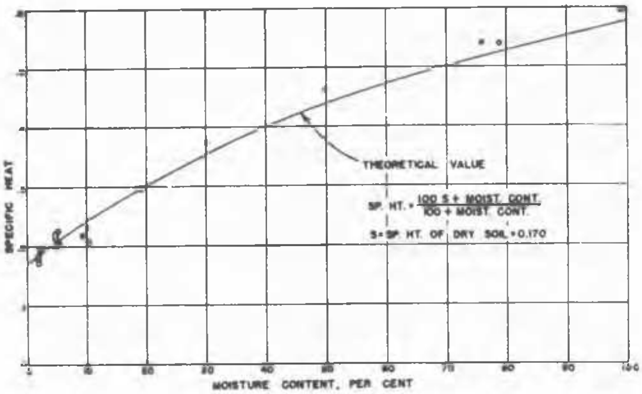

Relationship of specific heat of soil-water mixtures and moisture content.
Soil P 4701 graded Ottawa sand. Mean temperature 70° F.

FIG.5

CONCLUSIONS.

1. The specific heats of a variety of soils-(sands, silt loams, and crushed rocks)-differ by only a small amount (about 0.01) and average 0.19 at 140° F.
2. Specific heat values of soil decrease with a decrease in temperature. In a temperature range of from 140° to 15° F, the change amounts to approximately 11 per cent for a drop in temperature of 100° F.
3. Based on tests on just one soil, it may be stated that the specific heat of soil-water mixtures may be calculated by proportion according to the percentage by weight of the two components and the respective specific heats.
4. In making specific heat tests by the addition of soil to water in a calorimeter, the heat of wetting of the soils must be taken into account in the calculations.

ACKNOWLEDGEMENT.

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APPARATUS FOR MEASURING THERMAL CONDUCTIVITY OF SOIL

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GENERAL DISCUSSION

As a part of a comprehensive program of research on problems encountered in building structures, such as runways and buildings in arctic regions where a condition of permafrost, or permanently frozen ground, exists, the University of Minnesota, Engineering Experiment Station, under contract with the Corps of Engineers, Department of the Army, undertook a study of the thermal conductivity of soil. Since soil is a material with properties entirely different from those types of materials which had previously been subjected to thermal conductivity tests, such as building materials and insulation, an entirely new apparatus was designed and built for these tests. The apparatus had now been in use for about two years, and since it is thought to be unique and possibly useful in other fields of research, it is described herein.

The design of the apparatus was patterned in part on the hot-plate equipment in use at the University of Minnesota for testing materials used in insulating buildings and in part on apparatus used by the U.S. Bureau of Reclamation for tests on concrete. The testing of soils called for a test chamber into which the material could be compacted to any desired density and at any selected moisture content. For this reason a tubelar type container was selected.

For purposes of description, the apparatus may be divided into the following parts:

1) A tubelar soil container consisting of a central pipe containing heaters and an outside cold chamber, together with a refrigerated, insulated box to keep heat losses at a minimum;
2) A motor generator with an exciter and voltage regulator for supplying power to the heaters;
3) A condensing unit, cooling and mixing tanks, and circulation system for supplying alcohol to the cold side of the soil container, with provision for controlling the alcohol temperature to attain the desired soil temperature on the cold face;
4) A system of power and temperature measurement and control.

A general view of the test apparatus is shown in Figure 1. In the photograph the cooling and mixing tanks are at the left front. This was originally constructed for four soil containers, but only two have been built. The alcohol cooling tank is in the center, with two mixing tanks on the opposite sides. The condensing unit for the main tank is at the right front. The soil containers are at the left behind the tanks; one, with the insulated cover down, is behind the column. The operating table is in the back beyond the soil containers. At the right and beyond the condensing unit of the alcohol tank is a smaller condensing unit for the soil containers. Beyond this is the motor generator unit and against the wall are two photo-electric relay units.

General view of soil thermal conductivily apparatus.

FIG.1

SOIL CONTAINER

A close-up view of a soil container is shown in Figure 2. Figure 3 shows the general assembly of this unit which is made up chiefly of concentric sections of three sizes of copper pipe with an over-all length of 20 inches. The smaller pipe, 2 3/8 inches in outside diameter is divided into three sections, the upper and lower sections each being approximately 4 inches in length and the center one 12 inches in length. The three sections are separated from one another by Micarta and rubber discs which hold, to a negligible amount, the flow of heat from one section to another. Within these section of pipe are located three cartridge type electrical heaters, one within each of the sections.

The upper and lower 4-inch sections are termed guard sections and their purpose is to regulate conditions at the two ends of the soil container, so that there is no tendency for the heat from the center or main heating section to flow upward or downward, thus insuring only a true radial flow of heat through the soil being tested.

Two thermocouple connections are set in the outside wall of the center section of the center column. These measure the temperature on the hot side of the soil sample.

Balancing couples connect the center section and the upper and lower guard sections. These couples are used to check the temperature in the guard sections against the central section, and thus aid in preventing any axial flow of heat from the main section.

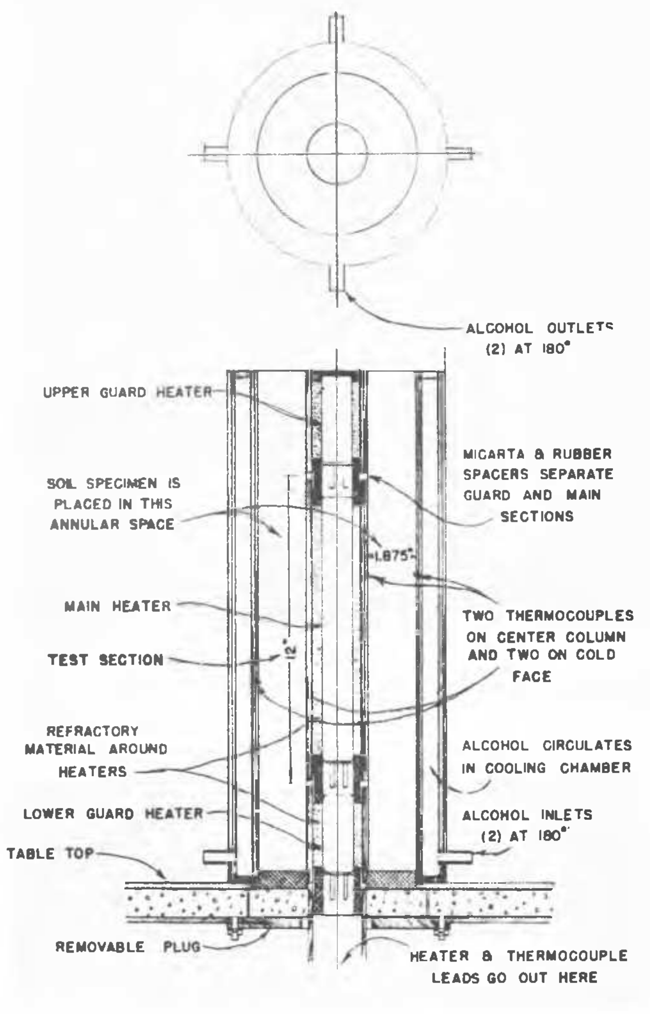
The annular space between the heaters and inside wall of the pipe is filled with a special refractory material which permits a ready flow of heat. The power and thermocouple leads also pass through this space.

The cooling chamber consists of two concentric copper cylinders, approximately 1/4 inch in wall thickness and 6 5/8 inches and 8 5/8 inches in outside diameter, respectively. The inside face of the smaller cylinder serves as the cold side of the soil container and is in direct contact with the soil. The two cylinders are assembled with rings at each end, the space between the cylinders serving as a chamber through which the alcohol is circulated.

Tabular soil container and refrigeration plates.

FIG. 2

The soil to be tested is placed in the an-



Soil container for thermal conductivity tests.

FIG.3

nular space between the 2 3/8-inch and 6 5/8-inch pipes. The center column itself is supported by an additional section of pipe placed below the bottom guard section, but separated from it by a Micarta spacer, and extending to the floor. At the bottom of the soil container the plug which encloses that end has a Micarta face in contact with the soil. At the top of the container the center column is held in a central position during filling by a metal "spider" having three arms extending across to the cold jacket. This is replaced after filling by a Micarta cap without arms.

Two thermocouple connections are made on the inside face of the 6 5/8-inch pipe which corresponds to the outside or cold face of the soil. These thermocouples are located directly opposite the two thermocouples on the center column.

A cover of bakelite and granulated cork fits over the top of the tubular container. The table on which the container is located and the plug at the bottom both have a 1-inch layer of cork for insulation.

The containers are located on a table approximately 2 feet high. The table top is fabricated of 1/4-inch steel plate to provide rigidity for the compaction of soil, 1 inch of cork to provide insulation during low temperature runs, and a 1/4-inch Masonite surface. The plug mentioned above which is used for the bottom of the container fits into a hole in this table.

To prevent excessive warming of the cooling liquid during runs at low temperatures, covers are provided for each soil container. These covers, in the form of large bottomless boxes, are constructed of plywood and 2 inches of cork insulation. They drop down over the soil container from above, are mounted on pulleys, and are counter-balanced to provide ease in handling.

To maintain a low temperature within the insulated covers, two refrigeration plates are mounted on the table for each soil container. These plates are connected to a 1 1/2-horsepower condensing unit. The refrigeration system is complete with expansion valve, thermostat, liquid indicator, strainer, etc. One condensing unit serves both soil containers. Separate thermostats in each box and solenoid valves in the liquid line provide separate control.

COOLING AND MIXING TANKS

The cooling and mixing tank unit consists of separate mixing tanks for each unit and a common central cooling tank. The tanks are of galvanized sheet steel and are insulated with 4 inches of granulated cork.

The cooling tank, which holds about 100 gallons of liquid, is equipped with a cooling coil. A circulator mounted at one end of the tank continually circulates the liquid to provide more efficient cooling and more even temperature control. The cooling coil is connected to a condensing unit which is controlled by thermostats whose bulbs are mounted in the tank.

Each mixing tank has a capacity of about 30 gallons. From each of these tanks a circulator feeds liquid to the cold side of a soil container. The mixing action is brought about by by-passing a part of the discharge of the circulator directly back to the mixing tank and also by the return liquid from the cold side of the soil container.

There are two inlets to the mixing tank from the circulation system in the cooling tank; one is controlled by a hand valve, the other by a solenoid valve. These provide a means for cooling the liquid in the mixing tank. An overflow connection is provided between the mixing and cooling tanks for the purpose of maintaining desired levels of liquid. An immersion heater is mounted in the mixing tank to provide necessary warming of the liquid for temperature control.

CIRCULATION SYSTEM

Separate circulation systems are provided between each mixing tank and soil container. The liquid is drawn from the bottom of the tank through a 1 1/4-inch circulator. Part is immediately returned to the top of the tank to provide mixing action, the amount returned being controlled by a hand valve. The balance of the liquid is conveyed in a single pipe to the table on which the soil container is mounted. A thermohm for detecting temperature change in the liquid is mounted in this line. At the table the line is divided and entrance into the cold chamber of the soil container is made at two points at its bottom, 180 degrees apart. The exit is through two points, at the top of the jacket, 180 degrees apart. The inlet and outlet connections are 90 degrees apart. This arrangement is meant to provide circulation throughout the entire volume of the cold chamber. The connections to the container are fitted with hand valves, and the pipes are insulated to keep losses at a minimum.

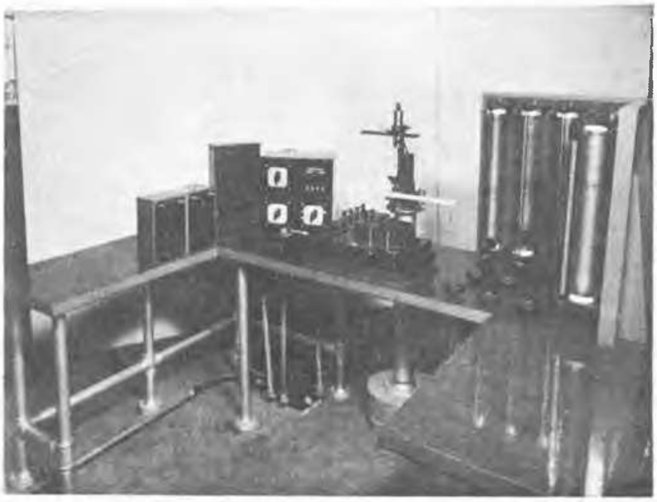
POWER SOURCE

The power for the heaters in the center section of the soil container is furnished by a motor generator set, 110 volts, D.C. Because of the accuracy required in the maintenance of specified temperatures and the rate of heat supplied to the soil, the voltage is controlled by a voltage regulator.

TEMPERATURE AND POWER MEASUREMENT AND CONTROL

Figure 4 is a view of the control table.

Temperature measurements are made at two points on the hot side and two points on the cold side of the soil sample. On the hot side thermocouples are mounted on the outside of the central heating section. The leads are carried through the wall and down through the refractory material into a conduit at the base. On the cold face the thermocouples are mounted on the inside pipe of the cooling chamber at the face confining the soil; these are embedded in porcelain in a groove in the pipe wall and led out under the cooling chamber into a conduit.



Control table

FIG. 4

The copper and Constantan leads are led through conduits to the control panel. Their circuit includes a cold junction (ice bath), a switch panel for the selection of the thermocouple to be read, a Leeds-Northrup type K-2 potentiometer, and a galvanometer.

Temperature control is accomplished in the following manner. For the cold side a thermohm is located in the pipe carrying the alcohol to the cold chamber of the soil container. The thermohm is one leg of a Wheatstone bridge circuit which affects a galvanometer in a photo-electric thermostat box. Any change in temperature from that selected initiates a relay which either contacts the heater in the mixing tank or opens a solenoid valve permitting colder liquid to enter the mixing tank from the cooling tank. The temperature is selected by adjustment of the resistance in one leg of the bridge

The temperature control on the hot side of the soil sample is achieved by the control of voltage applied to the heaters.

With this apparatus the power is measured only for the main heater and not for the guards. The voltage and amperage are determined by means of the potentiometer. The power in the main and guard sections is regulated by two rheostats in series in each circuit. The amount of heat furnished by the center heater is regulated so as to obtain the desired temperature on the hot side of the soil. A balanced temperature between each guard section and the center section is accomplished by control of the guard heaters. This balance is measured by a balancing couple between the end of the main heating section and the adjacent edge of the guard section.

USE OF APPARATUS

With this apparatus tests can be made on soils with densities varying from loosely poured to that obtained by heavy ramming and at moisture contents up to and beyond the optimum moisture content. The center column is reasonably water-tight, so that the wiring is protected. Tests have been made on peat soils having densities as low as 8 pounds per cubic foot and on gravels having densities as high as 133 pounds per cubic foot. Tests can also be made at a wide range of mean temperatures; frozen as well as unfrozen materials may be tested. With the apparatus built as described, thermal conductivity measurements have been made for a mean temperature as low as -20° F.

Upon completion of a test, moisture samples can be taken from the soil in place by means of a sampling tube. The results indicate whether or not any moisture migration has occurred.

CONCLUSIONS

The apparatus described herein is useful in determining the effect of the following factors on the thermal conductivity of soils:

1. Density;
2. Moisture content;
3. Mean temperature;
4. Grading;
5. Mineral composition.

The results of such tests should be useful in the design of buildings, pavements, or other structures to be built in areas of permafrost. They should also prove useful with respect to such problems as the determination of losses of heat from basements, panel heating systems in floors set on the ground, and other similar structures.

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