Device For Thawing Of Frozen Soils

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Abstract: The article examines the efficiency of the use of radiation and convective method applied to the creation of a new mobile device for thawing of frozen soils. We present a study sets the existing devices, methods and techniques used for thawing of frozen soil, elicit their disadvantages. The requirements for a new device are defined, for example the time for thawing of 1 m^2 of frozen soils should be no more than 3 hours. The requisite thermal power of the device is defined (15 kW), as well as the relation of the depth of freezing and time based on the proposed mathematical model and the results of natural and laboratory tests. The article also reviews the technical characteristics, principle of function, general form and the main advantages of the new mobile radiation and convective device. It gives an assessment of the device efficiency based on the comparative characteristics of technical means. The fulfilled work and studies have shown the expediency of radiation-convective method for thawing frozen soils.

[Sinitsyn A.A. **Device For Thawing Of Frozen Soils**. *Life Sci J* 2013;10(4):1651-1656] (ISSN:1097-8135). http://www.lifesciencesite.com. 218

Keywords: Gas radiators; burners; frozen soil; thawing of soil; radiation-convective device; repair and construction work

1. Introduction

The essence of methods of thawing and defrosting of frozen soil lies in changing of the structural state of one component – water (transition from solid to liquid) with the supplement of additional energy from the outside without breaking of the structural condition of the soil.

The same thermophysical processes take place when using a range of methods for preparation frozen soil for working by supplement of additional energy into the soil. In literature they are called artificial methods of thawing of soil [1].

Thawing of frozen soil is a complex thermodynamic process taking place in a heterogeneous capillary-porous environment complicated by the presence of phase transitions of soil moisture [2]. During the heating of the soil under the influence of thermal energy of the heater melting of the ice and redistribution of formed moisture and displacement of the boundary of de-frosting takes place. The intensity of the process and the formation of the temperature field depends on the soil conditions and thermal characteristics of the heater [3].

The depth of soil freezing depends on many factors and their combinations and can reach two meters or more. The more the depth of freezing is the less energy consumption are required for realization of the work. Defrosting is required if the size of work is not big or when it is impossible to loosen the soil with mechanical means because of technical or safety requirements in complex urban underground stuff [2].

The main disadvantages of the known methods of thawing of frozen soils are big energy consumption and long-term defrosting. The work is devoted to the creation of a new device which has none of these disadvantages. The article presents the results of research on the creation and the assessment of the efficiency of the device used for thawing of frozen soils during repair and construction work.

2. Review of Research and Methods

The search for new technology solutions and for systems of soil preparation during repair and constructive and emergency works is an important problem in our country because of its severe climate. The high mechanical hardness of frozen soils prevents from their operation with conventional technical means, that is why preliminary preparation of such soils are necessary. The basic methods of preparation of the soil upon conditions of winter are: the thawing and the subsequent operation of the thawed soil, preliminary mechanical loosening and operation of the of frozen soil. Now mechanized methods are the most prevalent but sometimes it is difficult or impossible to use special means of loosening or cutting soil because of technical or safety requirements in complex urban underground stuff. Primarily emergency, utility and energy supplying services and organizations face the problem of frozen soils operation within urban environment. In winter a large number of accidents is connected with ruptures of pipelines of various purposes. The time of the site recovery depends on the rapidity of opening of the damaged pipeline by repair crew. Another important aspect of the problem mentioned above is the soil preparation before construction. Building organizations working in winter face this target. It is impossible to squeeze frozen soil, that's why the usage of special means of loosening or cutting soils without enough amount of thawed soil does not allow to use the mixture for formation of mounds, backfilling of the ditches because it would cause ground sag after melting. Under the circumstances the usage of alternative methods of the soil operation during repair and constructive and emergency work expands the technical capacity of the organization and ensures the efficiency of the work. These questions can be solved due to the soil defrosting [2].

On several characteristics thawing of frozen soils is less efficient than mechanized methods. But in the cramped conditions of a complex urban underground stuff, in hard-to-reach places or if the size of work is not big or when it is impossible to use more economical and less energy consumption methods thawing of frozen soil is required. There are a large number of soil heating methods depending on the source of heat (electric power, steam, gas, fuel oil, coke, hot slag, etc.) and on the principle of action. The content of the method of defrosting is that the heat transmitted to the lay of frozen soil thaws the ice in its pores and turns the soil into liquid state. Existing methods of defrosting have the limits in its use because of high energy and time consumption or they are unacceptable because of the reasons of safety during the excavation of engineering communication (gas, electric networks). For instance, thawing of frozen soil with the help of open fire and electric field is restricted during certain kinds of work, for example, heating the site with chilled gas pipelines should be performed with a warm heater only. In this regard it is necessary to search for more effective, technically safe and economically justified method of thawing of frozen soils [6].

Summarizing these arguments we should say that the question of creation of energy saving mobile device for quick thawing of frozen soils during repair and constructive and emergency work is burning.

The review of the current technical level of development of means and methods of frozen soils thawing shows a wide range of them. Some problems are described in [2-9]. On the market the rival production is presented with the following devices: devices for soil and concrete heating WACKER NEUSON, steam generators STEAM MATE, liquid fuel infra-red heaters Master XL, thermal and electrical mats THERMOMAT, etc.

However all known methods and devices are ineffective and can't be used for quick thawing of soil in winter in conditions of a modern city. The patent search has shown the cleanness of the proposed solution, allowed to elicit the analogs and prototypes of technical equipment for the proposed device.

The idea of creation of a mobile energy-saving device for a rapid thawing of frozen soils during construction and repair and emergency works defines a new method of approach for heating of a frozen layer of soil with different parts due to the combination of radiation and convective components of heat transmission from the combustion of gas fuels.

Figure 1 shows the results of comparative analysis of the current level of the technical means and methods of realization of the process of artificial heating of frozen soil. Basing on research on the selection and rationale of the best variant of artificial thawing of frozen soil we have chosen artificial surface vertical heat (radiant and convective) supply of thermal energy with mobile device using gas fuel. You can find more information about selection of the best variant in the following works [9 - 11].

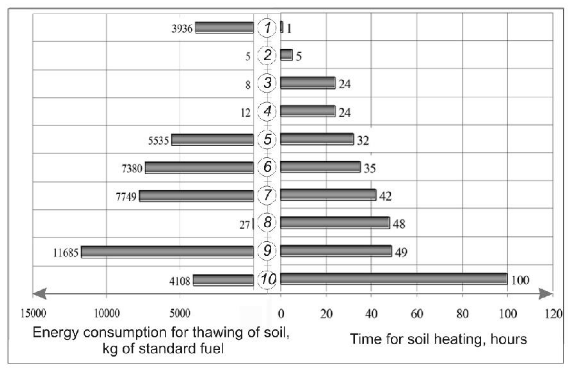

Figure 1. Comparative diagram of the main characteristics of different methods of the artificial thawing for 1 м^3 soil: 1 – high frequency currents; 2 – burners of infra-red eradiation; 3 – torch gas burner under a box; 4 – bonfire under a metal box; 5 – electric-reflected ovens; 6 – horizontal jet electrodes; 7 – electric enclosure; 8 – surface steam registers; 9 – vertical surface electrodes; 10 - electric heating panels

The target of creating device is to provide thawing of small areas at a predetermined depth in a certain time during emergency or repair and construction work if the other methods of thawing cannot or shouldn't be used.

The objective audience was defined according to the main characteristic of the executed work – this is preparation for operation of small amounts of frozen soil in conditions of negative temperatures outside. Depending on this characteristic all the consumes can be divided into the following groups: repair and construction organizations, emergency and utility services. Each of the objective groups were was studied depending on the answer to the question: much time should it take to thaw the frozen soil of a certain area and depth.

Device productivity should provide thawing of frozen soil in the definite time for the accident liquidation. Studying each of the groups we have elicited the time required for opening and repairing the damaged communication. Analyzing the total time of reconstruction work we have made the conclusion that it takes maximum 4 hours to open the communication in winter. We specify the depth that frozen soil should be defrosted basing on the climate of Vologda Region. By the end of winter in this region the depth of soil freezing is up to 1.5 meters. We have studied the acceptable depth of communication site for each of the objective group, they have formed the range from 0.8 to 2 m. Thus the requirement for the device is: it should take maximum 4 hours to thaw up to 1,5 m of frozen soil.

The size of the device for thawing of frozen soil were defined according to the area of the soil that should be defrosted and the requirements to the condition of transportation. During reconstruction work of different types of engineering networks and communications it is necessary to dig a ditch which minimum size are defined in the certain normative documents. For the objective groups mentioned above the minimum width of ditches is from 0,5 to 2,4 m. By reason of transportation the device must fit to the bodies of the cars used by emergency and repair teams of the cars and be easy to be carried to the work site. One of the most common types of cars in Russia used for the transportation of small loads is by GAZ Gazelle 3221-90. Basing on the minimal size of a ditch required for the operation and size of the body of Gazelle it was set that the dimensions of the device should vary from 1 m to 1,5 m in width and from 1,5 m to 2 m in length. It was specified that the quantity of personnel working with the device is a team consisted of two people one of which is a driver.

The main issue in the development of the requirements for the device is to define its productivity.

The Energetic device productivity depends on many factors: type, structure of frozen soil and its thermophysical properties, climatic conditions and the nature of the soil surface, size of thawed soils and the frequency of its removal from the ditch, etc. Regarding the latter factor we should notice that the experimental research on the speed of thawing of frozen soil with the experimental device carried out in natural conditions showed that the way of removing of the thawed part of the soil influenced deeply on the speed of thawing soil. With the energy consumption 1,3 kW and the thawing area of bulk sandy soil 85 $\bullet 10^{-3}$ m^2 the common experimental relation of the changing of the depth of artificial thawing of the soil in time is shown (see figure 2).

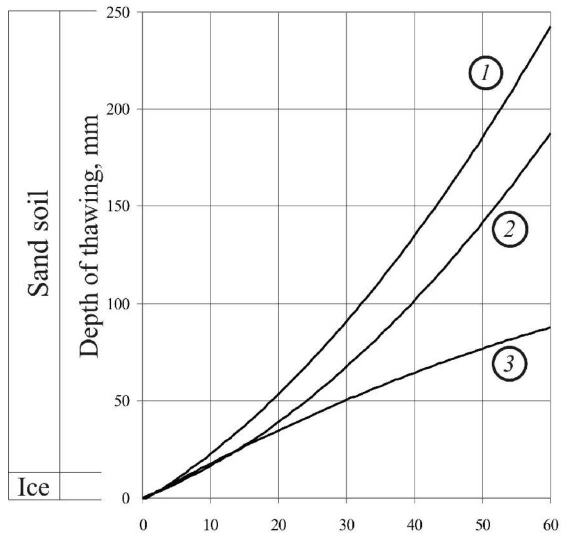

Figure 2. The summarizing experimental relation of change the depth of artificial thawing of frozen soil in time: 1 - constant removal of thawed part of frozen soil, 2 – periodical removal of thawed part of frozen soil, 3 - without removal of thawed part of frozen soil

The graph shows that the speed and thereafter the depth of thawing depends on the conditions of removal of thawing soil. If the soil is removed constantly (every 5 min) the depth of thawing is 3 times more than without removing it. If the removing of the soil is periodical (every 15 min) the depth of thawing is 2 times more than without removing, and this fact was taken into consideration during the development of the work technology on the device exploitation.

The mathematical model of heat transmission in frozen soil with the surface supply of thermal energy based on the work [8] and some studies [12, 13] was tested by experimental studies in natural and laboratory conditions. The convergence of the results between calculated and experimental studies (see figure 3) allows to say that the chosen model of heating the soil may be used in calculating of the heat capacity of a new device.

The questions studied above allowed to formulate common requirements to developed device for frozen soils thawing. Based on the mathematical model power of the device was assessed. During thawing of frozen soil of 1.5 m^3 for 4 hours with its periodic removal from the ditch the heat productivity is 15 kW which is equivalent to the consumption of liquefied gas 1.17 kg/h (see table 1).

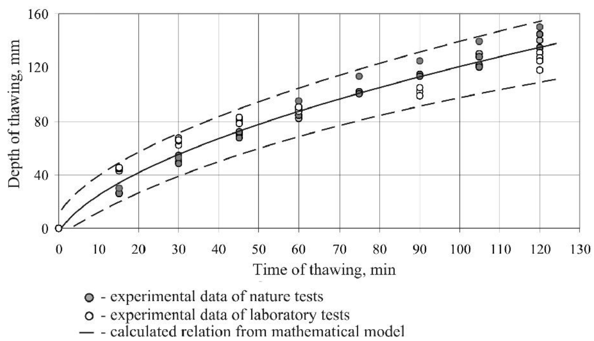

Figure 3. Graph of measuring of the depth of freezing

Table 1. Technical characteristics of a new thawing soils device

Characteristic	Unit of measurement	Quantity
Thermal power	kW	15
Electric power	kW	0,5
Efficiency	%	92,5
Consumption of gas (liquefied)	kg/h	1,17
Thawing time	h	3
Area of thawing	m	1 x 1
Depth of thawing	m	1,5
Weight of device	kg	110
Maximum pressure	Pa	5000
Size	mm	1200x1600x700

The device is a unified mobile gear (see figure 4) divided into three separate but connected zones: working, technical and a zone of electric engine where the burner, flue pipe, smoke exhauster, reflective screen, fan, heat-exchange unit and air heater are set. The work of the fan is carried out due to the electric engine connected with an electric accumulator. The electric engine and accumulator are placed in the zone of electric engine, the flue pipe, smoke exhauster, heat-exchange unit and air heater are placed in the technical zone and the reflective screen - in the working one.

Thawing of frozen soils with artificial surface method is achieved by using the device for radiation and convective heating of the working bodies. The basic equipment of the invention includes a burner which mixes fuel and air to form fuel-air mixture and to sustain its stable combustion, flue pipe where the growth of a torch and moving of the flue gases takes place, as well as heating the pipe to create a radiant and convective heat transfer from the tube to the environment, smoke exhauster inducing the movement of flue gases from the burner unit along the flue pipe to its exit to the air heater. In the air heater heat exchange between the outgoing flue gases and cold air happens, as a result the initial air is heated to the wanted temperature for the increasing of the efficiency of the mixture combustion. The reflective screen is at the top of the working zone of the device above the fire tubes and the fan. The fan creates the radiant and convective heat transfer and carries out the motion of heated gaseous agent in the working zone limited with the reflective screen and the heated material. The fan work is organized due to the electric engine connected with the electric accumulator.

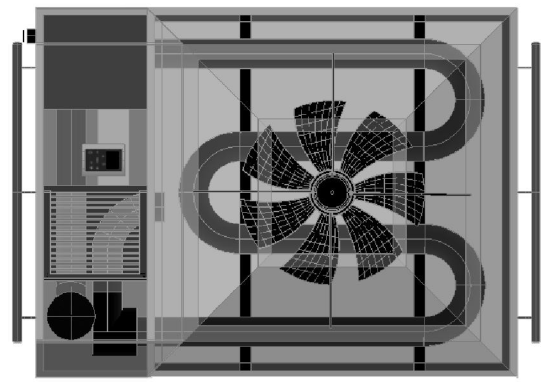
Figure 4. Common view of a mobile radiation and convective device

The efficiency is achieved by optimizing of the location of the basic elements of the device and combination of convective and radiative heat transfer methods.

3. Results

To assess the efficiency of the results we have made the comparison of the two devices which are the closest analogues to the developed device: thermoelectric mat THERMOMAT and the device WACKER NEUSON E700M – working on a liquid fuel gear used for defrosting the soil up to a depth of 1.5 m and for treatment to concrete. Table 2 shows the results of the comparison. The marked figures show the technical mean advantages over the other ones on this characteristic.

The proposed device is more effective on such characteristics as specific power of thawing for 1 m^2 of soil, defrosting time to a depth of 0.5 m, cost of thawing (in EUR/h·m^2) as well as temperature of heating. If we take into consideration such factors as size and weight of the device thermo mat is more attractive from the point of view of transmission and transportation, however, because of its less efficiency during thawing (about 30 hours.) these advantages are not substantial. The second analogue - a device for warming of soil and concrete E700M – can be used only for large areas of warming (up to 400 m^2), that is why it is ineffective and irrational in our conditions.

Thus, we can say that in comparison to the existing technical tools the developed device is effective and competitive.

In addition we have specified key capability of the proposed device:

- its construction and design have no analogues on the market of technical means for the repair and construction work;
- minimal time of thawing of frozen soil in comparison with the existing devices;
- device low specific energy consumption with combined method of heat transmission provides high efficiency of the unit;
- mobility and compactness of the device allows to move it in a cargo transport and produce work by the group of two men under any circumstances of cramped urban landscape;
- flexibility of regulating heat productivity of the device provides the possibility of using it for defrosting of building materials and heating of the building constructions of any purposes;
- energy saving combination of the device elements and thermo hydrolyzed body allows to carry out repair and construction work in any climate conditions.

Table 2. Comparative characteristic of the technical properties

Characteristics	Device	Thermal electric mat	Devices for soil and concrete heating E700M
Device power, W/m^2	7500	340	180
Time of thawing up to the depth of 0,5 m, hour	1,5	30	24
Expenses for thawing, EUR/h·m^2	0,1	0,6	3,7
Temperature of heating, ^{0}C	250	70	82
Size, mm	1200 x 1600 x 700	550 x 2740 x15	3390 x 1500 x 1970
Mass, kg	110	20	3346

Acknowledgements:

Foundation item: The Project of federal program Science and Pedagogical Personnel of Innovative Russia for 2009-2013 (No.: 14.132.21.1723). Authors are grateful to the The Ministry of Education and Science of the Russian Federation for financial support to carry out this work.

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8/19/2013