Discussion and Review of Symposium Papers

This discussion contains reports from the chairmen and members of three subcom-mittees established to digest and evaluate groups of symposium papers, and from thr additional members.

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In order that the maximum benefit might be derived from the papers published in Special Report 40 of the Highway Research Board, the Committee on Physico-Chemical Properties of Soils decided a special effort should be made to review all the pape and add any recent relevant research findings. The papers assigned to the discussor by Dr. Winterkorn were by Fukuda (1), Hutcheon (2), Czeratzki and Frese (3), Barb (4), Croney et al (5) and Guinnee (6).

Because the papers deal with related material, the writer has chosen to discuss t by subject matter to avoid repetition. Papers that contain a broad range of material may therefore be discussed under several different headings; others with a limited scope will be referred to in only one part of this review.

In reviewing these papers, no attempt has been made to cover all the material; fu ther, the assumption is made that the reader is at least partially familiar with the su ject matter in the original papers. Emphasis has been placed on those parts where n information has become available, either from the literature or through the research work of the National Research Council of Canada.

MOISTURE MOVEMENT

Thermally Activated Diffusion in Porous Media

Hutcheon's experimental findings on thermally activated diffusion in soil support t results of other research workers, particularly with regard to the observed rate of moisture flow. Bouyoucos (7), Winterkorn (8), and Taylor and Cavazza (9), among others, have reported the maximum experimental flow rate under temperature gradi to be from six to ten times the calculated rate based on vapor diffusion. Recently W side and Kuzmak (10) and Philip and DeVries (11) have independently reported an exp nation for this anomaly. There is still disagreement, however, with regard to magn tude.

The experimental work by Woodside and Kuzmak involved measuring the temperat on the surface of spheres stacked in an open-pack arrangement, in a field of constan heat flow. The average temperature gradient across the pore was found to be six ti the over-all temperature gradient, resulting in a vapor pressure gradient much grea than the one normally calculated. Philip and DeVries (11), using another approach, culated the average temperature gradient across the pore to be twice the over-all gr ent. It is also pointed out in these papers that in series (and perhaps also in paralle with the vapor-filled pores are segments of liquid water which permit rapid moistur transfer. This fact, together with the steeper vapor pressure gradients, would appe to account for the accelerated flow rate normally observed.

Hutcheon (2) points out that the nonlinear temperature/vapor pressure relationsh gives rise to a kind of surging flow and causes waves of higher moisture content thr the material. He also accounts for the small net transfer of vapor in relatively dry soils (dryer than the permanent wilting point). Here only a small change in moistur content brings about a disproportionate change in vapor pressure.

Hutcheon (2) shows, as did Croney et al (5) and Fukuda (1), that the direct temper ture effect on the surface tension is small and does not account for the increased tra

er of moisture normally observed under temperature gradients. It is now generally believed that thermally activated diffusion results from a potential created by a temperature gradient across the vapor phase. This gives rise to vapor flow in the direction of decreasing vapor pressure gradients and may be combined with series flow in the liquid phase. In an open system the net flow is in the direction of decreasing vapor pressure gradients.

In closed systems, at relatively high moisture contents (3/10 atm), a dynamic equilibrium moisture content distribution condition can be reached, which is dynamic in the sense that vapor phase flow is from warm to cold and flow in the liquid phase is from the cold to the warm side. Salt added to such a system can accumulate at the hot end, as was shown by Gurr et al. (12).

Isothermal Flow in Porous Media

Moisture suction arises from the attraction between water molecules and the solid. At low moisture contents, the water may be held as a film on the solid surface. As saturation is approached, pores are filled in a manner similar to the rise of water in a capillary tube.

The technique of measuring suction or tension in the water is of great importance both for research and in practice. Fukuda (1) has theoretically analyzed the Richards pressure plate method of measuring suction and the influence of relative humidity external to the apparatus on the measured moisture-content/suction relationship. He concludes that, with the technique normally used, both relative humidity outside the chamber and the temperature are of limited importance.

Predicting the moisture content changes that occur when the soil is covered and evaporation is interfered with is of great interest for highway and airport construction. The British Road Research Institute has reported some measure of success, provided the surface covering was impermeable and semi-infinite in size. For the isothermal case, according to Croney et al (5), the depth of the water table alone determines the ultimate pore water distribution. The moisture content distribution is calculated from the following equation:

$$u = s + \alpha P \tag{1}$$

in which

u = pore water pressure when sample is loaded
s = suction pressure with no loading
P = overburden pressure
α = compressibility factor

provided the water content as a function of s and the compressibility factor α are known.

This relationship has also been used to calculate moisture content distribution under grass cover and under bare soil from moisture tension values, measured as a function of depth. Variations in soil type with depth necessitated the use of several compressibility factors and moisture-content/suction relationships. Moisture contents calculated in this way were compared with moisture contents determined by boring and sampling. Good agreement was obtained and this was taken as further substantiation of Eq. 1. Undoubtedly, this concept of predicting moisture contents has much merit. It is believed by Croney and his co-workers that, together, suction and shrinkage results provide a valuable analytical method for estimating heave of structures resulting from either moisture changes when the surfaces are covered or a changed water table level. In the opinion of the writer this view warrants further consideration.

Guinnee (6) was concerned with determining moisture content changes and the source of the water in the soil under roads subsequent to construction. There is an obvious contrast between the approach used in the study by Guinnee and that of Croney et al (5) previously discussed. Throughout the various investigations reported by Guinnee, the emphasis appears to have been on determining the path of surface runoff water and its point of entry in the roadway. Certainly, in some of the work reported, the main entry appears to have been past the edges of the pavement. The writer finds it difficult, however, to draw any general conclusions from the various studies reported; in fact Guinnee himself draws no conclusions but leaves this to the reader.

Figure 1. Uneven settlement of sidewalk caused by removal of soil moisture by large trees.

Figure 2. Ice lenses in marine clay.

Frost-induced moisture flow is discussed here under isothermal flow, recog nizing that some vapor movement frequen ly, but not necessarily, accompanies the process. Hutcheon (2) concludes that "frost induced pressure gradients within the liquid phase will not cause any apprec able flow of water when soil moisture con ditions are dryer than those characteristi of moisture tensions in the vicinity of one atmosphere." Based on the work of the Division of Building Research, the limitir pF beneath the frost line is determined by the type of soil and density. However, in such freezing experiments the ice phase must be accommodated. In Hutcheon's ex periments, no provision was made for fro heaving. This would presumably result i positive pressures being developed within the soil-ice system. Positive pressures on the soil-ice system have the same effe as moisture suctions in the liquid phase o the unfrozen layer, that is, an increase i either one will bring about a reduction in the maximum of the other (13).

Subsequent to the frost action researcl reported in 1958 by the Division of Buildi Research (13), the rate of ice crystalliza tion has been studied in calcium lignosulf nate solutions as a means of investigating the retarding action it has on ice segrega tion in soils (14). Calcium lignosulfonate solutions, like some other organic solu- tions, cause a large reduction in ice crys tallization rate depending both on concen- tration and on the degree of supercooling. This is an additional rather than an alter tive mechanism to explain the reduction i frost heaving in soils treated with calciur lignosulfonate to those mentioned by Lam (15) or Hardy (16). Ice crystallization rates have recently been determined on variou molecular weight fractions of calcium lignosulfonate. A preliminary review of the re sults shows all fractions are probably about equally effective in reducing the ice crys- tallization rate in solution.

Further detailed research now nearing completion is concerned with the factors in- fluencing rate of frost heaving. These investigations show a strong positive relation- ship between heaving rate and heat flow. This is also true for heaving rate and frost penetration rate.

Ground Movements

Barber's paper on ground movements (4) brings out many useful facts on the effect of water movement on soil for the practicing engineer. Currently under investigation at the Division of Building Research are ground settlements due to desiccation by tree and subsequent damage to buildings (17). In Ottawa, settlements of 1½ in. due to shrinkage have been measured 20 ft from trees during a dry summer. Unfortunately, although some reswelling occurs in subsequent wet periods, a net settlement usually r sults. Artificial rewatering is sometimes partially successful. Figure 1 shows a pic ture of ground settlements around elm trees on an Ottawa street in a residential area

These trees, 45 to 60 ft high, are growing on marine clay. It is thought that safe dis-
tances between structures and trees can be worked out for this soil. The distances will depend largely on the height and kind of tree and foundation depth.

The effect of rate of loading influences the amount of consolidation in a consolidation test, according to Barber. This general problem was studied by the Division in some detail with a view to a more accurate evaluation of the preconsolidation load (18). Contrary to the results reported by Barber, at least for the Ottawa marine clay, the size of the load increment had practically no effect on the shape of the pressure void ratio curve when the load application was continued to the same degree of secondary consolidation. Further, when loading was carried out at a constant rate of strain, the greater rates gave a slightly higher indicated preconsolidation pressure. This tended to shift he virgin compression of the curve over to the right. For these and other reasons, he generalizations by Barber (4), though they may be correct for some soils, should e viewed with caution.

The problem of avoiding frost heaving under cold storage structures is also briefly nentioned by Barber. Some general design considerations have recently been published y the Division of Building Research (15). This followed experience with a cold storage lant that had heaved more than 1 ft in the center of the building to the point where it as unserviceable. The structure was reclaimed by supplying warm air through an xisting duct tile system under the building and thawing the frozen soil (20). The soil ad been frozen to a depth of 9 ft. Equilibrium resettlement was obtained in about six onths.

oil Structures and Frost Action

The macro-structures developed in soils under freezing conditions are extremely ell shown in the paper by Czeratzki and Frese (3). Comparing the structures develoed and the disposition of the ice for different soils, the authors might well have included the contrasting ice lens formation in coarse-grained soils. In these soils the e lenses are more flat and uniformly perpendicular to the direction of over-all heat ow.

Czeratzki and Frese show the vertical and horizontal ice forms as belonging to clay oils and the curved ice forms to loess soils. Ice lenses grown in marine clay containg 64 percent clay size and 36 percent silt show both forms possible in one specimen 'ig. 2). The sample was frozen at its natural moisture content of 60 percent. Water as also supplied at the bottom of the specimen. The "nutty" soil structure at the top thought to result when water for the ice phase is available in the immediate vicinity the freezing front involving a volumetric shrinkage of the soil. When the water content of the sample has been reduced so that the supply of water originates mainly from e groundwater table, the curved forms develop. The curious phenomenon is that the rved ice forms persist even when grown in a field of unidirectional heat flow as was e sample in Figure 2. This is, however, only one of the many problems in soils still be explained.

Finally, the writer wishes to compliment all the authors on their very worthwhile ntributions. The fact that some disagreement still exists between research workers erely points up areas where further work needs to be done and in no way detracts from e value of the papers.

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