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# The thermal condition and stability of underground tourist complex workings

# The thermal condition and stability of underground tourist complex workings

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**Abstract.** The article presents the development of measures to ensure the required thermal condition and recommendations for support setting of underground mine workings in the conditions of the cryolithozone, ensuring the stability of the workings and safe living conditions in the galleries of the tourist complex "The Kingdom of permafrost" (TKoP), located on the 5th km of the Vilyuysky tract in Yakutsk. The following research methods were used: field observation of the temperature condition, visual inspection of the slope and underground mining of the tourist complex, the choice of a rational type of support setting, calculation of the parameters of the support, mathematical modeling and numerical calculations of the temperature condition. The main research results are obtained: the results of field observation of the thermal condition of underground mine workings of the tourist complex "The Kingdom of permafrost" in the winter and spring period of operation, the results of visual inspection of the slope, galleries and chambers, and recommendations for ensuring stability and support setting the existing fallout zones are given. The calculation of the temperature condition of the TKoP and the required capacity of refrigeration machines was performed using the Museum CVM software package developed in the Laboratory of Mining Thermophysics of the IGDS SB RAS. To reduce the energy consumption for the production of artificial cold in the summer, it is recommended to carry out annual autumn and spring cooling charges with artificial ventilation. The recommendations for support setting mine workings have been developed.

## 1. Introduction

One of the main directions of improving the efficiency of mining in the mines of the Republic of Sakha (Yakutia) is to further improve the support setting and maintenance of underground mine workings with maximum use of the natural bearing capacity of frozen rocks. First of all, this is a significant dependence of the stability of the workings on the temperature and rock moisture and a significant role in the selection of types of supports is taken into account by the thermal condition.

The resulting delamination and dislocation of the roof rocks of the untimbered underground mine workings of the tourist complex "The Kingdom of Permafrost" was a wake-up call in terms of ensuring their stability and ensuring safe operation.

Scientific and Educational Center "Geotechnologies of the North named after M. D. Novopashin" with the involvement of the N. V. Chersky Institute of Mining of the North (IGDS SB RAS) and the NEFU named after M. K. Ammosov Mining Institute by request of the tourist complex "The Kingdom of Permafrost", the contract work "Recommendations for ensuring the stability of underground mining of the tourist complex of TKoP" was carried out, in the course of the work, researches of the thermal condition of TKoP in the winter period of operation were carried out, a visual survey of the slope and the underground mining of TKoP was made, and recommendations were given for ensuring the stability of underground mining, for regulating the temperature condition, for conducting additional engineering and geological surveys, as a result of these researches, recommendations are given for support setting the underground mine workings of the TKoP.

In the space-planning solution TKoP (figure 1) consists of 2 galleries, knocked down by one cross, and 25 chambers, in which ice sculptures are placed. The length of the gallery №1 is 102 m, the gallery №2 is 124 m, the length of the cross is 21 m, the cross-section of the workings is not the same and on average is 9.3 m2 of galleries, 10 m2 of chambers. The support setting of the underground mining with the exception of the working collar was not carried out. In winter, the underground mining is forcibly vented with cold air pumped by blow fan, and their surfaces are covered with a layer of ice glazing 50 mm thick by spraying thinly sprayed water, thereby providing cold charging of the wallrock, the required humidity level and protection from weathering.

The wallrock complicated frozen repeatedly interstratified fine and sandy silt ranging from 2 to 10-15 m and the same type sandy loam, medium loam, and heavy loum with the thickness of the individual layers from 0.1 to 1-2 m.

The natural temperature of the rocks is -2,5 ÷ -3°C; the total humidity content of 15.1 ÷ 20%; the unit specific gravity of 1.83 ÷ 2,12 g/cm$^3$, porosity of 0.45 ÷ 0,87.

Mechanical properties of frozen rocks: uniaxial compressive strength -8.0 - 25.0 kg / cm$^2$; tensile strength -1.5 - 4.5 kg / cm$^2$; equivalent adhesion -3.5 - 12.5 kg/cm$^2$.

By category of hardness (SNiP IV. 5. 82.) the rocks belong to the group of frozen soils type "B".

Thermophysical properties of frozen rocks: volume heat capacity -460 ÷ 482 kcal/m$^3$ deg; coefficient of thermal conductivity -1.26 ÷ 2.69 kcal/m h.deg; thermal diffusivity -27.2 ÷ 53.210-4 m$^2$/hour.

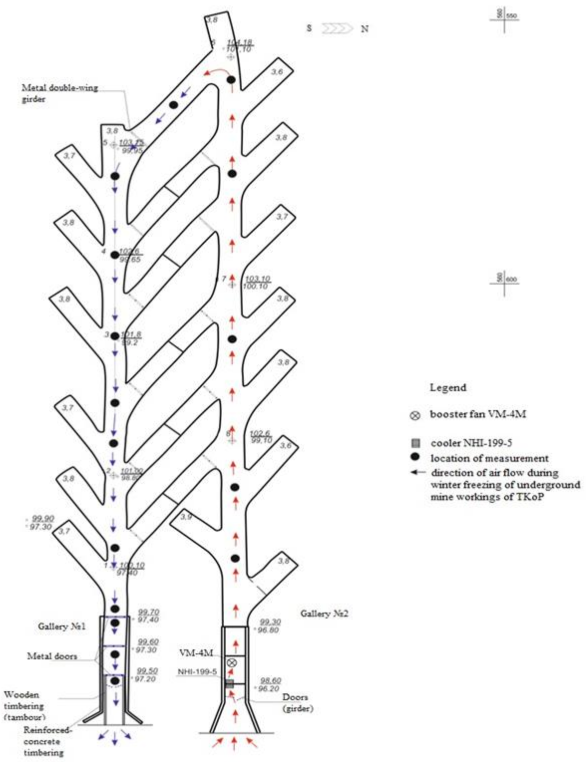



**Figure 1.** The diagram of underground mine workings of the tourist complex "The Kingdom of Permafrost".

The screens made of tent fabric are installed on all the doors of the tambours of the galleries to limit the flow of warm air during the visit of the complex by tourists.

In the absence of support as a result of weathering of rocks, in the roof of some underground mine workings of TKoP in 2017, there were 3 falls. The largest of them (weighing about 200 kg) occurred at the junction of the gallery №1 with the chamber №4. (figure 2), since the glazing of the underground mine workings has not been performed since 2014.

**Figure 2.** The fall of the roof rocks in the area of the junction of the gallery №1 and the chamber №4 of TKoP.

## 2. The research of the thermal regime, calculation of the temperature regime and recommendations for support setting of "The Kingdom of Permafrost"

The temperature regime of TKoP during the year is formed as a result of the combined action of many factors: seasonal changes in the temperature and humidity of atmospheric air; solar radiation on the surface of the slope and the working collar; the speed, temperature and humidity of the air flow during the winter frost; the intensity of air exchange during the opening of the entrance doors of the tambours; heat flows from tourists, lighting devices, heated entrance premises; incoming artificial cold produced by refrigerating machines in the summer. In accordance with the requirements, the features of the heat transfer processes (quantitative and qualitative) should be taken into account when choosing engineering solutions to ensure the stability of the underground mine workings , annual cold charging modes, when laying engineering communications of the refrigeration complex, choosing refrigeration equipment, etc.

The research of the temperature regime by the staff of the IGDS SB RAS were conducted in December 2017 and January 2018 according to the method of the former LGI [1,2,3]. Measurements of the air temperature were carried out by the CENTER-314 device, the contact layer of rocks by the Testo 845 and Leica DistoD8 devices. The measurement points were located starting from the tambours and further along the length of both galleries (figure 1).

The measurements were made with the doors of the tambours closed, the lighting devices turned on, the refrigeration unit not working, the lack of ventilation and the presence of a small number of tourists. Cold charging of the underground mine workings was not carried out. The outside air temperature was -42 °C.

The results of the observations are shown in figure 3. Summarizing them, we can conclude that, as expected, the lowest air temperatures are recorded in the tambours, and then this parameter gradually increases along the length of the underground mine workings, reaching a maximum value in the cross between the galleries.

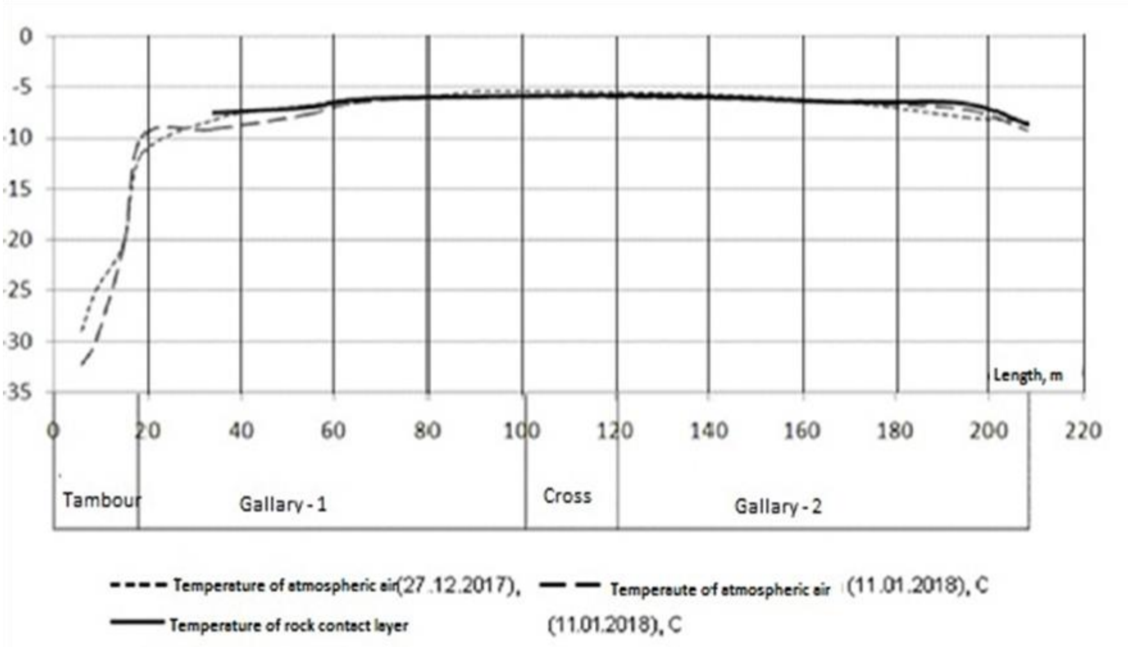



**Figure 3.** Dynamics of air temperature values and the contact layer of rocks in the workings of TKoP.

The lowest temperature of the contact layer of rocks was recorded at the collar of the galleries -2 (-8.7°C) and differed from the air temperature by 2°C. Then this indicator increased along the length of the gallery and also slightly differed from the air temperature.

The state of the ice sculptures in individual chambers suggests that their deformation is visible by naked eye as a result of the plastic flow of ice.

The temperature regime of TKoP is controlled by several household thermometers installed at various points, their readings correspond to those measured during the research.

After the rock failure that occurred, it was necessary to monitor the air environment in 2018 using the same method from December 2018 to April 2019.

The measurements were carried out by the CENTER-314 device. The outdoor temperature was -39 °C in December, -18°C in February, 7 °C in March, and 6 °C in April. In January, measurements of the air temperature of the galleries were carried out during the cold charging of the workings. The outside air temperature was - 32 °C.

After the observations were completed, the following results were obtained: the lowest air temperature was recorded in the tambours in December before the workings were purged, and then it increases as in the measurements made in December 2017. In January, the lowest temperature - 24 °C was recorded at the beginning of the gallery №2 on which the workings were purged, and at the beginning of the gallery №1 on the vestibules, the temperature remained within -10 °C. In February, after the end of the purge, the minimum temperature at the beginning of the gallery №2 was -15 °C, which confirms the increase in temperature after the end of the purge in the range of 10 °C. In March and April, the average air temperature in the workings was about 8°C. Along the entire length of the galleries, also in April, there is an increase in temperature to almost 0 °C on the tambour at the entrance of the gallery №1. It can also be concluded that during the process of cold charging of workings, the lowest possible temperatures are maintained for a length of 30 m.

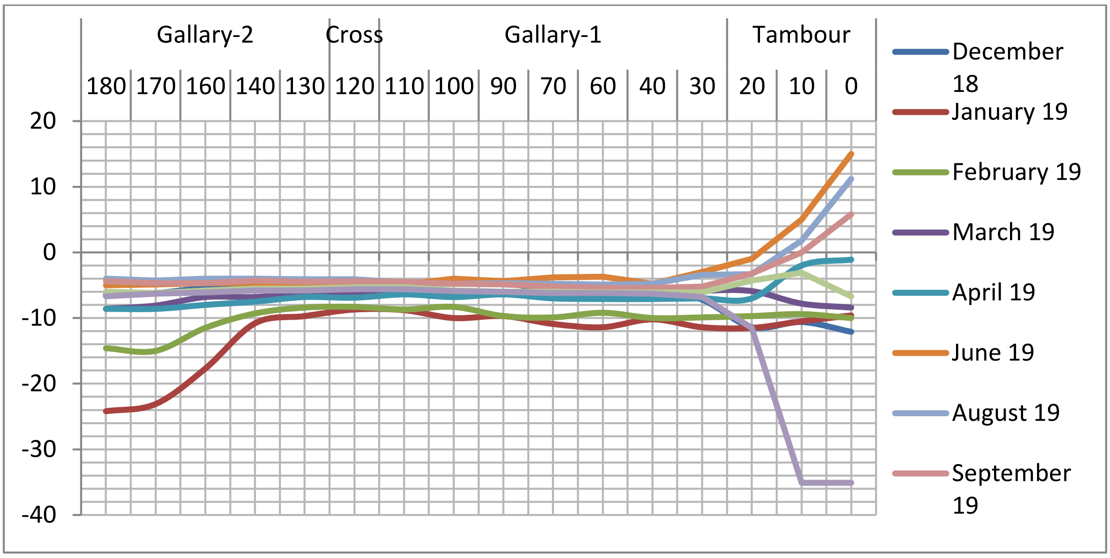



**Figure 4.** Dynamics of air temperature from December 2018 to December 2019.

Measurements of the humidity parameters of the air environment were not made, but the observations made allow us to assume that both condensation and evaporation processes occur in the underground mine workings, and the latter clearly prevail. As a result, there is a sublimation of ice glazing, ice sculptures, and, possibly, schlieren ice, as well as active siccation (weathering) of the near-contour rock mass and its spontaneous disintegration in the absence of cementing ice (figure 5).

**Figure 5.** Weathered side of the mine workings of TKoP with an installed temperature sensor.

It should be noted that the humidity balance is variable along the length of the underground mine workings. Condensation processes are most developed in the tambours and collar of the galleries, where warm air enters from the heated entrance room; then they slow down and manifest themselves to a lesser extent.

The conducted survey of underground mine workings with the presence of frost and a thick contact layer of weathered rocks did not allow us to detect the cleavage using the simplest methods – sound and vibration [4,5,6]. So it is possible that in addition to the previously discovered roof collapses and visible cracks with a small opening, individual cleavage are undetected, but there is a possibility of their presence in other places that are currently inaccessible for viewing.

The calculation of the temperature regime of TKoP and the required capacity of the refrigerating machines was performed using the "Museum CVM" software package developed in the Laboratory of Mining Thermophysics of the IGDS SB RAS [7]. It is based on the use of a developed three-dimensional mathematical model of heat exchange processes in the gallery, which allows for a long-term forecast depending on various design and technological parameters: the geometric dimensions and depth of the gallery, the angle of slope, the thermophysical properties of the wallrock, the operating mode (flow rate of tourists, the number of electric lamps), the cold charging mode (time of year, the temperature of the supplied air, the intensity of ventilation), the mode of use of refrigeration equipment.

The task of calculating the temperature regime of the gallery of TKoP is to determine at each time step: the distribution of the air temperature inside the adit; the distribution of the temperature in the rock mass around the gallery; the thermal load on the refrigeration equipment; the energy costs for ventilation and for the production of artificial cold, the total operating energy costs.

The calculations were carried out under the various options listed below for regulating the temperature regime of the underground mine workings:

- natural mode, in which there is no regulation of the temperature regime (without cold charging and the use of refrigeration units);
- autumn cold charging without the use of artificial cold;
- spring cold charging without the use of artificial cold;
- autumn-spring cold charging without the use of artificial cold;
- autumn-spring cold charging using artificial cold.

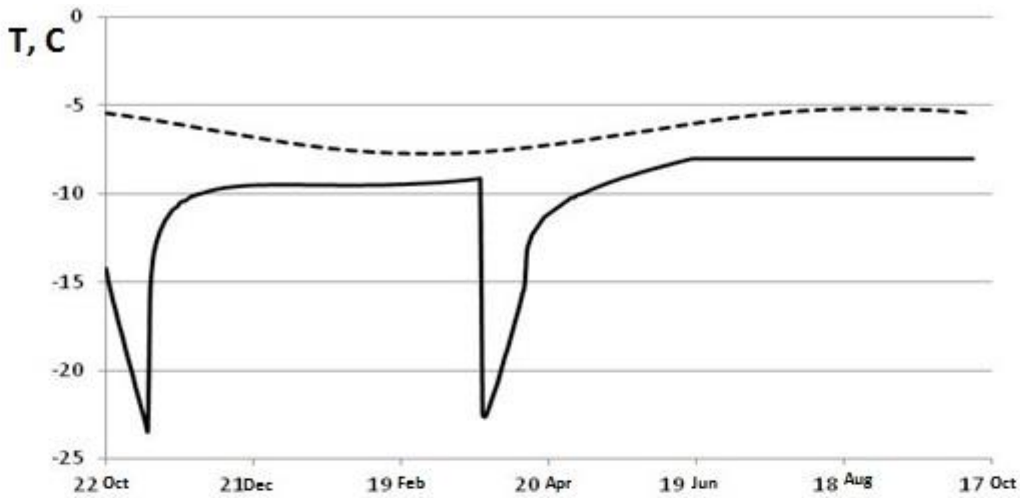
The flow rate of tourists is accepted in the following amount:

- in summer, 50 people/day;
- in winter, 20 people/day;
- each tourist is in TKoP for 1 hour.

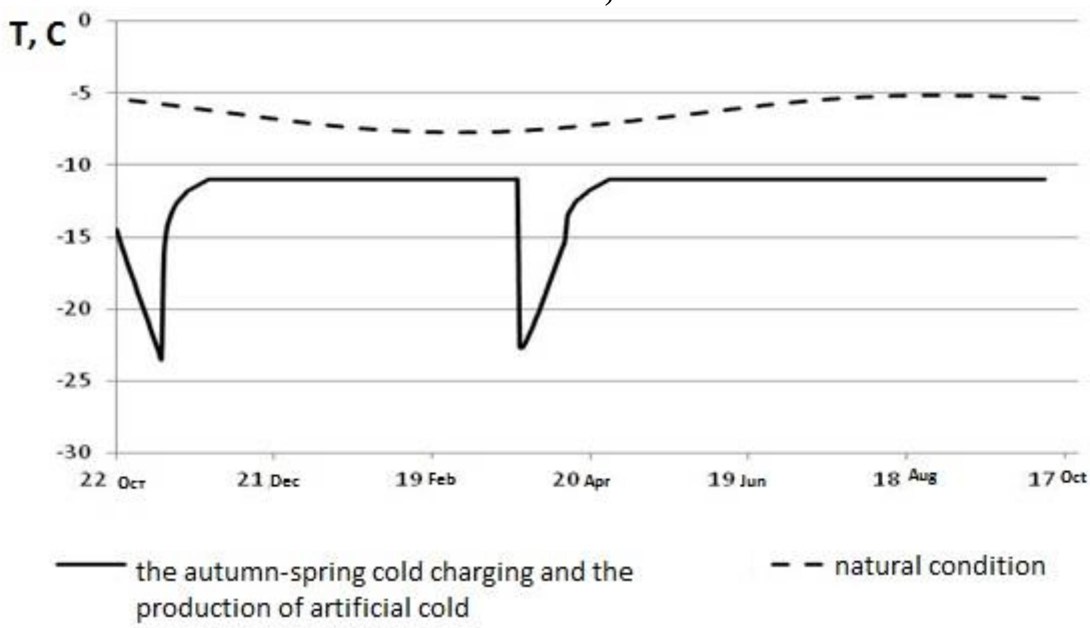
There are in the gallery has 25 electric lamps with a power of 40 W, which are turned on for 8 hours a day. Cold charging with atmospheric air in the spring and autumn periods is carried out at an intensity of 15 m3/s for 12 hours a day. To preserve the ice figures, it is necessary to maintain the air temperature in the gallery no higher than -8°C -11°C.

Calculations have shown that for all variants of temperature control, the average air temperature in TKoP decreases. At the same time, the cooling charge carried out only in the spring (from the end of March for 20 days) is insufficient and does not ensure the maintenance of the required storage temperature of ice figures both in summer and in winter. And with the autumn cold charging (from the end of October for 20 days) , only in the winter months it is possible to maintain the temperature below -8°C. Thus, in order to reduce the energy consumption for the production of artificial cold in the summer, it is necessary to carry out annual cold charges in both autumn and spring. In the period of extremely low temperatures, cold charging is undesirable, in order to avoid frost-breaking cracking of the near-contour layer of rocks in underground mine workings.

Figure 6 shows the dynamics of changes in the average air temperature in the gallery during the autumn-spring cold charging and the development of artificial cold in the third year of operation of TKoP. From the graphs shown, it can be seen that if the maintenance of a temperature of -8°C is provided by the operation of refrigeration units only in the summer, then for the maintenance of a temperature of -11°C their operation is necessary-both in summer and in winter.




a)




b)

**Figure 6.** The values of the average air temperatures in the gallery during the autumn-spring cold charging and the production of artificial cold: a) -8°C b) -11°C (the third year of operation of TKoP).

Calculations for support setting the workings were performed according to known methods [8,9,10]. The places of rock failure and areas of underground workings that are prone to cleavage, exposed to weathering, are subject to support setting. Recommended types of support: in places of rock failure, frame metal support; in areas prone to cleavage, exposed to weathering, rockbolts support with ice lagging and Rabitz mesh.

It is recommended to fasten the places of large rock failure at the junction of gallery №1 and chamber №2, chamber №4, as well as at the junction of gallery №2 and chamber №12 with a metal frame support.

Support material – I-beam №10 and №18 or special profile SVP-17.The support is rigid. The connection of the support elements in the joint, by arc welding. Tightening of the roof and sides of the workings is made with a 50 mm edged board, with pre-treatment with a fire-resistant impregnation. The backing of the fixed space is made with a round wood with a diameter of 15-20 cm, also with a preliminary impregnation with a fire-retardant composition. The construction of the support is shown in figure 8.

The scheme of rockbolting with a Rabitz mesh and ice lagging is shown in figure 7. Other areas are recommended to be fixed with rockbolt fastening with a Rabitz mesh and ice lagging, in these conditions it is recommended to use rockbolts fixed in the hole along the entire length of the rockbolt body. The use of lock types of rockbolt in these conditions is unacceptable due to the inefficiency of fixing spacer locks in the end part of the holes in loose rock conditions.

Under these conditions, it is recommended to use rockbolts fixed in the hole along the entire length of the rockbolt body. The use of lock types of rockbolts in these conditions is unacceptable due to the inefficiency of fixing spacer locks in the end part of the holes in loose rock conditions. From the existing types of rockbolt supports for the conditions under consideration, lockless structures with an active radial spacer of the fixed part can be used. For example, friction tubular rockbolts of the SplitSet and Swellex type pressed into the well, rockbolts fixed with expanding compositions, fixed with friable mineral aggregate. The advantages are: fast installation, reliable support setting and versatile for a number of conditions, loading the rockbolt to the working load is possible immediately after its installation.

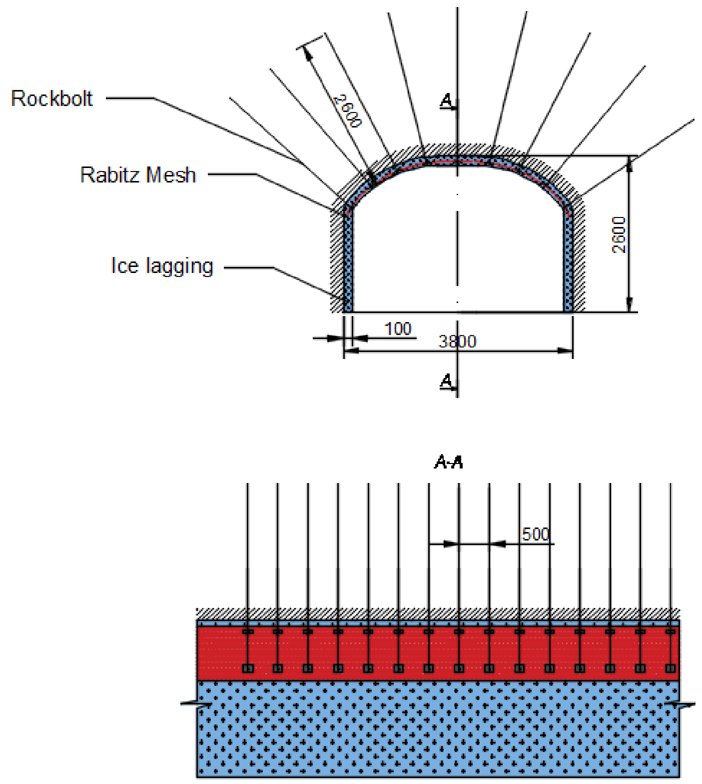



**Figure 7.** The scheme of the passport of support setting with rockbolts in underground mine workings of the tourist complex.

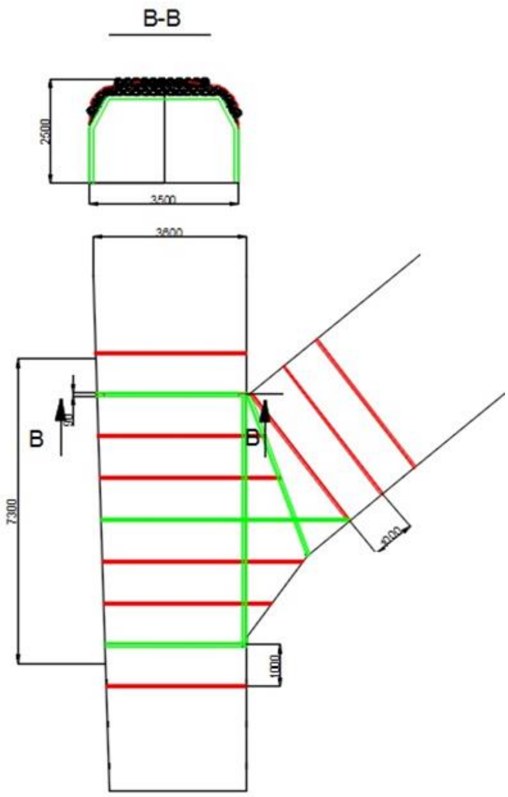



**Figure 8.** The scheme of support setting in the interfaces with frame support.

## 3. Conclusion
In order to ensure the long-term safe operation of TKoP, periodic geomechanical monitoring of the state of the rock mass of underground mine workings and the displacements of their roof is necessary according to the VNIMI method [10]. Instrumental observations will allow to record the displacement of blocks, the formation of flaws and cleavages, the intensity of the formation and growth of cracks, which will undoubtedly contribute to the prevention of accidents.

According to the results of the conducted research, it is concluded that it is necessary to stabilize the technical condition of the underground complex and carry out phased large-scale repairs. For this purpose, recommendations were developed for support setting and regulating the thermal condition of the underground mine workings of TKoP. First of all, work should be carried out to remove the most weathered contact layer of rocks from the surfaces of the underground mine workings, fix the interfaces that have increased spans and are most susceptible to rock pressure. The identified areas that are prone to falling out are also subject to support setting.

Measurements of the air environment were carried out in 2019 after the implementation of these recommendations. The average air temperature in the workings compared to 2018, after the recommendations are implemented, remains in the range of -5 to -10 degrees, and during the cold charging process in January and February, it varies from -10 to -15 degrees.

The analysis of the conducted observations allows us to formulate the following conclusions:

The established temperature regime in the workings of TKoP can be considered optimal in terms of ensuring their stability and comfortable conditions for tourists. At the same time, to prevent plastic deformations of ice sculptures, it is desirable to provide reduced air temperatures in the range of -11÷ -12 °C.

To reduce energy consumption for the production of artificial cold in the summer, it is recommended to carry out annual autumn and spring cold charging with forced ventilation.

Thus, with careful and timely implementation of all recommended measures, the long-term stability of the workings and the safety of the tourists ' stay can be ensured, the optimal temperature and humidity conditions are stabilized with minimal energy costs, this will prevent the deformation of the ice sculptures and preserve the aesthetic appeal of the tourist complex.

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