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DETERMINATION OF THE INFLUENCE OF THE DEGREE OF FRACTURING OF THE ROCK MASS ON THE INDEX OF REDUCTION OF ITS STRENGTH

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ВСТАНОВЛЕННЯ ВПЛИВУ СТУПЕНЯ ТРІЩИНУВАТОСТІ ГІРСЬКОГО МАСИВУ НА ПОКАЗНИК ЗНИЖЕННЯ ЙОГО МІЦНОСТІ

Purpose. The purpose of research of the presented scientific publication is to establish the regularity of changes in the generalized coefficient of strength reduction of disturbed rock massif depending on the degree of rock fracturing.

Research methodology. To solve the set tasks we applied a complex approach, which consists in the analysis and generalization of previous studies on the study of the change in the strength of the rock massif depending on the degree of fracturing, scientific and technical justification of the possibility of generalizing the studied strength indicators of the disturbed massif, approximation of graphs of the change in the structural weakening coefficient, RQD and RMR depending on the fracture modulus.

Research results. Scientific data of domestic scientists on determining the value of the structural weakening coefficient depending on the factors affecting the overall strength of the rock massif, and foreign scientists on establishing indicators of the state of disturbed rock massifs have been analyzed.

To summarize the results of the presented assessment methods, the changes in the structural weakening coefficient, RQD and RMR indices depending on the fracture modulus of the rock massif are combined in one graph. Alignment of the mentioned graphical dependences showed the identical character of their changes. The curve of approximation (trend) for graphical dependences of the structural weakening coefficient, RQD and RMR on the fracture modulus, which can be described by a polynomial of the 3rd degree, has been obtained and the value of approximation reliability R^2= 0.8975 has been established.

Scientific novelty. The idea of methods and indicators for assessing the state of disturbance of rock massifs depending on various factors has been developed. The analytical dependence of the change of the generalized coefficient of strength reduction of a rocky rock massif on the fracture modulus has been obtained.

Practical significance. The established influence of rock fracture modulus on the degree of strength reduction of rock massif allows to determine reliable data on the condition of ledges and sides of the quarry and to develop organizational and technical measures for further development of technology of their mining.

Keywords: *rock massif, structural weakening coefficient, fracturing, rock, strength, strength limit, rock massif disturbance index, fracture modulus.*

Introduction. For effective operation of a mining enterprise it is necessary that all technological processes of rock preparation for excavation are performed on the basis of reliable data on the properties and condition of the rock massif. However, it is known that physical and mechanical properties of the rock in the sample and in the rock massif can differ significantly [1–3]. Therefore, for the reasonable use of the results of laboratory determination of rock strength, it is necessary to take into account the influence of humidity, rock pressure, scale effect, disturbance and fracturing of the rock massif and other factors [4, 5]. In view of this, one of the main tasks of scientists is to transfer the results of laboratory tests of rock samples of small sizes to large areas of the massif of complex structural structure as reliably as possible.

It should also be noted that the rock massif in each individual case has its own structure. It contains natural and artificial fractures with different degrees of opening and different materials that fill them, different degrees of water content, etc. The structure of the rock massif has its own structure. Consequently, there is always a spatial heterogeneity of the rock massif structure, which enhances the differences between its strength characteristics and those of its constituent rocks. To assess the magnitude of this difference, the concept of the coefficient of structural weakening of the massif (CSW) was introduced [6, 7].

So, research on improving the methodology for determining the coefficient of structural weakening and other criteria of strength reduction depending on the factors affecting the characteristics of the rock massif is relevant and represents an important scientific and technical task.

Analysis of recent research and publications. In general geomechanics expresses the structural weakening coefficient as the ratio of the value of the specific strength of the rock massif to the value of the rock strength, which was obtained from the results of laboratory tests of the sample.

Usually, the formula for determining the coefficient of structural weakening is represented by the ratio of the uniaxial compressive strength of rocks in the massif to the uniaxial strength of the rock sample, established by the results of laboratory tests [6, 7]. However, when investigating the identity of the indicators (parameters) of the empirical Hoek-Brown strength criterion [8] to the structural weakening coefficient, scientists came to the conclusion that the CSW can also be represented by the ratio of the tensile strength of rocks in a rock massif to the tensile strength of a laboratory sample. In addition, the scientific literature indicates that the CSW can also be defined by the ratio of the rock cohesion in the rock mass to the rock cohesion in the rock sample.

Thus, in essence, the coefficient of structural weakening characterizes the associated level of ultimate stresses and stress state parameters of a rock massif depending on the rocks that compose it.

In an ideal rock massif (without cracks, anisotropy, cleavage and other factors affecting strength reduction) the value of CSW is equal to 1. Since an ideal rock massif does not exist in nature, the numerical values of CSW are always less than 1. Depending on conditions, the lower limit of its variation can reach 0,1 and even less. A considerable number of scientists have been engaged in determining the numerical values of this coefficient. Factors affecting it have been established, formulas for its calculation have been obtained, graphical dependencies for determining the CSW have been constructed and normative and reference documentation has been approved.

The scientific publication [2] analyzes the factors that can affect the strength of the massif. As the authors note, the main of them are: the fracturing of the massif; different strength of individual structural blocks; their shape; the ratio of linear dimensions of these blocks; the presence of additional cracks in the rock massif, intersecting the main cracks at an angle of 40-45°; the mutual location of structural blocks in neighboring layers; the direction of the main stress on the rock massif under the action of external load; the nature of filling cracks with natural inclusions. It is also noted that in the overwhelming majority of formulas for determining the CSW the degree of fracturing of the rock massif is used as the main indicator. And only a small group of studies additionally take into account one or more of the above-mentioned factors, in particular, the angle of dip of the main natural cracks, the minimum size of the rock structural block in the massif, etc. [2].

There are other opinions, in particular, Prof. G.G. Litvinsky states that the uniaxial compressive strength of a rock massif changes sharply depending on the orientation in space of weakening surfaces compared to the strength of the specimen. This means that taking into account the reduction in the strength of the massif only by CSW is unacceptable and should be replaced by more reasonable approaches [9].

In foreign studies there is no term "structural weakening coefficient", but scientific research in the direction of studying and establishing the real strength properties of the rock massif is carried out thoroughly and at a high scientific level. In particular, in [10] a rock mass state indicator RMR (Rock Mass Rating) is proposed, and in [11] a rock quality indicator RQD (Rock Quality Designation) is proposed, which in essence are analogs of CSW. Also, to assess the state of a rock massif, researchers in [12] suggest using the rock mass index RMi (Rock Mass index), which was developed to characterize the strength of rocks. The criterion of transition from the strength of a rock sample to the strength of a rock massif according to the method of Hoek-Brown [13] and some others are also known. For most of these parameters, numerical values depending on the state of the rock massif have been established or formulas for their calculation have been proposed. It should be noted that the main parameter for their determination is the modulus (degree) of fracturing of the massif.

Formulation of the research purpose. The performed analysis of the state of rock massif strength shows that the main factor for determining the coefficient of structural weakening and its foreign analogs is the index of rock fracturing. Thus, based on the analysis of the latest scientific publications on the issues of studying the weakening of the strength of natural rock massif in comparison with the strength of a laboratory rock sample, the purpose of the research is formulated, which consists in generalizing the above-mentioned studies and establishing the regularity of changes in the generalized strength reduction coefficient of disturbed rock massif depending on the degree of rock fracturing.

Presentation of the main material. In the article [14] it was proposed to divide all scientific studies on determining the CSW of a rock massif and their foreign analogs into three groups. The first group includes data from tables and graphs on the determination of CSW depending on the parameters of rock massif fracturing. The second group of studies is proposed to be formed from publications that provide analytical calculation formulas for determining the CSW based only on the fracture modulus of the rock massif. The third group includes studies that propose to determine CSW by analytical expressions that take into account, in addition to fracturing, other factors of influence on the strength of the massif.

The first group includes, first of all, normative documentation and reference books, in which CSW is determined by the average distance between cracks in rocky rocks based on the data of engineering-geological surveys (Table 1) [14].

Table 1

Value of the coefficient of structural weakening of the rock massif K_s

Average distance between cracks in rocks, m	Specific fracturing, m	K_s
more than 1,5	less than 0,65	0,9
1,5…1,0	0,65…1,0	0,8
1,0…0,5	1,0…2,0	0,6
0,5…0,1	2,0…10,0	0,4
less than 0,1	more than 10	0,2

Also, depending on the type of disturbance of the rock massif, researchers L.M. Erofeev and L.A. Miroshnikova recommend to take values of the structural weakening coefficient, which are induced in Table 2.

Table 2

Coefficient of structural weakening of the rock mass K_s

Type of rock mass disturbance	Weakly fractured	Medium fractured	Strongly fractured	Geological disturbance zones
Specific fracturing, m	0,65…1,0	1,0…2,0	2,0…10,0	more than 10
Coefficient of structural weakening K_s	0,8	0,5	0,4…0,3	0,2…0,1

In the book "Scientific bases of quarry design" scientists note that the strength characteristics of rock massifs are mainly determined by the disturbance of rock and its weakening by fractures. In this case, the CSW of the massif for rocks of different fracturing can be determined by the data in Table 3.

Table 3

Value of the structural weakening coefficient of rocks of different fractures

Degree of fracturing	Characterization of cracking	Coefficient of structural weakening	
		The limits of change	Average value
1	Dense mesh in all directions, uncemented pieces	0,00…001	0,0005
2	Dense mesh of visible cracks in all directions	0,001…0,020	0,005
3	Dense fracturing	0,01…0,04	0,02
4	Above average fracturing	0,04…0,09	0,06
5	Average fracture after 20–30 cm	0,09…0,12	0,10
6	Below average fracturing	0,12…0,30	0,20
7	Mesh of deep fractures at 30–50 cm intervals	0,30…0,40	0,35
8	Low fractured rocks and closed fractures	0,40…0,60	0,40
9	Micro fractures are practically absent	0,60…0,80	0,70
10	Monolithic rocks without fractures	0,8…1,0	0,90

The recommendations of the "Instruction on design of capital mine workings fastening..." should also be referred to the first group. Based on the analysis of field measurements there is a graph of dependence of CSW of the rock massif on its fracture modulus, i.e. the number of cracks in the massif per one meter of the length of the rock massif (Fig. 1).

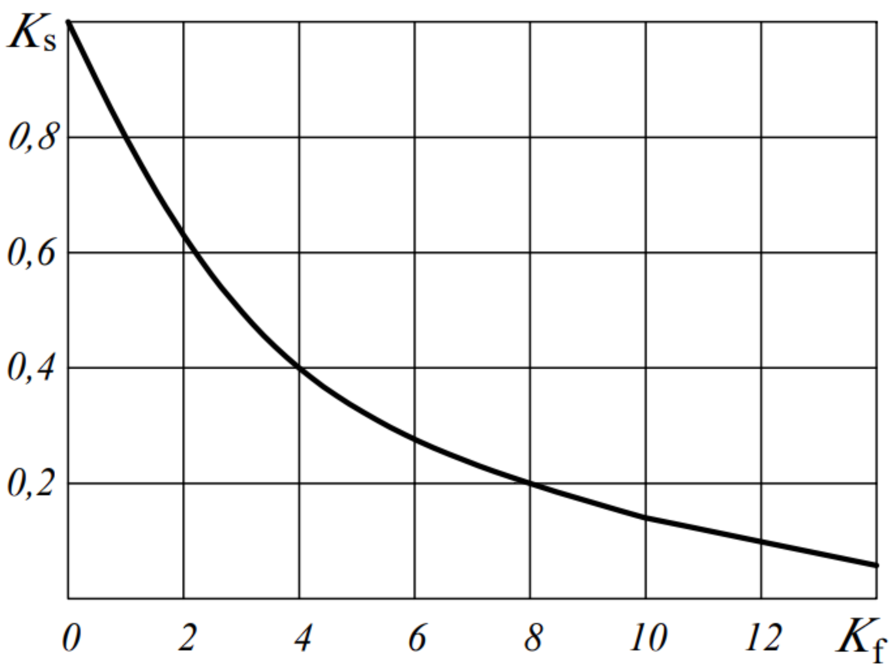

Fig. 1. Value of the structural weakening coefficient K_s depending on the fracture modulus of the rock massif K_f

Among empirical (analytical) formulas for determining the numerical value of CSW K_s depending on the degree (modulus) of massif fracturing in Ukraine, the Sakurai formula is the best known (second group of studies):

$$K_s = 0{,}15 + \frac{0{,}85}{0{,}15K_f + 1}, \tag{1}$$

where K_f is the modulus of fracture.

A.M. Shashenko, a well-known scientist in the field of geomechanics, proposed the following expression to calculate the structural weakening coefficient:

$$K_c = \frac{0{,}7 + 0{,}8(1 - V_\sigma)}{1{,}25(0{,}2J_f + 1)}, \tag{2}$$

where V_σ is the coefficient of variation of individual values of rock strength in laboratory tests: varies from 0 to 0.5; J_f is the fracture modulus of the rock massif.

The scientific publication [14] also provides a formula for calculating CSW for rocky rock massifs in coal regions:

$$K_s = 0{,}8 - 0{,}29\ln W + 0{,}01\ln^2 W, \tag{3}$$

where W is the fracture modulus, which is defined as the number of cracks per unit length ($W=1/l_f$, where l_f is the average distance between cracks).

In the same publication the dependence for determining the values of structural weakening coefficient for rock massifs of Kazakhstan is given:

$$K_s = \frac{1}{J_f^{0{,}94}}, \tag{4}$$

where J_f is the modulus of fracture.

However, as can be seen, formula (7) loses its meaning for continuous monolithic massifs when the fracture modulus J_f =0, as well as for rock massifs when the structural weakening coefficient is equal to one in the presence of cracks (J_f =1).

Outside Ukraine, the state of disturbance of rock massifs is assessed by other indicators. In many cases they are similar to the structural weakening coefficient. In particular, in the U.S., the methodology for assessing the fracturing of a rock massif by the rock quality index RQD (Rock Quality Designation) [4] is used, which is determined by the following formula

$$RQD = Z\left(\sum \frac{l_i}{L}\right), \tag{5}$$

where Z is the value of core yield, %; Σl_i is the total length of undisturbed core pieces with a length of at least 10 cm; L is the length of the investigated well interval, cm.

In [11] tabulated data of RQD index depending on the quality of rock massif (natural fracturing), which corresponds to our category of fracturing (Table 4).

Table 4

Relationship between RQD and rock mass quality

Massif quality	Very poor	Poor	Satisfactory	Good	Perfect
Average distance between fractures, m	less than 0,1	0,1–0,5	0,5–1,0	1,0–1,5	more than 1,5
RQD, %	less than 25	25–50	50–75	75–90	90–100

The classification of rock massif by RMR (Rock Mass Rating) is also known. In [10], the values of *RMR* depending on the classification of the rock massif are given (Table 5). As can be seen from the tabular data, the rock massif is also divided into five classes, as well as the classification of rocks by the degree of fracturing in Ukraine. This suggests that the RMR values have a similarity with CSW [15].

Table 5

Classification of rock massif based on RMR value

Value RMR, %	100–81	80–61	60–41	40–21	20–0
Class of rock massif	I	II	III	IV	V
Classification	very good	good	satisfactory	bad	very bad

It should be noted that there are some studies that indicate the inaccuracy of determining K_s only on the basis of the fracture index and additional factors (the third group of scientific studies) should also be taken into account [14, 15]. These include the orientation of cracks in the space of the array, the degree of crack opening, the material of filling the fracture space, cohesion at the contacts of individual pieces of rock, the scale effect (the size of the massif under study), the water content of the massif, etc. The results of the studies of these scientists allow us to increase the accuracy of determining Kc only on the basis of the fracture index. Indeed, the results of the studies of these scientists can improve the accuracy and reality of assessing the state of the disturbed rock massif, but it greatly complicates the research itself and significantly increases their duration.

So, consideration of various methods of establishing CSW and indicators of assessing the state of disturbed rock massif shows that their essence both in Ukraine and abroad is the same. In order to summarize the results of the presented methods of assessment, the graphs of changes in CSW and indicators of assessment of the state of disturbance of the massif RQD and RMR depending on the fracture modulus were combined on one graph (Fig. 2). RQD and RMR are presented in relative units.

As can be seen, Fig. 2 are presented studies on CSW of the first and second groups, because only in them it is possible to distinguish the dependence $K_s = f(K_f)$. For the formula (5) the coefficient of variation of rock strength is taken $V_\sigma = 0{,}3125$, because at it $K_s = 1$, if the fracture modulus is $J_f = 0$.

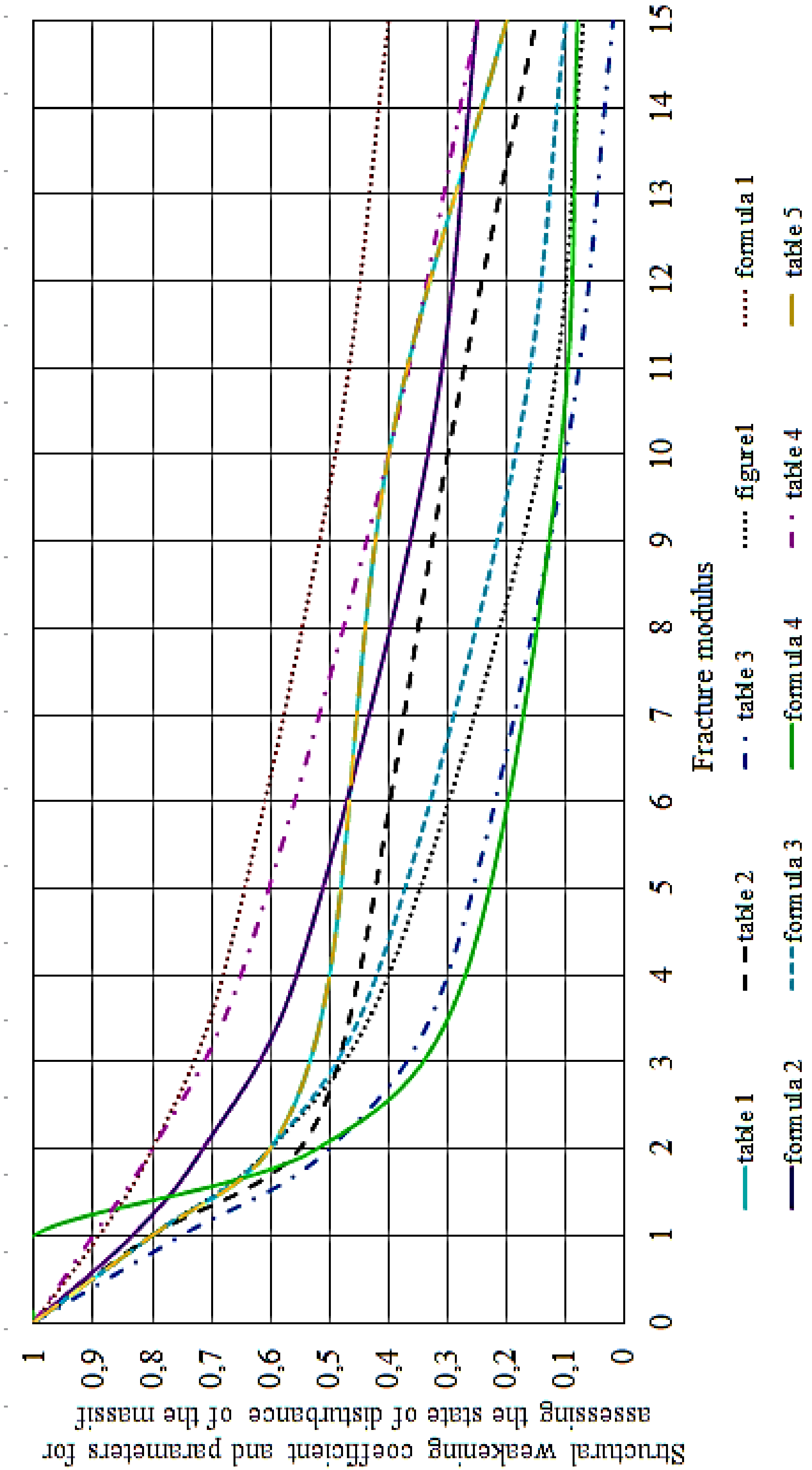

Fig. 2. Value of structural weakening coefficient and RQD and RMR indices as a function of rock fracture modulus at different assessment methods

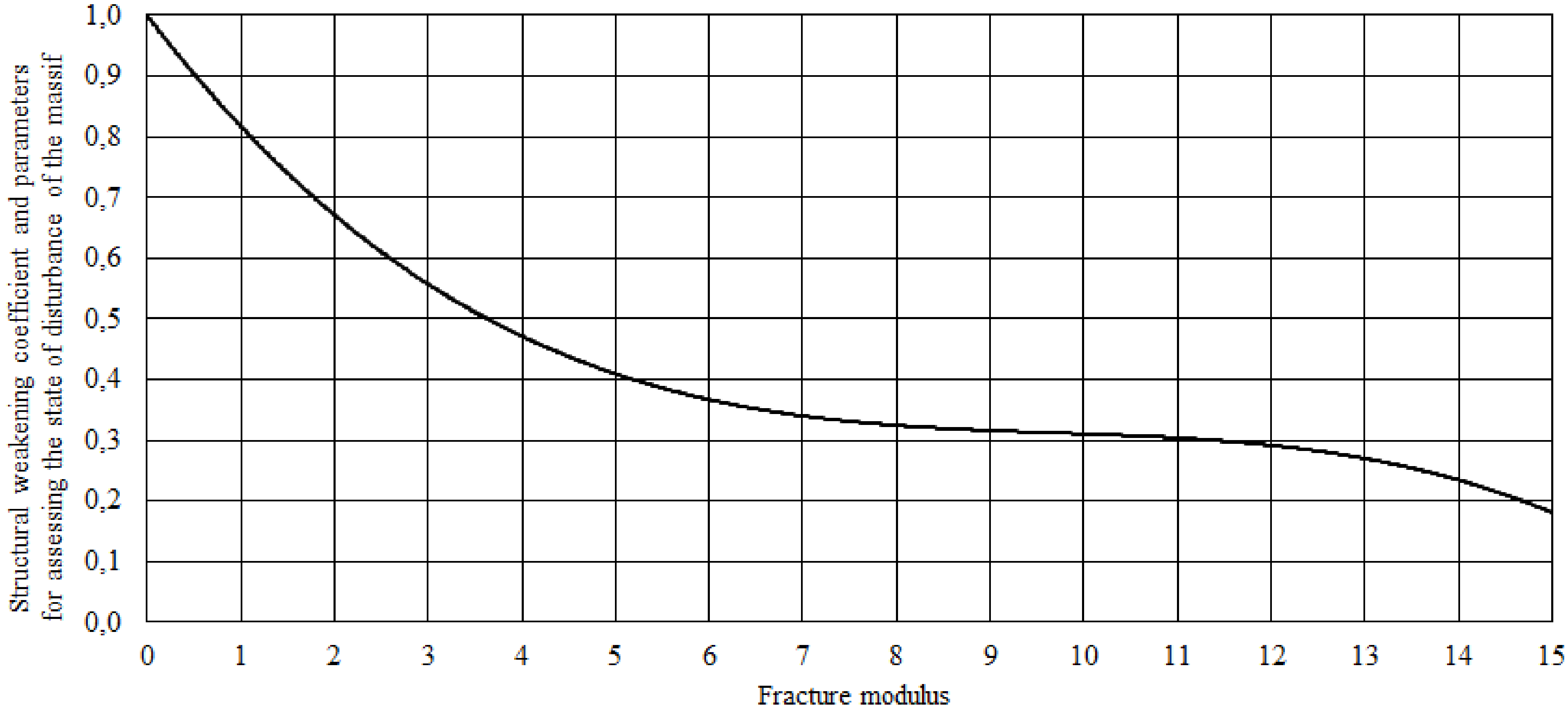

Fig. 3. Graph of approximation of values of the structural weakening coefficient and indicators of assessment of the state of disturbance of the rock massif depending on the fracture modulus

From all the graphs presented in Fig. 3 graphs, the dependence plotted by formula (7) is significantly different from all the others. In addition, as it was noted earlier, it loses its meaning at fracture modulus J_f =0. Therefore, in the following, the graphical dependence of formula (7) is excluded from consideration. For all other graphical dependences of CSW, RQD and RMR on fracture modulus, an approximation (trend) curve was constructed (see Fig. 3) and the value of approximation reliability R^2 was established.

After analyzing the graphs of changes in the structural weakening coefficient and indicators of evaluation of the state of disturbance of the rock massif from the fracture modulus, approximation of the indicators was carried out and a graph was obtained, which can be described by a polynomial of the 3rd degree:

$$K_{sr} = 1 – 0,2021K_f + 0,0203K_f^2 – 0,0007K_f^3, \quad (6)$$

where K_{sr} is the generalized coefficient of reduction of rock mass strength.

The value of reliability of approximation is as follows R^2 = 0,8975.

Conclusions. The analysis of previous scientific studies has shown that the structural weakening coefficient characterizes the associated level of ultimate stresses and stress state parameters of a rock massif depending on the type of rocks that compose it.

The article summarizes the data of scientists on determining the value of the structural weakening coefficient depending on the fracture modulus. A detailed analysis of foreign studies on establishing the state of disturbance of rock massifs is performed. For RQD and RMR indices their tabular data depending on the quality of rock massif state (natural fracturing) are given.

The analysis of the presented methods of establishing CSW and foreign indicators of assessing the state of disturbance of the rock massif (RQD and RMR), showed that their essence is the same. Therefore, in order to generalize the results of the presented methods of assessment, the graphical dependencies of the Ks coefficient and RQD and RMR indicators depending on the fracture modulus of the rock massif are combined in one graph. Alignment of these graphical dependencies shows that the nature of their change is the same.

An approximation (trend) curve was constructed for the graphs of the dependences of CSW, RQD and RMR on the fracture modulus of the rock massif. It can be described by a polynomial of the 3rd degree. The value of approximation reliability R^2 = 0.8975 was also established.

According to the results of approximation it is proposed to introduce a generalized coefficient of reduction of strength of rock massif K_{sr} instead of the coefficient of structural weakening Ks, the indicator of rock quality RQD and the indicator of the state of disturbance of rock massif RMR. At the same time, it should be taken into account that the calculation formula for its determination may change over time due to the improvement and addition of new strength indicators.

Therefore, further research will be aimed at improving the presented dependence for determining the coefficient of strength reduction of rock massif K_{sr} and at integrating this indicator into the process of calculating the parameters of rock massif fracture under the action of dynamic loads.

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АНОТАЦІЯ

Мета. Метою досліджень представленої наукової публікації є встановлення закономірності зміни узагальненого коефіцієнта зниження міцності порушеного гірничого масиву залежно від ступеня тріщинуватості скельних порід.

Методика дослідження. Для розв'язання поставлених завдань застосовано комплексний підхід, що полягає в аналізі та узагальненні попередніх досліджень з вивчення зміни міцності скельного масиву залежно від ступеня тріщинуватості, науково-технічному обґрунтуванні можливості узагальнення досліджуваних показників міцності порушеного масиву, апроксимації графіків зміни коефіцієнта структурного ослаблення, RQD і RMR залежно від модуля тріщинуватості.

Результати дослідження. Проаналізовано наукові дані вітчизняних науковців щодо визначення значення коефіцієнта структурного ослаблення залежно від чинників, які впливають на загальну міцність гірничого масиву, та зарубіжних науковців щодо встановлення показників стану порушеності гірничих масивів. Для узагальнення результатів представлених методів оцінювання, на одному графіку поєднано зміни коефіцієнта структурного ослаблення, показників RQD та RMR, залежно від модуля тріщинуватості скельного масиву гірських порід. Поєднання зазначених графічних залежностей засвідчило ідентичність характеру їхньої зміни. Отримано криву апроксимації (тренду) для графічних залежностей коефіцієнта структурного ослаблення, RQD і RMR від модуля тріщинуватості, яку можна описати поліномом 3-го ступеня, і встановлено значення величини достовірності апроксимації R^2= 0,8975.

Наукова новизна. Розвинуто уявлення про методи та показники оцінки стану порушеності гірських масивів залежно від різних чинників. Отримано аналітичну залежність зміни узагальненого коефіцієнта зниження міцності скельного гірського масиву від модуля тріщинуватості.

Практичне значення. Встановлений вплив модуля тріщинуватості скельних порід на ступінь зниження міцності гірничого масиву дає змогу визначити достовірні дані щодо стану уступів і бортів кар'єра та розробити організаційно-технічні заходи щодо подальшого розроблення технології їх відпрацювання.

Ключові слова: *гірський масив, коефіцієнт структурного ослаблення, тріщинуватість, скельна порода, міцність, межа міцності, показник порушеності гірського масиву, модуль тріщинуватості.*