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Stressed-deformed state of mountain rocks in elastic stage and between elasticity

The problems of the stress-strain state of rocks in the elastic stage and beyond the elastic limits, and the ways of schematizing the tension and compression diagrams were reviewed in the article.

To simplify calculations outside the elastic range, the tension (compression) diagrams are usually schematized, i.e. are replaced by curved smooth lines having a fairly simple mathematical expression and at the same time well coinciding with the experimentally obtained diagrams. When diagram is to be schematized, it is necessary to take a constant temperature of superheated water steam if a rock test is planned in a relaxed form. Note that when the diagram is schematizing, the difference between the limits of proportionality and fluidity is erased. This allows the limit of proportionality to be considered the limit of fluidity. Schematicization can be carried out in the area where the tensile strength (compression) is planned to be destroyed with the established weakening of rocks by exposure to water steam or chemical reagents.

Samples of rocks in natural form were tested and weakened by means of superheated water steam (220 °C and more) and chemical reagents for tension and compression.

The data are obtained, the diagrams of deformation are constructed and schematized in the elastic stage and beyond the elastic limit. Based on the schematic diagrams of deformation, the components of stress and strain were composed in the elastic stage and beyond the elastic limit.

It is established in the publication that rocks under compression and stretching deform, both within the elastic stage, and beyond the limits of elasticity. This could be seen when the samples, both in natural and in weakened state, with superheated water steam (more than 220 °C) or chemical reagents were tested. In their natural form, they are mainly deformed within the elastic stage and are destroyed as a brittle material, and in a weakened form they can deform beyond the elastic stage and destroy as a plastic material. In the elastic stage, the link between stress and strain is linear.

Keywords: *stresses; deformation; rocks; superheated water vapor; weakening of rocks; elastic stage of work; beyond elasticity; fluidity point.*

Objective. Give an assessment of the stress-strain state of rocks working on compression and stretching in the elastic stage and beyond elasticity.

Results of the research. Literary sources [1–25] consider the stress-strain state of reinforced concrete structures. However, they do not reflect the stress-strain state of rocks, especially when used in designs that have been subjected to compression and stretching in an elastic stage and beyond elasticity. Therefore, the topic is relevant and timely.

1. Deformation in the elastic stage. Rocks under natural conditions are well resists compression and poor stretching. During compression and stretching, rocks are mostly destroyed as a brittle material in the elastic state.Rocks in overheated water vapor (more than 220 °C) for 30 days or under the influence of chemical reagents (for example, hydrochloric acid HCl) under tension, compression or detachment are destroyed beyond the limits of elasticity, i.e. In the elastoplastic state, based on the diagrams of stretching or compression of rocks obtained as a result of investigations. Graphically, this is expressed by the dependence of stress and strain. In this case, the force P stretching (or compressing) the sample is attributed to the original cross-sectional area F_0, and the elongation (or shortening) of the sample Δl – to the initial design length of the sample l_0, then the stress $\sigma = P/F_0$, the deformation $E = \Delta l/l_0$, i.e. do not take into account the change in the cross-sectional area of the sample and assume uniform deformation along the entire length.

This graph is a conditional diagram (schematization) of the stretching (compression) shown in Fig. 1.

Since in the initial stage of the voltage of such a graph, as shown in Fig. 1, Hooke's law holds, where the stress-strain relation is only linear, at a certain voltage (the limit of proportionality of the rock – $\sigma_{l.p}$) The linear dependence is violated and a fluidity surface appears where the sample deforms at a constant force (flows). The corresponding stress is the fluidity point $\sigma_1 = \sigma_{l.p}$.

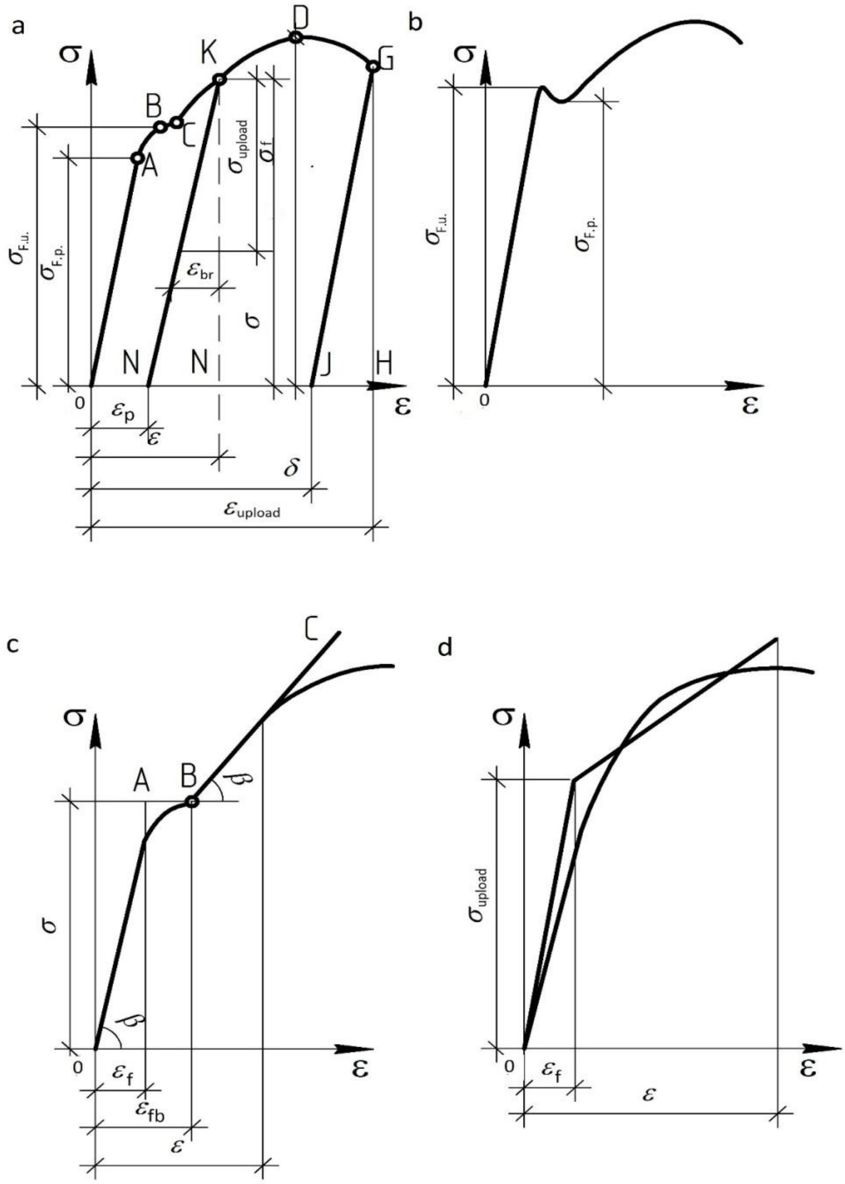

Figure 1. Schematic diagram of the stretching diagram

In some rocks (for example, basalt, diabase, clay shales, etc.), the transition from the straight section of the diagram to the flow site does not occur smoothly, but with the formation of an acute stress peak, that is, these rocks have an upper $\sigma_{f.u.}$ and the lower $\sigma_{f.l.}$ fluidity limits. After reaching a certain voltage, this «skeleton of brittleness», which connects certain grains of rocks (for example, feldspar, mica), is destroyed, as a result of which a «fluiditying tooth» appears on the tension diagram (in Fig. 1, b).

In many rocks (quartzites, granites, sandstones, etc.) this process is absent, i.e. Destruction takes place without a «toothed tooth». In these rocks the flow area smoothly passes into the hardening curve. For example, in carbonate rocks, syenites, gabbro, trachytes, porphyry, the hardening point is equal to the strength limit (Fig. 1, c).

Rocks of higher viscosity, such as basalts, diorites, andesites, diabases, shales with a stress equal to the tensile strength or somewhat less, a local hardening, the «neck», appears on the specimen. Gradual development of the «neck» more weakens the sample and requires less force to deform it. In such rocks, the diagram becomes without a «flow area» (in Fig. 1, d).

If the sample of the rock is stretched to the stress $\sigma \geq \sigma_{l.p}$, then gradually unload it, then the discharge diagram does not coincide with the primary voltage diagram. It is a straight line that is parallel to the initial voltage, and occurs at a distance ε_p (Fig. 1, a). This is the effect of unloading, i.e. The decrease in the voltage at unloadingσ_{unload} is directly proportional to the deformation decrease ε_{unload}

$\sigma_{unload} = E \cdot \varepsilon_{unload}$;

where E – modulus of elasticity of rocks.

Consequently, the total deformation consists of elastic and permanent deformation, i.e. $E = E_{el} + E_{per}$.

At the moment of sample rupture, it is conditionally instantaneous unloading. Therefore, subtracting the original length from the sum of the lengths of the sample halves, we can determine the residual elongation at break Δl_{br}. The ratio of this elongation to the original length is l_0, i.e. $\sigma = \Delta l_{br}/l_0$ characterizes the density of the rock.

It should be noted that in the elastic stage of rock work, the relationship between stresses and deformations, both at stress and during unloading, is linear, at this time, both outside elasticity, this dependence is nonlinear at the stress, and linear at unloading.

To simplify calculations outside the elastic range, the tension (compression) diagrams are usually schematized, i.e. Are replaced by curved smooth lines having a fairly simple mathematical expression and at the same time well coinciding with the experimentally obtained diagrams, as shown in Fig. 1, d. When diagramming the diagram, it is necessary to take a constant temperature of superheated water vapor if a rock test is planned in a relaxed form. Note that when diagramming diagrams, the difference between the limits of proportionality and fluidity is erased. This allows the limit of proportionality to be considered the fluidity point. Schematicization can be carried out in the area where the tensile strength (compression) is to be destroyed with the established weakening of rocks exposed to water vapor or chemical reagents.

Dependences of stresses and deformations in different parts of the schematized diagrams have the following form:

a) for a tensile diagram with a fluidity point and linear hardening (Fig. 1, a):

$$\begin{gathered} -\text{for} 0 \leq \varepsilon \leq \varepsilon_f = (\sigma_f/E) - \sigma = E_\varepsilon; \\ -\text{for} \varepsilon_f \leq \varepsilon \leq \varepsilon_{fb} \cdot \sigma = \sigma_f; \\ -\text{for} \varepsilon \geq \varepsilon_{fb} \cdot \sigma = \sigma_f + \mathrm{E}_{fb}(\varepsilon - \varepsilon_{fb}) = \sigma_f \left[1 - (1-\gamma)^{\varepsilon_{fb}}/_{\varepsilon_f}\right] + \mathrm{E}_{fb} \cdot \varepsilon \end{gathered} \tag{1}$$

where:

ε_f – deformation corresponding to the fluidity point; $\varepsilon_{fb}$is the deformation corresponding to the beginning of hardening to the fluidity point; E_{fb} is the modulus of hardening before fluidity, numerically equal to $tg\beta$ (Fig. 1, c). The hardening parameter $\gamma = E_{fb}/E$. The hardening module γ largely depends on how to draw a straight line BC (Figure 1, c), and this, in turn, depends on the schematization of the section of the stretching diagram. It is known that the conditional fluidity strength for rocks is the stress at which the residual (plastic) deformation ε_f= 0,2 %.

b) if the section of the stretch diagram is schematized before deformation of 4 and 5 %, the straightening is carried out, as shown in Fig. 1 c. Then we obtain ε_{fb}= 1.25 %. (at 5 %) and $E_{fb}$are determined from the chosen scale as$E_{fb} = tg\beta$. The stretching diagram without a fluidity point (Fig. 1 d) can be schematized by a broken line consisting of two straight lines or a polygonal line consisting of a straight line and a parabola portion (Fig. 1 d). The first, schematized diagram, is called a stretching diagram with linear hardening, and the second (with a bold line) is a stretching diagram with adjacent hardening. The stresses and strains for these schematized diagrams can be obtained from the following equations:

$$\begin{gathered} -\text{for} 0 \leq \varepsilon \leq \varepsilon_{fb} \cdot \sigma = \mathrm{E} \cdot \varepsilon; \\ -\text{for} \varepsilon_{fb} \leq \varepsilon \leq \varepsilon_{fb} \cdot \sigma = \sigma_f; \\ -\text{for} \varepsilon_{fb} \cdot \sigma = \sigma_f \left(\frac{\varepsilon}{\varepsilon_{fb}}\right)^m \end{gathered} \tag{2}$$

where the exponents m vary from 0 to 1.

The values $\sigma_f$and E_{fb} are obtained by testing the experimentally constructed diagrams of rock stretching by the method of least squares with respect to deformation equal to $5E_{fb}$.

From the schematized diagram of rock stretching, it is seen that the relationships between stresses and deformation at a certain stress value (up to about 10 %) are rectilinear, reflecting the elastic stage of operation. Within the limits of elasticity, these dependences have the form:

$$\begin{gathered} \varepsilon_\mathrm{x} = \tfrac{1}{\mathrm{E}}\left[\sigma_\mathrm{x} - \mu(\sigma_y + \sigma_z)\right]; \ \varepsilon_y = \tfrac{1}{\mathrm{E}}\left[\sigma_y - \mu(\sigma_\mathrm{x} + \sigma_z)\right]; \\ \varepsilon_z = \frac{1}{\mathrm{E}}\left[\sigma_z - \mu(\sigma_\mathrm{x} + \sigma_y)\right] \\ \gamma_{xy} = {}^{\tau_{xy}}/_{G}; \ \gamma_{xz} = {}^{\tau_{xz}}/_{G}; \ \gamma_{yz} = {}^{\tau_{yz}}/_{G} \end{gathered} \tag{3}$$

where E and G are the modulus of elasticity and the shear modulus of the rock; μ is the Poisson ratio.

Between these quantities there is the following relationship:

$$G = \frac{\mathrm{E}}{2}(1+\mu) \tag{4}$$

When stretching (compression) in the rock occurs a volumetric deformation, related to the normal stresses σ_x, σ_y, $\sigma_z$in the following form:

$$\theta = {}^{(\sigma_\mathrm{x} + \sigma_y + \sigma_z)}\Big/_{3K} \tag{5}$$

where K is the bulk modulus of elasticity, which depends on the elastic modulus E, MPa, and Poisson's ratio, determined by the following formula:

$$K = \mathrm{E}/3(1-\mu) \tag{6}$$

The value of stress components in the elastic stage of rocks as a function of deformations can be determined:

$$\begin{gathered} \sigma_x = 2G(\varepsilon_x + \mu/1 - 2\mu\theta);\ \sigma_y = 2G(\varepsilon_y + \mu/1 - 2\mu\theta); \\ \sigma_z = 2G(\varepsilon_z + \mu/1 - 2\mu\theta); \\ \tau_{xy} = G\gamma_{xy};\ \tau_{xz} = G\gamma_{xz};\ \tau_{yz} = G\gamma_{yz} \end{gathered} \tag{7}$$

Within the elasticity of the relationship between the components of the stress deviator and the components of the deviator of deformations are:

$$\begin{gathered} e_x = \varepsilon_x - \varepsilon_0 = \frac{1}{E}\left[\sigma_x - \mu(\sigma_y + \sigma_z)\right] - \frac{1-2\mu}{3E}(\sigma_x + \sigma_y + \sigma_z) = S_x/2G; \\ e_y = \varepsilon_y - \varepsilon_0 = \frac{1+\mu}{E}(\sigma_y - \sigma_0) = S_y/2G; \\ e_z = \varepsilon_z - \varepsilon_0 = \frac{1+\mu}{E}(\sigma_z - \sigma_0) = S_z/2G; \end{gathered} \tag{8}$$

where σ_0 is the initial voltage; ε_0 is the initial deformation.

From here:

$$\varphi = e_x/S_x = e_y/S_y = e_z/S_z = (\gamma_{xy}/2)/\tau_{xy} = (\gamma_{yz}/2)/\tau_{yz} = (\gamma_{xz}/2)/\tau_{xz} = 1/2G \tag{9}$$

It can be seen from (9) that within the elastic range, the stress deviator components in rocks are proportional to the components of the deviator of deformations, with the proportionality coefficient being the doubled shear modulus. Then, the stress intensity in the elastic stage of the rock operation depends on the deformations ε_i in the process of testing the samples. This expression can be written in the following form:

$$\sigma_i = 3G\varepsilon_i \tag{10}$$

Thus, in the elastic stage of work for rocks, the relationships between stress and strain are linear in nature and obey Hooke's law.

2. Deformation. In weakened rocks, which are overheated by water vapor or chemical reagents, destroyed by weathering, low-strength rocks (ground), which are in the loose state, when the load acts above the structural strength, destruction occurs beyond the limits of elasticity. In such cases, the relationships between stress and strain components are as follows:

$$\begin{gathered} \sigma_x - \sigma_0 = 2\sigma_i/3\varepsilon_i(\varepsilon_x - \varepsilon_0);\ \sigma_y - \sigma_0 = 2\sigma_i/3\varepsilon_i(\varepsilon_y - \varepsilon_0); \\ \sigma_z - \sigma_0 = 2\sigma_i/3\varepsilon_i(\varepsilon_z - \varepsilon_0); \\ \tau_{xy} = \sigma_i/3\varepsilon_i\gamma_{xy};\ \tau_{xz} = \sigma_i/3\varepsilon_i\gamma_{xz};\ \tau_{yz} = \sigma_i/3\varepsilon_i\gamma_{yz} \end{gathered} \tag{11}$$

Dependences of stress components on deformation components in the absence of hardening were first obtained by Genki, but in the form (11) was written down A.A. Ilyushin. The same dependence is applicable in the conditions of a rock with the weakening of the rock-forming minerals in the rock by the water vapor or chemical reagents, because as a result of weakening and weathering of the rocks, only linear deformation changes, with identical values. Therefore, the components of the deviator of deformations with the weakening of rock-forming minerals do not change. Volumetric deformation with weakening of rocks by superheated water vapor or chemical reagents remains the same, but a linear deformation is added, which occurs when weakening or weathering the so-called softened volume deformation Δ. Then, taking into account softening of the rock, the volume deformation will have the form:

$$\Delta = (\sigma_x + \sigma_y + \sigma_z)/3K + \theta$$

or (12)

$$\varepsilon_0 = \sigma_0/3\mathrm{K} + \theta_{vwd}$$

When the rock is weakened by superheated steam or chemical reagents, the volume weakened deformation θ_{vwd} weaning depends on the influence of superheated water vapor or chemical reagents on the softened rock-forming minerals (eg, feldspar, mica, carbonates or sulphates) of rocks and is determined experimentally.

The components of the deformations within the elastic and plastic stage will have the form:

$$\begin{gathered} \varepsilon_x = \frac{1}{E}\left[\sigma_x - \mu(\sigma_y + \sigma_z)\right] + \varphi(\sigma_x - \sigma_0); \\ \varepsilon_y = \frac{1}{E}\left[\sigma_y - \mu(\sigma_x + \sigma_z)\right] + \varphi(\sigma_y - \sigma_0); \\ \varepsilon_z = \frac{1}{E}\left[\sigma_z - \mu(\sigma_y + \sigma_x)\right] + \varphi(\sigma_z - \sigma_0); \\ \gamma_{xy} = \frac{\tau_{xy}}{G} + 2\varphi\tau_{xy};\ \gamma_{yz} = \frac{\tau_{yz}}{G} + 2\varphi\tau_{yz};\ \gamma_{xz} = \frac{\tau_{xz}}{G} + 2\varphi\tau_{xz}. \end{gathered} \tag{13}$$

It can be seen from formula (13) that the first terms are the components of elastic deformation, and the second ones are the components of plastic deformation upon weakening of rocks. It is known that within the elasticity range $\omega = \frac{1}{2G} + \varphi$

where

$$\varphi = \frac{3}{2} \cdot \frac{\varepsilon_i}{\sigma_i} - \frac{1}{2G} \tag{14}$$

The components of plastic deformation of rocks with the weakening of rock-forming minerals will be:

$$\begin{gathered} \varepsilon_{x,p} = \varphi(\sigma_x - \varepsilon_0);\ \varepsilon_{y,p} = \varphi(\sigma_y - \varepsilon_0);\ \varepsilon_{z,p} = \varphi(\sigma_z - \varepsilon_0); \\ \gamma_{xy,p} = 2\varphi\tau_{xy};\ \gamma_{yz,p} = 2\varphi\tau_{yz};\ \gamma_{xz,p} = 2\varphi\tau_{xz} \end{gathered} \tag{15}$$

Since $\varepsilon_{i,p} = \frac{2}{3\sigma_i\varphi}$, hence $\varphi = \frac{3}{2} \cdot \frac{\varepsilon_{i,p}}{\sigma_i}$, we obtain the following form:

$$\begin{gathered} \varepsilon_{x,p} = \frac{3}{2} \cdot \frac{\varepsilon_{i,p}}{\sigma_i}(\sigma_x - \sigma_0);\ \varepsilon_{y,p} = \frac{3}{2} \cdot \frac{\varepsilon_{i,p}}{\sigma_i}(\sigma_y - \sigma_0);\ \varepsilon_{z,p} = \frac{3}{2} \cdot \frac{\varepsilon_{i,p}}{\sigma_i}(\sigma_z - \sigma_0); \\ \gamma_{xy,p} = 3\frac{\varepsilon_{i,p}}{\sigma_i}\tau_{xy};\ \gamma_{yz,p} = 3\frac{\varepsilon_{i,p}}{\sigma_i}\tau_{yz};\ \gamma_{zx,p} = 3\frac{\varepsilon_{i,p}}{\sigma_i}\tau_{zx}. \end{gathered} \tag{16}$$

The dependence of the strain intensity on the stress intensity within the elasticity of rocks has the form:

$$\varepsilon_{i,e} = \sigma_i / 3G \tag{17}$$

If we add (17) and (15), we get the intensity of total deformations for weakened or weathered low-strength rocks and soils, i. e:

$$\varepsilon_{i,e} + \varepsilon_{i,p} = \varepsilon \tag{18}$$

It follows from (18) that the intensity of complete deformations of weakened rocks by the action of superheated water vapor or chemical reagents consists of the intensities of elastic and plastic deformations.

It should be noted that within the elasticity of rocks the coefficient of transverse deformation (Poisson's ratio), the modulus of elasticity and the shear modulus *G*, for a certain value of the operating stresses are constant, and outside the elasticity in weakened or weathered rocks, they have a variable character.

Outside the elasticity of weakened and weathered rocks, the coefficient μ increases and becomes μ_0 = 0,25 to 0,5 with increasing plastic deformations.

In the region beyond the elastic limits of weak and weakly weathered rocks and soils, the variable parameters μ_0, E_0, G_0 are determined by the following expressions:

$$E_0 = \frac{\sigma_{i/E_i}}{1 + \frac{1-2\mu}{3E} \cdot \frac{\sigma_i}{E_i}};\ \mu_0 = \frac{0{,}5 - \frac{1-2\mu}{3E} \cdot \frac{\sigma_i}{E_i}}{1 + \frac{1-2\mu}{3E} \cdot \frac{\sigma_i}{E_i}};\ G_0 = \frac{\sigma_i}{3E_i} \tag{19}$$

As can be seen from (19), the variable elasticity and plasticity parameters are interrelated and can be determined if the stress intensities σ_i and strains E_i and the constant elasticity parameters *E*, μ, *G* for these rocks or soils are known. The change in the shear modulus in the elastic-plastic states of weakened rocks by the method of superheated water vapor or chemical reagents can be determined with the help of the two variable parameters E_0 and μ_0 according to the following relationship:

$$G_0 = \frac{E_0}{2(1 + \mu_0)} \tag{20}$$

To solve the elastoplastic problem using the variable parameters method, one can use the method of successive approximations. First, a diagram is constructed of the dilutions of weakened (weakened) or weathered rocks, after softening the rock-forming minerals by introducing into the rock composition superheated water vapor or chemical reagents. In the first approximation, it is assumed that the variable parameters are equal to the constant parameters in the elastic stage *E*, *G*, μ and an elastic problem is solved, as a result of which the stresses and deformations are determined in the first approximation σ_x, σ_y, σ_z, τ_{xy}, τ_{xz}, τ_{yz}, E_x, E_y, E_z *u* γ_{xy}, γ_{xz}, γ_y by (3) and (9). According to these values, the intensity of stresses and deformations is determined at each point of the rock body or weathered soil using the following formulas. In the first approximation σ_i, E_i will be:

$$\begin{gathered} \sigma_i = \frac{1}{\sqrt{2}} \sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_x - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)} \\ \varepsilon_i = \frac{\sqrt{2}}{3} \sqrt{(\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_y - \varepsilon_z)^2 + (\varepsilon_z - \varepsilon_x)^2 + \frac{3}{2}(\gamma_{xy}^2 + \gamma_{yz}^2 + \gamma_{zx}^2)} \end{gathered} \tag{21}$$

As shown in the deformation diagrams (Fig. 2) in the coordinates $\sigma_i \sim E_i$ the stressed and deformed state of some point of the body is represented by the point 1 lying on the ray, the slope of which is proportional to the value of $3G$.

In the second approximation, $3G_{vwd} = \sigma_{vwd}/\varepsilon_i$ – is received. The parameters E_0, μ_0, G_0 determine the values of σ_{vwd} and the corresponding strain intensity $\varepsilon_i$from the deformation diagram. These parameters are different from the previous ones. Thus, the problem arises of determining the stresses in the «inhomogeneous» body of weakened or weathered rocks, the elastic-plasticity parameters at different points have different values. Then solve this problem and define $\sigma_{x,2}$, $\tau_{xy,2}$, $\varepsilon_{x,2}$, $\gamma_{zx,2}$, which is the second approximation.

Then the stress and strain intensities are calculated according to (21) in the second approximation $\sigma_{i,2}$,. $\varepsilon_{i,2}$. Here, the stressed and deformed state of rock body points is represented by points 2 and 3 on the ray, the slope of which is proportional to $3G_{vwd,1}$ (Fig. 2).

In the third approximation, the value of $3G$ is taken to be equal to the ratio of the strain intensity $\varepsilon_{i,2}$ along the deformation diagram (Fig. 2).

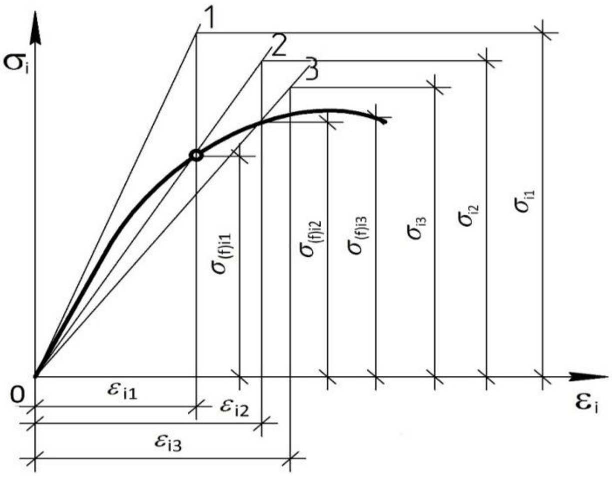

Figure 2. Deformation diagram

$$3G_{vwd,1,2} = \sigma_{vwd,1,2} / \varepsilon_{i,2} \tag{22}$$

By $\sigma_{vwd,1,2}$ and $\varepsilon_{i,2}$ find the same parameters and are used to determine stresses and deformations in the third approximation. The calculation is continued until the results in the next approximation are close to the corresponding results in the previous approximation.

On the basis of the foregoing, the following conclusions can be drawn:

1. The rocks under compression and tension are deformed, both within the elastic stage, and beyond the elastic limit. This can be seen when testing samples, both in natural and in weakened state, with superheated water vapor (more than 220 °C) or chemical reagents. In their natural form, they are mainly deformed within the elastic stage and are destroyed as a brittle material, and in a weakened form they can deform beyond the elastic stage and collapse like a plastic material. In the elastic stage, the relationship between stress and strain is linear.
2. Some rocks, such as basalts, diabases, clay shales, feldspars, diorites, andesites, even in the natural state, have sufficient viscosity to form a «flow tooth» before fracture and smoothly transfer to «local hardening-the neck». Diagrams of deformation under tension and compression can be schematized and written by the dependence of the stress-strain state within the elastic stage and beyond elasticity by a formula with linear hardening.
3. In the elastic stage, rocks are destroyed conditionally instantaneously and the tension (compression) diagram is schematized, i.e. Is replaced by a straight line before destruction.
4. To simplify calculations beyond the elastic stage, the tension (compression) diagram is schematized. Are replaced by curved smooth lines that have a fairly simple mathematical expression and at the same time are in good agreement with the experimentally obtained diagrams. When diagramming diagrams, the difference between the limits of proportionality and fluidity is erased. This allows us to consider the limit of proportionality as the fluidity strength. Schematicization of the expansion (compression) diagrams is carried out in the area where rocks begin to break down.
5. The schematized diagram can be called a diagram with linear hardening or with power hardening depending on the schematization of straight or broken sections of the joint before the destruction of rocks in the process of operating loads.
6. Within the elastic stage of rocks, the coefficient of transverse deformation (Poisson's ratio μ), the elastic modulus E and the shear modulus G are taken as constant values, and outside the elastic stage these parameters are taken as μ_0, E_0, G_0 variables and interrelated.

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