Organisational and technological reliability of pile foundation construction flow in permafrost

Igor Stoyanov *

Moscow State University of Civil Engineering, 26, Yaroslavskoye shosse, Moscow, 129337, Russia

Abstract. The construction of pile foundations in permafrost conditions is a durable and cost-effective design that shows high performance of piles in contrast to slab, block and strip foundations. In the Russian experience of construction in permafrost conditions, the most common methods of piling are the following: sinking method, driven method, drill-and-pile method, and drill-and-pile method. Descending method, where the piles are driven into thawed and liquefied soil. Pile driving method, in which piles are driven into frozen ground using percussion mechanisms. Drill-and-pile method, which combines the use of sinking and drilling piles. Drill-and-pile method, in which a borehole is drilled first and then the piles are driven into the frozen ground. Organisational and technological flow reliability involves the efficient use of resources, compliance with standards, organisation of work processes and safety. This allows the objectives to be achieved efficiently and ensures reliable process operation. The main indicators are: system uptime without failure $T_o$, delays in information transfer $H_o$, equipment reliability $P_o$, material quality $F_o$, operator errors $D_o$. In fact, the control of these indicators affects the organisational and technological reliability of the flow and the work production system as a whole.

Keywords: pile foundations, organisational and technological flow reliability, permafrost, perennially frozen ground, permafrost, development of new territories.

1 Introduction

Perennially frozen ground - ground that has been frozen continuously for three or more years [1].

The discovery of deposits of nickel, iron ore, tin and hydrocarbons in the Arctic zone, as well as the possibility of transporting cargoes from Asia to Europe via the Northern Sea Route gives an opportunity for comprehensive development of the north of Russia.

The decree of the government of the Russian Federation from 30.03.2021 №484 requires accelerated development of the Arctic zone, for the realisation of the set tasks requires improvement of construction technologies [2].

* Corresponding author: goga.stoyanov99@mail.ru

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All buildings and structures rest on foundations. It is difficult to predict the operating behaviour of pile foundations in permafrost soils, which provides special attention to their construction [3].

To ensure the integrated development of the Arctic territories, it is necessary to develop a strategy in which modern technologies and sustainable use of resources will be applied [4].

Due to the trend of the last 15-20 years, the temperature on the planet is beginning to increase, which in turn leads to the degradation of permafrost. These phenomena pose a danger to the objects already realised and planned according to the principle of permafrost permanence [5].

The construction of pile foundations in permafrost soils is a durable and cost-effective construction, showing high performance characteristics of piles in contrast to slab, block and strip foundations [6].

2 Methods

The methodology is based on system analysis, scientific generalisation, modelling of organisational systems.

3 Results and discussion

The composition and temperature of permafrost soils determine the choice of pile foundation technology. Perennially frozen soils are distinguished as plastic (high-temperature) - temperature above -1°C, and hard frozen (low-temperature) - temperature below -1°C [8,9].

In the Russian experience of construction in permafrost conditions, the following piling methods are the most common:

- Descending method, where piles are driven into thawed and liquefied soil.
- The driven method, in which piles are driven into frozen ground using percussion mechanisms such as a hammer.
- Drill-and-pile method, which combines the use of sinking and drilling piles.
- The bored-pile method, in which the borehole is drilled first and then the piles are driven into the frozen ground.

The sinking method can only be used on soils that are solid frozen fine and dusty sands and clay soils. To use this method, the average ground temperature must be at least -1.5°C over the entire length. Steam needles are used to thaw the soils, and the diameter of the thawed soil should be 2-3 times the diameter of the pile (Fig.1). A steam vibroleader is used for borehole penetration, after the borehole is penetrated it leaves a hot soil mass, which is used for backfilling the slots. A crane loading method can be used to achieve the design grade of the pile during installation, but in some situations it may be necessary to use a vibratory pile driver.

In foreign permafrost construction practice, the steam thawing method has not been widely used due to its insufficient reliability, the difficulty of ensuring the required geometric shapes and dimensions of the borehole, the probability of collapse and swelling of its walls, as well as the large number of manual works and long freezing times. However, steam thawing of boreholes is sometimes used abroad in combination with other pile driving methods.
The driven method is a technique in which the piles can be driven directly into the ground without first drilling a borehole. This method is usually used on plastic and frozen soils of high temperature. The driven method is usually used in summer and autumn. Before starting work, it is necessary to determine the design depth of the pile, the location of the pile driving equipment, and the locations for pile delivery and driving. The following types of equipment are used to perform these works: pile driving rigs, cranes, tractors and excavators (Fig.2).
In order to drive the pile to the design grade, the soils must be plastic-frozen, high-temperature and have low strength characteristics. Driven piles are often used in areas where there are intermixed layers of warm and permafrost soils, as well as sites with non-converging permafrost.

The drill-and-pile method is the process of sinking a pile into a borehole that has been pre-drilled and filled with mortar. The diameter of the borehole exceeds the diameter of the pile by 50 mm. This method is widely used in the far north on clay and sandy soils. The ground temperature should be kept above -0.5ºC for successful performance of the work.

The installation of bored piles includes several stages that must be carried out in a certain technological sequence:

1. borehole drilling: This stage is carried out using specialised equipment, which is installed on a sand and gravel or slag base. This arrangement of the equipment allows its movement, especially when working on soils with low stability, to prevent the collapse of the soil inside the well. The borehole is drilled in the active soil layer to provide the necessary stability for the pile.

2. Filling the borehole with mortar: After the borehole is completed, the borehole is filled with sandy clay mortar to a certain level. The volume of mortar should be sufficient to fill the gaps between the walls of the borehole and the pile after sinking. This is necessary to ensure a secure bond between the pile and the soil and to prevent the penetration of water or other materials into the space between the pile and the borehole walls.

3. Pile Immersion: The pile is lowered into the filled borehole, accompanied by squeezing of the mortar. This allows the pile to set firmly and ensures a good bond between the pile and the soil.

4 Casing Removal: After the pile is completed, the casing is removed using specialised equipment such as core drilling, thermo-mechanical drilling, percussion drilling, percussion-rotary drilling, rotary drilling, rotary drilling, vapour-vibro-leader drilling and so on.

Cranes or drilling machines equipped with a winch with a rope providing the necessary lifting and lowering force can be used to drive the pile into the borehole.
Pile driving involves two main stages: drilling of boreholes and driving of piles into these boreholes using a pile driving machine. This method is used in areas with low-temperature plastic-frozen soils and requires the use of a vapour vibratory pile driver to drive the boreholes. The bored pile driving method is widely used in areas with low-temperature hard-frozen soils.

The bored pile driving process consists of two stages. In the first stage, the main boreholes are drilled, the diameter of which is 1-2 cm smaller than the diameter or side of the pile. In the second stage, the piles are lowered into the boreholes up to the specified mark with the help of a vibratory hammer or diesel hammer. In the process of lowering the pile, the soil is pushed from the edges of the pile to its centre. The melting of the soil occurs due to the heat generated by the vibration or hammer impact, as well as by dislodging excess soil from the borehole. The freezing of the piles into the ground occurs very quickly, with the temperature around the piles increasing by a few degrees, sufficient to thaw the topsoil (Fig. 4).

To perform this technological process, different types of machines are used, such as diesel rod hammers, crane, excavator, and self-propelled piling units, which are mounted on tractors, vehicles and excavators. These machines have highly mechanised operations, energy autonomy, mobility and manoeuvrability.

Organisational and process flow reliability (OPFR) is the properties of systems and processes aimed at ensuring their operability and efficiency in case of failures, unforeseen situations within the stipulated time and finances. Organisational and process flow
reliability refers to the efficient use of resources, adherence to standards, organisation of work processes and safety. This enables efficient achievement of the objectives and reliable process operation [10, 11].

OTNP highlight the indicators to evaluate the system:
- System uptime without failure $T_o$
- Delays in the process of information transfer $H_o$
- Equipment reliability $P_o$
- Quality of materials $F_o$
- Operator errors $D_o$

\[ J_{opfr} = T_o + H_o + P_o + F_o + D_o \]  

(1)

The interrelationship of indicators of organisational and technological reliability of the flow is presented in Figure 5.

Fig. 5. Organisational and technological reliability of the flow

4 Conclusions

Management of output capacity of an industrial housing construction enterprise is a complex organisational task for its management. It requires a systematic approach to the analysis of the production system of the enterprise, decomposition of its constituent structural elements. Having resorted to the process method of enterprise management and having considered the economic activity of the enterprise from the position of the life cycle of its product, it becomes possible to present it as a set of ordered interrelated processes and to consider the output power of each of them. Having investigated the factors influencing the transformation of the potential of an individual process into its input capacity and the reasons causing its loss, it is possible to take measures to increase the output capacity of this process. Consistency of output capacity of each process provides the maximum output capacity of the industrial housing construction enterprise.
References


