

Method of calculating the parameters of the mountain pressure epure

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Abstract. Elevated bearing load pressure is formed near the exposed part of the coal seam, compared with static stresses normal to the reservoir. The loading of the near-bottom part of the coal seam is formed by linearly damped, according to the principle of Saint-Venant, from the bottom of the face to the massif of the tangential stresses from contact friction between the formation and lateral enclosing rocks in the form of a reference rock pressure, the epure of which is described by a convex quadratic function whose initial value is normal stress at the top of the bottom hole fracture, and the final stress is to the rock pressure in the zone of the intact massif. In connection with the above scientific position, a method has been developed for determining the vertical normal stress at the top of the bottom hole fracture, the length of the epure, and the distance from the bottom to the maximum of the reference pressure.

1 Introduction

In modern conditions, the solution of issues of rock pressure only by methods of mine observations and modeling by equivalent materials does not allow to reveal the mechanism of formation of the reference pressure.

Since the second half of the last century, work has been carried out to control mountain pressure [1]. Rejecting all other approaches to the critical analysis of various theories based on the fact that they are described by ascending and descending exponents, while the real epures of rock pressure have the form of quadratic functions, A.A. Borisov gives his experimental and theoretical epure of himself and other authors (Fig. 1). Known approaches to the construction of the epure of rock pressure, including A.A. Borisov, are reduced to three types of representation of the epure of rock pressure in the form:

- 1) a downward stress epure, characterized by its maximum value above the face;
- 2) one ascending and other descending exponent or exponential function of stresses intersecting at the point of the maximum value of the reference pressure. In this case, the ascending epure is based on the constant value of contact tangential stresses arising from contact friction;

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3) a convex quadratic function with an initial voltage value equal to zero.

However, any known analytical formula necessary for calculating the driving force control parameters of mountain ranges from their set does not describe the experimental convex epure of vertical stresses of the reference rock pressure on coal seams with an initial value not equal to zero (Fig. 1, epure 2).

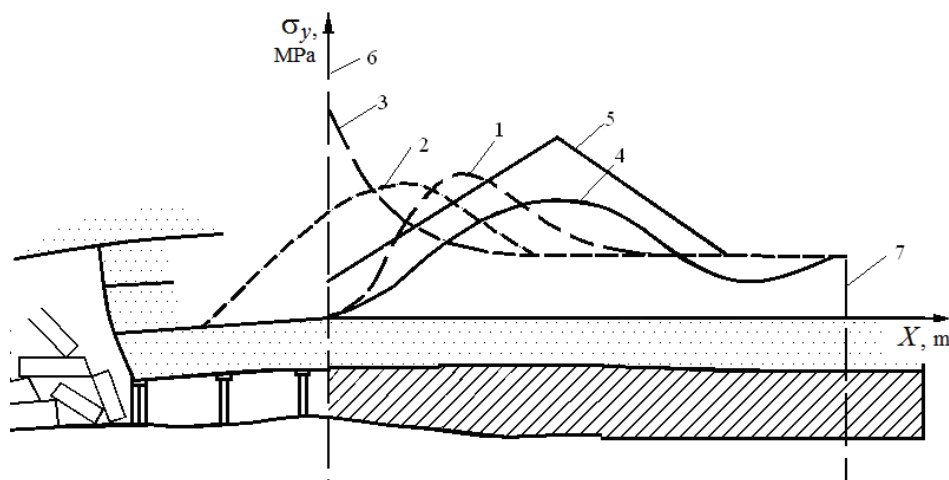


Fig. 1. Distribution patterns of the reference pressure in the middle part of the lava by various authors (according to A.A. Borisov): 1- according to V.D. Slesarev; 2- according to mine observations; 3 - according to the theory of stress concentration; 4 - according to the theory of beams on an elastic foundation according to A.A. Borisov; 5 - by V.V. Hodot; 6 – bottom line; 7 – line of the intouched array.

Researchers continue to use unrealistic formulas for describing the reference pressure epure [3]. There are many examples.

In works [3 - 7], it is assumed that the vertical deformation decreases with removal deep into the reservoir in a linear dependence. This assumption brings the plot of rock pressure closer to the real one (Fig. 1, curve 2). But it is not sufficiently analytically substantiated and not brought to a high accuracy of calculation.

2 Methods

The bearing capacity of the seam is associated with the emergence of a bottom-hole support pressure zone. The reference pressure is formed by increased, compared with static, normal to the seam stresses acting near the exposed part of the reservoir. The reference pressure reflects the coal seam loading around the workings due to the exposure of the massif. The reference pressure determines the processes occurring in the marginal parts of the seam. It occurs constantly when a cavity is formed, also when conducting workings. Support pressure plays an important role in the occurrence of rock bursts, sudden outliers, pressing of coal, heaving, influences the stability of workings, causes blockages of lavas, etc. The patterns of the manifestations of the reference pressure depend on many factors, but it is important to know the dominant ones. This has become one of the important problems of rock mechanics in revealing the physical nature of the reference pressure, in developing ways to control not only the manifestations of the reference pressure, but also the physical processes caused by them. Under the influence of the load, the material of the massif is damaged, irreversible deformations occur in the marginal part of the formation, cracks form in the latter, and the roof is displaced. Therefore, we will pay attention to the issue of

disclosing the mechanism of the formation of the reference pressure, on which there is no consensus among scientists. The magnitude of the rock pressure on the contact surface is formed in the form of a certain regularity - the epure of rock pressure. This pattern is not sufficiently disclosed. To reveal the mechanism of rock pressure loading, we use experimental observations of other researchers from the mechanics of a deformable body, which claim that contact shear stresses decay linearly from places of stress concentration deep into a deformable body in accordance with the principle of Saint-Venant [8].

The seam is represented together with the enclosing rocks in the form of an elastic system in the form of a strip enclosed between rigid plates. The rock pressure acts on the upper plate. Between the enclosing rocks and the formation, shear stresses due to contact friction, resulting from the deformation of the coal seam, act and are directed deep into the massif.

It is generally accepted that the magnitude of the rock pressure on the seam is determined by the weight of the column of overlying rocks of a single section

$$\sigma_r = \gamma H, \text{ Pa}, \quad (1)$$

where γ – the specific gravity of rocks, N/m^3 ; H – height of the rocks column, m.

The reference pressure at a certain distance from the bottom reaches a maximum and then decreases to level values corresponding to the state of an intact massif. It is directly related to the distribution of contact normal stresses in the bottom hole zone (Fig. 2).

We put forward a concept that does not exclude the influence of contact friction and describes the epures of rock pressure in the form of a convex quadratic function [9] with an initial value not equal to zero (Fig. 1, epure 2). The author of the book [8], based on the principle of Saint-Venant, argues that friction decreases with distance from the free surface along the length of the slab. In general, it is obvious that the displacement of the reservoir towards its outcrop should stop at a certain distance from the bottom in the untouched zone. To calculate the linear attenuation of the contact shear stress, we introduce the parameter t_l , reflecting the change in the coefficient of contact friction and equal $t_l = 1/l_m$, where l_m is the length of the reference zone, m. Using the linear attenuation of the contact friction coefficient f_i according to the law $f_i = f_k(1 - t_l l)$ (Fig. 2), (where l is the distance from the bottom of the studied contact area), we can write the epure of rock pressure in the form of the linear pressure L. Prandtl [9, 10]

$$\sigma_{y_i} = \sigma_{y_{\xi}} (1 + f_k (1 - t_l \cdot l) \cdot l/h), \text{ Pa}, \quad (2)$$

where $\sigma_{y_{\xi}}$ – vertical normal stress at the top of the crack, Pa; f_k – coefficient of the contact friction between the formation and lateral rocks; h – seam width, m; it is necessary to write down the important condition that $f_i = f_k(1 - t_l l)$ at $\sigma_{y_i} = \sigma_r$, (in the zone of the untouched massif).

Now we will determine the length of the loaded zone and the length of the epure. In general, the epure crosses the horizontal line γH at two points: the near point determines the size of the unloading zone, which will be discussed in detail in the separate article of this collection. The distant point is on the descending branch of the epure, in the zone of the untouched massif (Fig. 2). The farthest point of intersection of the epure with the horizontal line γH determines its length. Due to the fact that at point a (Fig. 2) the effective shear stress reaches the value of k_n – the limit of the resistance of the material to shear, a crack is formed, which develops along the trajectory of maximum effective tangential stresses (TMETS). The epure changes its value all the time, because in the bottom hole section of the TMETS ξ , a crack develops and the normal stress $\sigma_{y_{\xi}}$ increases until the bearing

capacity σ_c in the reference pressure zone reaches the value of γH . The value will be equal to the normal stress at the top of the crack. The beginning of the reference pressure diagram is shifted to the depth of the coal mass by the abscissa of the top of the crack. The console value x_ξ is formed because of the bottom hole formation will be out of load. A zone of irreversible deformations wide $x_\xi = x_0$ is formed (Fig. 2).

Then the distribution of normal contact voltages is described by a quadratic function (Fig. 2).

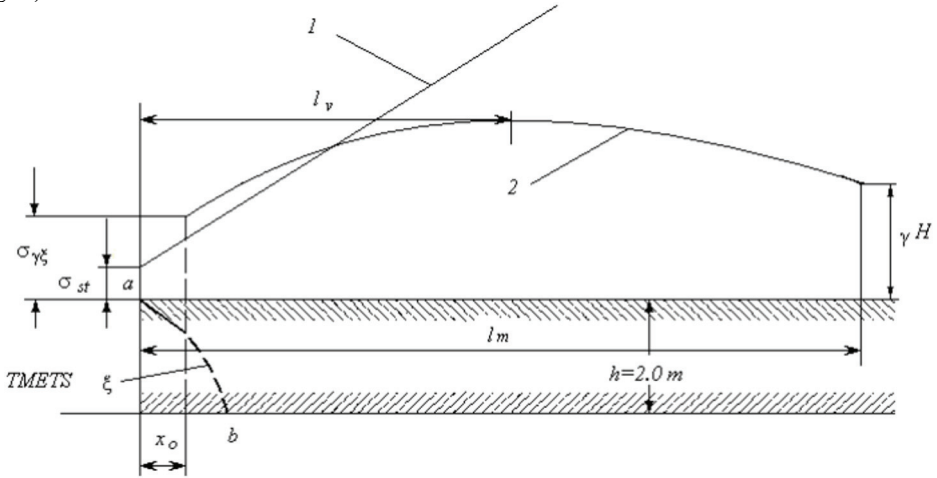


Fig. 2. Dependencies of the reference pressure according to L. Prandtl [1] and according to the author [2].

The figure indicates: x_0 – zone of irreversible deformations, m; σ_{st} – limit the strength of coal, Pa; $\sigma_{y\xi}$ – limit value of the normal voltage in top of the crack, Pa.

The formula for calculating the length of the epure is obtained from the transformation of formula (2)

$$l_m = \frac{1}{2t_l} + x_\xi + \sqrt{\frac{2x_\xi t_l - \frac{4t_l \cdot h}{f_k} \left(\frac{\gamma H}{\sigma_{y\xi}} - 1 \right)}{2t_l}}, \text{ m}, \quad (3)$$

where $t_l = 0.1, 1/\text{m}$.

The vertical stress $\sigma_{y\xi}$ at the top of the crack is determined by the system of equations [10]

$$\sigma_{y\xi} = \frac{1}{\mu} \left(\frac{k_n \left(1 + \sin \rho \sqrt{1 - b_\xi^2} \right) \cdot \exp(-2\mu(\beta_\xi + \beta_b))}{1 - \sin \rho \sqrt{1 - b_b^2}} - k_b \right), \quad (4)$$

where k_n – limit shear resistance at the crack top, Pa; μ – internal friction coefficient; $\rho = \arctg \mu$ – angle of internal friction of coal, rad; β_ξ – the value of the angle of inclination of the TMETS ξ relative to the horizontal from contact friction, rad; β_b – the value of the angle of the trajectory exit to the contact surface, rad; k_b – the current value of the shear

resistance at point b (Fig. 2), Pa; dimensionless parameters b_ξ at the crack top and b_b at point b

$$k_b = \frac{(k_n + \mu \sigma_{y_\xi}) (1 - \sin \rho \sqrt{1 - b_\xi^2})}{(1 + \sin \rho \sqrt{1 - b_b^2}) \exp(-4\mu\beta_b)}; \quad (5)$$

$$b_\xi = \frac{f_k \left(1 - \frac{2y}{h}\right) \cdot \sigma_{y_\xi} \left(1 + \frac{2f_k \cdot x_\xi}{h}\right)}{k_n + \mu \cdot \sigma_{y_\xi} \left(1 + \frac{2f_k \cdot x_\xi}{h}\right)}; \quad (6)$$

$$b_b = -\frac{f_k \cdot \sigma_{y_\xi} \left(1 + \frac{2f_k \cdot x_b}{h}\right)}{k_b + \mu \cdot \sigma_{y_\xi} \left(1 + \frac{2f_k \cdot x_b}{h}\right)}, \quad (7)$$

where x_ξ – abscissa of the top of the crack, m; x_b – the abscissa of the intersection point of TMETS ξ with the reservoir soil, m.

The angle of the bottom hole crack ξ

$$\alpha_\xi = \frac{\pi}{4} + \frac{\rho}{2} - \beta_\xi, \text{ rad}, \quad (8)$$

where ρ – internal friction angle, rad.

In accordance with the principle of Saint-Venant, in expression (5) the linear attenuation of shear stresses from external friction along the thickness of the seam is taken into account according to the expression $\frac{1-2y}{h}$. Point b for TMETS ξ is fixed. Therefore, the value of the tangential stress from external friction is taken into account by the abscissa value x_b at $y = h$. The minus and plus sign in expressions (4) and (5) indicates the different role of external friction on the contact planes.

The angle values β_ξ and β_b are determined using the equations

$$\beta_\xi = -\frac{1}{2} \operatorname{arctg} \frac{b_\xi \cos \rho}{\sin \rho - \sqrt{1 - b_\xi^2}}; \quad (9)$$

$$\beta_b = -\frac{1}{2} \operatorname{arctg} \frac{b_b \cos \rho}{\sin \rho - \sqrt{1 - b_b^2}}. \quad (10)$$

To calculate the parameters of the bottom part of coal seams, experimental values of the shear resistance limit against bedding, the coefficient of internal friction of coal and the contact friction between the layer and the immediate roof rocks are necessary. Therefore, coal and roof rock were sampled from the face of the i_3^I and k_2^n seams and Public Joint Stock Company (PJSC) Krasnodonvuhillia. The coefficients of external friction of coal-sandy slate pairs were determined, which amounted to 0.5-0.55. The values of the coefficient and angle of internal friction of coal samples from the seam i_3^I on the bedding and perpendicular to the bedding are $\mu = 0.98$ and 1.0 and $\rho = 0.73$ rad and 0.78 rad. The

limit of the resistance of coal to the bedding shift is $k_n = 0.6-0.7$ MPa, perpendicular to the bedding $k_n = 1.5-1.85$ MPa. The values of the coefficient and angle of internal friction of coal samples of the reservoir are perpendicular to the bedding $\mu = 0.80$ and $\rho = 0.68$ rad. The shear resistance limit is perpendicular to the bedding $k_n = 1.27 - 1.4$ MPa.

Using indicators of the physicommechanical properties of coal, the estimated marginal state of the layers. The friction coefficient, which is equal to zero, is in the region of the intact massif, where the rock pressure is $\gamma H = 15.0$ MPa for the seam depth of 600 m mine management "Molodohvardiiske", for the seam depth in 1000 m mine management "Sukhodilska-Skhidna" $\gamma H = 25.0$ MPa at the rate of $\gamma = 2.5 \cdot 10^4$ N/m³. For a seam with indicators of coal with $k_n = 1.5$ MPa, $\rho = 0.78$ rad, $h = 1.8$ m, $f_k = 0.5$, the length of the epure taking into account the console length for the depth of the seam 600 m mine management "Molodohvardiiske" at $\gamma H = 15.0$ MPa is equal to 7.1 m, for a depth of seam of 1000 m mine management "Sukhodilska - Skhidna" with $\gamma H = 25.0$ MPa is equal to 8.3 m.

3 Results and discussion

For the first time, a method has been developed for calculating parameters of the epure of rock pressure in the form of a convex quadratic function. Its initial value is equal to the normal stress at the top of the bottom hole fracture, and the final value is to the mountain pressure in the zone of an intact massif corresponding to the experimental measurements. The basis of the methodology for developing a method for calculating epure parameters is the analytical determination of the vertical normal stress at the top of the bottom hole fracture, the length of the epure of the reference pressure.

The method can be used to solve many problems of mining: managing the state of the massif near the mine workings in order to increase their stability or unload from the pressure of coal seams for their degassing.

Conclusions

1. The vertical stress at the top of the bottom hole fracture is determined by a system of equations that takes into account the properties of coal: shear resistance limit, internal friction angle, contact friction coefficient, geometric parameters of the crack.

2. The loading of the bottom part of the coal seam is formed by the shear stresses linearly damped from the bottom of the face deep into the massif from the contact friction between the seam and lateral host rocks in the form of a reference rock pressure, whose epure is described by a convex quadratic function. The initial value of this function is equal to the normal stress at the top of the bottom hole fracture, and the final value is the mountain pressure in the zone of the untouched massif.

3. The paper presents a method for calculating parameters of rock pressure sealing: vertical stress at the top of the bottom hole fracture, the length of the epure, the distance from the bottom to the depth of the morning formation to the maximum of the rock pressure.

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