Mining Science, vol. 32, 2025, 253–266

www.miningscience.pwr.edu.pl

Mining Science

(Previously Prace Naukowe Instytutu Gornictwa Politechniki Wroclawskiej, ISSN 0370-0798)

ISSN 2300-9586 (print)
ISSN 2353-5423 (online)

Received October 7, 2025; Reviewed; Accepted December 31, 2025

ANALYTICAL METHOD FOR CALCULATING PARAMETERS OF DESTRUCTION DIAGRAMS OF CYLINDRICAL ROCK SAMPLES WITH THEIR WEDGE FORM OF DESTRUCTION

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Abstract: This study aims to develop an analytical method for calculating the parameters of destruction diagrams of cylindrical rock samples experiencing wedge-shaped fractures, facilitating the effective disintegration of rocks. The method employs analytical modeling to simulate the destruction process of cylindrical rock samples, leveraging experimental values of three key rock properties: shear resistance limit, internal friction coefficient and external friction coefficient. The proposed method accurately determines the limit and residual strength of the rock samples using these three indicators, which can be experimentally obtained through straightforward procedures in mining enterprises. This research marks the first instance of analytically modeling the destruction of cylindrical rock samples with wedge-shaped fractures while accounting for both internal and external friction. The practical application of this method allows for the rapid assessment of stress-strain parameters in rock samples, thereby enhancing the efficiency of rock disintegration processes in mining operations.

***Keywords*:** *rock; tensile strength; destruction; crack; “stress–strain” diagram.*

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doi: 10.37190/msc/217842

1. INTRODUCTION

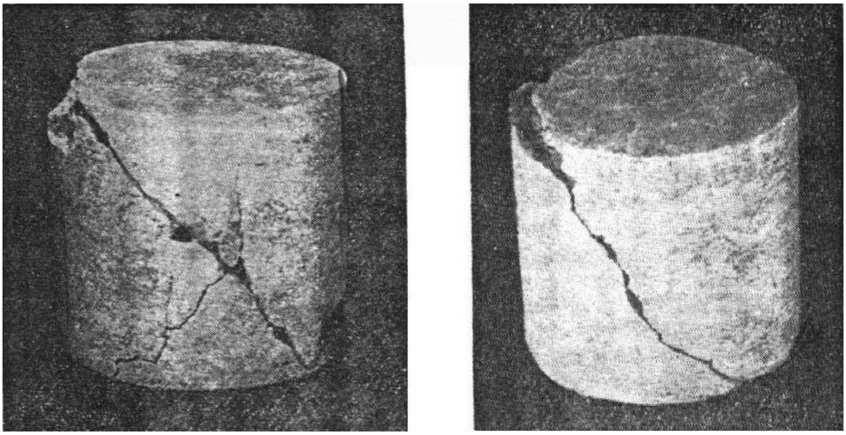
The proposed method makes it possible to determine the parameters of the stress–strain diagrams of cylindrical rock samples with their wedge-shaped fracture. Analytical modeling of the process of destruction of cylindrical rock samples with their wedge form of destruction was carried out using experimental values of three indicators of rock properties – shear resistance limit, internal and external friction coefficients, which in simple ways can be established experimentally in the conditions of mining enterprises, where the calculation results can be quickly used to assess the effective destruction during disintegration. The scientific novelty of the article lies in the fact that it was the first to carry out analytical modeling of the process of destruction of cylindrical rock samples with their wedge-shaped fracture taking into account internal and external friction.

One of the important information characteristics necessary to control the stress–strain state of a rock mass and their effective destruction during disintegration is the tensile strength and residual strength of samples, determined from the "longitudinal stress–strain" diagrams of their ultimate destruction. Since the 60s of the last century, these characteristics have been taken on special presses, which are available in some research institutes, for example, at the Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine and Krivoy Rog National University. However, this work requires highly qualified personnel, and the equipment is located far from the consumer, where prompt information about the properties of rocks is precisely needed. Therefore, there is a need to develop an analytical method for calculating the strength limits of samples with knowledge of the properties of rocks, determined by simple methods available to mining enterprises. Attempts have been made to mathematically model the processes of destruction of samples (Nesmashny 2017; Bingxiang 2013; Meyer 2013; Tarasov 2013; Zhu 2019; Wang 2021; Zhou 2022; Tin 2012). But these models have not been brought to the level of completed analytical methods for calculating the strength parameters of rock samples.

To experimentally determine the parameters of rock fracture diagrams, prismatic or cylindrical samples are used. Methods for analytical determination of parameters for prismatic samples are described in detail in the book (Vasilyev 2018). Perhaps more widely than prismatic samples, cylindrical samples from core drilling are used to determine experimental parameters. Therefore, there is a need to develop analytical methods for calculating strength for cylindrical samples.

2. METHODOLOGY

It is known that during uniaxial compression of cylindrical samples, a wedge form of their destruction is formed (Fig. 1) – one of the most common of the five well-known ones.



a) wedge b) diagonal

Fig. 1. Forms of destruction of a rock sample according to A.I. Baron

It seems possible to analytically determine the strength of samples with this form of destruction using the following method. To describe the process of rock destruction, the Coulomb criterion of maximum effective shear stresses on slip lines (SL) and slip surface (SS), is widely used, in our opinion, more successfully. The Coulomb criterion (Vasilyev 2018; Aptukov 2016; Kurguzov 2019; Vasiliev 2015; Kostandov 2016; Vasiliev 2016) for cohesive media is based on the assumption that the shear resistance of rock τ_α on the inclined SL site under consideration is equal to the sum of the resistance to pure shear (ultimate shear strength) and a value proportional to the normal stress σ_α on this site (compression is positive), from internal friction. When the sample fails, a crack forms on the SL. As the crack develops, some of the material is released from the load. If we know, according to the plane strain model, at each moment the coordinates of the tip of one or two cracks, it is possible to determine the load-bearing part of the material of the sample, which is equal to the initial area of the latter minus the part that came out from under the load during the development of the crack along the SL. The part of the sample released from the load is determined from the abscissa values of the crack tip as $x = y \operatorname{ctg} \alpha$, where y is the ordinate of the OY axis, α is the angle of inclination of the surface at the crack tip relative to the x-axis. If we know the stresses σ_y at the crack tip, its coordinates and the pattern of the contact stress distribution function on the load-bearing part of the sample, it is possible to develop, based on the Coulomb criterion, a method for calculating the parameters of the sample fracture diagrams in the presence of values of four property indicators – shear resistance limit, external (contact) and internal coefficients friction, elastic modulus.

First we'll describe the concept of sample failure. In Figure 2 we show a sample. The sample is subject to a vertical load and contact tangential stresses arising from contact friction and directed against the transverse deformation, into the interior of the sample.

The center of the coordinate axes is located in the upper left corner of the sample. On the upper plane of the left longitudinal half of the sample, the contact shear stresses τ_c have a positive sign, and on the lower plane they have a negative sign. On the right half the signs have opposite meanings. Note that under the action of a vertical load, the sample acquires a convex shape. Therefore, the rule of pairing of tangential stresses is applicable in the corners of the sample.

The wedge shape is formed on one of the halves of the contact plane and is characterized by the intersection of the SL of the vertical plane of symmetry with its exit to the opposite half of the sample.

First of all, it is necessary to decide in which direction the crack will develop from top to bottom or bottom to top. A crack may form on one of the contact planes at the point with the lowest resistance to fracture.

The essence of the problem does not change if we consider the development of a crack according to the diagram (Fig. 2), starting from the upper horizontal plane of the right half of the sample. It's more clear this way. As can be seen from the figure, we are dealing with a dissimilar pair of sliding surfaces (one convex, the other – concave), at the meeting point of which the stresses should have the same values. Such a meeting point is the point O' on the vertical plane of symmetry (Fig. 2), at which the contact tangential stresses are zero. Let us imagine that a crack first forms at point n, at a distance x_0 from the right corner of the sample. According to our ideas, according to the accepted scheme in Fig. 2, the crack develops along the SL ξ, the second (left) of them is connected at the moment when the crack reaches the SL η, at the point at which the load on it reaches a value exceeding that on the SL ξ.

To describe the evolution of the formation of a wedge-shaped fracture of a cylindrical sample, it becomes necessary to develop a law for the distribution of contact stresses. For a prismatic sample of unit width by L. Prandl (Vasilyev 2018), this law is represented by the formula

$$\sigma_{yi} = \sigma_{y_0}\left(1 + \frac{2 f_c x}{h}\right), \tag{1}$$

where:

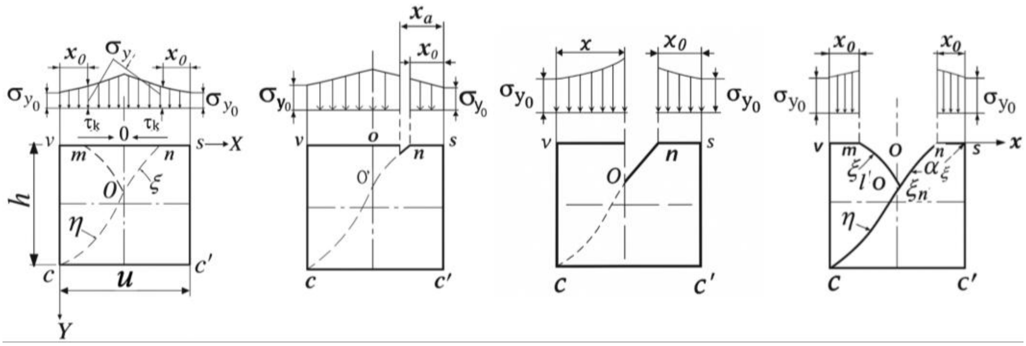
σ_{y_0} –vertical normal stress at the corner point of the sample, Pa,

f_c –contact friction coefficient,

x – abscissa of the point under consideration, m,

h – sample height, m.

Now we should relate formula (1) to the area of the cylinder, but it should be different. Unlike a prismatic sample, in which the width of the sliding surface remains constant, in a cylindrical sample this surface is constantly expanding. We tried several models, but they gave less than satisfactory results. Let us describe the proposed approach to the distribution law of contact normal stresses.



a) b) c) d)

Fig. 2. Scheme of wedge formation during compression of a rock sample:
a) at the moment of pre-fracture, b) at the moment of formation of the right side of the wedge,
c) at the moment of formation of the left side of the wedge,
d) at the moment of formation of the wedge shape

First of all, let's write the formula for the circumference of a cylinder in the *XOY* coordinate system (Fig. 3)

$$(x-y)^2+y^2=r^2, \tag{2}$$

where:

x and y – abscissa and ordinate of the point in question on the circle, m,

r – radius of the cylinder circle, m.

In Figure 3 are marked: O – center of the sample circle, vY and vX – axes of the coordinate system, φ – segment opening angle, rad, a, b, c, and d are points on the circle that limit the length of the chords.

From the transformation of formula (2), we have

$$y=\sqrt{2rx-x^2},$$

where y is the ordinate of the chord points, m.

Then the formula for the segment chord length has the form

$$a=2\sqrt{ux-x^2}, \tag{3}$$

u – circle diameter, m.

Then, using expressions (1) and (3), we write the formula for the distribution of vertical stress on the contact surface of a cylindrical sample similarly to L. Prandl's formula for prismatic samples, and we associate the abscissa x to one of the SL, for example, to the left SL ξ_1 (Fig. 2)

$$\sigma_{yi} = \sigma_y \left(\frac{2\sqrt{ux_\xi - x_\xi^2}}{u} + \frac{4 f_c}{uh} x_\xi \sqrt{ux_\xi - x_\xi^2} \right), \text{ Pa}, \tag{4}$$

where σ_y – normal stress at the crack tip, Pa.

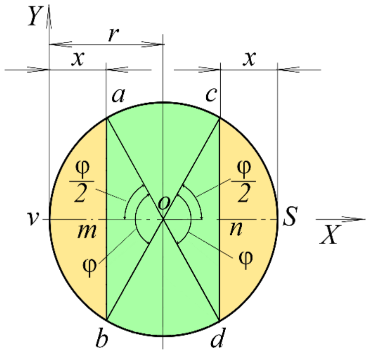


Fig. 3. Scheme of the formation of a bearing area during the development of two symmetrical cracks in a cylindrical sample

Let us write, according to expression (4), the formula for the force of influence on the part of the sample P (N) emerging from the load at the moment of crack development, in the form

$$P = 2\sigma_y \int_0^x \left(\frac{\sqrt{ux_\xi - x_\xi^2}}{u} + \frac{2 f_c}{uh} x_\xi \sqrt{ux_\xi - x_\xi^2} \right) dx, \tag{5}$$

Now, using tabular integrals, we will solve the integrals of formula (5), taking into account that according to (Kostandov 2016), the distribution functions of normal contact stresses for different SL (Fig. 2) have different forms:

at $x \geq 0.5u$

$$P = 2\sigma_y \left(\begin{array}{l} \left((2A-1)\dfrac{\sqrt{uA-A^2}}{4u} - \dfrac{1}{8u}\left(\dfrac{\pi}{2} - \arcsin 2\sqrt{uA-A^2} \right) \right) \\ + \dfrac{2 f_c}{uh} \left(\begin{array}{l} -\dfrac{(uA-A^2)\sqrt{uA-A^2}}{3} + \dfrac{(2-1)\sqrt{uA-A^2}}{8} \\ -\dfrac{1}{16}\left(\dfrac{\pi}{2} - \arcsin 2\sqrt{uA-A^2} \right) \end{array} \right) \end{array} \right), \tag{6}$$

where $A = (0.5 + x_0 - x_a)$;

at $x \le 0.5u$

$$P = 2\sigma_y \left(\left((2B-1)\frac{\sqrt{uB-B^2}}{4u} - \frac{1}{8u}\left(\frac{\pi}{2} - \arcsin 2\sqrt{uB-B^2}\right) \right) + \frac{2f_c}{uh}\left(-\frac{(uB-B^2)\sqrt{u-B^2}}{3} + \frac{(2B-1)\sqrt{u-B^2}}{8} - \frac{1}{16}\left(\frac{\pi}{2} - \arcsin 2\sqrt{uB-B^2}\right) \right) \right), \quad (7)$$

where $B = (0.5 + x_0 - x_\eta)$.

To determine the specific force p on the contact plane during crack development (beyond the elastic limit), the value of the force should be divided by the value of the area emerging from the load. Then, based on expressions (6) and (7), we find the value of the specific force on the load-bearing part of the sample equal to $\pi u^2/4$ (circle area) minus the area released from the load during crack development:

at $x \ge 0.5u$

$$p = \sigma_y \left(\frac{\pi u^2}{4} - 2\left((2A-1)\frac{\sqrt{uA-A^2}}{4u} - \frac{1}{8u}\left(\frac{\pi}{2} - \arcsin 2\sqrt{uA-A^2}\right) \right) + \frac{2f_c}{uh}\left(-\frac{(uA-A^2)\sqrt{ua-A^2}}{3} + \frac{(2-1)\sqrt{uA-A^2}}{8} - \frac{1}{16}\left(\frac{\pi}{2} - \arcsin 2\sqrt{uA-A^2}\right) \right) \right) \Bigg/ \left(\frac{\pi u^2}{4} - (2A-1)\right)\frac{\sqrt{uA-A^2}}{4u} - \frac{1}{8u}\left(\frac{\pi}{2} - \arcsin 2\sqrt{uA-A^2}\right), \text{ N}; \quad (8)$$

at $x \le 0.5u$

$$p = \sigma_y \left(\frac{\pi u^2}{4} - \left((2B-1)\frac{\sqrt{uB-B^2}}{4u} - \frac{1}{8u}\left(\frac{\pi}{2} - \arcsin 2\sqrt{uB-B^2}\right) \right) + \frac{2f_c}{uh}\left(-\frac{(uB-B^2)\sqrt{ua-B^2}}{3} + \frac{(2B-1)\sqrt{u-B^2}}{8} - \frac{1}{16}\left(\frac{\pi}{2} - \arcsin 2\sqrt{uB-B^2}\right) \right) \right) \Bigg/$$

$$\left(\frac{\pi u^2}{4}-(2B-1)\right)\frac{\sqrt{uB-B^2}}{4u}-\frac{1}{8u}\left(\frac{\pi}{2}-\arcsin 2\sqrt{uB-B^2}\right),\ \text{N}, \tag{9}$$

Now it is necessary to determine the stresses σ_y at the crack tip. We use the method described in article (Vasiliev 2016) for a prismatic sample. Then the system for calculating stresses for the right SL ξ should be written taking into account the fact that on the plane of symmetry, the contact friction is zero

$$\begin{cases} \sigma_{y_\xi}=\dfrac{1}{\mu}\left(\dfrac{k_n\left(1+\sin\rho\sqrt{1-b_\xi^2}\right)\cdot\exp(2\mu\cdot\beta_\xi}{1-\sin\rho}-k_O\right); \\ k_o=\dfrac{\left(\mu\sigma_{y_\xi}+k_n\right)\left(1-\sin\rho\sqrt{1-b_\xi^2}\right)}{(1+\sin\rho)}, \end{cases} \tag{10}$$

where:

μ and ρ = arctgμ – coefficient and angle of internal friction, rad,

β_ξ – angle of rotation of the SS ξ from contact friction at the crack tip, rad,

k_n – limit of material shear resistance,

k_o – effective shear stress at point *O*, Pa,

$$\sigma_\xi=\frac{f_c\cdot\sigma_y\left(1-\dfrac{2y}{h}\right)\cdot\left(1+\dfrac{2f_c(u-x_\xi}{h}\right)}{k_n+\mu\sigma\cdot\left(1+\dfrac{2f_c(u-x_\xi)}{h}\right)}, \tag{11}$$

$$\beta_\xi=-\frac{1}{2}\text{arctg}\frac{b_\xi\cos\rho}{\sin\rho-\sqrt{1-b_{\xi'}^2}}. \tag{12}$$

In this case, it is necessary to comply with the condition: $x_\xi \geq 0.5u$, $x_\xi = u - x$.

The angle of inclination α_ξ, rad, of the SS ξ is determined by the formula

$$\alpha_\xi=-\frac{3\pi}{4}-\frac{\rho}{2}+\beta_\xi. \tag{13}$$

Now consider the development of a crack along the left PS η at $x \leq 0.5u$. Stresses σ_{y_η} are determined by the system of equations

$$\begin{cases} \sigma_{y_\eta} = \dfrac{1}{\mu}\left(\dfrac{k_n\left(1+\sin\rho\sqrt{1-b_\eta^2}\right)\cdot\exp(-2\mu(\beta_\eta+\beta_c))}{1-\sin\rho} - k_c\right); \\ k_c = \dfrac{\left(\mu\sigma_y + k_n\right)\left(1-\sin\rho\sqrt{1-b_\eta^2}\right)}{\left(1+\sin\rho\sqrt{1-b_c^2}\right)\cdot\exp(-4\mu\beta_c)}, \end{cases} \tag{14}$$

where:

$$b_\eta = \frac{f_c\left(1-\dfrac{2y}{h}\right)\cdot\sigma_{y_\eta}\left(1+\dfrac{2f_c x_\eta}{h}\right)}{k_n+\mu\sigma_{y_\eta}\left(1+\dfrac{2f_c x_\eta}{h}\right)},$$

$$b_c = -\frac{f_c\cdot\sigma_{y_\eta}}{k_c+\mu\sigma_{y_\eta}},$$

$$\beta_\eta = -\frac{1}{2}\operatorname{arctg}\frac{b_\eta\cos\rho}{\sin\rho-\sqrt{1-b_\eta^2}},$$

$$\beta_c = -\frac{1}{2}\operatorname{arctg}\frac{b_c\cos\rho}{\sin\rho-\sqrt{1-b_c^2}},$$

where β_η and β_c – angles of rotation of the SS η from contact friction on the SS η itself and on the lower contact plane at point *c*, rad.

In this case, it is necessary to comply with the condition: $x_\eta \le 0.5u$, $x_\eta = x$.

The angle of α_η, rad, inclination of the SS η is determined by the formula

$$\alpha_\eta = \frac{3\pi}{4} - \rho/2 + \beta_\eta. \tag{15}$$

Now, using the value of the specific force acting on the load-bearing (not released from the load) part of the sample, one should proceed to the stresses along its initial semi-circle areas equal to $\pi u^2/8$.

Based on formulas (8) and (9) using expressions (10)–(15), we determine the values of the specific force *p* on the load-bearing part of the sample. If we know the values of the specific force *p*, it is possible to determine the current values of deformations ε during the development of a crack – one of the parameters of the stress-strain diagram during uniaxial compression of samples according to the well-known formula

$$\varepsilon = \frac{p}{E}, \tag{16}$$

where E – elastic modulus, Pa.

Using formula (16), a straight line of the true diagram is constructed (Fig. 4). Now it is necessary to determine the values of the second parameter – the current value of the strength of the sample on the beyond-limit branch of the conditional diagram. To do this, you need to multiply the specific force values by the ratio of the load-bearing area of the sample to the initial area of the latter. Multiplying these parameters should provide an initial value of stress equal to the value of the specific force, and a decrease in strength on the beyond-limit branch of the diagram. To do this, we express the area emerging from the load in the form of a segment (Fig. 3), using the well-known formula

$$S_{abv} = \frac{u^2}{8}(\varphi - \sin\varphi), \tag{17}$$

where φ – segment opening angle, rad.

Angle φ

$$\varphi = 2\arcsin\sqrt{1 - \left(\frac{u - 2x_\xi}{u}\right)^2}. \tag{18}$$

Then the area of segment *abv* (Fig. 3) during crack development

$$S_{abv} = \frac{u^2}{4}\left(\arcsin 2\sqrt{ux_\xi - x_\xi^2} - 2(1 - 2x_\xi)\sqrt{ux_\xi - x_\xi^2}\right). \tag{19}$$

Then the load-bearing area of the semicircle of the sample

$$S_1 = \left(\frac{\pi u^2}{4} - \frac{u^2}{4}\left(\arcsin 2\sqrt{ux_\xi - x_\xi^2} - 2(1 - 2x_\xi)\sqrt{ux_\xi - x_\xi^2}\right)\right), \text{ m}^2. \tag{20}$$

Now, taking into account that the area of the semicircle is equal to $\pi u^2/8$, we write the strength formula on the beyond-limit branch of the "longitudinal stress–strain" diagram based on expressions (8), (9) and (20) in the form

$$\sigma_c = \frac{8p}{\pi u^2}\left(\frac{\pi u^2}{8} - \frac{u^2}{4}\left(\arcsin 2\sqrt{ux - x^2} - 2(1 - 2x)\sqrt{ux - x^2}\right)\right). \tag{21}$$

Now the specific force and abscissa x should be given specific values in relation to determining the current values of the sample strength on the beyond-the-limit branch of the diagrams according to formulas (8) and (9).

So, when at $x \geq 0.5u$

$$\sigma_c = \frac{8p}{\pi u^2}\left(\frac{\pi u^2}{8} - \frac{u^2}{4}\left(\begin{array}{l}\arcsin 2\sqrt{u(x_o + x_\xi) - (x_o + x_\xi)^2} \\ -2\left(1 - 2(x_o + x_\xi)\right)\sqrt{u(x_o + x_\xi) - (x_o + x_\xi)^2}\end{array}\right)\right); \quad (22)$$

at $x \leq 0.5u$

$$\sigma_c = \frac{4p}{\pi u^2}\left(\frac{\pi u^2}{4} - \frac{u^2}{4}\left(\arcsin 2\sqrt{ux_\xi - x_\xi^2} - 2(1 - 2x_\xi)\sqrt{ux_\xi - x_\xi^2}\right)\right). \quad (23)$$

Using formulas (16), (22), and (23) using intermediate expressions, it is possible to determine the parameters of the true and conditional stress–strain diagrams by iteration, which researchers obtain on presses with a wedge-shaped fracture of cylindrical samples in the form of a function of the limiting branches $\sigma_c = \varphi(\varepsilon)$. In Figure 4 presents these functions at a value of elastic modulus E = 2000 MPa and various values of rock property indicators for a sample with a height and diameter equal to unity.

An important conclusion should be drawn from the analysis of the diagrams: the slope angle of the limiting curve $\sigma_c = \varphi(\varepsilon)$, the so-called decay modulus M, accepted by researchers as a constant characteristic of the material, similar to the elastic modulus E, depends on the numerical values of the rock properties and is not constant. To confirm the conclusion in Fig. 4 shows branch 5 at $f_c = 0$.

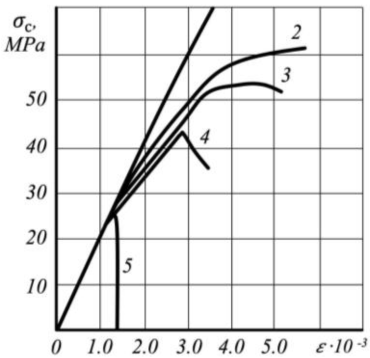


Fig. 4. Excessive curves of the wedge form of destruction of samples at:
k_n = 10 MPa, f_c = 0.25, E = 2000 MPa;
1 – true diagram, 2 – ρ = 39°, 3 – ρ = 35°, 4 – ρ = 30°, 5 – ρ = 39°, f_c = 0

The researchers note that with a wedge-shaped fracture and a load above 70–80% of the maximum, significant nonlinearity occurs. Let us add on our own that in the initial part of the transcendental curve there is a so-called strengthening of the material according to an increasing curve with its subsequent decline.

Many authors explain the roundness of the trans-branches by the plasticity of the rocks. In our opinion, these roundnesses have nothing to do with plasticity. Rocks are highly fragile materials. The roundness of the beyond-limit branches of the diagrams reflects the nonlinear relationships between stresses and areas released from under the load during the development of a crack. It should be noted that Hooke's law is observed on the load-carrying part of the sample (line 1), i.e., the true diagram looks like a straight line, despite the fact that the conditional diagrams have non-linearities.

To confirm the reliability of the proposed method, we will compare the calculated values of the ultimate strength with experimental data borrowed from the inventory (Table 1). The coefficient of variation was 10.8%, which corresponds to good convergence for rocks according to the method for assessing the convergence of calculated and experimental data by Prof. L.I. Baron.

Table 1. Comparison of the calculated strength limits of cylindrical samples with wedge-shaped fracture with experimental data

Rock type	Experimental			Calculated		Cadastre
	k_n, MPa	ρ, degree	σ_c, MPa	σ_c, MPa	coefficient of variation, %	
Severely modified monocyte	28.0	22	164	131.2	0.2	104
Argillite	5.0	30	24.0	24.7	0.03	171
Sandstone	10.0	30	55.0	49.5	0.11	158
Limestone	12.0	30	60.0	59.2	0.08	158
Siltstone	6.5	31	35.0	33.3	0.06	174
Magnetite oxidized	20.0	32	97.0	96.0	0.01	66
Hornwort	16.0	34	84.0	83.8	0.10	67
Slate	6.7	35	35.0	32.7	0.10	59
Argillite	7.8	35	46.5	42.9	0.10	172
Argillite	4.0	35	24.0	21.7	0.07	172
Marbled limestone	8.0	35	37.0	42.8	0.13	66
Sandstone	6.6	36	32.5	37.3	0.16	172
Hematized tuff	25.0	36	134.0	139.-	0.04	67
Skarned porferite	15.0	37	78.5	86.3	0.10	66
Hornweed	25.0	39	138.0	158.0	0.20	66
Garnet skarn	20.0	39	112.0	124.2	0.15	67
Magnetite skarn	10.0	39	68.0	62,.4	0.09	67
Average coefficient variations					0.11	

3. CONCLUSION

1. An analytical method has been developed for calculating the parameters of stress-strain diagrams for wedge-shaped fracture of rocks using three indicators of their properties (k_n – limit of material shear resistance, coefficients of contact f_c and internal μ friction), available for experimental determination in laboratories of industrial enterprises in simple by technical means.
2. The limiting branch of strength $\sigma_c = \varphi(\varepsilon)$ in the initial region has a sharp linear increase in strength, the so-called hardening, which has not received a theoretical explanation in the theory of plasticity, followed by a transition to a smooth convex curve with a decrease in strength. We explain this phenomenon by the transition of the fracture process from a convex sliding surface to a concave sliding surface, characterized by this feature. It should be noted that Hooke's law is observed on the load-bearing part of the sample, i.e., the true diagram looks like a straight line, despite the fact that the conditional diagrams have non-linearities.
3. From the analysis of the diagrams, an important conclusion should be drawn: the slope angle of the limiting curve $\sigma_c = \varphi(\varepsilon)$, the so-called decay modulus *M*, accepted by researchers as a constant characteristic of the material, similar to the elastic modulus *E*, depends on the numerical values of rock properties and is not constant.

   Based on the maximum and minimum values of the normal stresses of the limit curves of the diagrams, the values of the limits and residual strength of the samples can be determined, which are equivalent in value to those obtained from the stress-strain diagrams obtained on presses. A comparison of the calculated tensile strengths with experimental data confirmed the high reliability of the developed method with a coefficient of variation within 0.108.
4. In the future, it is planned to test the method with other forms of destruction (diagonal, longitudinal and explosion-like).

ACKNOWLEDGEMENTS

This study was financially supported by Institute of Geotechnical Mechanics NAS of Ukraine.

BIBLIOGRAPHY

NESMASHNY E.A., BOLOTNIKOV A.V., 2017, *Determination of the strength of rocks using modern equipment using the example of the Bolshaya Glivatka deposit,* Metallurgical and Mining Industry, No. 3, 82–87.

BINGXIANG H., JIANGWEI L., 2013, *The effect of loading rate on the behavior of samples composed coal and rock,* Int. J. Rock Mech. Min. Sci., 61, 23–30, DOI: 10.1016/j.ijrmms.2013.02.003.ui.adsabs.harvard.edu.

MEYER J.P., LABUZ J.F., 2013, *Linear failure criteria with three principal stresses*, Int. J. Rock Mech. Min. Sci., 60, 180–187, DOI: 10.1016/j.ijrmms.2012.12.040.Osti+2ui.adsabs.harvard.edu+2Experts @Minnesota+2.

TARASOV B., POTVIN Y., 2013, *Universal criteria for rock brittleness estimation under triaxial compression*, Int. J. Rock Mech. Min. Sci., 59, 57–69, DOI: 10.1016/j.ijrmms.2012.12.006.

ZHU W., WONG L.N.Y., 2019, *Crack initiation and propagation in rock under uniaxial compression*, Engineering Fracture Mechanics, 210, 262–275.

WANG Y., LIU Q., ZHANG X., 2021, *Deformation and failure characteristics of rock under triaxial compression*, Rock Mechanics and Rock Engineering, 54, 3897–3912.

ZHOU H., XIONG F., LIU J., 2022, *Mechanical behavior and failure characteristics of rock under different loading paths*, Int. J. Rock Mech. Min. Sci., 149, 104960.

MA H., ZHU Z., LI X., 2020, *Effect of end friction on rock failure under uniaxial compression*, Int. J. Rock Mech. Min. Sci., 130, 104319.

TIN A.G., 2012, *Mechanics of Rocks. Modeling of Destruction*, SPb: Publishing and Printing Company "KOSTA", 280 pp.

VASILYEV L.M., VASILIEV D.L., MALICH N.G., ANGELOVSKY A.A., 2018, *Mechanics of Formation of Fracture Modes of Rock Samples During Their Compression*, Dnipro: IMA-press, 174 pp.

APTUKOV V.N., 2016, *Deformation criterion for destruction of salt rock samples*, FTPRPI, No. 3, 30–45.

KURGUZOV V.D., 2019, *Comparative analysis of destruction criteria for artificial materials and rocks*, FTPRPI, No. 5, 79–89.

VASILIEV L.M., VASILIEV D.L., 2015, *Taking into account contact friction in the problem of destruction of rocks by compression*, FTPRPI, No. 3, 48–56.

KOSTANDOV Yu.A., 2016, *On the influence of contact conditions on estimates of the limiting parameters of elastic moduli and the nature of destruction of compressive samples*, FTPRPI, No. 1, 82–90.

VASILIEV L.M., VASILIEV D.L., MALICH N.G., 2016, *Analytical method for calculating the tensile strength of prismatic rock samples with their wedge-shaped fracture*, Metallurgical and Mining Industry, No. 6, 65–70.