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Apparatus for Strengthening Soft Water-Saturated Soils by Freezing under Engineering Objects and Structures in Cold Regions

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Abstract

The paper is devoted to the construction of various earth and engineering structures being operated on soft soils in the northern regions of Russia with a pronounced continental climate and a lot of wetlands.
The problem of year-round cooling of water-saturated soil to freezing temperatures in order to convert it into a frozen state of permafrost is considered. To convert the soil into a frozen state of permafrost and keep the state all year around, including the summer period, the new soil cooling apparatus has been developed. The apparatus is economical; it has no moving parts and can operate for a long time without involving any staff.

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Keywords: strengthening of soils; freezing; thermopiles

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1. Introduction

For cold regions the most efficient approach, consisting of preserving the soil in the frozen condition, has gained widespread interest. Soils in the frozen condition possess high strength parameters but in summer the soils are in the thawing conditions in which the soils are very weak. All attempts connected with construction management of roads, bridges, buildings, and other structures are based on using devices created in the foundations of structures, railways, and motorways for thermal stabilization of soils (thermopiles or thermosyphones) [1,2]. Thermopiles usually consist of pipes plugged at the bottom and filled with fluid coolant, e.g., kerosene. The operation of thermal stabilization apparatuses involves transferring of the natural cold to the foundation bottom to maintain constant negative temperatures in the permafrost, so that the heat coming from the structures or from natural processes is balanced. The apparatuses require no power cost and automatically start working due to the difference of temperature between the soil and outside air. The applicable scope of thermal stabilization devices is wide: linear structures; engineering structures; buildings, including civil engineering applications; and hydraulic engineering structures.

Over the spring and summer period, however, when permafrost soils weaken, thermopiles do not work [3]. The fluid in the pipes congeals into a stable, laminated condition; and its circulation stops.

The summer thawing of frozen soils creates difficulties in the building and operating of structures. For this reason, a lot of problems arise, requiring support for building and transportation on weak, saturated soils in the climate conditions described. The apparatus is developed to avoid intensive actions of thawing of the frozen soils in summer period. The apparatus is economical; it has no moving parts and can operate for a long time without involving any staff.

2. The task of creating the apparatus

Therefore, the main and first task of creating an apparatus ensuring year-round soil cooling in large areas (no less than 2,000–3,000 m^2) was set to prevent thawing of the soil under railways, motorways, buildings, and other constructions for a period not less than 4 months. The apparatus should be easily transported to scarcely populated regions (the second task) and be operational in a self-inclusive state without permanent working staff (the third task), and also be environmentally clean and of low price (the forth tasks).

For completing the tasks, the following suggestions are contributed.

For cooling the soil, screw thermopiles are proposed, the blades of which ensure lowering the piles into the weakened soil and at the same time function as heat-exchange devices. This construction helps to freeze much wider zones surrounding the axes of the piles.

The primary sources of energy to ensure operation of the apparatus use the natural sources - solar radiation and wind. In the Yamal-Nenets autonomous District, it is possible to use related gases after burned on oil production additionally. The cooling of thermopiles is supposed to be realized with help of a coolant (kerosene) having negative temperature, moving naturally without pumps, and being cooled with the natural sources named.

The system of thermopile cooling is proposed to be made in a block-modular way, using one module for cooling several hundreds of thermopiles.

3. Description of the apparatus

The proposed apparatus is covered by a patent [4] and the scheme of the apparatus is presented in Figure 1.
The apparatus consists of the thermal piles (1) connected by pipes (3) to the thermal battery (4) and the heat-exchange unit (5). The thermal battery is filled with thermal-energy storage material. The effectiveness of the thermal battery (4) is determined by the mass and volume of thermal-energy storage material. There are promising material, based on the reversible phase transitions providing high energy density and a wide range of operating temperature of the battery.
The promised storage materials are divided into low-temperature (up to 120 ° C), medium (120-400^{o}C) and high temperature (400-1000^{o}C).

Organic compounds such as paraffins, petroleum waxes, and etc., are convenient to their chemical inertness and stability characteristics in the melting-solidification cycles but have a low operating temperature, which decreases the velocity of the circulation of coolant. Salts and alkalis have the high operating temperatures but very high