relation of the thermal conductivity coefficients of the insulant and sand (parameter η) with different concentrations of the insulant in the mixture (parameter m). From the charts it is visible that the lower the parameter η and the higher is the parameter m, the higher is the value of the target function. That is, the lower is the thermal conductivity coefficient of the insulant and the higher the insulant's concentration in the mixture, the more efficient is the two layer structure of thermal insulation layer compared to the single layer structure. With increase in the thermal conductivity coefficient of the insulant or decrease of the thermal conductivity coefficient of sand (for example, through prior drying), that is, with increase of the parameter η, the role of the concentration of the insulant in the mixture decreases – at the concentration of 0.3, the curves in the figure are virtually merging. In addition, the value of the target function approaches zero and there is no practical purpose in constructing a two layer thermal insulation structure in this area of values of the parameters.

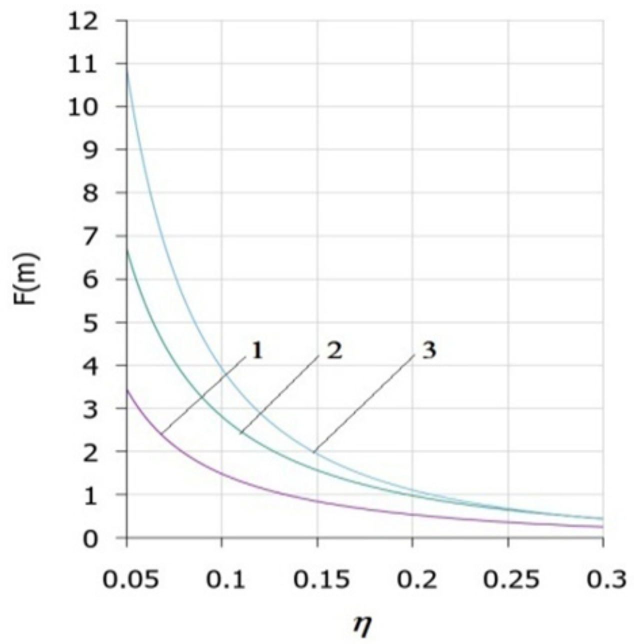

Figure 1: Change in the target function depending on the parameter η with different concentrations of m insulant in the mixture: 1-0.2; 2 – 0.4; 3 – 0.8;

This can be seen well on the 3D chart in figure 2. The figure 2 is showing the change of the target function depending on the parameter η with different concentrations of the insulant in the mixture. For example, when the value of the parameter η is 0.4 it is visible that the lower part of the plane is nearly parallel to the axis m. That is, the concentration of the insulant in the mixture has no influence on the final result. The upper part, on the other hand, with the value of the parameter η being 0.1, has a highly visible curved shape, which points to a significant dependence of the concentration of insulant in the mixture on the choice of technical solution for the thermal insulation layer structure. The higher the concentration,

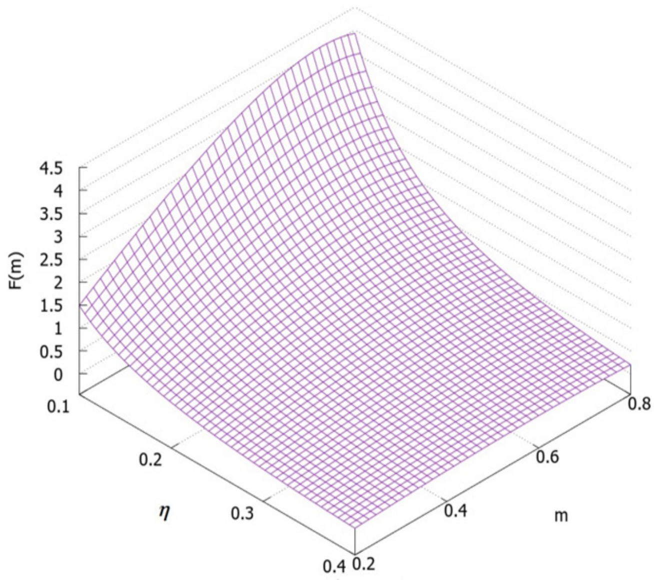

Figure 2: Change in the target function depending on the parameter η with different concentrations m of the insulant in the mixture

the higher the dependence. The target function with the concentration of insulant 0.2 has a value of 1.5. When the concentration of the insulant is equal to 0.8, the value of the target function is equal to 4.0. That is, it almost 2.7 times higher. The chart below shows that there is an effective area of relations of the parameters η and m in which the considered task is relevant. In order to determine the area, formulas (7) and (8) can be used. The results of the calculation are represented in the form of charts in the figure 3 and figure 4.

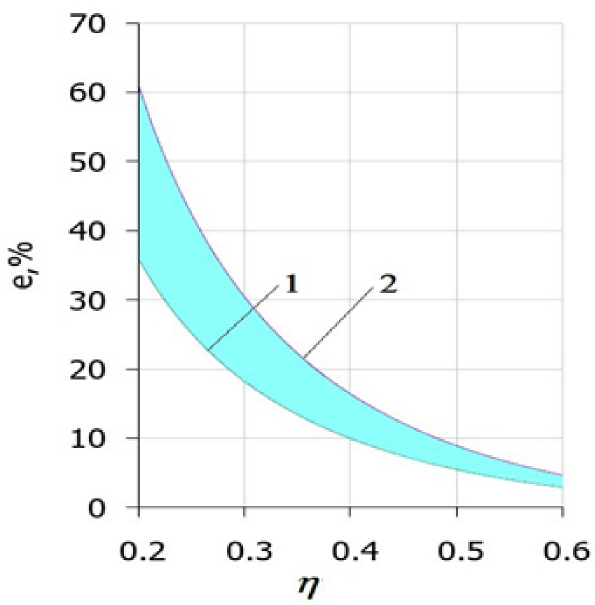

Figure 3: The change of thermal resistance when a mixture instead of layered structure of thermal insulation is used with different concentrations of the insulant in the mixture: 1 – 0.8; 2 – 0.4;

In the figure 3, the area of change in thermal resistance (increase in %) of the layered structure of thermal insulation layer when the concentration of the insulant in the mixture changes from 0.4 to 0.8 is filled. If the engineering principle that at most 10% change is permitted is followed, this area is delimited by the values of the parameter η 0.4 – 0.48. This is clearly visible in the figure 4, where the 3D chart of dependence of increase of thermal resistance of the structure using the layered method instead of the single layer method of thermal insulation.

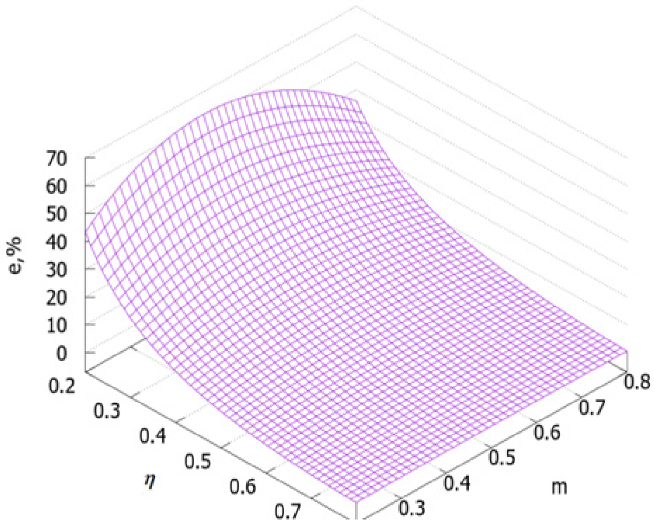

Figure 4: The change in thermal resistance of the structure when the layered method of application of sand and insulant is used

From the figure it is visible that the upper part of the plane has a clearly curved shape, while the lower part represents a straight line. That is, as was mentioned above, the concentration of the insulant when the parameter η exceeds 0.48 does not influence the thermal insulation structure as the increase of thermal resistance will not be higher than 10%. The results of the solution of the second task are presented in the form of a 3D chart in the figure 5. The X axis represents the thickness of the sand bedding, the axis Y represents the fraction of the insulant material in the mixture which determines the value of the coefficient of thermal conductivity coefficient of the thermal insulation mixture - λ_2. As can be seen in the chart, there is both a positive and a negative area of the change of the parameter β. The latter means that a given concentration of the thermal insulant in the mixture and a value of the thermal conductivity coefficient of the mixture, the thermal insulation layer will increase compared to a regular sand bedding. That is, application of a thermal insulation mixture is not expedient. It needs to be noted that this area (denoted blue in the figure) is not very large. Nevertheless, when designing road pavements with thermal insulation in the permafrost zone it is necessary to consider the expedience of use of thermal insulation mixtures according to the methodology developed.

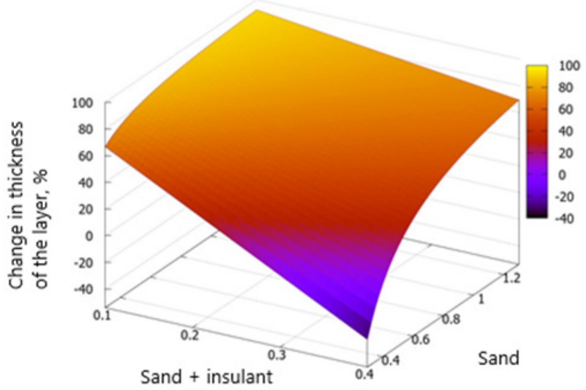

Figure 5: Change in thickness of thermal insulation bedding compared to sand bedding

CONCLUSIONS

The problem of choosing a method of construction of thermal protection layer of the road pavement in permafrost zones was solved. Simple engineering formulas to justify the choice of the type of thermal insulation structure were obtained. It was determined that, from the perspective of maximizing thermal resistance, a structure composed of two layers (a layer of insulant and a layer of sand) is always more efficient than a thermal insulation mixture (mixed insulant and sand) consisting of one layer. At the same time, the quantitative assessment demonstrated that in many cases relevant for practical application, the difference in the values of thermal resistance of the two types of structures is not very large and is within the boundaries of the permissible precision of engineering calculations. For this reason, it is expedient to also consider the technological demands of creating one or the other type of thermal insulation layer, in addition to the thermal resistance calculations. Formulas to find the area of rational use of thermal insulation mixtures (sand and thermal insulation materials) instead of merely sand bedding were devised. It was determined that the thickness of bedding in one or the other case is significantly dependent on the ratio of thermal conductivity coefficients of the sand and the insulant. In addition, the change in relative thickness of the layer can have both negative and positive values.

REFERENCES

1. Dmitrienko, I.A., Perfilov, V. A. (2019) Features of the construction of pile foundations in permafrost zones at oil and gas industry facilities: a review. Engineering Journal of the Don, no. 8.
2. Dugartsyrenov A.V., Belchenko E.L. (2009) The parameters of insulation when the soils are frozen at an acceptable depth. MIAB. Mining Inf. Anal. Bull., no. 5, 44-47

3. Zhang X., Feng S.G., Chen P.C. (2013) Thawing settlement risk of running pipeline in permafrost regions. Oil Gas Storage Transporation, no. 6, 365–369
4. Zhang, J., Qu, G., Jin, H. (2010) Estimates on thermal effects of the China–Russia crude oil pipeline in permafrost regions. Cold Regions Science and Technology, vol. 64, no. 3, 243–247. https://doi.org/10.1016/j.coldregions.2009.10.001
5. Galkin A.F., Kurta I.V., Pankov V.Yu.(2020) Use Of Burned Rocks In Underground Laying Of Cable Lines In The Cryolitzone. Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering, vol. 331, no. 12, 131–137. https://doi.org/10.18799/24131830/2020/12/2946
6. Guizhi Liu.(2018) Study of the Method Laining Fiber Optic Cable in the Same Trench with Pipeline in Permafrost Region. Proceedings of the International Petroleum and Petrochemical Technology Conference, 152–158. https://doi.org/10.1007/978-981-13-2173-3
7. Kondratiev, V.G., Kondratiev, S. V. (2013) How to protect the Amur Chita-Khabarovsk federal highway from dangerous engineering-geocryological processes and phenomena. Engineering Geology, no. 5, 40–47
8. Galkin, A.F. (2015) Thermal conditions of the underground town collector tunnel. Metallurgical and Mining Industry, no. 8, 70–73
9. Shatz M.M., (2011) The current state of the city infrastructure of Yakutsk and ways to increase its reliability. Georisk, no. 2, pp. 40–46
10. Yartsev, V.P., Ivanov, D. V., Andrianov K.A. (2010) Prediction of the durability of extruded polystyrene foam inroad structures. Scientific Bulletin of VGASU. Construction and architecture, no. 3, 99–104
11. Bek-Bulatov, A.I. (2000) The use of Styrodur® C in road construction. Building materials, no. 12, 22–23
12. Galkin A.F., Kurta I.V., Pankov V.Yu. (2020) Calculation Of Thermal Conductivity Coefficient Of Thermal Insulation Mixtures. IOP Conference Series: Materials Science and Engineering, vol. 918, no. 1, 012009.https://doi.org/10.1088/1757-899X/918/1/012009
13. Malenfant-Lepage, J., Doré, G., Fortier, D., Murchison, P. (2012) Thermal performance of the permafrost protection techniques at Beaver Creek experimental road site, Yukon, Canada. Proceedings of the 10th International Conference on Permafrost, June 25-29, Salekhard, Russia, no. 1, 261-266
14. Dore, G., Cote J., Segui, P. and N. Ghafari (2019) Insulating Performance of Foam Glass Aggregate (FGA) in Cold Regions Roads and Highways. GRINCH 2019 “Groupe de Recherche en Ingénierie des Chaussées”, Waterloo, Ontario, Canada. https://doi.org/10.13140/RG.2.2.19498.77768
15. Schwerdtfeger, P. (1963) The thermal properties of sea ice. Journal of Glaciology, no. 4, 789–807

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