Importance of Resultant Action of the Mining Machine Actuator for Stresses in Impact Zone of a Separate Cutter

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Abstract: Two stress levels are considered in the general pattern of stress-strain state of the rock destroyed by the mining machine. The authors also ground the necessity of considering the interaction of all cutters of the actuating device when calculating the process of cutting with a separate cutter.

1. Introduction

The works are being completed to develop tunneling machines of a new class – geohods [1, 2], to the systems of which special requirements are imposed [1, 2].

When calculating the actuating devices of mining machines we determine the forces of interaction between the cutter and the rock and then the forces, affecting the cutters, are summed up [6]. But these calculations do not take into account the impact of the summed stress upon the stress-strain state in the local impact area of a separate cutter.

In works [4-8] a different approach to forming the initial data and designing actuating devices of the mining machines is grounded. The approach is based upon considering the background stress influence.

2. Results and Discussion

Let us divide the general pattern of stress-strain states in the effective area of the actuating device into two stress levels.

– *the first level of stresses* – local (element) stresses which are formed in the area of contact between the face rock and the cutter, the cutter tooth or other rock-cutting tools;
– *the second level of stresses* – total (background) stresses which are formed by the actuating device (worm screw, cutter head, drum, etc.). The total stresses are the result of summing up the stresses of the first level, all contact (local) influences;

If we don't take the elastic deformation of tools and rock into consideration the contact between them can be considered to be a point one. Theoretically under the point contact the area of contact tends to zero and the stresses, even under small forces, tend to infinity. But, as the stresses cannot exceed the break-down point of the rock, then with increase of the contact effort it is not the stress that is going to grow but the area where the stresses enough to destroy the rock will emerge, in other words the area of destruction will grow larger.

When considering the interaction between the separate cutter and the rock we can see that its impact area is quite small and varies from several millimeters to several dozens of millimeters. That's why such geometrical parameters as the size of the cutter head or worm screw, diameter of the working, presence or absence of a shelf, etc. do nat have much impact upon the stresses developed by a separate cutter in the local area.

In the given case we speak about the stresses caused by the interaction of a separate element (cutter, tooth, etc.) with the face rock, and the stresses caused by other cutters of the actuating device are not taken into consideration. Dependence of local stresses upon the distance to the contact point along optional axis can be expressed through a generalized polynomial of the following type:

$$\sigma = \frac{A_1}{x} + \frac{A_2}{x^2} + \frac{A_3}{x^3} ..... \frac{A_n}{x^n} \quad \text{when } x > x_0 \tag{1}$$

where x – distance to the contact point, x_0 – distance from the contact point to the point where the stresses achieve the break-down point of the rock (the destruction area), A_i – empirical constants.

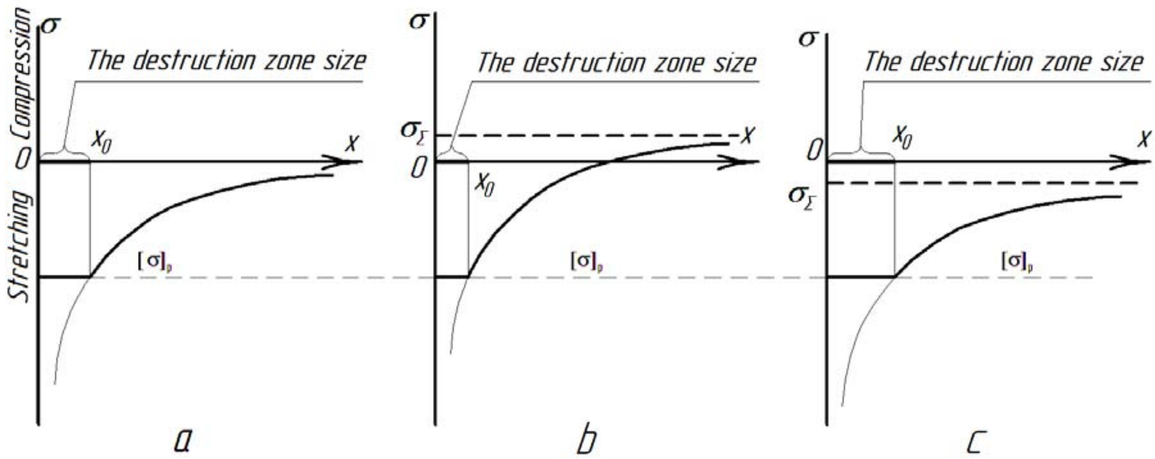
Figure 1 a shows the diagram of stresses dependency upon the distance to the contact point.

If the rock massif is influenced by other forces including those produced by other cutters of the actuating device, then the value of stress can be obtained through application of the principle of superposition $\overrightarrow{\sigma_\Sigma} = \sum \overrightarrow{\sigma_i}$, where $\overrightarrow{\sigma_i}$ - stresses caused by the i-th force with consideration to its direction.

If we consider the stress-strain state in the local impact area of a separate cutter with the account of other forces, then expression (1) will look as follows:

$$\vec{\sigma} = \overrightarrow{\sigma_\Sigma} + \overrightarrow{\left(\frac{A_1}{x} + \frac{A_2}{x^2} + \frac{A_3}{x^3} ..... \frac{A_n}{x^n} \right)} \tag{2}$$

where $\overrightarrow{\sigma_\Sigma}$ – «background» stress of the rock caused by other forces, *second level of stresses.*



a) absence of background stresses σ_Σ, б) compressing σ_Σ, в) stretching σ_Σ

Figure 1 – Influencing of total (background) stresses σ_Σ upon the destruction area in the local impact area of a separate cutter

The values of main stresses in the point can be estimated from the projections of expression (2) on the main axis:

$$\sigma_1 = \sigma_{\Sigma 1} + \left(\frac{A_{1.1}}{x} + \frac{A_{2.1}}{x^2} + \frac{A_{3.1}}{x^3} ..... \frac{A_{n.1}}{x^n} \right)$$
$$\sigma_3 = \sigma_{\Sigma 3} + \left(\frac{A_{1.3}}{x} + \frac{A_{2.3}}{x^2} + \frac{A_{3.3}}{x^3} ..... \frac{A_{n.3}}{x^n} \right) \tag{3}$$

The modulus of stresses caused by a separate cutter decreases abruptly with moving away from the contact point in all directions. Gradient of these stresses modulus is directed from the rock to the contact point and its modulus decreases even faster.

The gradient of the background stresses modulus (second level stresses) is directed from the rock to the surface and its value is smaller and it does not change so abruptly (Fig. 2). That'swhy background stresses within the local area can be considered a constant value to some extent.

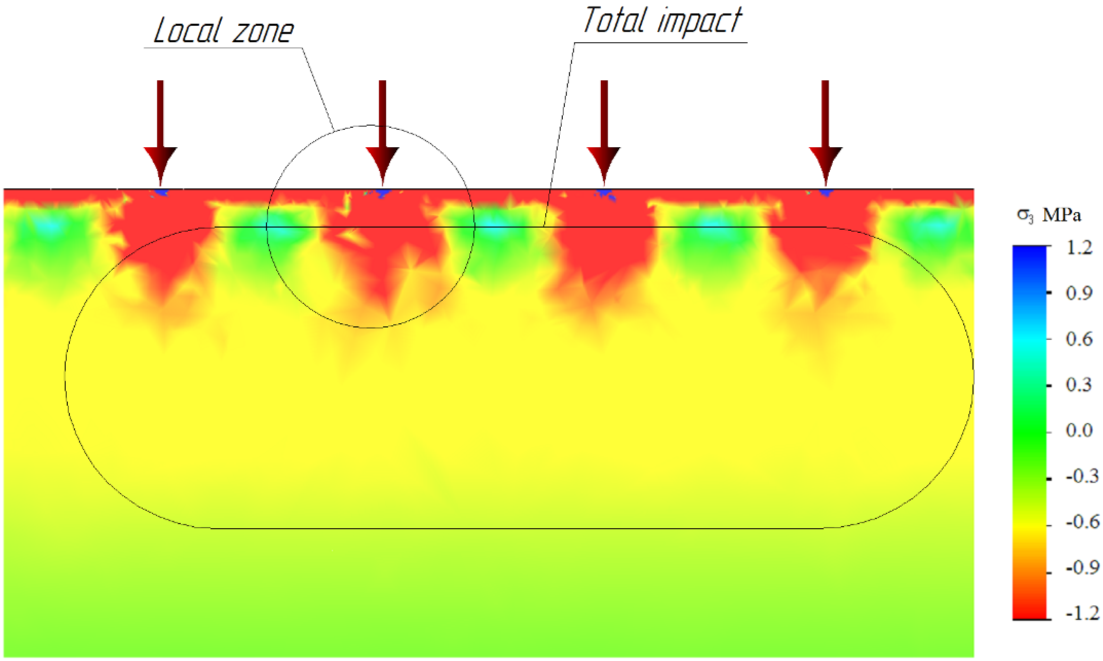


Figure 2 – The field of stress distribution in the area of the actuating device impact

$$grad(\sigma)=-\frac{A_1}{x^2}-\frac{2A_2}{x^3}-\frac{3A_3}{x^4}-.....-\frac{nA_n}{x^{n+1}} \quad (4)$$

According to Mohr's theory mountain rock is destructed only by shear or stretching [2]. Thus, at least one of the two conditions fulfilled: exceeding the break-down limit for pulling stresses or shear stresses (tangential stresses) which maximal value is determined by main stresses and equal half of the difference between σ_1 and σ_3. (Fig. 3).

Let us suppose that constant force which does not depend upon the destruction process is applied to a point. Let us estimate the impact of background stresses σ_Σ upon the destruction area.

If the rock is destroyed due to exceeding the break-down limit for pulling in the local area, then background stresses will influence the size of destruction area. Figure 1 a shows a curve described by expression (1). The curve illustrates stress distribution in the local area under absence of background stresses. Under background stresses the curve shifts up by σ_Σ (Fig. 1 b) under compressing stresses or down (Fig. 1 c) under pulling stresses σ_Σ. Compressing background stresses σ_Σ lead to reduction of destruction area (Fig. 1 b), and pulling – to its increase (Fig. 1 c).

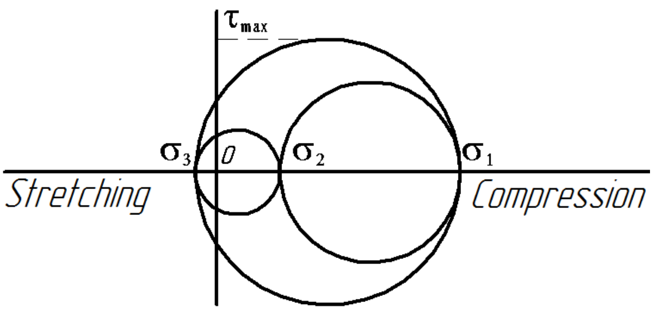
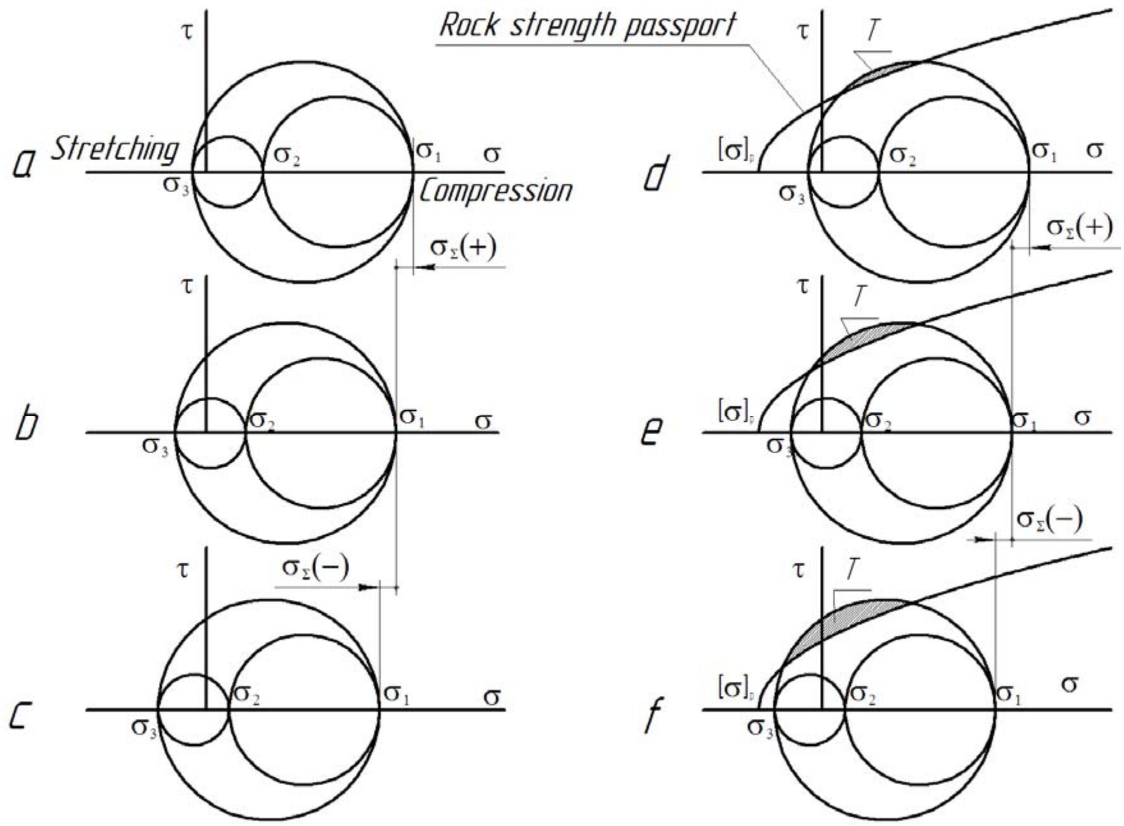


Figure 3 – Mohr's circles

In the cases when main stresses σ_3 do not reach the breaking strength limit, the rock is destroyed by tangential stresses. The value of tangential stresses depends upon the difference between the stresses σ_1 and σ_3 $\tau = 0.5(\sigma_1 - \sigma_3)$. The left side of Figure 4 shows that tangential stresses do not depend directly upon the background stresses. But if we apply the Mohr's circles on the strength certificate (Fig. 4, on the right), then we can judge about the size of destruction area by the limits of segment T cut by the strength certificate curve from Mohr's circles. From the figure we can see that compressing background stresses lead to reduction of destruction area (Fig. 4 d) and pulling – to its increase (Fig. 4 f).

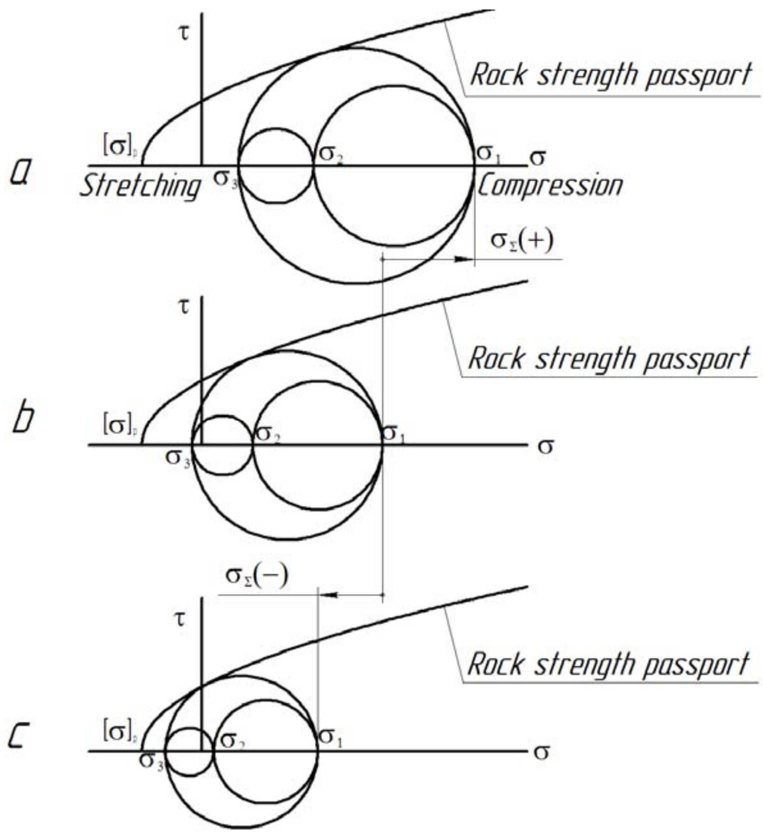


a), d) compressing background stresses σ_Σ, b), e) absence of σ_Σ, c), f) pulling σ_Σ

Figure 4 – Shifting of Mohr's circles caused by background stresses, their influence upon the size of destruction area

If there is constant force applied to the cutter and the cutter moves at a constant speed, then energy spent to produce the movement of the cutter will also be constant. Increase of destruction areas under constant energy input into the cutter leads to the growth of productivity and reduction of specific energy density of rock destruction.

In the cases when the actuating device moves the tool at the specified rate and trajectory, i.e. mode of motion does not depend upon the rock resistance to cutting, constant productivity is ensured. The value of the force applied to the cutter determines the diameter of the large Mohr's circle. Large Mohr's circle touching the line of strength certificate means minimal sufficient cutting force. Figure 5 shows the influence of background stresses upon the value of sufficient cutting force. Shifting of stress towards pulling will reduce the cutting force and, thus, to increase of required energy under the specified productivity.



a) compressing background forces σ_Σ, b) absence of σ_Σ, c) pulling σ_Σ

Figure 5 – Influence of background forces upon the cutting force

3. Conclusion

1) the size of the local destruction area depends upon the back ground forces created by other forces in the rock massif;
2) the size of the local destruction area increases under pulling background stresses and reduces under the compressing stresses;
3) energy density of rock destruction decreases under pulling background stresses.

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