Investigation of the stress-strain state of the frozen mass, leading to a change in the cylindrical shape of the ice wall

Kuzina Alexandra Vladimirovna
Senior Lecturer
Moscow Polytechnic University
Krynkina Vera Nikolaevna
Candidate of Technical Sciences, Head of Department
Moscow Polytechnic University

Abstract

Among the specific features of modern underground construction is an increase in the depth of deposits and, as a consequence, the complexity of mining and geological conditions, which, in turn, is connected with increasing the depth of unstable watered rocks, which require special construction methods, in particular, the artificial freezing of rocks. These conditions include high rock and hydrostatic pressures, heat flows and other factors that complicate the sinking process. Under such conditions, the existing calculation models, which consider the ice wall as a homogeneous isotropic body of a regular circular shape, distort the actual picture of the frozen mass stress-strain state. The paper substantiates the need to develop new ice wall calculating models and methods, taking into account the unfavorable combination of geological and technological factors.

Keywords: ice wall, stress-strain state, calculating models, safe design solutions

New mineral deposits are characterized by complex geological and hydrogeological conditions. Construction of barrels in such conditions is possible only with the use of special methods.

As the world experience in underground construction shows, one of the most versatile and reliable special methods is the method of freezing rocks. In mining practice, using the method of freezing rocks, 70-75% of all vertical shafts are constructed in difficult conditions.

Today, deposits are being developed at depths that have passed the 1000 m mark.

Today, there are several groups of methods for calculating the parameters of an ice wall, based on analytical design schemes. In calculations, the shape of the ice wall is assumed to be cylindrical with uniform surfaces.

However, these design schemes do not take into account that with an increase in the depth of the fields being developed and, consequently, the depth of the shafts, traversed by the method of artificial freezing, the load on the ice wall increases significantly. In addition, the stress-strain state of the ice wall is significantly influenced by mining and technical factors, such as the effect of lining, temperature fields, which in total affects the shape of the outer contour of the ice wall, its reliability, strength and stability.

Unfortunately, due to the deviation of the shape and dimensions of the ice wall from the design, its surfaces are uneven, which causes an incorrect setting of the external load on the surface of the ice wall, thereby leading to a difference in the stress-strain state of the ice wall from the calculated one.

In addition, the reliability of the ice wall is often negatively affected by the rigidity of the ice wall. It was found from practical experience that the higher the stiffness index of the ice wall system, the higher the stress concentration around the ice wall itself. Excessive rigidity of the ice wall leads to the formation of asymmetric stress-strain state of the frozen rock mass, which increases with the depth of the shaft.

In such fields as Gremyachenskoye in the Volgograd Oblast, Nivenskoye, in the Kaliningrad Oblast, the thickness of the aquifers also increases, which often leads to an increase in the temperature of the rocks, an increase in stress and the development of plastic deformations during shaft sinking, to deformation and destruction of freezing columns, violation of the stability of ice wall and water breakthrough into the trunk. At the same time, as the quantity and thickness of clay layers increases, the thickness and strength of the ice wall decreases, which leads to a large displacement of the ice wall and the bottom.

At high loads on the outer contour of the ice wall, the latter works like a pipe that loses its stability, which corresponds to a critical loss of stability with deformation of the ring into an ellipse. In addition, as stated in [2], along with the main forms of buckling, there are also transitional forms of critical buckling, and the deformation in the transitional form can be deeper than in the basic one.

During the formation of the ice wall, as already noted, its shape and dimensions deviate significantly from the design ones, as a result of which the mechanical characteristics of the frozen rocks and, therefore, the stress-strain state in the ice wall walls will differ from the calculated ones. The thickness of the ice wall especially influences the acting stresses.

It should be noted that in the calculation of the ice wall, its shape is taken to be cylindrical with uniform surfaces. However, due to the unevenness of the processes taking place, in some cases the shape of the ice-rock cylinder may be oval. The deviation of the shape and dimensions of the ice wall from the design ones causes an incorrect setting of the external load on the surface of the ice wall, thereby leading to a difference in the stress-strain state of the ice wall from the calculated one.

It is known that the strength of frozen rocks largely depends on the magnitude of their negative temperature [3]. In this regard, the question of the distribution of temperatures in the ice-soil wall becomes of great importance (Table 1).

Table 1. Compressive strength of frozen soil

Soils saturated with water	Compressive strength (in MPa) at temperature, C^{o}				
	From-1 to-5	From-5 to -10	From-10 to -15	From-15 to-20	From-20 to -25
Sand	2.5-8.5	8.5-12.7	12.7-14.4	14.4-15.2	15.2-18.0
Sandy loam	2.0-6.5	6.5-8.8	8.8-10.5	10.5-12.2	12.2-14.0
Clayey	1.5-4.5	4.5-6.0	6.0-7.5	7.5-9.5	9.5-10.0
Dusty	1.0-1.5	1.5-3.5	3.5-4.5	4.5-6.5	6.5-7.0

Consequently, the determination of the strength of the developed frozen rocks in the face at the design stage is of great importance. For this, the values of the strength of the frozen rocks at various points of the ice wall must be determined. Since it is almost impossible to measure the strength value in a frozen massif, we will use the relationship between the strength of rocks and temperature at each point.

To determine the average temperature of the ice wall, it is necessary to know the temperature distribution in three characteristic planes: axial, passing through the axes of two adjacent freezing columns, the main one passing through the axes of the freezing columns perpendicular to the line of their location, and the interlocking one, passing through the key line parallel to the axes of the freezing columns and perpendicular to the line of their location. In each of these planes, the temperature distribution has specific features and is described by various equations, while the temperature value at the point of intersection of the axial and locking planes is of greatest practical interest.

In the main plane, the temperature is calculated by the formula:

$$\boldsymbol{t}_{\text{г}} = \boldsymbol{t}_{cn} \frac{\ln \frac{\xi}{y}}{\ln \frac{\xi}{r_0}} \tag{1.1}$$

In the locking plane, the temperature

$$\boldsymbol{t}_{\text{зм}} = \boldsymbol{t}_{cm} \frac{\ln \frac{2\xi}{\sqrt{4y^2 + S^2}}}{\ln \frac{\xi}{r_0}} \tag{1.2}$$

where $t_{\text{г}}$- temperature in the main plane,°C ;

$t_з$- temperature in the locking plane,°C ;

y- distance of the considered point from the axial plane, m;

S- distance between adjacent freezing columns, m

Since the process of formation of the ice wall is long in time, then, as follows from equation (1.2), the temperature distribution does not depend on the properties of the frozen rocks.

To simplify the calculations, the following temperature distribution assumptions are accepted;

1) in the main plane - the lowest temperature near the "soldered into the array" freezing column. Hence, the greatest strength of the frozen rock should also be in this plane.

2) in the locking plane, between the two freezing columns, the temperature in the initial period of the ice wall closing is 0.3-0.4t_{cm}^{0}, then, with an increase in the design thickness, the temperature in the locking plane may drop to 0.7 – 0.8t_{cm}^{0}.

Thus, it is assumed that the locking plane is the most reliable (Fig. 1).

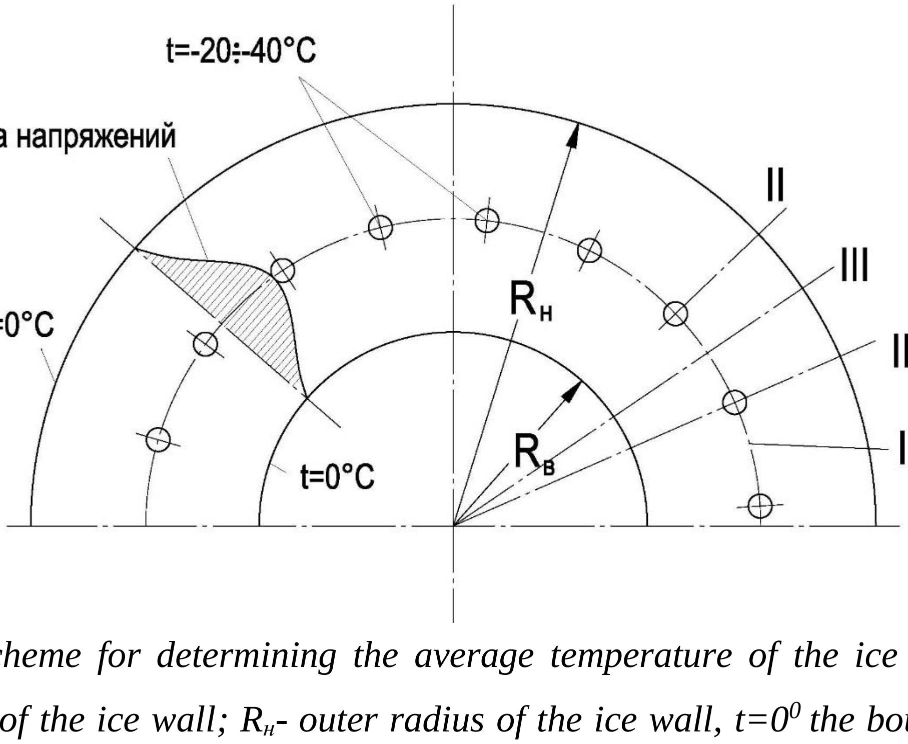

Fig.1-*Scheme for determining the average temperature of the ice wall.* $R_в$-*inner radius of the ice wall;* $R_н$*- outer radius of the ice wall,* $t=0^0$ *the boundary of the ice wall*

However, in practice, the weakening of the rock mass during the drilling of freezing wells has been repeatedly recorded, therefore, the metal column is separated by the drilling fluid from the mass. At temperatures down to -10°C, ice strength is not taken into account at all [BCH189-78], and at temperatures of -20°C (normal freezing), ice strength does not exceed 1.8 MPa. For comparison, the strength of sand in similar conditions is 14 MPa, and that of clay is 7 MPa. If we consider the compressive stresses in the frozen cylinder depending on the external radial load, then in the locking plane they will be calculated, and on the annular weakening contour by the borehole in the main plane, the stress concentration coefficient near the hole should be taken into account equal to 2. Therefore, the ice wall is not a monolithic cylinder what must be taken into account in the calculations.

The deformation characteristics of the ice wall change in such a way that the ice wall begins to work in the elastic-plastic stage, which leads to the formation of a plastic zone in the ice wall. The parameters of the plastic zone are determined by the geometrical parameters of the support, and do not depend on the external load on the ice wall.

References.

1. Palankoev I.M. A.V. Korchak, A.V. Kuzina Improving the efficiency of ground-freezing shaft sinking method. Sofia. – P. 85-89
2. Volmir A.S. Stability of deformable systems. – 2nd ed, rev. and add. – M.:Science: Main editorial office of physical and mathematical literature,1967
3. Baklashov I.V., Kartozia B.A. Mechanics of underground structures and support structures.– M.:Bowels, 1965.
4. *HuXiangdong*. Prediction of the safe state of the ice wall during shaft sinking / Materials of the round table "Scientific and technical problems of the development of environmentally friendly technologies for the construction and operation of underground structures in difficult mining and geological conditions" sci.-pract. conf. Miner's Week-97. – M.: MSUH, 1997, – P. 85-88.
5. Kuzina A. V. Systematization of the causes of damage to freezing columns during the construction of deep vertical shafts using the method of artificial freezing // GIAB. – 2006. –№11. – P.396-420.
6. Lieberman Yu.M. Method for calculating the wall thickness of an ice-bearing cylinder. Freezing of rocks during shaft sinking. –M. Publishing house of the AS of the USSR, 1962. – 24 P.