Stressed state and destruction of contacts between seam and the enclosing rocks during work at stope

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STRESS STATE AND FAILURE OF SEAM CONTACTS WITH ENCLOSING ROCKS IN DRIVING A STOPE

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The features are considered for shear and normal stress concentration at the interface of enclosing rocks with a seam during its mining. The relations determining the parameters of support pressure zone depending on the seam occurrence depth, its dip angle, length of the mined-out section, lateral pressure coefficient, and the average specific weight of the overlying rocks are presented. Conditions of origination and character of shear failure manifestation on the contact between the seam and the rocks beyond the peak of support pressure are defined.

Stresses, failure, seam, contact surfaces, support pressure

During underground mining of seams and relatively thin sheetlike deposits the stress concentrations arise, plastic and post-limit strains occur, and the strength properties of rocks change near the workings. Usually, all this is associated with the seam compression by enclosing rocks and is referred to a relatively small zone characterized by the maximums of stress concentrations and distances from them to the boundaries of workings.

At the same time, under certain mining and geological conditions the high shear stress concentrations arise at the surfaces of contact between the seam and the rocks. Basically, they are connected with the rupture shear displacements of roof and floor relative to each other in the mined-out section of the seam and can be one of the main reasons of dynamic rock-pressure manifestations.

Let us examine conditions of formation and characteristic features of shear stress concentration at the interface of rocks with inclined seam. Figure 1 shows the cross-section of the seam (θ is the dip angle) and the section mined-out along the strike with freely overhanging roof when the span is $2L$. The coordinate systems Oxy and $Ox'y'$ are connected so that the x-axis coincides with the direction of the seam, and the x'-axis is arranged horizontally at a depth H_0.

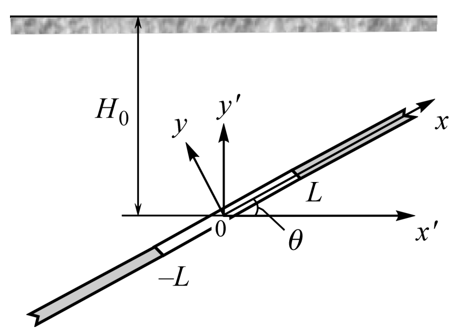

Fig. 1

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Solution to the problems on distribution of stresses and displacements in the rock mass in mining the sheet deposits is well known [1 – 5]. Following [5], we assume that disregarding the plastic and post-limit strains and with the initial stress state of rocks,

$$\sigma^0_{x'} = -\alpha\gamma(H_0 - y'), \quad \sigma^0_{y'} = -\gamma(H_0 - y'), \quad \tau^0_{x'y'} = 0 \quad (y' \le H_0) . \tag{1}$$

This solution at the interface with the seam to the rise and to the dip from the mined-out section shown in Fig. 1 has the form

$$\begin{aligned} \sigma_x(x, 0) &= \sigma^0_x(x, 0) + \gamma_y S(x), \\ \sigma_y(x, 0) &= \sigma^0_y(x, 0) + \gamma_y S(x), \\ \tau_{xy}(x, 0) &= \tau^0_{xy}(x, 0) + \gamma_{xy} S(x), \end{aligned} \tag{2}$$

where $\gamma = \rho_0 g$, ρ_0 is the density, g is the gravitational acceleration, and α is the lateral thrust coefficient,

$$S(x) = \left(1 - \frac{|x|}{\sqrt{x^2 - L^2}}\right)(H_0 - x\sin\theta) - \frac{L^2 \sin\theta}{2\sqrt{x^2 - L^2}}, \tag{3}$$

$$\sigma^0_x(x, 0) = -\gamma_x(H_0 - x\sin\theta), \quad \gamma_x = \gamma(\sin^2\theta + \alpha\cos^2\theta), \tag{4}$$

$$\sigma^0_y(x, 0) = -\gamma_y(H_0 - x\sin\theta), \quad \gamma_y = \gamma(\cos^2\theta + \alpha\sin^2\theta), \tag{5}$$

$$\tau^0_{xy}(x, 0) = -\gamma_{xy}(H_0 - x\sin\theta), \quad \gamma_{xy} = \gamma(1-\alpha)\sin\theta\cos\theta . \tag{6}$$

Prior to mining the seam,

$$L = 0, \quad S(x) = 0, \quad x < \frac{H_0}{\sin\theta} ,$$

and the initial stresses on its boundary are determined from (4) – (6).

As a result of inelastic deformations near the working, the seam compression by enclosing rocks is always such that the maximum of the support pressure q^* is at some distance l from the working. The character of pre-peak pressure distribution is usually indefinite and insignificant. But we can consider the distances l, which are small as compared with the span of overhanging roof, and the support pressures q^s near the “actual” boundary of the mined-out section to be known. All this gives a reason for confining ourselves to the linear distribution of stresses in the seam section of pre-peak support pressure.

We write it in the form

$$-\sigma_y(x) = q^* - (q^* - q^s)\frac{x^* - x}{x^* - x^s}, \quad |x^s| < |x| < |x^*| , \tag{7}$$

where x^* is the value of x, at which in (2), $\sigma_y(x, 0) = -q^*$, i.e.,

$$\sigma_y(x^*, 0) = -q^* , \tag{8}$$

x^s and q^s are the values of x and $-\sigma_y(x^s)$ associated with the “actual” boundary between the seam and the mined-out section. In this case, q^s is the minimal rock pressure in the vicinity of a working, which is governed by the corresponding plastic and post-limit strains near the free surface.

Note that if necessary, we can point out parameters relating to up-dip or on-dip from the mined-out section; let us designate them by subscripts 1 or 2, respectively. Up-dip

$$q^s = q_1^s, \quad q^* = x_1^*, \quad x_1^* - x_1^s = l_1, \quad x_1^* > x_1^s > 0, \tag{9}$$

on-dip

$$q^s = q_2^s, \quad q^* = q_2^*, \quad x_2^* - x_2^s = l_2, \quad x_2^* < x_2^s < 0. \tag{10}$$

In order to pass from stress distribution (2) to linear distribution (7) not disturbing the equilibrium in the pre-peak support pressure sections, we are to require the equality of corresponding total forces acting in these seam sections in addition to condition (8), i.e.,

$$\int_{x_1^s}^{x_1^*} \sigma_y(x)\,dx = \int_{L}^{x_1^*} \sigma_y(x,0)\,dx, \quad \int_{x_2^*}^{x_2^s} \sigma_y(x)\,dx = \int_{x_2^*}^{-L} \sigma_y(x,0)\,dx. \tag{11}$$

On integration, Eqs. (8) and (11) with regard to (2) and (7) are reduced to the form

$$\frac{q_i^*}{\gamma_y H_0} = F(x_i^*, L), \qquad \frac{q_i^* + q_i^s}{\gamma_y H_0} = R(x_1^*, L, l_i), \quad i = 1, 2, \tag{12}$$

where

$$F(x, L) = \frac{|x|\left(1 - \dfrac{x}{H_0}\sin\theta\right) + \dfrac{L^2}{2H_0}\sin\theta}{\sqrt{x^2 - L^2}}, \tag{13}$$

$$R(x, L, l) = \frac{2}{l}\left(1 - \frac{x}{2H_0}\sin\theta\right)\sqrt{x^2 - L^2}. \tag{14}$$

Figure 2 presents graphs *1* and *2* of functions $F(x, L)$ and $R(x, L, l)$ depending on $(x - L)/H_0$ for some values of L/H_0; $\theta = 60°$ and $l/H_0 = 0.02$.

Two independent groups of equations (12) with subscripts 1 and 2 are connected with each other by the relation

$$x_1^* - x_2^* = 2L^s + l_1 + l_2, \tag{15}$$

where $2L^s$ is the distance between x_1^s and x_2^s, which can be considered a span of the mined-out section of seam with regard to plastic and post-limit strains.

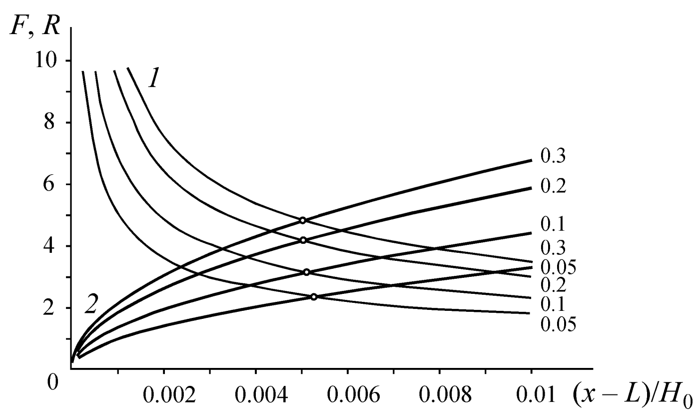

Fig. 2

Solution of (12) and satisfaction of condition (15), when the values of H_0, L_s, l_i, and q_i^s are prescribed, result in unambiguous determination of x_i^*, L, and q_i^*. Besides, according to (9) and (10), we find x_i^s in terms of x_i^*,

Similar to σ_y, let us analyze τ_{xy}. It is evident from (2) and (3) that when $x = \pm L$, $\tau_{xy}(x, 0)$ and $\sigma_y(x, 0)$ have the same singularity. In this connection, in all cases, when the working affects the change in strain-strength properties of rocks and seam (including the contact surfaces) only in the section of pre-peak support pressure, the distribution of shear stresses $\tau_{xy}(x)$ from x^s to x^* can be written in the form

$$-\tau_{xy}(x) = \tau^* - (\tau^* - \tau^s)\frac{x^* - x}{x^* - x^s}, \quad |x^s| < |x| < |x^*|. \tag{16}$$

Here, τ^* is found from the continuity condition

$$\tau_{xy}(x^*, 0) = \tau_{xy}(x^*) = -\tau^*, \tag{17}$$

and τ^s — from the equality of the total shear forces acting in the corresponding sections of seam

$$\int_{x_1^s}^{x_1^*} \tau_{xy}(x)\,dx = \int_{L}^{x_1^*} \tau_{xy}(x, 0)\,dx, \quad \int_{x_2^*}^{x_2^s} \tau_{xy}(x)\,dx = \int_{x_2^*}^{-L} \tau_{xy}(x, 0)\,dx. \tag{18}$$

Using expression (2) for $\tau_{xy}(x, 0)$ in (17) and (18) and with the help of (16), we calculate integrals. As a result, we obtain the system of equations for τ^s and τ^* similar to (12) with the same values of the parameters x_i^*, x_i^s, and L:

$$\frac{\tau_i^*}{\gamma_{xy} H_0} = F(x_i^*, L), \quad \frac{\tau_i^* + \tau_i^s}{\gamma_{xy} H_0} = R(x_i^*, L, l_i), \tag{19}$$

where $F(x, L)$ and $R(x, L, l)$ are the functions determined in (13) and (14).

Note that systems of equations (12) and (19) are solvable only at small values of $(x^* - L)/H_0$ and $(x^* - L)/L$. For example, it is seen from intersection of the graphs with equal values of L/H_0 (Fig. 2). We can point out $(x^* - L)/H_0$ and $(x^* - L)/L$ in (13) and (14) and neglect them as compared with one. As a result, we have approximate formulas

$$F(x, L) = \frac{\sqrt{2}}{2}\sqrt{\frac{L}{x - L}}, \quad R(x, L, l) = \frac{2\sqrt{2}}{l}\sqrt{L(x - L)}. \tag{20}$$

In addition to it, when at the edge of the seam with a free surface the support pressure q^s on the side of the working is small in comparison with q^*, we can neglect it in (12). As a result, we obtain simple approximate formulas:

$$\frac{q^*}{\gamma_y H_0} = \sqrt{\frac{2L}{l}}, \quad x^* = L + \frac{l}{4}. \tag{20'}$$

Since in (12) and (19) the right parts are equal, then

$$\frac{q_i^*}{\gamma_y H_0} = \frac{\tau_i^*}{\gamma_{xy} H_0}, \quad \frac{q_i^s}{\gamma_y H_0} = \frac{\tau_i^s}{\gamma_{xy} H_0}. \tag{21}$$

From (20), Eqs. (7), and (16) we have

$$\frac{\tau_{xy}(x)}{\sigma_y(x)} = \frac{\tau^s}{q^s} = \frac{\tau^*}{q^*} = \frac{\gamma_{xy}}{\gamma_y}, \quad |x^s| \le |x| \le |x^*| \tag{22}$$

over the whole section of the support pressure, and from (2), (5), and (6) it follows:

$$\frac{\tau_{xy}(x, 0)}{\sigma_y(x, 0)} = \frac{\gamma_{xy}}{\gamma_y}, \quad |x| > L, \tag{23}$$

$$\frac{\tau^0_{xy}(x, 0)}{\sigma^0_y(x, 0)} = \frac{\gamma_{xy}}{\gamma_y}, \quad |x| < \infty . \tag{24}$$

All these equalities indicate that on the boundary between the rocks and the seam to the rise and to the dip from the mined-out section, the ratio of the shear stresses τ_{xy} to the normal σ_y is everywhere constant and equal to γ_{xy} / γ_y, i.e., as prior to mining the seam. According to the designations adopted

$$\frac{\gamma_{xy}}{\gamma_y} = \frac{(1-\alpha)\text{tg}\theta}{1+\alpha\text{tg}^2\theta} . \tag{25}$$

Shear stress distribution (2) and (16) with condition (17) concerns the cases when adhesion of the seam with enclosing rocks can be disrupted only in the section from the working to the peak support pressure. At the same time, the shear disturbances of adhesion, which spread beyond this section, are of great interest. They are connected with the rupture displacements of roof and floor, the manifestations and consequences of which must be predicted and controlled. We determine these disturbances by the Coulomb – Mohr criterion

$$\tau_n = C + \sigma_n \text{tg}\rho . \tag{26}$$

The cohesion C and the internal friction angle ρ relate to the contact of enclosing rocks with the seam. If there is an interlayer or a rock bench with lower strength parameters in the seam, then in (26), C and ρ relate to them.

Since the initial stress state of rock mass (1) is in equilibrium, then according to (26), (5), (6), and with regard to (24) on the seam boundary prior to its mining

$$\left| \frac{\gamma_{xy}}{\gamma_y} \sigma^0_y(x, 0) \right| < C + \left| \sigma^0_y(x, 0) \right| \text{tg}\rho, \quad x < \frac{H_0}{\sin\theta} . \tag{27}$$

Inequality (27) is zonal in reference to the seam, i.e., the values of C and ρ change along the seam strike and can be considered constant only within the definite zones with relatively stable deformation-strength properties of the joints.

Consider the inequality similar to (27) for the stresses $\sigma_y(x, 0)$ determined in the seam sections by relations (2) and (7):

$$\frac{|\gamma_{xy}|}{|\gamma_y|} |\sigma_y(x, 0)| < C + |\sigma_y(x, 0)| \text{tg}\rho . \tag{28}$$

If this inequality is fulfilled along the whole boundary with the seam, starting from the peak support pressure, then the shear failures cannot occur on it during driving a stope. Since the cohesion $C \ge 0$, then it is obvious that if

$$\operatorname{tg}\rho \geq \frac{|\gamma_{xy}|}{|\gamma_y|}, \tag{29}$$

then inequality (28) is fulfilled at any concentrations of the compressive stresses $\sigma_y(x, 0)$. Consequently, the zones with the internal friction angles ρ corresponding to (29) can be called absolutely stable zones in reference to the shear failure of contacts between the enclosing rocks and the seam. The stress distribution in the pre- and post-peak support pressure section is described by (2), (7), and (16).

In the zones with the strength properties of contact on the seam boundary

$$\operatorname{tg}\rho < \frac{|\gamma_{xy}|}{|\gamma_y|}, \tag{30}$$

inequality (28) is fulfilled only, where

$$-\sigma_y(x, 0) < \frac{C}{\frac{|\gamma_{xy}|}{|\gamma_y|} - \operatorname{tg}\rho}. \tag{31}$$

Hence, two cases are possible in distributing the stresses $\sigma_y(x, 0)$ described by Eq. (2). When $x = x^*$, the first case is

$$q^* = -\sigma_y(x^*, 0) < \frac{C}{\frac{|\gamma_{xy}|}{|\gamma_y|} - \operatorname{tg}\rho}. \tag{32}$$

Inequalities (31) and, consequently, (28) are fulfilled in the whole region of influence exerted by the stope, and the shear failure of the contact on the boundary with the seam beyond the peak support pressure is impossible according to criterion (26). Distribution of stresses $\sigma_y(x, 0)$ and $\tau_{xy}(x, 0)$ in the corresponding sections is described by (2), (7), and (16) as in (29).

In the second case, when

$$q^* = -\sigma_y(x^*, 0) > \frac{C}{\frac{|\gamma_{xy}|}{|\gamma_y|} - \operatorname{tg}\rho}, \tag{33}$$

condition (31) is fulfilled only in some seam section of the post-peak support pressure; we denote this section boundary by $\tilde{x}$. On it

$$-\sigma_y(\tilde{x}, 0) = \frac{C}{\frac{|\gamma_{xy}|}{|\gamma_y|} - \operatorname{tg}\rho}. \tag{34}$$

Using expression for $\sigma_y(x, 0)$ in (2), we obtain the equation determining $\tilde{x}$. With regard to (13), it can be written in the form

$$F(\tilde{x}, L) = \frac{C}{\gamma_y H_0 \left(\frac{|\gamma_{xy}|}{|\gamma_y|} - \operatorname{tg}\rho \right)}. \tag{35}$$

Thus, according to criterion (26) and with inequalities (30) and (33) when the peak support pressure q^* is greater than the limit compression of seam $C/(|\gamma_{xy}|/|\gamma_y| - \text{tg}\rho)$, the shear failure of contact between the enclosing rocks and the seam and, consequently, the shear stress redistribution occur beyond the section of plastic and post-limit strains near the working, i.e., $x \in [x^*, \widetilde{x}]$. It is apparent from (35) that the less is $C/(\gamma_y H_0 (|\gamma_{xy}|/|\gamma_y| - \text{tg}\rho))$, the greater is the value of $|\widetilde{x} - x^*|$.

Let us pay attention to the characteristic features of forming the sections of contact shear failure beyond the post-peak support pressure. They are associated with the seam zonality with respect to strength parameters [6]. Usually, these sections form in the zones with the internal friction angle ρ satisfying inequality (30). Outwardly, such zones can be distinguished, for example, by explicitly expressed contacts with the mirror surfaces of seam and enclosing rocks. As the working approaches the zone, where inequality (29) is fulfilled, ρ increases to the peak support pressure, the section of contact shear failure decreases, and it does not arise at all in the zone. In this zone near the working, the plastic and post-limit strains take place; the strains in question can be associated with the failures of contacts between the enclosing rocks and the seam but only within the pre-peak support pressure. Thus, when the working approaches the zone with comparatively high strength characteristics of the contacts, the rock rupture-shear displacement section of the pre-peak support pressure decreases and completely vanishes if condition (29) is fulfilled. The stable reduction in loosening of the coal can be the consequence of this.

As applied to the problem on rock burst manifestation during mining the inclined and steeply pitching seams, the cases when the working approaches the zone with relatively low cohesion $\widetilde{C}$ and internal friction angle $\widetilde{\rho}$, at which $\text{tg}\widetilde{\rho} < |\gamma_{xy}|/|\gamma_y|$, can be of great interest. In this zone, the beginning of forming the section of contact rupture-shear failure can have dynamic character.

In this connection we consider the features of stress redistribution consistent with the criteria of contact failure near the junction of two zones. The working and the peak support pressure corresponding to it are in the zone, where $C > \widetilde{C}$, $\rho > \widetilde{\rho}$, and $\text{tg}\widetilde{\rho} < |\gamma_{xy}|/|\gamma_y|$. Let us denote the distance from this peak to the zone that the working approaches by $\bar{r}$, and the distance, where $-\sigma_y(x, 0) = \widetilde{C}/(|\gamma_{xy}|/|\gamma_y| - \text{tg}\widetilde{\rho})$, by $\widetilde{r}$. The shear stresses $\tau_{xy}(x, 0)$ do not reach the limit values of $\widetilde{\tau}_n$ and τ_n in the corresponding zones, while $\bar{r} > \widetilde{r}$. At $\bar{r} = \widetilde{r}$ we have $\tau_{xy}(\widetilde{x}, 0) = \widetilde{\tau}_n(\widetilde{r})$. When $\bar{r} < \widetilde{r}$, the section between $\bar{r}$ and $\widetilde{r}$ belongs to the zone with low strength characteristics of contacts, and here, the shear stresses $\widetilde{\tau}_{xy}(x, 0)$ cannot exceed the limit ones

$$\widetilde{\tau}_n(x) = \widetilde{C} + |\sigma_y(x, 0)| \, \text{tg}\widetilde{\rho}. \tag{36}$$

But according to (2), in the section of the post-peak support pressure, $\tau_{xy}(x, 0) > \widetilde{\tau}_n$.

After $\bar{r}$ becomes less than $\widetilde{r}$, the shear stresses $\widetilde{\tau}_n(x)$, which are less than $\tau_{xy}(x, 0)$, arise in the section $[\bar{r}, \widetilde{r}]$. At the same time, the section $\bar{r}$ prevents the development of rupture shear displacement of roof and floor; therefore, as $\bar{r}$ decreases, the shear stresses $\bar{\tau}_{xy}(x)$ increase more intensive than $\tau_{xy}(x, 0)$. The relation between $\bar{\tau}_{xy}(x)$ and $\widetilde{\tau}_n(x)$ is established according to the equilibrium state of enclosing rocks in the sections $x \le \bar{r}$ and $\bar{r} \le x \le \tilde{r}$. In other words, how much the total growth of shear stresses becomes slower in the section $[\bar{r}, \tilde{r}]$, so much it increases in the section $x \le \bar{r}$ when the working approaches the zone with low strength characteristics of the contacts.

This occurs only till the section $\bar{r}$ is greater than the critical $\bar{r}^*$, where $\bar{\tau}_{xy}(x, 0)$ reaches the limit values

$$\bar{\tau}_n(x) = C + |\sigma_y(x, 0)| \operatorname{tg}\rho . \tag{37}$$

Thus, if the distance between the working and the zone with low strength characteristics of the contacts, where $\operatorname{tg}\tilde{\rho} < |\gamma_{xy}|/|\gamma_y|$, decreases to the critical distance (Fig. 3), then the contacts fail in this section, and the impediment to the rupture shear displacement of roof and floor from the peak support pressure to the distance $\tilde{r}$, where $\tau_{xy}(x, 0) = \tilde{C}/(|\gamma_{xy}|/|\gamma_y| - \operatorname{tg}\tilde{\rho})$, almost instantly disappears. In general, the displacement has a dynamic character and can initiate another dynamic events, for example, rock burst in the form of sudden loosening of the coal.

The energy level of the dynamic displacement manifestation at constant L/H_0 and l/H_0 depends mainly on the values of $\tilde{C}/(|\gamma_{xy}|/|\gamma_y| - \operatorname{tg}\tilde{\rho})$, $\bar{C}/(\operatorname{tg}\bar{\rho} - |\gamma_{xy}|/|\gamma_y|)$, and $\bar{\tau}_{xy}(x, 0)$ which form in the section $[\bar{r}, \tilde{r}]$. Usually, failure occurs when the shear stresses on the contact surfaces reach the limit value. The section $[\bar{r}, \tilde{r}]$ is distinguished by the fact that it is under conditions of strict limitation for the rupture shear displacements. Therefore, with the definite deformation-strength properties of geomaterials, the cohesion is nonzero in the section $[\bar{r}, \tilde{r}]$ near the joint surfaces, and the corresponding shear stresses have the form

$$\tilde{\tau}_n(x) = \tilde{C} + |\sigma_y(x, 0)| \operatorname{tg}\tilde{\rho} . \tag{38}$$

With geomaterials forming more brittle joints, the limit stresses also appear in the same sections, but $\tilde{C} = 0$, i.e.,

$$\tilde{\tau}_n(x) = |\sigma_y(x, 0)| \operatorname{tg}\tilde{\rho} . \tag{39}$$

In the case of (38), as compared with (39), the critical distance from the working to the zone, where $\operatorname{tg}\tilde{\rho} < |\gamma_{xy}|/|\gamma_y|$, is less, and the energy level of dynamic manifestation of the rupture displacement of roof and floor is higher. In both cases, the critical distances are determined from the equation

$$\int_{x^*}^{\tilde{x}} \tau_{xy}(x, 0)\,dx = \int_{x^*}^{\bar{x}^*} \bar{\tau}_n(x)\,dx + \int_{\bar{x}^*}^{\tilde{x}} \tilde{\tau}_n(x)\,dx , \tag{40}$$

where in place of $\bar{r}$ and $\tilde{r}$, the corresponding values of $\bar{x} - x^*$ and $\tilde{x} - x^*$ are taken

Using the expression for $\tau_{xy}(x, 0)$ in (2), we can write

$$\frac{\gamma_{xy}}{\gamma_y} J(\tilde{x}, x^*) = \bar{C}(\bar{x}^* - x^*) + \tilde{C}(\tilde{x} - \bar{x}^*) + \operatorname{tg}\bar{\rho}\, J(\bar{x}^*, x^*) + \operatorname{tg}\tilde{\rho}\, J(\tilde{x}, \bar{x}^*) , \tag{41}$$

where

$$J(a, b) = \int_b^a \sigma_y(x, 0)\,dx .$$

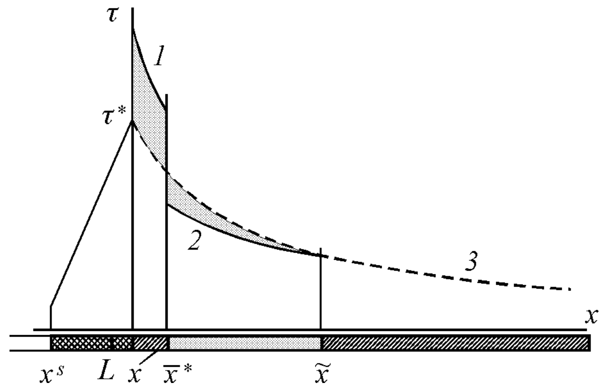

Fig. 3. Scheme of seam and limit shear stress distribution beyond the peak support pressure at the moment of sudden displacement of enclosing rocks: *1*, *2* —distribution of shear stresses $\bar{\tau}_{xy}(x,0)$ and $\tilde{\tau}_{xy}(x,0)$ in the sections of the limit stress state of contacts with high and low strength properties; *3* — distribution of shear stresses $\tau_{xy}(x,0)$ when there are no sections of the limit stress state of contacts

In the case of (39) and (41), the term $\tilde{C}(\tilde{x}-\bar{x}^*)$ is to be absent.

Thus, the sudden shear displacements of enclosing rocks during mining the inclined and steeply pitching seams are associated with the strength zonality of the contact surfaces. They occur when the working approaches the zone with relatively low internal friction angle of the contacts within the critical distance, where a section with the limit shear stresses forms. The critical distance is always greater than the distance to the peak support pressure. In addition to it, the more is the difference between the contact cohesion in the corresponding zones and the length of the limit shear stress section, the greater is the energy of dynamic manifestation of sudden displacement of enclosing rocks.

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