Frost Action in Soils–A Symposium Analysis

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● THE PURPOSE of this symposium is to make an up-to-date assessment of knowledge of the basic considerations pertaining to frost action in soils. The scope of the symposium was divided into four parts and four authors were invited to prepare papers on each part. Draft versions of the papers were presented at the summer meeting of the committee in August 1958, the contents were discussed and a number of persons were invited to submit formal discussions to the papers.

The papers are arranged in such an order that the reader is first acquainted with the mechanism of frost action, a fundamental phenomenon that escaped the comprehension of scientists and engineers for many decades. Then the important contribution of moisture in frost action is discussed. Next the extent to which temperatures in the ground can be related to weather conditions is reported, and finally the influence of soil type on frost action is completely reviewed. In reality it is impossible to separate the influences of soil type, water, and temperature conditions on the mechanism of frost action and there is therefore a certain amount of overlapping in the four papers.

The application of fundamental principles to the mechanism of frost heaving has reached an interesting and useful stage. This development has occurred almost entirely in the last thirty years. The classical work of Taber and Beskow postulating the migration of water under freezing conditions in certain soils to form ice lenses is now universally accepted. An explanation of the exact mechanism requires a knowledge of the forces which act to move the water and a satisfactory concept of channels of unfrozen water up to the growing ice lens.

In order to explain his experimental results, Penner invokes thermodynamic principles which relate soil pore size to freezing point depression in the pore water and to pressure changes in the liquid water. A qualitative appraisal of these two relationships in harmony with film adjustment in the adsorbed water phase around the particle is suggested as an explanation of the mechanism of ice lensing.

In discussion, Martin, also using a qualitative approach, suggests that maximum crystal growth rate plus preferential growth of the larger crystals accounts for lensing quite independent of pore size. Miller argues that osmotic pressure is the energy source for frost heaving. Jumikis emphasizes the profound influence on ice lensing of the mutual interaction of the heat exchange between a freezing soil system with its surroundings and thermally activated moisture migration.

Low and Lovell consider the supercooling and freezing of adsorbed water. They suggest that in addition to the thermodynamic limit to the rate of crystallization and a consequent supercooling of the water, the reduction in the potential energy of water near the mineral surfaces due to attractive forces is a factor in the freezing point depression in the water and hence in the ice lensing mechanism.

Although there may be doubt about the mechanism of frost lensing, carefully controlled laboratory experiments have provided some important concepts. These include a better understanding of the influence of pore size, and indirectly the grain size, on ice lensing; the secondary effects of density, homogeneity and water supply; the dependence of frost heave on overburden pressure; the probable relationship between rate of heave and rate of heat extraction; the dependence of number and thickness of ice lenses on rate of crystallization and soil water proerties; the necessity of considering unsaturated permeability factors in frost heaving considerations; and the probable effect of chemical stabilizers on the mechanism of ice lensing in soils. This is certainly a welcome addition to the engineering literature.

Engineers in general have been forced by their rather practical training to neglect the fundamental influence of water on the properties and performance of materials. It is particularly appropriate therefore to record in this symposium the admirable interpretation of the scientific literature on the properties of water in the paper by Low and Lovell.

While supplementing and encouraging the authors Jumikis reminds the reader that under transient temperature conditions several properties of the water in a clay-water system are changing continuously. For this reason much work is yet to be done to extend basic knowledge and to apply it in practice. Dolch supplements the paper with numerous examples of the unusual behavior of solid-liquid interfaces.

Due probably to problems of instrumentation, the changing soil water conditions under pavements are not well documented. However, Low and Lovell found sufficient material to make several useful generalizations which indicate that a substantial change may occur, particularly during the early life of the pavement. Much less is known of the effects these changes may have on the performance of the pavement. The authors noted an increasing interest in the magnitude of the equilibrium water content under the pavement and less emphasis on the obtaining of maximum densities which may in fact be temporary. The implications of ice lensing in these considerations are obvious.

The development of a satisfactory method of predicting frost penetration in soils is the subject of Kersten's contribution to this symposium. In this prediction water again plays an important and complicating role by introducing discontinuities in the heat flow process due to changes in state and movement through the soil media. In order to allow for these difficulties in thermal computations corrections are applied and thermal constants are used which neglect moisture transfer in their determination and in their application.

In a limited study in Minnesota, Kersten found a satisfactory correlation between frost depth and the square root of degree-days below an arbitrary temperature of 29 F. Sanger questions whether this method would have as general an application as the air-surface correction factor.

The two most popular heat flow formulas applied to frost penetration computations (the Stefan equation and the modified Berggren equation) are discussed and the assumptions and possible errors are given a thorough treatment. Significantly, it is pointed out that a considerable error may result from assuming that all water freezes in a fine-grained soil and that there is usually a rather large discrepancy when dealing with fairly dry granular soils. Because of such difficulties, attention is being directed to a micrometeorological approach in which an attempt is made to balance heat flow inward and outward at the earth's surface. While this unique approach shows much promise it is in its infancy. Of more immediate interest are the numerical solutions and the use of computers described by Aldrich.

There is a limit to the possible accuracy of computed temperature conditions under pavement due to the difficulty of selecting appropriate thermal constants and of handling the complex transient heat flow conditions. This is further complicated by changing soil moisture conditions with time after construction and seasonally. In his discussion, Pryer quotes experience in the Labrador peninsula to illustrate the marked effect on frost penetration of the weather just before freeze-up. There is, however, ample justification for employing methods outlined in this symposium for the prediction of frost penetration in most circumstances.

In their paper, Linell and Kaplar point out that the control of soil characteristics is the most feasible method with which to control detrimental frost action. It is of particular value to the engineering profession to have the stated opinion of these authors that the original Casagrande frost criteria is "the most expedient rule-of-thumb means of identifying without benefit of laboratory freezing procedure soils in which damaging frost action may occur." Based on evidence from a long-term investigation by the Arctic Construction and Frost Effects Laboratories of the U. S. Corps of Engineers, certain qualifications to the simple Casagrande criteria are introduced and the recognition of the most difficult soil groups are discussed. Other criteria such as the capillarity of the fine-fraction in the soil did not impress the authors.

The authors recognize the potential loss of strength and density due to frost action and indicate how this is taken into account in the Corps of Engineers design procedure. Laboratory test methods for rating the frost susceptibility of a soil are described in detail.

It is suggested by Woods in discussion that pedological and geological aspects in frost-action areas should be given more emphasis and several practical observations are given in support of this suggestion. Matthews points out that the "frost evaluation system can be readily adapted to the pedological system" and notes that this is done in Michigan on the basis of experience.

This symposium has attempted to provide for the practicing engineer a background of information to assist in assessing the possibility and severity of detrimental frost action in a particular region. A second symposium will consider the problems of design in frost areas.

On the basis of meteorological information and certain test results or assumptions it has been show that, in most cases, a satisfactory assessment of frost penetration can be made. Although it is not discussed, it is clear that a statistical treatment of weather probabilities may be necessary for design.

Too little is known of the availability and treatment of water under pavements. It is a problem, however, that is receiving increased attention—much of a fundamental nature. In an engineering assessment it is usually assumed that an unlimited supply of water is available unless there is reliable evidence to the contrary.

The assessment of soil material with regard to its frost susceptibility is a complicated matter. There is little argument against the qualitative use of the Corps of Engineers criteria. Much effort is being devoted to an improvement of the criteria.

These considerations only assess the potential heaving of a soil due to frost action. One is impressed by the lack of technical information on the loss of bearing capacity resulting from thawing. Again it is noted that attention is being directed to this aspect of the problem. In the meantime the susceptibility of a soil to ice lensing must be taken as an indication of its frost action potential.

Concerning the mechanism of frost lensing in a soil it is apparent that much progress has been made in recent years. The fact that the matter has not been completely resolved is illustrated by the difference in interpretation of basic physical laws by the several contributors. There is reason to believe that essential agreement on the mechanism is not far off.

A most important conclusion is that if engineers are to be able to treat properly frost action problems in the field, they must understand the mechanism in order to determine which factor can be treated most economically. For instance, should a subgrade be insulated against the penetration of frost or should the frost be encouraged to penetrate rapidly? Should attempts be made to remove soil moisture or should the properties of the moisture be changed? Should the natural soil be replaced or treated mechanically or physically? What is the most effective treatment? These are questions that are being answered slowly by carefully controlled basic studies.

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