# SOIL TEMPERATURE STUDIES—A PROGRESS REPORT

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## SYNOPSIS

The variation throughout the year of the temperature in soils at varying depths beneath the ground surface might not appear, at first glance, to be a matter of much significance. A little consideration will show that a large number of economic problems are dependent on soil temperature conditions. These include the operation of heat pumps, the depth at which water and sewer pipes have to be buried in colder climates, the design of house foundations, the stability of cold storage plant foundations, heat losses from electrical conduits, gas mains and other utilities, and perhaps above all the stability of highway and airport pavements with special reference to frost action It was one such economic problem which first attracted attention in Canada to the fact that very little was actually known about soil temperature variations. Some experiments were started in Canada in 1945 and these soon showed the importance of the state of compaction of the soil of which temperature was being measured Concurrently a continuing study of the available literature suggested many gaps in even a general overall picture of the problem.

Further studies have shown the importance of moisture migration in soil and it now appears that this is probably the most important factor of all, when associated with the state of compaction of the soil. Further field experiments have therefore been started to investigate these and other factors, some details of which are given in the paper. Because the experimental time cycle for such research is unfortunately one year, and because results are affected by local climatological conditions, this progress report is being presented in the hope that it may stimulate interest in the problem and assist in developing cooperation in further progress.

It is not uncommon for a very simple question to initiate a study which may develop into a major research programme. It was such a simple question which started the work upon which this paper is a first progress report. In the early months of 1943 the senior author was asked, while assisting with special problems on one of Canada's great wartime construction projects, if he could tell the Chief Engineer the temperature of the soil at the building site in question, 3 ft below the surface of the ground at the beginning of the month of May. The information was needed since a pipe was to be buried at this depth designed to carry benzol which has the unfortunate property of freezing at 40 F. It was thought that the answer would be available in some suitable reference. The answer, in general terms, is still being sought.

A search through appropriate literature was started but little specific information was found in the records of engineering. When the search was broadened to include agricultural scientific papers, a number of publications were found which gave details of soil temperatures as observed by agricultural scientists. In all cases, however, these records extended only to shallow depths down to about 18 in. The search was broadened still further to include purely scientific papers. Finally a record was found of a series of measurements taken on the campus of McGill University in the closing years of the last century, the results of which were published in the *Transactions* of the Royal Society of Canada This work was done under the direction of Professor Callendar (of steam table fame) and the readings were obviously taken with great accuracy by competent observers. This paper provided the necessary clue to a few other records but even today the available printed records of soil temperatures are few in the extreme

Study of Professor Callendar's paper and the few other records which were discovered demonstrated vividly the annual cycle of soil temperature variation and the fact that any soil temperature records which did not cover a period of at least one full year would be most misleading. Records of two or three years' duration are often desirable to obtain average conditions. The fact that the time unit in soil temperature studies is one year has probably been responsible in part for the neglect of this interesting soil property. The limitations which this one-year interval impose upon research work will become apparent in this paper. Since the writers are already conscious of the relative brevity of their respective life spans, in relation to soil temperature studies, they have decided to present this progress report at this time in order to share their experience with others interested in the problem. They wish also to solicit assistance from others who may be able to assist with the investigation of some of the many complex phases of this singularly complicated subject.

### ECONOMIC ASPECTS

The economic importance of soil temperature variations is not at first obvious. A little study will show however, that the problem which started this investigation is probably the least important of those which are affected by soil temperature variations. The more the problem has been studied, the more widespread have its economic implications been found to be even in the field of engineering. It would not be fitting to list all those which have so far been recognized, but the following is a partial list of the more important economic aspects. The items are not listed in the order of their relative importance but merely as they have come to the writers' attention.

*Heat Pump Operation*—The entire basis on which heat pumps operate is dependent on the temperature difference between the soil in which the ground coil is placed and the atmosphere. The long term operation of heat pumps involves changes in the soil temperature regime which are not yet fully understood.

*Water and Sewer Pipes*—In all climates in which frost is likely to occur, water and sewer pipes must be buried for protection. The depth to which they are buried is dependent or should be dependent upon soil temperature variations.

*House Foundations*—The growing tendency to build houses upon flat slabs is creating many examples of structures which effect a change upon soil temperature patterns, the full significance of which is not yet fully appreciated. Correspondingly, the heat losses from conventional basements are dependent upon ground temperatures.

*Radiant Heating Installations*—Many domestic and industrial radiant heating installations consist of coils embedded in concrete floor slabs placed directly on the ground surface which induce an even greater change in soil temperature conditions than ordinary flat slab foundations.

*Cold Storage Plants*—The artificially cold conditions set up in cold storage plants have already led to a number of unusual foundation failures, due to the changes in soil temperature conditions thus induced.

*Vegetable Storage*—The writers have been surprised to find that approximately 80 percent of the vegetables used in the province of Ontario during winter months are stored in excavations which depend for their efficiency on suitable soil temperature conditions.

*Heat Losses From Conductors*—One of the most important economic problems which is not at first apparent is the heat loss from electrical conductors, gas mains and other buried utilities due to the temperature difference between the conductors and the surrounding soil.

*Permafrost Conditions*—In those areas of the world where permafrost exists, the significance of soil temperatures is perhaps more obvious than anywhere else.

*Highway and Airport Construction*—Probably the most important of all the economic factors so far considered is the profound effect which soil temperature variations may have upon the stability of roadway and runway construction, especially in connection with freezing conditions. Correspondingly, in hot climates, troubles are already being experienced due to moisture migration which is now known to be one of the most important factors related to soil temperature conditions.

When it is recalled that the foregoing is only a partial list of the economic implications of soil temperature variations, considered only in relation to engineering problems, the importance of this somewhat unusual study of a characteristic of soil in place will be apparent. It will also be clear that the problem cannot properly be studied except in relation to the specific soil types involved. A thorough investigation of past work and a programme of research to augment available information has therefore been started by the Division of Building Research of the National Research Council of Canada. It is hoped, with the aid of information from others who are interested in the same problem, to establish the factors influencing temperature variations in soil, and the order of their importance. It is planned to study these by means of field tests and observations, assisted by laboratory tests where necessary. When the several factors are evaluated, means of controlling temperature variations in soil and of reducing frost penetration will be investigated.

## BRIEF REVIEW OF PAST WORK

As has already been noted, when the problem was first investigated during the war years, no record could be found of any previous work in this field related to the engineering properties of soils. A good deal of work, however, had been carried out and recorded in connection with the interest in soil temperature of agricultural scientists. Some progress had been made at correlation of temperature variations with moisture content, the presence of organic matter and soluble salts, the nature of surface vegetation (the presence of turf having an appreciable effect), the annual variation of climatic conditions, and the cooling effect of rain in summer. The heat-transfer properties of different kinds of soil had also been tested and results showed the order naturally to be expected, varying from sand (best) to peat (poorest).

In the last few years, and particularly in connection with studies of frost penetration and frost action in highway and airport work, some valuable work has been done in this field with engineering objectives in view. Mention need be made here only of the work carried out at the University of Minnesota by Kersten (*1*)[1] and Algren (*2*) in order to indicate the valuable type of information which is now being added to the general store of knowledge in this interesting study The bibliographic work of the Committee on Frost Heave and Frost Action in Soils of the Highway Research Board (*3*) is also revealing information previously unsuspected. The authors are therefore engaged upon a critical review of all the information now known to be available and hope to publish the results of this review when it has been completed

It may be useful to mention briefly here some of the noteworthy investigations that have been made of soil temperatures. It appears that some of the earliest work in this field was carried out in Germany, notably by Wollny (*4*). The first extensive investigation in the United States seems to have been undertaken by Bouyoucos (*5*) Some work had also been carried out in England, as indicated by a paper by Rambaut (*6*) Textbooks on soil physics related to agriculture, usually contain some treatment of the subject, as for example the notable volume by Baver (*7*) Among the most significant work carried out in recent years by scientists interested in the agricultural implications of the matter is that of Smith (*8* and *9*) It should be noted that all the earlier references, those here mentioned and all others studied, dealt with the subject from the agricultural point of view, investigations being generally limited to shallow depths.

The first recorded measurements of soil temperature studies in Canada appear to be those already mentioned, made at McGill University in Montreal and reported by Callendar (*10*) and Callendar and McLeod (*11*) More recently, records have been published of observations taken in Saskatchewan by Harrington (*12*) and at Winnipeg by Thomson (*13*). A useful summary has been published by Ruedy (*14*). It was only after the initial search had been completed, while the senior author was on the staff of the University of Toronto, that it was found that quite the most complete Canadian records were available less than a mile from the office. These had been taken at the grounds of the head office of the Meteorological Service of Canada by Dr. John Patterson, then Controller of the Service, but they had never been summarised or published. This valuable set of records was generously made available by Dr Patterson, and by Dr Andrew Thomson his successor, and some of the information contained in it is presented graphically later in this paper

[1] Italicized figures in parentheses refer to list of references at the end of the paper.

### THE PROBLEM OF SOIL TEMPERATURE VARIATION

With so many records now available, it may be wondered why there should still exist any "problem" connected with soil temperature variation. Basically, the matter is relatively straightforward. The top 20 or 30 ft. of the earth's crust may be regarded, for this purpose, as a semi-infinite mass of solid material at a constant temperature at any appreciable depth, and subject to a variation of temperature at its surface, this variation being that due to changes in air temperature and other climatic factors, easily measurable and varying within reasonable limits. The thermal properties of the material of which the crust is composed can be determined. By application of the laws of heat transfer, it should therefore be possible to determine, theoretically, what the pattern of soil temperature variation throughout the annual cycle of climatic change should be. This can be done, and the results are reflected in the patterns of actual soil temperature which have been measured and recorded, such as those given by Callendar and by Algren.

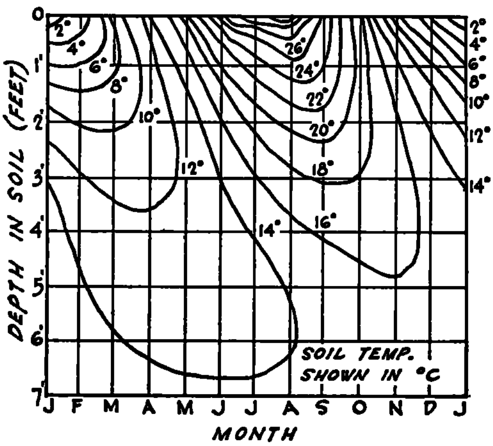


**Figure 1. Lines of Equal Soil Temperature with Depth and Time at Tiflis (from Hann, 1906)**

The general pattern is most clearly shown by plots of actual records obtained. Typical charts are therefore presented as Figures 1 to 5. The first of these, taken from an old meteorological handbook by Hann (*15*), is of interest because, although taken at Tiflis in the Caucasus, it shows the same general pic-

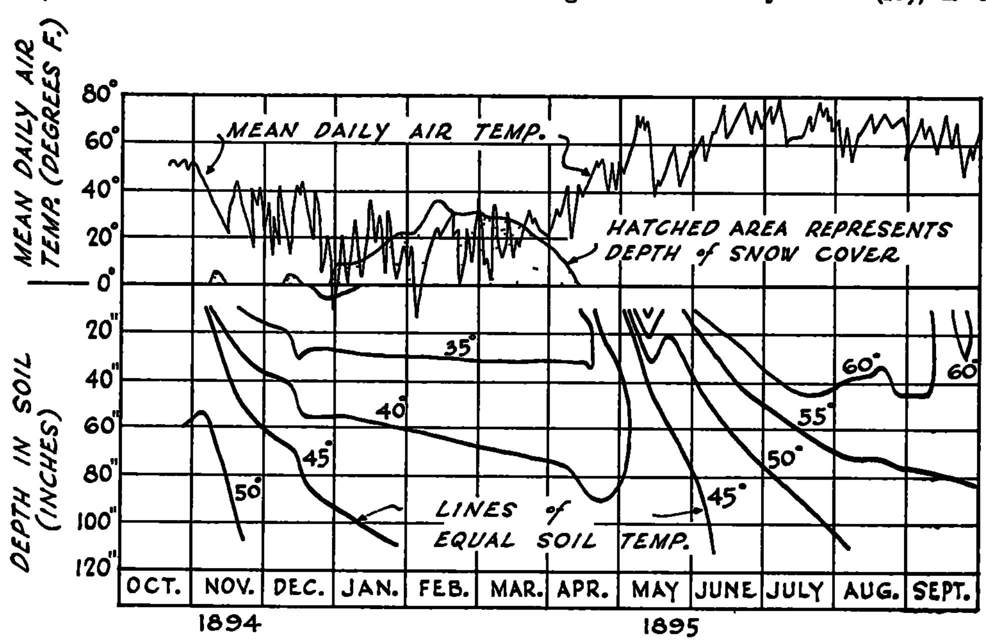


**Figure 2. Soil and Air Temperature Records at Montreal, 1895 (from Callendar and McLeod, (1896)**

ture of ground temperatures as that obtained from records in North America under completely different climatic conditions. Figures 2 to 4 are reproductions of the charts which were originally published by Callendar. These show temperatures under grass in loose sand underlain by clay at a depth of 9 ft., with water in the sand for a little distance above

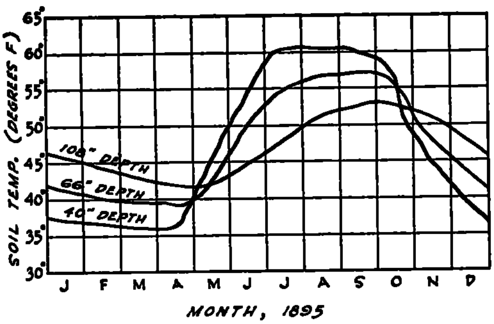


**Figure 3. Variations of Soil Temperature with Depth at Montreal (from Callendar, 1895; and Callendar and McLeod, 1896)**

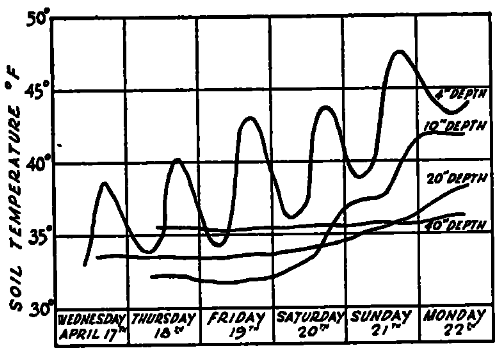


**Figure 4. Daily Soil Temperature Variations with Depth at Montreal, April 1895 (from Callendar, 1895)**

the clay. Since the *Transactions* of the Royal Society of Canada are not widely available, it was thought that these pioneer records might well be included with this paper and this is done by permission of the Society. Figure 5 is extracted from the set of records already mentioned, obtained in Toronto by the Meteorological Service of Canada, and is reproduced here by permission of the Controller. It shows the variation of soil temperatures with depth in different months of the year in sand with the ground water level at some depth.

Three different methods of plotting are used in these charts. If they are carefully studied, they will be found to show the most prominent features of the pattern of ground temperature variation. Daily variations occur only to depths of a few inches, changes below 10 inches following only an annual cycle. The range of variation decreases with depth below the surface, and a nearly constant temperature is reached at about 20 feet, even in cold climates. Below this depth, it is well known that this steady temperature gradually increases, the rate of increase in northern Ontario being about one deg. F. for every 115 ft. of depth, as recently recorded by Misener (*16*).

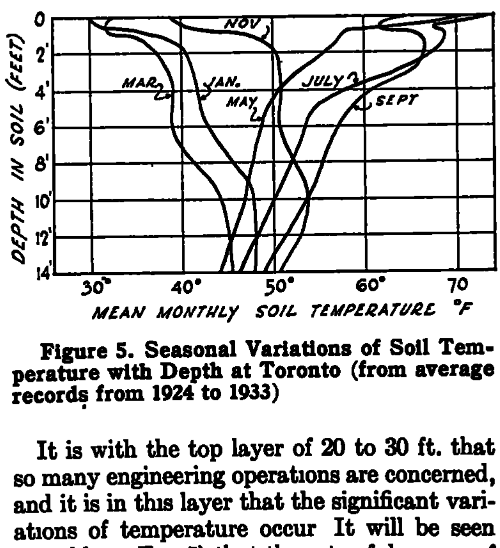


**Figure 5. Seasonal Variations of Soil Temperature with Depth at Toronto (from average records from 1924 to 1933)**

It is with the top layer of 20 to 30 ft. that so many engineering operations are concerned, and it is in this layer that the significant variations of temperature occur It will be seen (notably in Fig 5) that the rate of decrease of the temperature range is not constant, but itself decreases with depth below the surface. This is to be expected from the laws of heat transfer In Toronto, for example, at a depth of 6 ft below the surface, the annual variation of temperature usually amounts to less than 20 deg. F. Correspondingly, there is a pronounced time lag with depth. Although obvious from the basic physics of the problem, this is the feature which usually occasions more surprise than any other on the part of those who come to look at the problem for the first time. The fact, for example, that the coolest region in Toronto in July is to be found 20 ft. beneath the surface, due to the six months' time lag, is a seemingly ridiculous assertion until records such as those given in Figure 5 are carefully studied.

Examination of other published records, such as those of Algren (2) will show similar patterns of the variation of temperature throughout the year at increasing depths below the ground surface. The variations are readily understandable and agree well with theory. It would appear, therefore, that engineers already have available to them all the information on temperatures which they need for their diverse subsurface activities Unfortunately, there are a few complications which mar this otherwise beautifully simple picture; these must now be considered.

### SOME COMPLICATIONS

The term "frost penetration" is one commonly used in engineering practice, it usually connotes the depth at which the soil temperature just reaches the freezing point at some time during any one annual cycle. The term provides a serviceable and simple yardstick for a discussion of the general phenomenon and will be so used in this paper If reference be made to Figure 2 it will be seen that the frost penetration, even in a normal Montreal winter, was not more than about 18 in. Figure 5 shows that the corresponding average figure for Toronto is no more than 6 in. If these figures be compared with the known fact that water pipes will freeze solid (under eastern Canadian conditions) at depths up to 6 or even 7 ft, the first of the unusual features of this apparently simple matter will become evident. It may be noted that both at Montreal and Toronto there was an appreciable snow cover at the observation sites for most of the winter. The presence of snow is certainly a contributing factor to the low penetration of frost but since it is quite usual to have some degree of snow cover over pipe trenches, it does not provide the whole answer.

Study has therefore been made of the manner in which these and other available comparable records were taken It is found that in all instances, temperatures were taken in undisturbed ground, usually by the insertion of a temperature measuring device into a small diameter hole bored for some distance into the side of an excavated trench Pipes, on the other hand, are buried in trenches, the backfilling of which is always done with much disturbed soil, compaction methods rarely being used at all. The available scientific records suggest that those responsible for the measurements realised that the state of the soil had some influence upon soil temperature variation but surprisingly enough no written record of this suspicion has yet been found.

Brief study of the effects of proper compaction of soil on other soil properties suggested to the senior author that this was a matter which deserved investigation. As a start, therefore, a relatively simple experiment was started at Toronto in 1944. In the grounds of the head office of the Meteorological Service of Canada, a large pit was excavated about 10 feet away from the soil temperature measuring installation established in 1924. Bulbs of a simple temperature recording instrument (of the mercury-in-steel type) were then buried in the backfill of the pit at depths corresponding to three of the established points. The workmen who backfilled the pit were instructed to proceed exactly as usual. Such compaction as the soil received was, therefore, no more and no less than would be the case in ordinary practice

This dual installation is still in operation. The results obtained are so striking that the authors feel that they cannot possibly be typical and they are not therefore here given. Suffice to say that the frost penetration in the case of the disturbed soil is very much greater than that in the undisturbed soil, to such a degree that, making every possible allowance for special local conditions, it is clear that for comparable soil and surface conditions to those at this site, the state of compaction of the soil is a singularly important factor in relation to its temperature.

As a further step in the study of this first major complicating factor, the engineering authorities of a Canadian city (which for the time being must remain nameless) kindly arranged for the controlled backfilling of a number of trenches in different soil types in the fall of 1948 When the performance of the backfill with respect to frost penetration was examined by actual inspection in the spring of 1949, it was found that, apart from some minor variations, there was no significant difference between the frost penetration in compacted and uncompacted soil.

This disappointing result added the second of the major complications so far recognised to the overall problem. For it was soon noted that, whereas in the Toronto experiment the surface cover was turf, the trenches in this more recent investigation were covered over, upon completion, with 8 inches of concrete overlain by 2 inches of asphalt, thus effectively sealing off the soil from direct contact with the atmosphere The relative absence of snow cover over the trenches, as compared with the Toronto site, may possibly be another factor but it is not thought to be of significance as compared with the sealing-up of the ground surface

In the face of such discordant results, it is natural to seek another approach. An obvious way of coming at the problem from another angle is to investigate the thermal properties of soils of different types to see if and how they vary. A start at this work was made in 1945 at the University of Toronto. Professor E. A. Allcut, head of the Department of Mechanical Engineering at the University, and Mr F. R. Hooper of his staff kindly interested themselves in the problem and carried out a series of tests on samples of soil at different moisture contents and at different degrees of compaction. Most of the experiments were made on a glacial till, but some other soil types were also studied.

Results were obtained which are similar to those recently published by Kersten (*1*). One of the most important findings was a direct increase in conductivity with increase in density of the soils studied. This is to be expected in view of the nature of heat transmission. It was found also by Kersten (see Figures 15 to 18 of his paper). If soil behaved in place in accordance with this well-observed laboratory characteristic, then the looser and less compact the soil, the less should be the frost penetration. Exactly the reverse is the case in the Toronto experiment, thus adding a third complexity to the general problem, at first sight so simple.

Before reviewing the matter in a somewhat general way, two more practical aspects may well be mentioned. In the first place, it has been an old practical custom in the colder parts of Canada to cover the outlet pipes from septic tanks with a layer of tar paper immediately before backfill is placed over them. These pipes carry a very small flow indeed and are rarely buried to a depth of more than a foot or two It is known, however, that if tar paper is used to cover them, there will be no danger of freezing even in extremely cold weather. Making all due allowance for the heat capacity of the contents of the tank, the prevention of freezing can still not be explained merely by the insulating property of the tar paper, and this common material is not known to have any mysterious property which could be relevant, it is, however, relatively impervious to moisture vapour

The second practical matter to be recorded comes from the Canadian city already mentioned. A year or two ago, this city purchased a large quantity of new snow removal equipment; its snow clearing staff are keen and efficient and operated their new equipment, even in a winter of light snowfall, so well that all main city streets were practically clear of snow throughout the winter of 1947–48. During the same winter, the water department of the same city encountered a very large number of frozen water mains and hydrants. This increase bore no relation at all to the relevant degree-days of freezing, using this statistic to indicate the severity of local winter weather. The removal of the relatively thin layer of compacted snow, due to the efficacy of snow clearing as compared with previous years, would not appear to provide a satisfactory explanation of the change in frost penetration. This suggests the possibility of other complicating factors, one of which may be the colour of the surface exposed to cold temperatures during winter nights, while even the effect of traffic (which would be influenced by the reduction of the compacted snow layer) may be appreciable.

### A GENERAL NOTE

Without going further in discussion of some of the peculiar aspects of soil temperature variations which are revealed by study of actual field experience, it can be seen that the matter is one of great complexity and not at all the straightforward phenomenon which theoretical study would suggest. In the first place, the solid material being considered is not a solid material in the usual sense of that word. Despite this, it is rare to find any accurate descriptions of the actual soils studied in most of the earlier papers, the word "soil" being used in the delightfully general and yet vague way which was common until relatively recent years. Even in this paper, soil types have only rarely been mentioned. This was done, however, in order to direct attention to other and less obvious influences upon soil temperature variation. Clearly, however, the type of soil will have a profound influence upon its behaviour under the conditions which affect soil temperature changes.

Consider next the fact that soil, far from being a solid material, is a complex three-phase system, including soil matter, air, and water both free and fixed, and some of the facts already cited take on a different complexion. The nature of soil temperature variations cannot satisfactorily be considered without a detailed study of the effect of temperature changes upon the water associated with soil particles. The authors have been led to the point of believing that it is this phenomenon, more than any other, which really determines the "penetration of frost", reverting to this simple term for simplicity. To justify their present opinion would involve a detailed discussion of the soil-water relation. This has been done so well by those expert in the field that it would seem presumptuous to attempt even to summarize here the complex theories involved. Reference may rather be made to other workers and in particular to the papers of Winterkorn (*17*) which explain most lucidly an aspect of soil physics which will be of increasing concern to the authors as their work slowly advances.

One other general aspect of the matter must, however, be noted. Whenever soil samples are tested for their thermal properties in any of the usual ways involving exposure to a temperature gradient, a migration of water will occur from the hot side to the cold side of the experimental apparatus. The migration cannot be prevented. It is usually noted by workers in this field, but generally regarded as an accompanying nuisance "up with which one has to put" (if a satiric phrase of Mr. Churchill's may be borrowed for such a paper as this). It seems apparent to the authors that this moisture migration is an important part of the phenomenon of heat transfer in soils and that its neglect may render results obtained in the conventional type of heat transfer equipment not as accurate as is desirable They therefore welcome steps which are being taken to develop means of determining the thermal properties of soils relatively quickly. A Dutch device for this purpose has already been developed which appears to be most promising. It is at present under study at the University of Toronto (under Professor Allcut and F. R. Hooper); its perfection will provide a most useful tool for the study with which this paper is concerned.

Once again, however, field experience does not seem to be in complete accord with laboratory findings. Evidences of moisture migration which have been observed under roadways in hot climates and under heated slabs in cold climates appear to suggest that moisture has accumulated in warm regions in preference to cool ones, rather than the reverse. Evidence in this regard is still very meagre but the results of the survey reported by Hicks (*18*) present enough food for a great deal of thought, and suggest the need for detailed study, even of this single result of soil temperature variations. Winterkorn and Eyring (*19*) have dealt briefly with the matter; it is almost certainly related to the complex action of the fixed water usually associated with soil particles.

To go further would lead to discussion too detailed for a general progress report such as this. It may be useful, therefore, to bring this brief general review to a close by listing what now appears to be the more important factors which do influence the pattern of soil temperature variations at any given locality, all of which must be investigated and assessed before any one set of observations can have full value. The authors suggest the following:

1. Type of soil;
2. State of compaction of the soil;
3. Moisture content during test;
4. Position of water table during test;
5. Type of surface cover, including its colour;
6. Amount and nature of traffic over site; and, of course,
7. Local climatic conditions.

### CANADIAN WORK NOW IN PROGRESS

Attention has already been drawn to the discouraging difficulties of solving the soil temperature problem by theoretical methods. It is by no means on account of any mathematical qualms that so many early investigators took to the field to improve their knowledge. Actual readings of ground temperature are now, and because of the complexity and varied nature of the factors involved, probably always will be the best approach to the problem. This line of attack is therefore being used by the Division of Building Research of the National Research Council of Canada to add to existing information. A programme of field observations under controlled conditions has been drawn up in two parts, one of which is of a more fundamental nature than the other.

A basic field study has begun at the Montreal Road Laboratories of the Council in

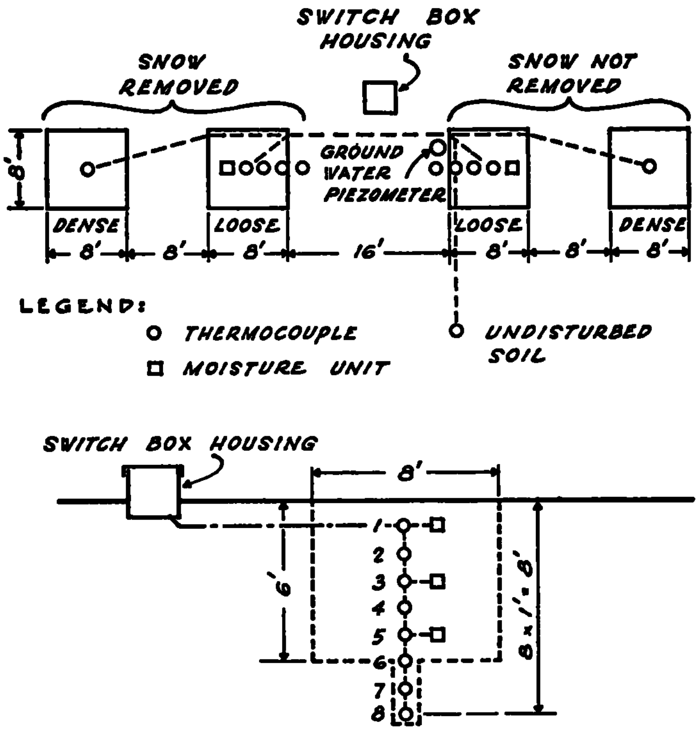


Figure 6. Schematic Diagram of Experimental Test Pits in Clay

Ottawa in an attempt to investigate some of the variables in question. As a start it is planned to study at one time the effects of soil type, state of compaction, and snow cover on ground temperatures, and the installations for this purpose will be briefly described. Eight test pits have been dug, four in a clean, coarse, uniform sand and four in a stiff marine clay. This clay, which is remarkably hard and brittle in the undisturbed state, is medium soft and plastic when remoulded. Its natural moisture content is about 45 percent, with a liquid limit of 60 and a plasticity index of 32. The sand and the clay soils were picked from among those conveniently located for testing as having the greatest difference in their heat-transfer properties, and are therefore intended to represent two widely different conditions.

In each group of four pits, two were backfilled in the usual manner with workmen tramping the soil in place. In the remaining pits the soil was compacted in layers with compressed-air vibrators, in an attempt to replace it at a density as near as possible to that of its natural condition. It is recognized, of course, that this operation completely alters the original structure of the clay.

The effect of the third variable—snow cover—will be found by clearing the tops of half the pits of snow in winter, while allowing the others to retain their snow covering. All are surfaced with turf.

A variety of continuous readings is needed to make these test installations as useful as possible. Temperatures are read in each pit at 1-ft. intervals to a depth of 8 ft. To offer a useful comparison with temperature patterns in the clay pits which are densely compacted, temperatures are also obtained to a total depth of 15 ft. in the undisturbed clay nearby. The level of the ground water table is followed at both test sites, and continuous weather records are available from a meteorological station less than a mile away. The layout and dimensions of the test pits in clay are shown in outline form in Figure 6; those in sand are quite similar.

A few of the details of these tests may be of interest to any who plan similar work, and for comparison with other installations described in the literature.

Temperature measurements are being made with thermocouples and a portable potentiometer with an ice bath reference junction. Thermocouples which can be easily made in the laboratory compare well in reliability with purchased units, in the authors' experience, and represent quite a saving in cost. Copper-constantan wire of 20 gauge is used, provided with a waterproof coating. After soldering, the ends of the wire are effectively sealed against moisture by dipping in a special type of plastic. Each string of thermocouples is then mounted on a wooden pole and installed in position in the test pit.

Although the pits are thought to be large enough to suit their purpose, thermocouples have also been put horizontally at the 5-ft. level as shown in Figure 6. In this way it is hoped to detect any side effect due to the pits that might affect the central readings.

Piezometer pipes which are simple and easy to install are being used to follow the seasonal rise and fall in ground-water levels. Before driving, the bottom end of each pipe was pinched, liberally drilled with holes, and filled for a short distance with coarse sand to act as a clean filter. Ground-water depths seem to range from 9 to 10 ft. in sand and 5 to 10 ft. in clay.

The usefulness of being able to check any moisture migration in the soil that might occur due to temperature changes was recognized in planning the tests, and some satisfactory means of following such moisture changes was sought. Small resistance units for this purpose are sold commercially in two or three different forms, but a great deal of difficulty was encountered in calibrating them for these particular soils. Finally, a nylon absorption type of unit developed and described by Bouyoucos (20) was adopted for use in the clay pits in positions as shown in Figure 6. So far, no satisfactory means has been found of taking similar readings in sand.

The installations which have just been described were made in the fall of 1949. It will be therefore some time before proper results are obtained from them. It is planned to continue readings for at least two years and until what are considered to be typical results are developed. The test pits will then be excavated, correct values for density and moisture content of the soils obtained, and the accuracy of all the apparatus checked.

The second part of the programme of field operations is being carried out in that Canadian city which, at the risk of once more arousing the reader's curiosity, must still remain nameless. It will be readily understood that the aim of the project in this case is to find the effect of snow cover on the frost penetration under streets, and the full cooperation of the water and engineering departments of the city has been lent to speed the work. As will be apparent shortly, however, no matter how well such work is planned and how promptly carried out, the weather very definitely has the final word in deciding if the results are worth while, or indeed are obtained at all.

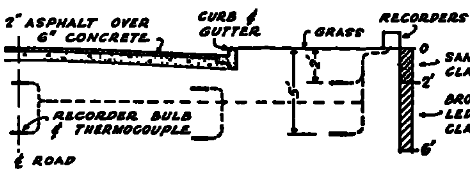


**Figure 7. Schematic Diagram of Experimental Installation under a City Street**

In this instance, two locations have been chosen, one again in uniform, fine sand and the other in the same stiff marine clay previously described. At each location, the bulbs of some mercury-in-steel recording thermometers have been placed under a street in the positions shown in Figure 7, at depths of 2 and 5 ft. Arrangements have been made with the city authorities to plow the snow level from the crest of the pavement to the top of the curb at these places The thermometer bulbs are therefore placed individually so as to be under the centre of the street where snow cover is at a minimum, under the gutter where snow cover will be partial and, for the sake of comparison, behind the curb where snow cover will be normal

At the site of the installation in clay (shown in Fig. 7), thermocouples were recently put in the ground beside the recording thermometer bulbs, to check the relative accuracy and reliability of these two methods of temperature measurement

These tests were started in the fall of 1948, but the following winter was the mildest for many years in that locality, with very little snow. As a result, frost penetration was far from typical and no worth-while records have yet been obtained.

If research by the methods described is successful, each may be expanded to find the effect of other important variables. Both may be extended to other typical soil types such as gravel and silt, and used to compare the amount of frost penetration under identical conditions, but with and without pavement cover and traffic. It is hoped to proceed with studies such as these as soon as possible, but results will not be available for a few years at least.

## CONCLUSION

Strictly speaking, this paper should have no conclusion, since it is a progress report upon work which has been started but which has not yet yielded any specific results. The reasons for this have been explained and it is hoped that the explanation has provided a reasonably clear statement of the many problems and difficulties associated with the investigation of soil temperature variations, particularly in disturbed ground.

It will be clear that the programme of work which has been described is but a part of the necessary broader programme which will be necessary before the phenomenon of soil temperature variation is properly understood. Since the time unit for all such experimental work is at least one year (but usually two or three years), the unusual course of the authors presenting this progress report may perhaps be understood and so appreciated.

The first records obtained from the programme which has been described are interesting and suggestive. It is therefore hoped that a further report may be presented to supplement this introduction just as soon as enough records have been accumulated to be of general interest and of value in connection with further investigations.

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# PAVEMENT PERFORMANCE CORRELATED WITH SOIL AREAS

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## SYNOPSIS

This paper is a continuance of one entitled "Analysis of Spring Break-up Data in Virginia", presented by Messrs T E. Shelburne and A W Maner at the Twenty-Eighth annual meeting of the Highway Research Board The original paper considered data only from the Culpeper District of the Virginia Department of Highways, whereas this paper includes an analysis of performance of 18,000 miles of roads throughout the State—nearly 8500 miles of primary and 9500 miles of hard-surface secondary roads

Road performance surveys were conducted during the spring break-up of 1948 and uniform ratings were originated These ratings, five in all, which were dependent upon the degree of pavement distress, depicted road conditions when lowest support characteristics prevailed. During the survey, maps of each county, showing performance ratings of primary and secondary roads were prepared. These data were summarized and a map of primary routes was developed for each of the eight districts By combining these district maps a composite for the State was prepared

An expedient method of digesting the maze of information collected was to tabulate all data according to several categories Since non-hard-surface secondary roads vary so extensively, only primary and hard-surface secondary roads were considered under each category Road performance first was studied according to twelve general soil areas, established by grouping soils on a basis of physiography, geology and pedology. Further study of performance was made by grouping according to base and surface types

Studying pavement performance on a soil-area basis was a valid approach, for the percentage of total mileage in any one soil area was about equal to the percentage of the State within that soil area Based upon the 1948 spring break-up data, pavements were found to perform best in three soil areas—sandstone and

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