Environmentally friendly material for the construction of pile foundations on permafrost

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Abstract. Modern construction of pile foundations in permafrost conditions includes a cycle of operations: conducting geological and geodesic surveys; developing design and estimate documentation; construction and installation work; monitoring. Six main indicators are considered to determine the organizational and technological reliability of pile foundations for industrial tanks in permafrost soils: environmental performance (EF), intensity (Cf), cost (Cf), innovation (Mf), operational reliability (ORf), quality (Qf). Eco-friendliness depends on the material, the immersion technology, embedding depth, engineering and environmental survey, and other factors. Quality depends on determining the characteristics of the soil, assessing the depth of the hard frozen ground, methods for analyzing the strength characteristics of piles, pile inspection methods, materials, sinking technology, and other factors. The intensity depends on the volume and duration of the work. The duration depends on the depth of the foundation, pile installation technology, climatic conditions, soil characteristics, and other factors. The cost depends on the depth of embedding, immersion technology, material, construction area, the complexity of the project, and other factors. Innovativeness depends on introducing new technologies, resistance to climate change, material, structural changes in piles, and other factors. Operational reliability depends on permafrost soil characteristics, foundation design parameters, material performance characteristics, process parameters, operating conditions, inspection and maintenance, and other factors.

1 Introduction

Perennially frozen soil – soil that has been frozen continuously for three or more years [1].

Areas of permafrost occupy 65% of the territory of the Russian Federation and include such regions as Yakutia; Kamchatka; Krasnoyarsk Krai; Zabaikalsky Krai; and Tomsk Region; where there are a huge number of natural resources. Following the decree of the Government of the Russian Federation from 30.03.2021, No. 484 is required to ensure the accelerated development of these areas with the preservation of the environment [2].

Permafrost soils can absorb high loads in addition to their enormous strength. However, the construction of pile foundations in such conditions is a costly and time-consuming

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process. Seasonal cycles of thawing and freezing, anthropogenic factors, as well as changes in the average annual temperature affect the properties of permafrost soils [3].

Due to climatic changes over the past 15-20 years, there has been rapid warming in the permafrost zone of the Russian Federation – this can lead to the degradation of permafrost, which in turn poses a danger to the facilities already built and planned for construction on the principle of their permanence [4].

Pile foundations erected in permafrost conditions are subjected to various influences, such as uneven soil frost heave, negative friction forces, varying degrees of shrinkage, etc. [5].

An analysis of the effect of certain materials on soils was carried out to determine the rational pile material. Metal is the most environmentally friendly material for constructing pile foundations on permafrost [6].

The work aims to determine a complex indicator of the organizational and technological reliability of pile foundations for industrial tanks in permafrost soils, taking into account environmental safety.

2 Materials and methods

The methodology is based on research, modeling of organizational systems, scientific generalization, and system analysis.

3 Results and discussion

Most of the permafrost soils' oil, civil, social, transport, and gas infrastructure was built on pile foundations.

Modern construction of pile foundations in permafrost conditions includes a cycle of operations: geological and geodesic surveys; development of design and construction documents; production of construction and installation works; monitoring [7, 8].

Ecology is of great importance when choosing a construction site. The selected area must meet the following requirements: public health safety, energy, and resource supply.

Permafrost is a collection of different soil types and minerals, such as coal, gravel, and sand. One of the main reasons for engineering surveys on permafrost soils is to protect the environment, so during the survey should consider the seasonality due to changes in the soil structure in the annual period.

Construction of pile foundations for industrial tanks in permafrost conditions can cause a number of environmental problems, such as the destruction of permanent multi-layer freezing soil destruction of topography (Figure 1).

To ensure environmental safety in the construction of pile foundations, it is necessary to follow several rules:

- Comprehensive analysis of physical and mechanical properties and determination of foliation of permafrost soil.
- A detailed approach to selecting sites for constructing a pile foundation for industrial tanks.
- The use of environmentally friendly materials, which will reduce soil contamination.
- The use of modern technologies that reduce the impact on the environment.
- Observance of operating rules. Regular monitoring of permafrost and the environmental situation around the site.

When developing design solutions for pile foundations in permafrost soils, the stability factor affecting operational reliability should be considered. Further development of the

design and construction of pile foundations also depends to a large extent on strict compliance with legislation on the protection and rational use of natural resources [9].

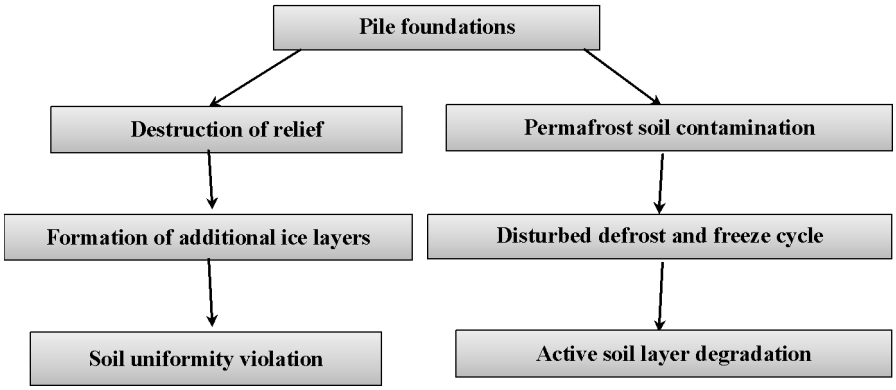

Fig. 1. The impact of pile foundations on the environmental situation around the construction site.

Currently, the following technologies are used in the production of construction and installation work [10, 11]:

- screwing piles
- boring method (installation is carried out in a borehole of smaller diameter)
- mechanized method
- immersion of the pile in thawed soil (using electricity or steam needles)
- mechanized method of installation of piles
- pile driving

To ensure the durability and reliability of tanks in permafrost conditions, it is necessary to monitor pile foundations because when the temperature changes, the soil deforms, displacing piles and causing their destruction.

When monitoring pile foundations, pressure sensors installed on piles are used to record changes in pressure in the ground, which allows us to determine the foundation's condition.

Geodetic measurements are also used for monitoring; geodetic benchmarks are installed near the piles, and surveys are taken during operation to record deviations.

Another method is micro-relief observation, angular rotation sensors are installed on the piles, and using laser ranging devices, changes in the height of the foundation and its displacement are recorded [12].

Pile foundations must be monitored to preserve the environment and identify unacceptable deviations from the design documentation.

Monitoring includes:

- daily visual observation

Visual observation includes observation of the development of negative engineering and geological processes; observation of environmental changes at the risk of soil contamination, gas emissions, etc.

- evaluation of the results obtained with the design data;
- development of a set of measures to eliminate the negative consequences;
- control over the implementation of the measures taken [13].

Organizational and technological reliability (OTR) are properties of systems and processes that ensure their performance and efficiency in case of failures and contingencies. Organizational and technological reliability is achieved through balanced control and

management systems as well as well-organized processes. The importance of OTR is especially high in critical industries such as construction and others [14, 15].

The OTR includes a set of indicators needed to evaluate the system [16, 17] (Figure 2):

J OTR = □ i,,j(Ef, Kf, Pf, Sf, Mf, ENf)R,t (1)

where R – risk aggregate
t – time period
i – set of materials
j – production process
E_f – environmental friendliness
Q_f – quality
P_f – intensity
C_f – cost
M_f – innovation
EN_f – operational reliability of the foundation and others.

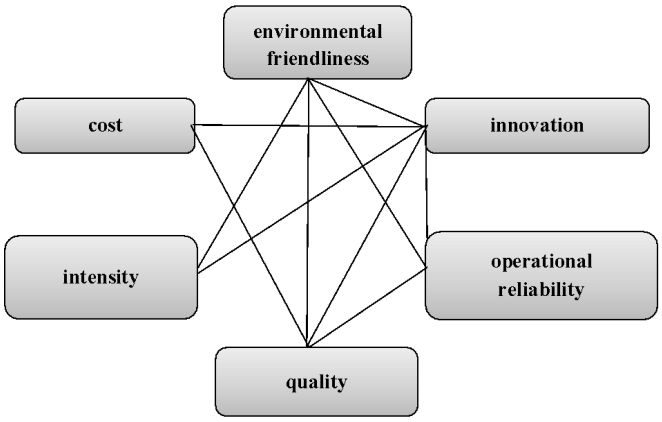

Fig. 2. Indicators of organizational and technological reliability of the production process for pile foundations.

To determine the environmental friendliness index (Ef), the following factors must be taken into account:

- Pile material selection
- Choice of pile immersion technology
- Depth of embedding
- Characteristics of engineering-environmental surveys in the construction area
- And others.

Carrying out works following environmental safety standards, the choice of environmentally friendly technology and materials will help minimize the negative impact on the environment from the foundation.

To determine the quality index (Qf), the following factors must be taken into account:

- Determination of soil characteristics
- Permafrost depth assessment
- Application of methods for analyzing the strength characteristics of piles
- Application of pile control methods

- Evaluation of material properties affecting strength and stability
- Evaluation of pile-driving technology
- And others.

Calculation of the intensity index (P_f)

$$P_f = \frac{V}{T}, \quad (2)$$

where V – the amount of work performed,
T – work duration.

To determine the work duration, the following factors must be considered:

- Depth of embedding
- Pile installation technology
- Soil characteristics
- Climatic conditions
- and others.

To determine the scope of work, the following factors must be considered:

- Depth of embedding
- Soil characteristics
- Size and type of piles
- Design features of the tank
- and others.

To determine the cost indicator (C_f), the following factors must be taken into account:

- Construction area
- Depth of embedding
- Pile material
- Project complexity
- Immersion technologies
- and others.

To determine the indicator of innovation (M_f), the following factors must be considered:

- Introduction of new technologies
- Resilience to climate change
- Application of new materials
- Structural changes of piles
- and others.

To determine the operational reliability index (OP_f), the following factors must be considered:

- Soil characteristics
- Structural parameters of the foundation
- Operational characteristics of materials
- Technological parameters
- Operational conditions
- Control and maintenance and others [18, 19]

4 Conclusion

The organizational and technological reliability of pile foundations for industrial tanks is characterized by six main indicators: environmental friendliness, quality, intensity, cost, innovation, and operational reliability. All indicators are interrelated and influence each other. The control of these indicators affects organizational and technological reliability.

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