Frost Determination by Electrical Resistance

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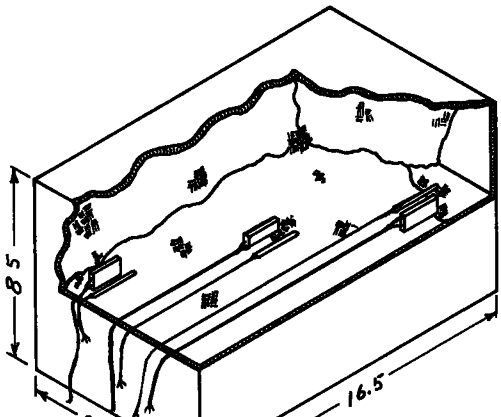
A preliminary report on a new method of determination of frost in the soil profile in situ. The method involves interpretation of electrical resistances obtained with a soil-moisture block and their associated soil temperatures, a method developed at the Michigan Hydrologic Research Station as a result of correlations noted from daily field records of soil moisture and temperatures. A hypothesis relating these phenomena was formulated and was substantiated by field and laboratory studies. Under certain conditions an abrupt 200-ohm increase in the electrical resistance of the plaster-of-paris moisture unit was a satisfactory indicator of the commencement of crystallization of moisture. Test instrumentation and graphic results of the laboratory tests are illustrated.

● THIS paper presents a simple method for determining the commencement of initial freezing, or water crystallization, of soil moisture in situ. The method was developed at the Michigan Hydrologic Research Station as a result of correlations noted between field observations of frost penetration depths and soil-moisture readings made with moisture blocks. This method of frost determination, which utilizes principles of soil-moisture measurement by variations in the electrical resistance of porous units buried in the profile, is discussed in preliminary form, because of the wide interest evidenced by agronomists and by highway and agricultural engineers.

The electrical-resistance method of determining the moisture content of soil utilizes a porous unit (containing a pair of equidistant electrodes) buried in the soil profile. The moisture content of the unit varies with that of the soil in which it is embedded, and the electrical resistance between the electrodes varies with the moisture. Temperature also affects the resistance of the unit, but this effect may be corrected if the temperature is known. A number of types of such moisture-sensitive units are in use today, primarily differentiated by the type of dielectric used in construction. The most-widely used units utilize plaster-of-paris, nylon, fiberglass, and similar materials as a dielectric. The plaster-of-paris unit developed by Bouyoucos and Mick[1] is used at the Michigan Hydrologic Research Station for the daily recording of soil moisture at several locations and depths. This method has given indications that it might be used to tell when initial freezing of the soil moisture takes place. Various authors have indicated that frozen soil causes abnormally high resistance, but none of them



FROM LEFT TO RIGHT
BLOCK 128 TEMPERATURE UNIT PLACED DIRECTLY BELOW THE MOISTURE BLOCK.
BLOCK 129 TEMPERATURE UNIT AND BLOCK IN THE CENTER. UNITS PLACED SIDE-BY-SIDE.
BLOCK 130 TEMPERATURE UNIT PLACED DIRECTLY ABOVE THE MOISTURE BLOCK.
NOTE: DIMENSIONS ARE OF THE SOIL SAMPLE. THERMOMETERS ARE 0.5 INCH FROM THE MOISTURE BLOCKS

Figure 1. Schematic drawing of soil sample used in second freezing experiment, showing instrumentation. Notice that measuring units are so placed as to show progress of freezing from all sides towards the center.

[1] Bouyoucos, G. J., and Mick, A. M., an electrical method for the continuous measurement of soil moisture under field conditions Michigan Agricultural Experiment Station Technical Bulletin 172, 1940.

have presented data to pinpoint the commencement of the freezing process.

Comparison of resistance readings from the daily soil moisture studies with manually determined frost-penetration depths in the cultivated watersheds indicated that there was a probable correlation between soil temperatures, moisture-block resistances, and presence of frost in the profile. A preliminary field study correlating these factors was carried on during the winter of 1951—52, and showed a high degree of correlation. Data used in this preliminary field study consisted of the daily soil temperature and moisture readings from the hydrologic investigations, supplemented by actual frost-penetration data obtained by probing with a Veihmeyer soil-sampler. Analysis of this data provided the basis for an hypothesis regarding the determination of the commencement of crystallization.

This hypothesis predicated that an abrupt 200-ohm increase in the electrical resistance of a soil-moisture block under stable temperature conditions in the range of 30 to 32 F., followed by an increase in resistance and a slowly decreasing or static soil temperature, indicates the commencement of crystallization of soil moisture. An elementary laboratory study was designed to substantiate this hypothesis.

In this study, seven similar samples of soil from the cultivated watersheds were placed in baskets of hardware cloth and frozen in a conventional ice-cream-storage cabinet. The cabinet was thermostatically controlled to maintain a box temperature ranging from 8 to 11 F. Plaster-of-paris moisture units were centrally placed in three of the soil samples, while resistance thermometers were similarly placed in three other samples. A seventh sample was not instrumented, but was utilized for physical determination of frost penetration by probing. The seven samples were installed in the freezer and the cooling process commenced. Temperatures and resistances of the soil samples, box temperatures, and the probed depth of frost penetration were noted at frequent intervals throughout several freezing-and-thawing cycles.

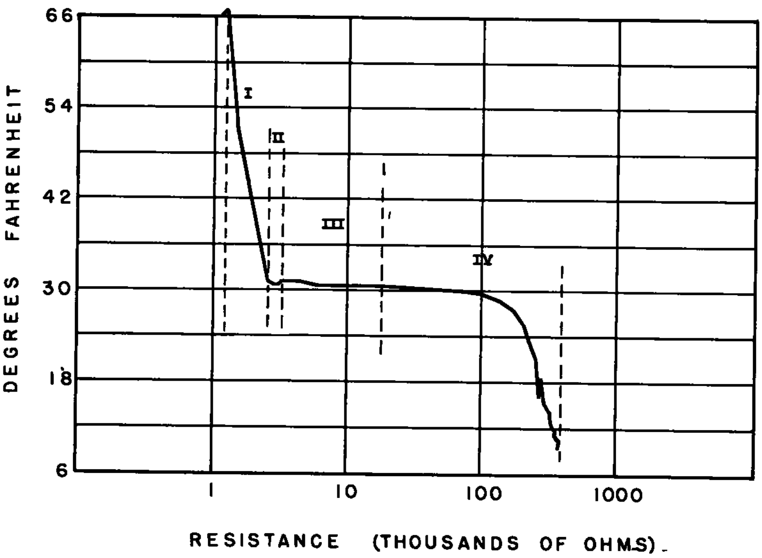


Figure 2. Temperature-resistance relationships from the preliminary freezing experiment. Note particularly those relationships around 31 F., characterized by a bulge. This is considered to indicate the commencement of crystallization, and is followed by static temperatures and sharply increasing resistances until the completion of crystallization.

The resulting data, when plotted and analyzed, clearly supported the basic hypothesis but also indicated several difficulties in experiment design. A more-elaborate study was devised to offset these objections.

The second laboratory study entailed observation of temperature and resistance

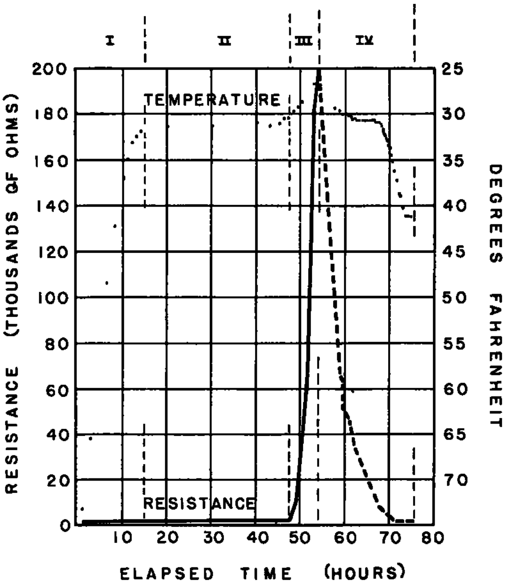


Figure 3. Resistance and temperature variations noted in one complete freezing-thawing cycle, utilizing a single, large soil sample. Temperature and resistance have each been plotted against elapsed time, and in opposition to each other, to illustrate the decisive point of commencement of crystallization, and show their relationship to each other at any given time. It will be noted that temperature and resistance values are quite similar before and after freezing.

at 15-minute intervals throughout the experiment, with 1-minute observations during periods of critical change. In order to accomplish the difficult task of making rapid and accurate instrumental readings, especially during the periods when observations were made at 1-minute intervals, a multi-switch selector panel was designed. This device permitted switching from one instrument to another without opening and closing the freezer box, thereby eliminating a major source of error in uncontrolled heat-exchange. Physical probing of the sample was necessarily omitted in the second experiment. The seven small soil samples of the first experiment were replaced by a single, large sample, instrumented with three plaster-of-paris resistance blocks and three resistance thermometers arranged so as to show penetration of cold from above and below, and to the center of the sample (see Figure 1). Regular observations were maintained throughout one freezing-thawing cycle in the second experiment, covering an elapsed time of 72 hours.

Data from the second study were carefully tabulated and plotted so as to show all possible relationships. Resistance was plotted against temperature, resistance against time, temperature against time, and resistance and temperature were plot-

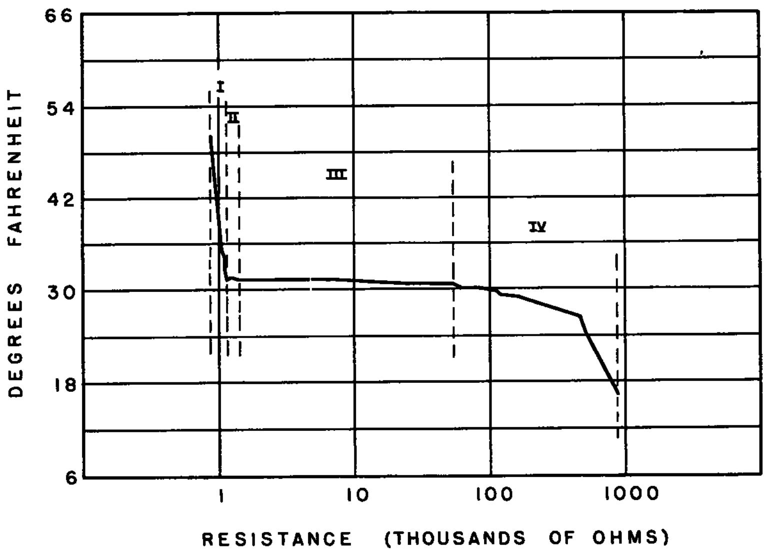


Figure 4. Temperature-resistance relationships from the final freezing experiment. Note the marked similarity between relationships found in the preliminary and final freezing experiments. Early difference in resistance noted in the two experiments may be ascribed to differences in moisture-content of the samples.

ted against time and in opposition to each other. The graphic correlations which resulted (see Figures 2, 3, and 4) clearly illustrate the decisive period of the freezing process and verify the basic hypothesis that an abrupt 200-ohm increase in resistance, under certain circumstances, indicates the commencement of crystallization of soil moisture.

Review and analysis of the tabular and graphic data resulting from field and laboratory observations lead to the following conclusions: (1) A characteristic 200-ohm increase in resistance indicates the commencement of the freezing process. (2) A period of stable temperature and resistance conditions always preceded freezing. (3) Similar results were obtained in field and laboratory studies. (4) After thawing, field and laboratory measurements showed values similar to those noted before the freezing process. (5) Increases in resistance at temperatures below 32 F. are caused by the dehydration of soil moisture resulting from freezing and indicate the degree of completion of crystallization. (6) Freezing of mineral soils within the available moisture range commences at temperatures of between 31.00 and 31.75 F. (7) Field and laboratory studies fully substantiate the original hypothesis that, under specified conditions, an abrupt 200-ohm increase of resistance of a plaster-of-paris soil-moisture unit indicates the commencement of crystallization of soil moisture.

Discussion

CARL B. CRAWFORD, Division of Building Research, National Research Council, Ottawa, Canada—Advancements in instrumentation in recent years have encouraged large-scale studies of the variation in soil temperatures and soil moisture content. Considerable interest has been shown in attempts to predict frost penetration in various soils and efforts have been made to establish the frost line by nondestructive methods.

Correspondingly, attempts have been made to simplify the determination of the frost line by direct measurement. A simple boring tool for this purpose is described in detail by Goodell (1). Another method (2), developed in France, employs a series of capillary tubes which are installed in the ground and may be withdrawn periodically to obtain a direct observation on the region of freezing.

Many observers are content to determine the position of the frost line by interpolation of soil temperatures measured in a vertical profile. It has been established by the authors and others, notably the Corps of Engineers (3), that it is reasonably accurate to assume that the frost line occurs at the 32-F. isotherm. The fact that the position of the frost line can be estimated at any time by interpolation of temperatures appears to be an advantage over the use of moisture meters for this purpose. A further disadvantage to the use of moisture meters for locating the frost line is that continuous readings are required to establish the time of initial crystallization. Consequently, the electrical-resistance method appears to have no advantage over temperature-sensing elements in field installations which are read periodically. It is probably, however, that electrical-resistance units could be used to advantage for detailed studies of freezing phenomena.

The detection of freezing by means of the change in dielectric constant was reported by Powers and Brownyard in 1947 (4). This test is based on the fact that the dielectric constant for water is about 80 and that of ice about 4.

A good review of work on the freezing point of soil moisture is given in a paper by Richards and Campbell (5) in which it is pointed out that the preparation of samples for laboratory tests may have an appreciable effect on results. For this reason it is important that the exact procedure be described in reporting work of this nature.

Ground-temperature records are now being collected at ten locations in Canada by the Division of Building Research of the National Research Council. Most of this work is being done jointly with other organizations. In all cases the depth of frost is determined by interpolation of the temperature profile assuming that the frost line and the 32-F. isotherm coincide.

In addition to the temperature observations, an attempt is now being made to collect depth of frost information at 13 locations across Canada. In order to simplify the field work, records include only date, location, depth of frost, soil type, and surface cover conditions. It is hoped that a comparison of these records with air temperature records will assist in the empirical approach to the prediction of frost penetration. If preliminary work is successful, this frost survey will be extended to include more regional variations in climate.

Closely linked with the work on ground temperatures is a study of soil moisture fundamentals. The first stage of this study was a review of literature on nondestructive methods of measuring soil moisture content (6). Apparatus is now being assembled for the evaluation of electrical resistance suction meters.

References

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