comparison
JKMRC, 1996 (Kaushik & Phalguni, 2003)		Introduction of trial blast results
JiangHan, 2000 (Kaushik & Phalguni, 2003)	$K = \{L, S, R_{cd}, E_d, P_c, d_{cp}\}$	Relative explosivity with the use of a back wave propagation method from the data set
Bieniawski, 1973 (Heinen, & Dimock, 1976)	$R_{c.mas} = \sigma_{ci} s^{\alpha}$	RMR classification applies following six parameters: uniaxial compression strength of rocks; rock quality designation RQD; distance between fissures; state of fissure surface; orientation of fissure strike; and availability of underground water influx. Value of RMR index is determined as total of rating values
Laubscher, 2000 (Laubscher & Jacubec, 2000)	$MRMR = RMR \cdot K$	Each rock mass parameter, being involved, is evaluated by means of numbers. Each parameter of the rock mass state adds certain numbers being summarized as a result

1. Rock mass – compressive strength, density, and Young's modulus.

2. Structure – average block size, and structural effect.

3. Planning – a size of a target fragment of the broken-down rock mass, projectable rock mass breaking down, blast energy keeping within the rock mass, and a level of the scheduled efforts.

4. Environment – water.

Data, concerning compression strength, density, and elasticity modulus, are used to describe basic strength and hardness of the rock material. Such parameters as a structure influence, the scheduled rock mass failure, explosion energy holding within the rock mass, and level of the scheduled efforts are applied as the modifying factors making blasting either easier or more complicated.

In 1973, Z.T. Bieniawski developed a concept of rating criterion of rock mass stability Bieniawski, 1989). After improvement and widening its application area, the concept was entitled as a rock mass rating (RMR). The RMR classification uses following six initial parameters:

uniaxial compression strength of rocks; RQD; distance between fissures; fissure surface state; fissure strike orientation; and availability of underground water influxes. RMR index value is determined as total of rating values.

To complete the classification by Z.T. Beniavski, D. Lobshir introduced a system of mining rock mass rating (MRMR) (Laubscher, 1990). The system is based upon RMR; however, it involves such additional correction coefficients as blasting parameter effect, variation of rock mass stress state, and disturbance parameter.

Being qualitative ratings, RMR and MRMR make it possible to determine operation schedules as well as parameters in the context of a number of mining and geological changes.

3.3. Discussion

Analysis of a summary table of rock masses in terms of explosivity and drillability (Table 2) helps conclude that the hardness scale by Professor M.M. Protodiakonov, accepted in the Russian Federation as well as in the majority of the Commonwealth of Independent States, is comparable with other Russian rating classifications.

The represented methods to compile classification are based upon the following: either powder factor or fissility is identified. Then, rock explosivity is identified according to the accepted range of values.

Analysis of the classifications shows nonavailability of rock separation into categories. Generally, the classifications involve only one of the basic factors effecting blasting efficiency while neglecting others being important as well.

Therefore, it turns out that some of the classifications involve prior determination of powder factor or availability of a certain share of granulometric mass or fissility degree and rock hardness.

As a result, in either case, optimal parameters of drilling-and-blasting are shifted; thus, they do not demonstrate the efficiency they could have.

The majority of foreign methods are not divided into classes and groups. They are calculated by means of empiric dependences in each specific case. Table 3 represents generalization of all the techniques intended to determine rock explosivity developed by different authors.

Analysis of Table 3 has shown that while compiling classifications, foreign authors accentuate physical and mechanical properties of rocks (i.e. density, fissility, compressive strength, tensile strength etc.) as well as mining ones (i.e. line of least resistance, well diameter and depth, stope height etc.) which determines higher reliability of blasting parameter calculation.

Rock fissility together with rock hardness is the dominating factor separating rocks on their explosivity in the context of Russian classifications.

Among all the listed foreign models determining rock mass state, geomechanical classification by Professor D. Lobshir (i.e. mining rock mass rating – MRMR) is the most adapted for mining conditions (Cunningham, 1987; Laubscher, 1990; Laubscher & Jacubec, 2000).

Comparison of Russian classifications in terms of complexity of rock mass breaking-down (i.e. explosivity) has helped form a bridge table where the most popular rock classifications are intercompared (Table 2).

Analysis of the world practices to compare rock explosivity classification has made it possible to understand that foreign methods differ from the Russian ones slightly since the former are empiric dependences calculated for each rock mass type individually. Geomechanical classification by Professor D. Lobshir (i.e. MRMR) is the most rated system for mining conditions abroad.

4. CONCLUSIONS

The represented classification reflects scientific interests and ideas of different world dominated schools of mining. It has been developed with consideration of extensive scientific literature review and involves papers by many researchers.

As a whole, evaluation of explosivity in open pits is characterized by the availability of several procedural developments which are not interconnected and cannot comprise all the processing chain from full-scale measurements to the obtaining of the synthesized analytical and cartographical information required to plan drilling-and-blasting. In this context, manual information processing prevails.

Hence, comparison of Russian and the world methods to calculate explosivity is possible if only elaborate analysis of mining and geological situation of drilling-and-blasting area takes place.

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УДОСКОНАЛЕННЯ КЛАСИФІКАЦІЇ ГІРСЬКИХ ПОРІД ЗА ВИБУХОВІСТЮ

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Мета. Вдосконалення класифікації гірських порід за вибуховістю на основі детального аналізу особливостей існуючих російських і закордонних рейтингових класифікацій.

Методика. Застосовано комплексний методичний підхід, що включає зіставлення розмірів гранулометричних фракцій, які визначали згідно вітчизняним і закордонним стандартам; збір та обробка інформації щодо існуючих класифікацій визначення труднощів вибуховості гірських порід; складання зіставної класифікації розглянутих класифікацій або методик.

Результати. Розглянуто вітчизняні та закордонні класифікації гірських порід за вибуховістю. При порівнянні вітчизняних класифікацій в частині труднощів руйнування гірського масиву (вибуховості) була побудована порівняльна таблиця, в якій між собою зіставляються найбільш популярні класифікації гірських порід. При аналізі закордонного досвіду складання класифікацій гірських порід за вибуховістю було виявлено, що їх методи дещо відрізняються від російських, і являють собою емпіричні залежності, та розраховуються для кожного типу масиву в кожному окремому випадку індивідуально. Встановлено, що найбільш популярною і рейтинговою системою для оцінки вибуховості гірських порід за кордоном є геомеханічна класифікація Д.Х. Лабшіра (MRMR). Показано, що закордонні автори, при складанні класифікацій, роблять акцент не лише на фізико-механічних показниках гірських порід (щільності, тріщинуватості, межі міцності на стиск і розтяг і т.д.), але й на гірничотехнічних (лінія найменшого опору, діаметр та глибина свердловини, висота забою і т.д.), що визначає суттєву достовірність розрахунку параметрів буропідривних робіт.

Наукова новизна. Представлена робота є першим кроком до розробки єдиної перехідної класифікації від російських шкал за вибуховістю до аналогічних закордонних методичним практикам в частині вибуховості гірського масиву.

Практична значимість полягає в можливості швидкого переведення однієї класифікації за вибуховістю в іншу. Результати роботи рекомендується використовувати при проектуванні буропідривних робіт на всіх типах родовищ корисних копалин, а також у навчальному процесі.

Ключові слова: *вибуховість гірських порід, класифікація, рейтинг, вибух, гранулометричний склад, вибухові речовини*

СОВЕРШЕНСТВОВАНИЕ КЛАССИФИКАЦИИ ГОРНЫХ ПОРОД ПО ВЗРЫВАЕМОСТИ

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Цель. Совершенствование классификации горных пород по взрываемости на основе детального анализа особенностей существующих российских и зарубежных рейтинговых классификаций.

Методика. Применен комплексный методический подход, включающий сопоставление размеров гранулометрических фракций, определяемых по отечественным и зарубежным стандартам; сбор и обработка информации о существующих классификациях определения трудности взрываемости горных пород; составление сопоставительной классификации рассматриваемых классификаций или методик.

Результаты. Рассмотрены отечественные и зарубежные классификации горных пород по взрываемости. При сравнении отечественных классификаций в части трудности разрушения горного массива (взрываемости) была построена сопоставительная таблица, в которой между собой сопоставляются наиболее популярные классификации горных пород. При анализе зарубежного опыта составления классификаций горных пород по взрываемости было выявлено, что их методы несколько отличаются от российских, и представляют собой эмпирические зависимости, и рассчитываются для каждого типа массива в каждом отдельном случае индивидуально. Установлено, что наиболее популярной и рейтинговой системой для оценки взрываемости горных пород за рубежом является геомеханическая классификация Д.Х. Лабшира (MRMR). Показано, что зарубежные авторы, при составлении классификаций, делают акцент не только на физико-механические показатели горных пород (плотность, трещиноватость, пределы прочности на сжатие и растяжение и т.д.), но и на горнотехнические (линия наименьшего сопротивления, диаметр и глубина скважины, высота забоя и т.д.), что определяет существенную достоверность расчёта параметров буровзрывных работ.

Научная новизна. Представленная работа является первым шагом к разработке единой переходной классификации от российских шкал по взрываемости к аналогичным зарубежным методическим практикам в части взрываемости горного массива.

Практическая значимость. Заключается в возможности быстрого перевода одной классификации по взрываемости в другую. Результаты работы рекомендуется использовать при проектировании буровзрывных работ на всех типах месторождений полезных ископаемых, а также в учебном процессе.

Ключевые слова: *взрываемость горных пород, классификация, рейтинг, взрыв, гранулометрический состав, взрывчатые вещества*

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