Present Methods of Preparing Frozen Ground for Excavation

Sovremennye sposoby podgotovki merzlykh gruntov k ekskavatsii

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Gorodskoe Khoziaistvo Moskvy,
vol. 27, no. 12, p. 19-23, Dec. 1953

Translated from the Russian
by Katherine Martinoff,
USA SIPRE Bibliography Project,
Library of Congress

U. S. ARMY SNOW ICE AND PERMAFROST RESEARCH ESTABLISHMENT
Corps of Engineers
Wilmette, Illinois
The 10-year plan for the reconstruction of Moscow calls for extensive ground work such as the excavation of foundation pits, trenches for the construction of buildings, and underground installations.

The present working method, in which only 20% of the year's work is done during the five winter months, is inefficient, since construction requires an even work distribution throughout the year. This means that 40% of the work should be done in the winter months. It is imperative to find effective methods for preparing frozen ground for excavation.

Various mechanical methods for working frozen ground are used in Moscow, the most noteworthy being blasting, mechanical crushing by means of wedge-shaped strikers, and soil thawing with warm water (water needles) and tubular electric heaters (electric needles).

Loosening the ground with small blasts is the most inexpensive and simple method. Small blastholes and the method of horizontal holes are the methods used.

The magnitude of the charges to be exploded in these 75-mm diam blastholes is approximated according to the formula: \( Q = KW^3 \) where \( Q \) = the quantity of the charge in kg.

\( K \) = the calculated specific consumption, kg/m³, of explosive used in the charge, depending on the properties of the explosive and of the ground.

\( W \) = calculated line of least resistance in m (equal to the depth of the blasthole).

According to data of the All-Union Bureau for Industrial Blasting Operations, the explosive factor \( K \), using "ammonite No. 9," should be: 0.8-1 kg/m³ for clayey soils and soils containing industrial debris; 0.6-0.8 kg/m³ for ground containing boulders; and 0.4-0.6 kg/m³ for sandy and humus soil.

The spacing between blastholes in electrical blasting varies from 0.8 - 2.0 \( W \), depending on the desired degree of fragmentation. The depth of the boreholes should be 0.75 the thickness of the frozen layer.

The method of horizontal holes is applied when the ground is frozen to a depth of 1.5 m and more. Concentrated charges are placed horizontally below the frozen layer. The magnitude of the charge is determined by the above-mentioned formula: \( Q = KW^3 \), where \( W \) is the calculated line of resistance, equal to the thickness of the layer to be destroyed.

The cross section of the holes ranges from 0.1x0.1 m to 0.25x0.25 m and the spacing between the holes equals 1 - 2.5 \( W \). The length of the holes is 1 - 1.2 \( W \).

Most effective results are obtained by blasting when there are two exposed surfaces. It is first necessary to blast vertical holes. Charges are then set off in rows parallel to these holes.

The cost of fragmentation of the ground, according to the Mosvzryvprom (Moscow Bureau for Industrial Blasting Operations) is 3 - 5 rubles/m³.

Despite the simplicity and low cost of this method, its application in cities is limited because of the safety hazard to the inhabitants and structures in the vicinity of the blasting site. However, present techniques of blasting have been perfected to such an extent that the danger to population and buildings is reduced to the minimum. Nevertheless, it would be desirable to simplify procedures still more and to further extend the limits imposed on blasting.

When the depth of freezing does not exceed 0.7 - 0.8 m and the height of the holes is 1 m greater than the thickness of the frozen layer, foundation pits and trenches can be excavated by mechanical means with wedge-shaped strikers. This method is successfully used by the Moscow Administration of Underground Construction.
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The striker is a cast iron wedge, weighing from 1.5 to 3 tons, suspended from the boom of a derrick of an excavator or crane. It is dropped from a height of 10 m or less and breaks the frozen ground into fragments which are easily excavated.

On the construction site of the Moscow Administration of Underground Construction, a 2.5-ton striker is dropped from a height of 9 m in special guides. To safeguard the excavator from damage from the unwinding cable, a tripping mechanism is used, which, however, requires an additional worker to fasten the cable hook to the ring of the striker after each strike.

By working intermittently with the striker and the scoop, the excavator OM-201-0.5 excavates up to 150 m$^3$ of frozen ground 0.7 m thick in one work shift.

The cost of the work is not more than 5-6 rubles/m$^3$.

A unit of the Ministry of Housing and Civil Engineering of the USSR devised an attachment to the C-80 tractor consisting of a guiding frame 4.5 m high and a steel wedge-shaped striker fastened to the frame by two channel-bar sliders. The sliders permit fragmentation of frozen ground in trenches and foundation pits to a depth of 2 m without deflection of the striker, with a working capacity of 130-200 m$^3$ per work shift, depending on freezing depth and soil type.

The Administration of Housing Construction of the Executive Committee of the Moscow Soviet successfully used a rounded striker weighing 2-2.5 tons instead of the wedge-shaped one. The advantage of the rounded striker is one of shape; changes in its position on dropping do not lessen the effectiveness of the impact. Wedge-shaped strikers, on the other hand, have to be dropped in a specified position or their impact force is reduced considerably. According to the Administration of Housing Construction, rounded strikers provide enough ground fragmentation for two excavators.

In order to increase the efficiency of this mechanical method, it is necessary to perfect techniques and to determine experimentally the most effective size and shape of strikers for various operating conditions.

At the end of winter, when freezing depths exceed 0.8 m and reach 1.5 m or more, the mechanical method becomes less effective. In this case, and when blasting cannot be performed for some reason, various methods of thawing the ground are applied, of which the most effective are thawing with warm water (water needles) and with tubular electric heaters.

Thawing with warm water is seldom used since it requires extensive preparatory work and thorough control of the installation. Besides, both the working technique and the equipment are not sufficiently developed.

The installation, developed by the VNIOMS (All-Union Scientific Research Institute for the Organization and Mechanization of Construction Operations), consists of a water boiler, a tool for drilling frozen ground, and a system of water needles connected with rubber hose.

The water boiler devised by engineer I. M. Pushkarenko (Fig. 1) is mounted on a uniaxial trailer. It consists of fire and air chambers and gas coils 50 mm in diameter, making four turns in order to utilize heat from exhaust gases. The total heating surface of the boiler is 5.5 m$^2$ and its water capacity is 400 liters.

A centrifugal pump, with a working capacity of 6 m$^3$/hr and a pressure equivalent to a 7 m column of water, is also mounted on the trailer on the same axis as a 2.2-kw electric motor. The pump, which is connected to the return line of the installation, sucks cold water from the needles and feeds it into the coils of the boiler, which uses solid fuel. The boiler is provided with a blower consisting of a small ventilator and a 0.25-kw motor. The mean coal consumption of the boiler at air temperatures of -20°C is 25-30 kg per work shift.

The water needles (Fig. 2) are made of two pieces of pipe with internal diameters of 63 mm and 25 mm, the smaller inserted into the larger. To eliminate possible clogging, a sleeve with a lid 25 mm in diameter is welded into the upper portion of the pipe.
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The thawing procedure is as follows: in an area cleared of snow and ice, 1.3 m deep holes are drilled at intervals of 1 m. The needles are inserted in the holes and rubber hoses are then connected to the suction and heating pipes of the boiler in a closed circuit. The needles can also be joined in a parallel series by means of general collector connection. To avoid freezing, the needles are covered with a 5-6 cm layer of sawdust or felt. Hot water is fed into the internal pipe. It flows down, enters the larger pipe, rises to the top, and flows to the next needle.

One boiler, heating water to 40-70°C, serves 50-60 needles simultaneously. The thawing process lasts several days. The cost of thawing does not exceed 10 rubles/m³.

The disadvantages of the method include the slowness of the process and the danger of freezing in case of a breakdown or electrical failure.

However, this method is inexpensive and should find wide application if the necessary equipment is mass-produced.

The thawing of frozen ground by electrical heating is widely used, in spite of the higher cost, because of the simplicity of the method and the rapid thawing.

The most inexpensive method of electrical heating has proved to be that proposed by N. I. Chernyshev, which uses tubular electric heaters. It is profitably used at the present by construction organizations of the Executive Committee of the Moscow Soviet. This method has a number of advantages over such other methods as horizontal and vertical electrodes, reflection heaters, etc.

It offers protection against electrical shock, provides a means for regulating the temperature, reduces the length of the thawing process, and consumes a minimum of electrical energy.

Figure 1. Water boiler system devised by engineer I. M. Pushkarenko.

Figure 2. Water needles. 1. Outer pipe. 2. Inner pipe. 3. Outlet. 4. Plug.

The equipment of the heating station includes:
1) a control and distributing panel, located in the cab of a trailer;
2) a system of tubular heaters with a total of 60 kw;
3) a supply cable;
4) rubber-sheathed, split cables for switching on the heaters;
5) a drum for winding the rubber-sheathed cable;
6) a device for drilling holes in frozen ground;
7) a tool kit.

The tubular heater, shown in Fig. 3, is used for deep warming of frozen ground. The casing of the heater is made of two seamless steel pipes with an internal diameter of 12 mm. Spiral heating elements of Nichrome wire are mounted inside the pipe. The spirals are provided with terminals for connecting them to the power source. Threaded brass tubes are welded to the upper sections of the terminals to facilitate fastening of the nuts. The pipes are filled with pressed magnesium powder, which has dielectric properties and good thermal conductivity. This design protects the terminals and spirals from short-circuiting and prolongs the life of the spirals which attain a temperature of 350°C. The capacity of each heater is 0.5-1 kw. The depth to which the heater is sunk is determined by a flange. The heaters are rated for 127-220 v.

The working procedure begins by clearing the area of snow and ice and by drilling holes for the heaters.
The drill, designed by N. I. Chernyshev (Fig. 4) and manufactured by the Administration of Housing Construction, is fast working, has no reducer, and is provided with a 5-kw electric motor, working at 1450 rpm. It is attended by two workers and drills 180 holes, 55 mm in diameter and 1.5 m deep, in one work shift.

The Moscow Administration of Underground Construction uses the M-1 drill rig (Fig. 5) which is mounted on a uniaxial trailer. The rig has a 3.4-kw electric motor and a reducer which decreases the number of rotations from 1450 to 510 rpm. The drill produces 50-55 holes 50 mm in diameter in one shift with the aid of two workers.

The heaters are inserted into the holes; their number depends on the power of the motor and the volume of ground to be excavated.

The interval between the needles is determined by the desired heating regime and usually varies from 0.5-1.3 m. Only the ground immediately surrounding the needles is heated. Soil heated to 1-2°C is easily removed by excavators together with fragments of frozen ground between the heated zones.

The time required for heating varies from 12-14 hr. Heating is done during the night shift, when electric consumption is low. During the day, the thawed ground is removed and the adjoining area is prepared for heating.

The heating regime may be varied by switching off part of the heaters during specified time periods. For this reason, the heaters are divided into two groups, which are used alternately. The municipal power network, as well as a mobile electric station of 50-100 kw, serve as power sources. In the latter case, the work is done by a brigade of seven workers, consisting of an electrician, three relief electricians, and three drillers.

According to the Moscow Office for the Mechanization of Housing Construction, the power consumption per cubit meter of thawed ground varies from 12-16 kw hr. The cost of thawing depends primarily on the cost of electricity.

Field work and laboratory experiments showed that the application of high temperatures for thawing ground is impractical since it leads to overexpenditures of heat. On the other hand, when the temperature is too low the process of thawing is slowed down considerably. Thus the optimum temperature regime (for heaters) ranges from 80-100°C.

A design for tubular heaters has been proposed recently which differs slightly from the above. Ia. B. Finkel'shtein and N. W. Troitskii devised an electric heater which they called the "liquid static needle" (Fig. 6). The needle is filled with mineral oil, which has good dielectric properties. The heat source is a welded wire spiral, through which a 7-9 v electric current flows. Each needle consumes 180-290 v, and the temperature of the oil in the upper part of the needle exceeds 100°C. From 24-31 needles are connected to an a-c network of 220 v. The total capacity of the system is only 5.7-7 kw, easily obtainable from a city power system.
The needle designed by A. P. Kir'ianov (Fig. 7) for the same optimum temperature regime consists of a metal gas pipe with an internal diameter of 63 mm, and 1.2 m long. An ebonite rod with a Nichrome wire wound around it is inserted into the pipe. The space between the rod and the pipe is filled with transformer oil which heats up to 60°C.

These needles were tested in the field with satisfactory results. The electric power consumed in thawing 1 m³ of ground was 11.4 kw/hr.

The manufacture of these installations was entrusted to the Electromechanical Instruments and Apparatus Plant (EMIZ) of the Streetcar Administration of Moscow.

In the search for other effective methods of working frozen ground, the Technical Administration of the Moscow Soviet, together with the Moscow Administration of Underground Construction and the Institute of Mining of the Academy of Sciences of the USSR, are engaged in working out the design of an excavator scoop which is provided with pneumatic hammers instead of teeth. Such a scoop was manufactured by the Trust "Moskvogokanalstroii" and tested on construction sites in 1952. It was provided with pneumatic hammers OMSP-5, the design of which was altered after preliminary investigations.

The results of the test confirmed the soundness of the underlying principle and showed at the same time that the scoop required hammers with a higher impact force. Hammers
with the necessary force have already been designed. A scoop, equipped with these hammers, will be manufactured and tested in 1954.

Another interesting suggestion is that of cutting the ground into sections which are easily excavated. Tests, made by the VNIOMS on the construction site of the Don-Volga Canal, showed that ground frozen to a depth of 1.5 m and cut to a depth of 60-80 cm is easily excavated without overloading the motor. But only one phase of the problem was solved, since preliminary cuts were made manually. The solution of the rest of the problem, i.e. the design of a machine for precutting, is being worked out by the Administration of the Executive Committee of the Moscow Soviet, VNIOMS, and the Institute of Mining of the Academy of Sciences of the USSR. At present VNIOMS is building a test model of a precutting machine for frozen ground. This machine is coupled to the C-80 tractor. Its principal mechanism is a serrated disk, 2100 mm in diameter.

In order to share the experience gained and to devise means for further increasing the effectiveness of excavation in winter, a meeting of builders was held at the Technical Administration of the Executive Committee of the Moscow Soviet in cooperation with VNIOMS and the Institute of Frozen Ground Studies and Mining of the Academy of Sciences of the USSR. It was decided that the most effective methods of preparing frozen ground for excavation at present are the methods described above, blasting, mechanical crushing with wedge-shaped strikers, and thawing with water needles and tubular electric heaters. All these methods can be effectively used in construction, depending on local conditions and the resources of construction organizations.