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# Predicting cavities and deformation of thawing soil around the underground horizontal workings.

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***Abstract.*** The article deals with the cases of the formation of parabolic cavities around horizontal workings due to uneven thawing of the soil after the termination of the freezing station. A solution to the problem of predicting the formation of cavities around workings is proposed.

Keywords: frozen rocks, artificial thawing of rocks, heat gain, parabolic cavity in the soil massif.

After driving a working in the area of frozen rocks, the work of the freezing station stops and the thawing of frozen rocks begins. Thawing of rocks can be natural and artificial. The duration of natural thawing of rocks depends on the amount of cold transferred to the rocks during their freezing, on the temperature at which the freezing was carried out, as well as on the thermophysical properties of the frozen rocks (thermal conductivity, heat capacity, etc.). The rate of temperature rise of rocks under the influence of the earth's heat influx is on average 0.10C Per day. Accordingly, the rate of natural thawing of rocks is on average 0.1 cm/day.

The natural thawing process of the soil can lead to uneven thawing of the ice wall. The uneven flow of the thawing process occurs due to different physical, mechanical and thermophysical properties of the soil, which change not only in layers of different rocks, but also within the same rock layer. Unfortunately, during the natural course of the thawing process, it is impossible to influence the heat transfer processes in the massif.

During artificial thawing of rocks around horizontal workings, discontinuities of rocks often occur in the form of various kinds of cavities. The formation of a parabolic cavity and the formation of a self-supporting rock arch around the mine are very often observed. With further thawing, the stability of the vault was broken, then a new vault was formed and the process was repeated [1].

To predict the development of the process of formation of cavities, a simplified solution of the following problem is proposed. To find the temperature distribution in the rock at the end of active freezing, we use a one-dimensional solution for a semi-bounded body, on the surface of which at the initial moment a constant temperature is established, in the conditions of Moscow city t = -7°C.

The solution to the problem has the following form [2]:

$$T(h,T) = -7\mathrm{erf}\,(\frac{h}{2\cdot\sqrt{at}}) \qquad (1)$$

where T( h,t)- average temperature of rocks during freezing;

h - distance from the heat exchange surface to the cavity;

t- time of coolant entering production;

$\alpha$ – thermal diffusivity of frozen rocks.

It is known that the physical and mechanical properties of frozen rocks depend on temperature.

Let us take the quadratic dependence of the soil deformation modulus E and the ultimate strength $\sigma_{сж.табл}$ on temperature.

$$ET = -1_6T \cdot (1 + 0{,}03125 \cdot T) \qquad (2)$$

Taking into account formula (1), it is possible to calculate the mechanical characteristics of frozen rocks at a height h from the working surface.

If we assume that the thawing mass is a set of arches located one above the other with a modulus of deformation variable in height, then it can be considered three-hinged, close to a circle at small angles $\theta$. Under the action of their own weight of thawing soils, these vaults produce pressure on each other (Fig. 1). As a result of their compression, vertical displacements occur, which leads to a break in the continuity of the thawing soil mass at a certain height from the working surface. Let us take the presence of limiting tensile stresses $\sigma_{\text{дл}}^{\text{р}}$ for the moment of crack appearance. Then the condition for disrupting the continuity of the soil massif can be expressed as follows:

where $k = \frac{h}{h_0}$

$h_0$- distance from the inner surface of the vault to rocks with negative temperatures;

ε – relative deformation along the height of a self-supporting vault;

$\varepsilon = \frac{dU}{dh}$

u- vertical movement of the lock section of the vault from the action of its own weight.

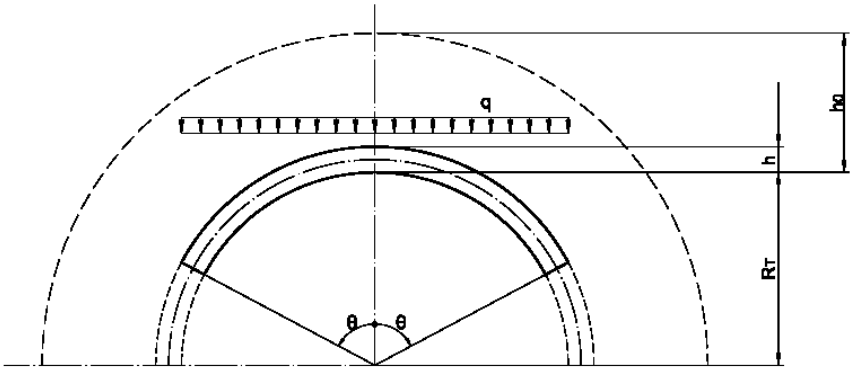

Fig.*1. Calculation scheme of a self-supporting rock arch.*

This movement can be determined by Mohr's formula:

$$U(h) = \int_s^h \frac{N \cdot N_q}{EF} dS \tag{4}$$

where N, $N_q$- normal forces in the vault of height h from the action of single unknowns and the vault's own weight;

S- the length of its arc;

$F = h \cdot 1$ - cross-sectional area.

Omitting intermediate calculations, we write expression (4) in the form

$$U = \frac{q \cdot A \cdot (R_T - y_c)^2}{EF} \tag{5}$$

where q- uniformly distributed load from the dead weight of a vault of unit thickness $(q = \gamma h)$ (;

γ – average volumetric mass of rocks of its own arch;

$R_T$- thawing depth;

$y_c$- coordinate of the center of gravity of the reduced section, measured from the inner surface of a self-supporting rock arch;

A- the value of the integral in expression (5), depending on the value of the central angle θ of the arch, given as $\theta=30^0;45^0;60^0;90^0$; A=1.31; 1.597;1.825;1.89.

Let us introduce the notations $k_1 = \frac{R_T}{h_0}$ and $k_2 = \frac{y_c}{h_0}$

Let us determine the coordinate of the center of gravity of the reduced section:

$$y_c = \frac{\int_0^h E(h) \cdot h \cdot F \cdot d_h}{\int_0^h E(h) \cdot F \cdot d_h} = h_0 \cdot k_2 \tag{6}$$

Differentiating (5) with respect to $h_1$, we obtain the condition for the discontinuity of the soil massif

Studies have shown that underground cavities can form in both thawed and frozen soils. With an increase in the thawing depth, the lock of the cavities tends to move into a more durable frozen rock mass. (Fig. 2) shows the graphical dependences of the vertical rock pressure on the size of the thawing halo.

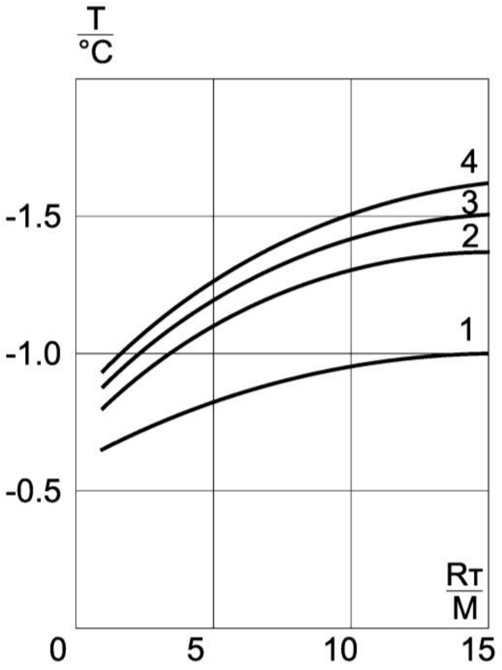

*Fig. 2 Dependence of the temperature in the joint of the rupture of the continuity of the soil mass on the size of the thawing halo (curves 1, 2, 3 and 4 with the value of $h_0$ equal to 1.3, 9 and 15 m, respectively).*

The established dependence of the temperature in the joint of the discontinuity of the soil mass on the size of the thawing halo is very useful for predicting the formation of cavities in natural conditions, as well as determining the risks of possible phenomena of surface subsidence due to the formation of the above cavities.

The fact of an increase in the size of cavities, which is associated with an increase in the thawing depth, established in practice, can be interpreted as a change in the size of an unsupported underground mine, in particular, an increase in its span. The dependence shown in (Fig. 2) allows one to predict the maximum soil temperature on the unsecured surface of the roof of the excavation at various spans of the excavation, which will save the massif from collapse.

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