An approach for automatization of geotechnical monitoring in cryolithozone

A Alekseev1,2, L Shilova1*, E Mefedov1
1Moscow State University of Civil Engineering, 26, Yaroslavskoe highway, Moscow, 129337, Russia
2JSC "RCC "Construction", N. M. Gersevanov research Institute National Research, 6, 2nd Institutskaya str., Moscow, 109428, Russia

E-mail: ShilovaLA@mgsu.ru

Abstract. The article presents an analysis of publications in the field of research devoted to the problems associated with the construction of buildings and structures in areas of permafrost soils, which belong to the cryolithozone. At the same time, the analysis of the research works made it possible to conclude that currently the data obtained because of monitoring, as a rule, are processed manually. In the article the process of geotechnical monitoring is presented in the form of a generalized diagram, from which a sufficiently large array of data is collected during the process of geotechnical monitoring. According to this information graphs of changes in the movement of the building foundations in time and graphs of thermometric observations of the soil massif, etc. are made. That fact justifies the need of automatization of the collection and processing of geotechnical monitoring data. The article presents an approach for automatization of geotechnical monitoring. Systematization of the geotechnical monitoring data and ensuring the operation of equipment synchronously in an automated mode will provide the timely notification of stakeholders about the identified deviations of the controlled parameters and reduce risks and avoid accidents.

1. Introduction
Currently, more and more attention is paid to the problems associated with the construction of buildings and structures in the areas of permafrost soils, which belong to the cryolithozone - the upper layer of the earth's crust, which is characterized by a negative temperature of rocks and soils and the presence or the possibility of the existence of underground ice. This fact is confirmed by publications presented in the bibliographic and abstract database Scopus. At the same time, 255 publications are displayed in the system for the keyword "cryolithozone", most of which (78%) belong to authors from the Russian Federation, this is primarily due to the fact that about 60-65% of this country territory belongs to the regions of the eternal permafrost. If we consider on a global scale, then permafrost occupies about 25%. The figure 1 shows the distribution of permafrost depending on the ice content as a percentage of the area.

At the same time, the construction of buildings, structures, and elements of transport infrastructure in cryolithozone against the background of climate change, as well as their subsequent operation, necessitates solving a complex of engineering problems.
Figure 1. Length and types of permafrost [1]

It should be noted that the studies presented in the publications can be conditionally divided into several groups. Some of them are devoted to modeling and calculating the states of the cryolithozone under the operating conditions of construction objects [2-16], as well as others are devoted to the study of changes in the state of soils and ecosystems taking into account global climate change [17-21, etc.].

For example, research work [2] is devoted to the assessment of the state of the road network in the Magadan region, taking into account the changing climatic conditions of its operation. The assessment of the state of the roadway was carried out by modeling the temperature regime of the soil at the reference points, for which there were data sets on long-term values of climatic data. As a result of the study, the risk values for the considered reference points were formed.

The peculiarities of the interaction of the railway subgrade and permafrost in the subarctic part of the permafrost zone, as well as the reasons for the degradation of permafrost soils, are described in [3]. In the publication [4], variants of design solutions for self-cooling stand-alone columnar foundations of factory production in conditions of degradation of permafrost are proposed, considering the latest achievements in the area under consideration.

A laboratory study of the bearing capacity of a metal pile depending on local geocryological conditions is presented in [5].

The work [6] presents the results of the analysis of data of long-term monitoring of accidents and safety of hydraulic structures in the permafrost zone from 1776 to 2015.

Interesting within the framework of this study are research works related to the use of modern information technologies to support the construction and operation of buildings and structures in the permafrost zone.

The article [7] presents an approach to solving the problem of maintaining the stability of the embankment slope due to its artificial freezing. At the same time, to calculate the heat flow in the embankment slope, a three-dimensional mathematical model was developed in the form of an application for Microsoft Windows. The application presented in the work allows you to form a long-term forecast of the temperature field in the embankment slope, depending on the design and technological features. As a result of the research, the efficiency of using seasonal cooling devices to increase the stability of embankment slopes due to their freezing was revealed.

The publication [8] describes an approach to detecting leaks from pipelines taking into account possible damage to the pipeline foundation due to thawing of permafrost; solving problems of automatic classification of defects that led to leaks; problems of prompt detection of corrosion spots in pipelines, as well as problems of determining the current state of the corrosion process in a pipeline using machine learning technologies.

The article [9] presents an updated algorithm for assessing the predicted risk of roadway operation for the climatic conditions of Yakutsk and Urengoy from the warming conditions characteristic of these zones.
The work [10] presents a set of programs for determining changes in the boundaries of permafrost zones in the conditions of the spread of thermal fields from various engineering objects operating in the Arctic regions. In the paper [11] algorithms and software are presented for determining the boundary conditions on the surface of frozen soil, taking into account the real process of freezing and thawing of the pore solution of the soil.

Intelligent management system of the automobile road's technical and operational condition in the cryolithozone are shown in the publication [13]. This system can be used for collecting information about the current state of the road, weather and climatic conditions, characteristics of traffic flows.

At the same time, the analysis of publications indicates that the most important issue in the construction and operation of structures in the areas where permafrost soils are spread is their preservation in a frozen state. The stability and durability of structures significantly depend on the temperature regime of the soils of the foundation, the provision of which is the main factor ensuring the safety of structures during construction and operation.

The control over the provision of the required temperature regime of the base soils is carried out by geotechnical monitoring. Geotechnical monitoring is understood as a set of works based on observations of the temperature and hydrogeological regimes of the permafrost soils, deformations of foundations and overground structures of buildings and structures.

Geotechnical monitoring also includes observations of the state of structural material, soil temperature at the base of structures; the air temperature in the underground; deformations of foundations; hydrogeological regime of the foundation, dynamic and seismic vibrations. Monitoring includes a wide range of multifaceted observations, performed both in automatic and manual modes.

Thus, the presented study is devoted to the development of an approach to the automation of geotechnical monitoring in the permafrost zone to reduce the timing of its implementation.

2. Methods and methodology
Geotechnical monitoring is carried out to timely identify and prevent irreversible processes in soil foundations, deformation of buildings and structures, as well as to reduce risks and prevent emergency situations. In addition, the results of geotechnical monitoring can be used to study the operational suitability of buildings and structures, as well as assess the environmental safety of the territory, which is one of the priority tasks in the construction of buildings and structures in permafrost conditions.

At present time, the rules for conducting the geotechnical monitoring during the construction of construction sites are strictly regulated. In the Russian Federation, SP 305.1325800.2017 «Buildings and structures. Rules for conducting geotechnical monitoring during construction» was developed and put into effect. In addition, SP 25.13330.2012 «Bases and foundations on permafrost. The updated version of SNiP 2.02.04-88» is important and describes the design rules for foundations and foundations of buildings and structures erected in the territory of permafrost (permafrost) soils, which includes a chapter with requirements for geotechnical monitoring [22,23].

3. Results
According to the valid regulatory documentation in Russian Federation the generalized scheme for conducting geotechnical monitoring is made by authors and shown in Figure 2.
Figure 2. Generalized scheme for conducting geotechnical monitoring of a construction site in permafrost conditions

Figure 2 shows that in the process of carrying out geotechnical monitoring, a rather large array of data is collected, on the basis of which graphs of changes in the movement of the building foundations in time are plotted (Figure 3a), and graphs of thermometric observations of the soil massif (Figure 3b) are made and etc.

Figure 3. The examples of graphs obtained as a result of geotechnical monitoring

All of the above leads to the need of developing an automated system for collecting and processing information obtained in the course of geotechnical monitoring, where the main task will be to
automate the information processing and to present the results as a graph using a simple scheme presented in Figure 4.

![Figure 4. Generalized scheme for processing the results of geotechnical monitoring](image)

At the same time, in the process of making decisions (figure 2) for the further operation of the construction object, it is necessary to consider various combinations of deviations of the controlled parameters (including the tendencies of their changes exceeding the expected ones) from the design values and the results of heat and geotechnical forecast. The algorithm of the program and its program code, as well as the software application itself will be presented in further works of the authors.

**Summary**

Systematization of the geotechnical monitoring data and ensuring the operation of equipment synchronously in an automated mode will provide the timely notification of stakeholders about the identified deviations of the controlled parameters and reduce risks and avoid accidents.

**References**

[1] Brown J, Ferrians O J, Heginbottom J A, Melnikov E S 2001. Circum-arctic map of permafrost and ground ice conditions. Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology

[2] Yakubovich A, Yakubovich I 2021 Using the response surface to assess the reliability of the Russian cryolithozone road network in a warming climate Advances in Intelligent Systems and Computing 1258 AISC 486-495 DOI: 10.1007/978-3-030-57450-5_42

[3] Ashpiz E S 2020 The problems of the railway subgrade construction in the subarctic part of the Russian cryolithozone and the ways of their solution Lecture Notes in Civil Engineering 49 295-302. DOI: 10.1007/978-981-15-0450-1_30

[4] Rozina V E, Komarov A K 2020 Main achievements and directions of scientific research in the field of foundation construction on sites composed of permafrost in the Russian Federation IOP Conference Series: Materials Science and Engineering 880 (1) 012016. DOI: 10.1088/1757-899X/880/1/012016

[5] Kudriavtcev S, Shin E-C, Kovshun V 2020 The laboratory investigation of load-bearing capacity of the metal pile depending on the local geocryological conditions 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering ARC 159084.

[6] Kronik Y A 2019 Analysis of the Data of Monitoring the Safety of Hydraulic Structures in the Cryolithozone Power Technology and Engineering 53 (2) 191-199 DOI: 10.1007/s10749-019-01059-z

[7] Romanova E, Khokhlova Y 2020 Maintaining thermal stability of a fill slope in cryolithozone E3S Web of Conferences 192 01021. DOI: 10.1051/e3sconf/202019201021.

[8] Timofeev A V, Denisov V M 2020 Machine Learning Based Predictive Maintenance of
Infrastructure Facilities in the Cryolithozone Studies in Systems, Decision and Control 255 49-74 DOI: 10.1007/978-3-030-31328-9_3

[9] Trofimenko Y V, Yakubovich A N, Yakubovich I A, Shashina E V 2020 Modeling of influence of climate change character on the territory of the cryolithozone on the value of risks for the road network International Journal of Online and Biomedical Engineering 16 (7) 65-74

[10] Filimonov M Yu, Vaganova N A, Akimova E N, Misilov V E 2020 Supercomputer technologies for long-term modeling of permafrost changes CEUR Workshop Proceedings 2543 362-369

[11] Vinokurova T A, Permyakov P P 2019 Identification of Heat Exchange Boundary Conditions at Various Natural and Technogenic Factors Journal of Physics: Conference Series 1392(1) 012090. DOI: 10.1088/1742-6596/1392/1/012090

[12] Tumel N, Zotova L 2019 Diagnostics and mapping of geocological situations in the permafrost zone of Russia Geosciences (Switzerland) 9(8) 353. DOI: 10.3390/geosciences9080353

[13] Yakubovich A N, Yakubovich I A, Trofimenko Y V, Shashina E V 2019 Intelligent Management System of the Automobile Road's Technical and Operational Condition in the Cryolithozone Systems of Signals Generating and Processing in the Field of on Board Communications 8706742 DOI: 10.1109/SOSG.2019.8706742

[14] Yakubovich A N, Trofimenko Y V, Yakubovich I A, Shashina E V 2019 A forecast model for a road network's section traffic capacity assessment on a territory of the cryolithozone in conditions of the climate change Periodicals of Engineering and Natural Sciences 7 (1) 275-280 DOI: 10.21533/pen.v7i1.380

[15] Debolskaya E I, Gritsuk I I, Debolskii V K, Ionov D N, Maslikova O Y 2018 Effect of Bank Deformations on Pollutant Transport in Rivers in Cryolithozone: Laboratory and Mathematical Modeling Water Resources 45 (4) 542-552 DOI: 10.1134/S0097807818040073

[16] Legostaeva Y, Ksenofontova M, Gololobova A 2017 The stability of ecosystems cryolithozone in the extraction hydrocarbon feedstock World Congress on Civil, Structural, and Environmental Engineering 139598. DOI: 10.1115/awspt17.111.

[17] Desyatkin R V, Desyatkin A R 2019 The Effect of Increasing Active Layer Depth on Changes in the Water Budget in the Cryolithozone Eurasian Soil Science 52 (11) 1447-1455 DOI: 10.1134/S1064229319110036.

[18] Butakov V I, Slagoda E A, Tikhonravova Y V, (…), Tomberg I V, Zhuchenko N A 2020 Hydrochemical composition and rare-earth elements in ice wedge of the Kara Region cryolithozone key areas Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering 31(2) 78-91 DOI: 10.18799/24131830/2020/2/2483.

[19] Goncharova O Y, Matyshak GV, Timofeeva M V, (…), Bobrik AA, Tarkhov MO 2019 Autotrophic and Heterotrophic Soil Respiration in Cryolithozone: Quantifying the Contributions and Methodological Approaches The Case of Soils of the North of Western Siberia Contemporary Problems of Ecology 12 (6) 534-543 DOI: 10.1134/S1995425519060040.

[20] Pomortsev O A, Pomortseva A A, Trofimtsev Y I 2019 Cyclic Organization of Geological Environment: Permafrost Zone of Yakutia IOP Conference Series: Earth and Environmental Science 272 (2) 022059 DOI: 10.1088/1755-1315/272/2/022059

[21] Kaverin D A, Lapteva E M, Shchanov V M, (…), Sharaya L S, Shary P A 2019 Climatic geoinformation analysis of the cryolithozone in the northeast of European Russia Earth's Cryosphere 23 (4) 68-78 DOI: 10.21782/KZ1560-7496-2019-4 (68-78)

[22] Alekseev A G 2012 Geotechnical monitoring during construction and operation of buildings and structures in areas of permafrost Modern Innovative Technologies of Survey, Design and Construction in the Far North 62-67.

[23] Alekseev A G 2019 Geotechnical monitoring on permafrost (Moscow) 112