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MOISTURE MIGRATION
2-8-54-1

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MOISTURE MIGRATION

Compiled by
Texas Transportation Institute
January 1964

1. Aitchison, G. D.,and J. W. Holmes, "Seasonal changes of soil moisture in a red-brown earth and a black earth in southern Australia", Australian Journal of Applied Science 4: n 2, pp 260-273, June 1953.

   The seasonal change in soil-moisture tension of two soils in their natural environment has been measured with a gypsum block technique. The range of pF* observed is less than 2.5 to about 4.2, the soils being commonly as dry as pF 4.2 to a depth of about 6 ft. at the end of the dry season (in a Mediterranean climate). Corresponding seasonal changes in soil water content are reported as measurable, in a red-brown earth, to depths of the order of 10 ft.

   The storage of water in the soil profile has been calculated for the two soils. The effect of soil swelling upon calculation of water storage is noted as of some importance. The buildup of stored water in the profile during the winter is established experimentally and compared to estimates obtained from rainfall minus evaporative losses.

   An example of the change in water content versus depth at the wet and dry limits of seasonal variations for soil type BE1 (for which data are given in preceding abstract) is given in the figure.

   *pF = Log_{10} (Neg. pressure in soil moisture, cm. water).

2. Aitchison, G. D., "Soil moisture in engineering investigations", Commonwealth Engr 40: n 8, Mar 1953, p 336-8.

   Defining soil moisture; relationship between water content and pF or relative energy status; soil moisture measurement; tensiometer and gypsum block moisture meter.

3. "Appareils pour la determination des lois et coefficients de permeabilite des milieux pulverulents," Technique des Travaux 23: n 5-6, May-June 1947, p 153-6.

   Apparatus for determination of law and coefficients of permeability of powdered materials; formula for study of flow of water through permeable soils contains factor which has no fixed value; conditions clarified by experiments; illustrated description of apparatus built in Hydraulic Laboratory, University of Liege, for study of flow through porous materials.

4. Bennett, P.T., "Effect of blankets on seepage through pervious foundations", Am Soc Civ Engrs--Proc 71: n 1, 3, 4, 6 , 8, Jan 1945, p 19-32, (discussions) Mar p 407-10, Apr p 597-8, June p 897-901, Oct p 1233-44.

Mathematical analysis of seepage through natural or artificial blankets of relatively impervious soils overlying pervious foundation is presented, indicating methods for application of formulas to design of earth dams; blanket formulas should not be considered as accurate means of computing flow conditions, but as aid to judgment of designer.

5. Black, W.P.M., D. Croney and J. C. Jacobs, "Field studies of movement of soil moisture", Great Britain, Sci & Indus Research Dept--Road Research Laboratory--Tech Paper n 41, 1958, 72p.

Experiments on movement of soil moisture in United Kingdom; method developed for estimating ultimate moisture distribution in soil mass in equilibrium with given water table and loading conditions; experiments on seasonal changes in pore water pressure and moisture content indicate transpiration from vegetation is more important than surface evaporation in removing water from soil; practical applications.

6. Bleck, A.T., "Bituminous flexible pavements", Roads & Streets 93: n 5, May 1950, p 74-76, 78.

Design considerations and construction practice in Wisconsin are discussed; evaluation of foundation for pavement depends not only upon reaction of soil with moisture but also upon potential quantity of moisture that will have access to soil; moisture movement; effect of radiation; use of soil maps.

7. Breazeale, E. L., W. T. McGeorge and J. F. Breazeale, "Movement of water vapor in soils", Soil Science 71: n 3, pp 181-5, 1951.

The moisture content of soil at various depths below the asphalt surfacing of an airfield runway in Arizona and at corresponding depths below the adjacent bare desert have been determined in the course of a botanical investigation. The values ranged from 2.0 and 1.95 percent respectively in the first foot below the surface to 10.8 and 4.0 percent

respectively at a depth of between 4 and 5 ft. In view of the arid climate of the district, it is thought that movement of water in the vapour phase has led to the accumulation of moisture under the asphalt surfacing

8. Buehrer, T.F. and J. M. Deming, "Factors affecting aggregation and permeability of hardspot soils", Soil Science 92: n 4, pp 248-262, October 1961.

A comparative study has been made on two Arizona soils, which in certain areas exhibit an unusually high degree of compaction, in contrast with the same soil series in areas where the soil is aggregated and structurally more favorable to soil and water movement and plant growth.

The "hardspot" condition is characterized by a highly compact, slowly permeable surface layer, low in organic matter, high in colloidal clay, and firmly cemented with carbonates of calcium and magnesium. This layer is characterized by comparatively high capillary porosity and low rate of rise of water by capillarity.

The hardspot soils are characterized by the predominance of micro-aggregates, of which 97 percent are less than 0.2 mm in diameter.

The well-aggregated soils were found to contain montmorillonite as the dominant clay mineral, whereas in the hardspot soils, illite was the predominent mineral. A high degree of correlation was found between degree of swelling of the colloidal clay with percentage of montmorillonite, and a close negative correlation with percentage of illite. Fracturing of the colloidal clay upon drying was observed to be extensive in the normal soils high in montmorillonite and very slight in the hardspot soils. Illite, with its slight lattice expansion in water as shown by swelling measurement, is concluded to be responsible in part for the compact condition of hardspot soils, together with the cementing action of calcium and magnesium carbonates.

9. Burgy, R. H. and V. H. Scott, "Some effectsof fire and ash on infiltration capacity of soils", Am Geophysical Union--Trans 33: n 3, June 1952, p 405-16.

Effects of certain physical and chemical relationship that may influence movement of water into soils and infiltration rates of some typical brushland soils; factors studied were effects of presence of ash, application of heat, burning of brush, and chemical constitutents of brush ash and their ramifications; infiltration may be influenced by burning brush and presence of ash.

10. Collis-George, N., "Calculation of permeability of porous media from their moisture characteristics", Am Geophysical Union--Trans 34: n 4, Aug 1953, p 589-93.

Interpretation of moisture characteristics, or relationship of moisture content to hydrostatic pressure deficiency, of porous medium is outlined, giving pore size distributions involved in simultaneous flow of wetting and nonwetting fluid; method of calculating intrinsic permeabilities to air and water flow at all fluid contents.

11. Croney, D., "Movement and distribution of water in soils", Geotechnique 3: n 1, Mar 1952, p 1-16.

Factors which affect moisture movements in soil; methods for estimating moisture distribution with depth beneath impervious pavements under equilibrium conditions; relationship between soil moisture absorption and moisture content can be used to estimate equilibrium moisture distribution in relation to incompressible, partially compressible, and fully compressible soils.

12. Croney, D. and J. D. Coleman, "Soil thermodynamics applied to the movement of moisture in road foundations", Proc 7th Internat. Congr. Appl. Mech 3: 1948, p 163-77.

The movement of water held in road foundations by surface tension and adsorptive forces is being studied at the Road Research Laboratory, Harmondsworth, England, this paper covers work carried out up to 1948. The relations between (1) soil-moisture suction and moisture content, (2) relative humidity of the soil-water and moisture content, (3) soil-suction, and relative humidity, are discussed. Transfer of held water in soil is shown to be affected by moisture and temperature conditions. Other relevant factors discussed are heat of wetting and latent heat of evaporation.

13. Croney, D., J. D. Coleman and P. M. Bridge, "Suction of moisture held in soil and other porous materials", Great Britain, Dept Sci & Indus Research--Road Research Laboratory--Tech Paper n 24, 1952, 42p, 2 supp plates.

Relationship between moisture suction and moisture content for porous materials; determining moisture suction by suction plate, centrifuge, consolidation, and electrical resistance method.

14. Delarue, J., "Movement of capillary water in soils and materials", *Reunion des Laboratoires d'Essais et de Recherches sur les Materiaux et les Constructions, Bulletin* n 18, 1954, p 21-3.

The movement of capillary moisture through soils is discussed generally and a new type of resistance-cell for measuring the changes in moisture content of soils is described and illustrated. The two electrodes spaced some distance apart each consist of a modified chromium-plated sparking-plug. Alternating current is used and impedances in the circuit are measured. The procedure is more useful for indicating general trends in moisture movement over long periods rather than for giving complete data during specific occasions. For example, it was found that a well-drained argillaceous tuff fried out continuously during summer, and it was possible to record the descent and petering out of the wet fringe in a sandy stratum after heavy rain.

15. de Vries, D.A., "Simultaneous transfer of heat and moisture in porous media", *Am Geophysical Union--Trans* 39: n 5, Oct 1958, p 909-15.

Simultaneous differential equations for transfer of heat and moisture under combined influence of gravity and gradients of temperature and moisture content; consistent distinction is made between changes of moisture content in liquid and vapor phase; discussion of interaction between heat and moisture transfer, using numerical values for clay loam and medium sand.

16. Duriez, M., "Examen de l'ensemble des conditions qui reglent la circulation de l'eau dans les sols et les fondations", *Annales des Travaux Publics de Belgique* 104: n 2, Apr 1952, p 201-16.

Conditions under which flow ofwater in soils and foundations is regulated; factors which affect flow; phenomena of adsorption, solvation, diffusion and osmosis, (In French, Flemish abstract).

17. Eagleman, J.R. and V.C. Jamison, "Soil layering and compaction effects on unsaturated moisture movement", *Proc Soil Science Society of America* 26: n 6, pp 519-522, Nov-Dec 1962.

Measurements of the velocity of flow and hydraulic gradients were obtained in the suction range of 0 to 700 cm of water across the plane of contact for three different soil textural

pairs, two of which were sampled from naturally occurring textural breaks in alluvial soil profiles. The hydraulic conductivity values across the textural breaks indicated that the soil properties were favorable for moisture transfer from large pores to smaller pores, but that a barrier existed for water movement from large pores to smaller pores, but that a barrier existed for water movement from smaller pores to large pores. The barrier developed as the suction increased in a coarse layer in contact with finer material. With water removal from the larger pores at moderately low suctions, flow from the fine soil layer into the coarse material was reduced. In the naturally occurring breaks in soil texture it was found that the compaction of the different soil layers determined the degree of expression of the barrier to water movement.

18. Elgar, W.H., "Soil movements as affecting paved surfaces", Surveyor 103: n 2746,1944, 427-8.

Soil movements causing cracking of road surfacings parallel to the edge of the road are discussed. Fluctuations in moisture content under the haunches cause expansion and contraction of the subgrade. The moisture content under the center of the road remains fairly constant and hence volume changes are small. Frost heaving, in the author's experiance, is more severe in gravel than in other subsoils. The drying and shrinkage of the subgrade under the edges of a road caused by moisture being drawn out of the surrounding soil by vegetation is stated to be the cause of longitudinal cracking of a road during a drought. Methods of preventing cracking due to the above causes are discussed.

19. Elgar, W.H., "Some exploratory boreholes in vicinity of trees", Surveyor 109: n 3028, Feb 17, 1950, p 95.

Four boreholes were made into heavy clay in Cambridge area to ascertain moisture content of soil near end of period of drought during 1949; each borehole was in vicinity of building where considerable subsidence and damage had occurred during drought; harmful effect of trees near buildings due to root action noted.

20. Ellison, W.D. and C. S. Slater, "Factors that affect surface sealing and infiltration of exposed soil surfaces", Agric Eng 26: n 4, Apr 1945, p 156-7, 162.

Effects of rainfall duration on surface sealing, rainfall splash, and soil physical properties; surface sealing represents major field problem; it influences factors of runoff, soil moisture, and ground water; data show some promise that new attack can be made on problem of infiltration through measuring amount of soil splashed by rain drops and determining physical properties. Bibliography.

21. Federick, J. C., "Soil percolation rates and soil characteristics", Pub Works 83: n 7, July 1952, p 46-8, 90.

In cases of septic tanks or leaching cesspools, proper absorptive capacities of various types of soils is both of economic and public health importance; this can be determined satisfactorily only by means of percolation test which is performed by excavating hole 1 sq ft and 18 in deep and observing seepage; percolation rates for various soil types.

22. Fireman,M. and O. C. Magistad, "Permeability of five western soils as affected by percentage of sodium of irrigation-water", Am Geophysical Union--Trans 26: pt 1, Aug 1945, p 91-3.

Data are presented for five western soils showing their permeability to Riverside tap water after preliminary leaching with waters of various percentages of sodium.

23. Gardner, Robert, "Relation of temperature to moisture tension of soil", Soil Science 79: n 4, pp 257-265, April 1955.

A study was made to determine the effect of temperature on soil moisture tension of three soils at constant moisture percentages. Data are presented which show a consistent tendency for tension to decrease at approximately 0.008 atmosphere per degree rise in temperature within the range of 0 to 50 C. The possibility of temperature-induced moisture percentage gradients in the soil at the time the tensiometers were read raises a question regarding the part of the tension variation that can be attributed to the direct effect of temperature on soil moisture tension and the part that should be attributed to the indirect effect through temperature-induced moisture percentage gradients. Regardless of this question, however, the data show that variations due to temperature may be so great that they cannot well be ignored in studies of soil-plant relationship or soil moisture movement.

24. Hadley, W.A., R. Eisenstadt, "Moisture movements in soils due to temperature difference", Heating, Piping & Air Conditioning 25: n 6, June 1953, p 111-4.

Heat pump coils buried in soil absorb up to 50% more heat than would be anticipated from thermal transfer calculations; moisture movement in soil may cause difference; study concerns form in which moisture is transferred; test results indicate that critical moisture content of about 4% separates liquid from vapor movement in soil.

25. Hadley, W.A. and R. Eisenstadt, "Thermally actuated moisture migration in granular media", Am Geophysical Union--Trans 36: n 4, Aug 1955, p 615-23.

Movement of moisture in granular media with varying temperature gradients studied by means of radioactive tracers in laboratory; mode of moisture movement is controlled by critical moisture content found theoretically and experimentally to be about 4%; results obtained with apparatus employing tube containing simulated soil.

26. Hall, W.A., Discussion of "Permeability and infiltration relationships in one dimensional infiltration in uniform soil", Am Geophysical--Trans 39: n 1, Feb 1958, p 123-4.

Discussion of paper indexed in Engineering Index 1957, p 1060, from issue of October 1956.

27. Hall,W.A., "Permeability and infiltration relationships in one dimensional infiltration in uniform soil," Am Geophysical Union--Trans 37: n 5, Oct 1956, p 602-4.

Equations developed for relationship between infiltration rate and time for 1-dimensional flow in uniform soil of constant permeability; depth of ponded water, permeability of soil and moisture deficit in transmission zone are principal parameters; equations compared with experimental data with reasonably satisfactory results.

28. Harrold, L.L. "Effect of vegetation on soil moisture", Am Soc Agric Engrs--Trans 1: n 1, 1958, p 6-8, 11.

Evaluation at Coshocton, Ohio, using Coshocton monolith lysimeters; water removal from soil as factor in hydrology-of-flood studies, in soil dryness, bearing strength and recharge

to groundwater, and in irrigation programs; effects of vegetal and land surface conditions on amounts of water distributed into various phases of hydrologic cycle.

29. Hide, J.C., "Observations on factors influencing the evaporation of soil moisture", Soil Science Society of America--Proc 18: n 3 pp 234-239, July 1954.

Important variables which influence the rate of evaporation of soil moisture are (1) the vapor pressure difference between the layer from which water is evaporating and that of the turbulent atmosphere and (2) the resistance to vapor flow of the intervening layer. The vapor pressure difference is associated with the temperature of the layer from which evaporation is taking place and the temperature and relative humidity (vapor pressure) of the turbulent air.

While capillarity moves water fast enough to keep the surface moist, the principal resistance to vapor flow is caused by the thin layer of nonturbulent air adjacent to the surface. Resistance increases rapidly as the surface dries so that water vapor moves through a thickening layer of dry soil. Adsorption of moisture by the dry layer and re-evaporation associated with the diurnal temperature cycle complicate the process.

Moisture movement in the upper layers of soil during the evaporation cycle was studied by periodic weighing of soil in vertically stacked porous bottomed containers and through the use of tensiometers. The data show the highly dynamic nature of the moisture regime in the surface layers of soil associated with diurnal temperature changes and the evaporation cycle.

30. Hollingsworth, J. and H. I. Meyer, "Two-dimensional gravity drainage profiles", Am Geophysical Union--Trans 39: n 4, Aug 1958, p 689-96.

Review of studies on shape of fluid-fluid interface of liquid which is draining by gravity from saturated porous medium; use of results of series of numerical solutions by digital computer to define area function, which is employed along with mass balance concept and idea of succession of steady states to derive expression of transient drainage from two dimensional saturated medium.

31. Hoshino, Kano, "An analysis of the volume change, distortional deformation and induced pore pressure of soils under triaxial loading", Proc 5th Int. Conf on Soil Mech & Found Eng, Paris 1: pp 151-157, 1961.

Triaxial tests carried out by the author and others have shown that the volume charg e of soils is influenced by both normal stress and shear stress.

Under shear stress, sands generally expand in volume and this has so far been described as swelling. Conversely, silt and clay often shrink. The pore-pressure induced under rapid loading is closely related to volume change, thus considerably influencing the stress-strain relationship and the ultimate strength of a soil.

After analysis of several triaxial test results and allowing for the effect of shear stress on the change in volume of soils, the author has revised his theory of soil mechanics presented to the London Conference in 1957. This theory has been applied to and compared with some typical laboratory test results under triaxial loading, with analyses of volume change and deformation observed under slow and rapid loading, as well as the induced pore-pressure under rapid loading.

32. Jamison, V.C. and J. F. Thornton, "Water intake rates of claypan soil from hydrograph analyses", J Geophysical Research 66: n 6, June 1961, p 1855-60.

Dominant factor determining soil moisture intake rate for silt loam studied is moisture content; temperature of soil surface during storm also influences intake rate, and perhaps soil fertility does also; increased plant cover will increase rainfall abstraction and decrease runoff and thereby increase apparent intake by soil.

33. Knight, B.H., "Effects of seasonal variations in soil moisture content", Civ Eng (Lond) 47: n 557, Nov 1952, p 911-13.

Account of variations under or near runways, roads and buildings, and suggestions for minimizing changes in soil moisture content and effect of such changes on structures supported by soil. Bibliography.

34. Kolyasev, F.E., "Factors affecting the movement of water in soil", Pochvovedenie (Pedology)(Moscow) n 2-3, 1944, p 80-6.

Laboratory experiments showed that below a certain moisture content, movement of soil moisture can take place only if there is a temperature gradient or a difference of osmotic pressure.

35. Kraijenhoff van de Leur, D.A., "Study of non-steady groundwater flow with special reference to reservoir-coefficient", Ingenieur 70: n 19, May 9 1958, p B87-94.

Problem of transformation of percolation into outflow solved for 2-dimensional flow in homogeneous profile on deep impermeable layer; reservoir coefficient and dimensionless diagrams introduced in course of mathematical analysis as new tools for study of groundwater flow. (In English).

36. Kravtchenko, J., G.Sauvage de Saint-Marc, M. Boreli, "Sur les singularities des ecoulements plans et permanents des nappes souterraines pesantes", Houille Blanche 10: n 1, 4 Jan-Feb 1955, p 47-62, Aug-Sept p 533-42.

Jan-Feb: Singularities of plane and permanent gravity flow of groundwater in porous medium which is isotropic and homogeneous; plane of movement is vertical, liquidis subject to action of gravity only; with conformal pattern in neighborhood of singularity given, problem can be solved completely. Aug-Sept: Study of singularity in two dimensional flows of ponderable fluids in porous media; typical example, namely case of point common to free surface and to impermeable wall.

37. Krumback, A.W. Jr., "Effects of microrelief on distribution of soil moisture and bulk density", J Geophysical Research 64: n 10, Oct 1959, p 1587-90.

In west central Mississippi total difference of elevation on plot was 1.8 ft; very small changes in elevation caused significant changes in moisture and bulk density of 6 to 12 in layer; variation in moisture appeared to be greater when measurements were by volume than by weight.

38. Kuznetsov, A.P., "Calculation of soil moisture content with calcium carbide", Avtom Dorogi 26: n 1, 1963, p 26. (In Russian.

A simple instrument developed in the USSR is described and

illustrated for determining the moisture content of sandy gravel and clay soils in any weather conditions from measurements of the gas pressure produced when calcium carbide reacts with water. Moisture contents and dry densities are read off from calibrated curves obtained for pure water and soil of various granular characteristics. The 2-kg instrument which is accurate to within ± 1 percent consists of a manometer calibrated for pressures up to 4 kg/sq cm set in an enclosed cylinder with an internal diameter of 7 cm and a height of 12 cm containing a concave diaphragm with a 14.5-mm hole covered by a 15-mm ball bearing. A sample of compacted soil placed in the cylinder below the diaphragm holding the powdered calcium carbide is shaken up with four ball bearings for 3 min to insure thorough mixing, and a pressure reading is taken. Curves are given which can be used to determine moisture content and density from the pressure readings.

39. Linares, R., "Consideraciones Para Determinar La Velocidad de Penetracion del Agua en el Suelo", Irrigacion en Mexico 25: n 4, Oct-Nov-Dec 1944, p 185-97.

Considerations for determination of velocity of penetration of water in soil; explanation of work undertaken in Tlahualilo region in Lagoon district.

40. Luthra, S.D.L, and G. Ram, "Electrical analogy applied to study seepage into drain tubes in stratified soil", Irrigation & Power, J of Central Board of Irrigation & Power (India) 11: n 3, July 1954, p 398-405.

Application of electric analogy method in solving problems concerning underground flow of water when two or more horizontal layers of different permeabilities exist; of interest in study of seepage and uplift pressures below dams and weirs.

41. Malcor, R., "Ecoulement a surface libre de l'eau dans les terrains poreux", Travaux 34: n 183, Jan 1950, p 23-8.

Flow of water at free level in porous soils; study based on Darcy law and method by Lamb; calculation of radius of curvature of free water surface; diagrams.

42. Malcor, R., "Equilibres capillaires limites--theorie de l'essorage", Annales des Ponts et Chaussees 127: n 4, July-Aug 1957, p 473-500.

Limits of capillary equilibria, theory of drainage; cohesion of water with granulated bodies (soils, for instance) in which it is included may become unstable, through phenomenon of draining drip or capillary extraction; condition of stability established by theoretical considerations and checked experimentally.

43. Mamanina, L., "The effect of insulating layers on the rise of capillary moisture in heavy loams", Pochvovedenie (Pedology) (Moscow) n 2-3, 1944, p 101-5.

Laboratory experiments on the effectiveness of insulating layers in preventing the rise of capillary moisture in heavy loams led tothe following conclusions: (1) of the three types of material studied, gravel, sand and compacted loam, the best results were obtained with a coarse sand (0.09 to 0.02 in), A 0.8-in. layer of this sand gave complete insulation. (2) A 1.5-in layer of gravel had an appreciable insulating effect if the material was carefully cleaned. Otherwise a considerable thickness was required, as was also the case with medium sand. (3) A layer of compacted loam could not prevent the rise of capillary moisture, but could hinder and delay it.

44. Mandel, J., "Ecoulement de l'eau sous une ligne de palplanches," Travaux 35: n 197, Mar 1951, p 273-80.

Study of flow of water beneath sheet piling, with view to determining pegging of piles required in water-bearing soil; exact and approximate solution given; it is assumed that permeable stratum is homogenous and of indefinite thickness or that base of stratum is at definite distance; nomographs can be applied both to dams and to excavation in water-bearing strata; diagrams.

45. Mansur, C. I., "Laboratory and in-situ permeability of sand", Am Soc Civ Engrs--Proc 83: (J Soil Mechanics & Foundations Div) n SM1, Jan 1957, paper 1142, 21p.

Seepage analyses and seepage control measures for structures such as dams, levees, etc, require data on permeability of sand strata involved; laboratory tests on remolded sand samples are compared with data from field pumping tests in which permeabilities of individual sand strata were determined from drawdown curves and measured flow from strata.

46. Markwick, A.H.D., "Soil mechanics and road foundation," Surveyor 105: n 2819, 2820, 2821, Feb 1 1946, p 79-83, Feb 8 p 107-10, Feb 15 p 121-2, (discussion) n 2834, 2835, May 17 p 387-90, May 24 p 407-8.

Effect of moisture content on mechanical properties of soils and methods of designing flexible and rigid pavements including their bases reviewed; road behavior, stresses in subgrade, and defects arising from subgrade conditions discussed; description of road construction on wet subgrades, moisture movement, frost action and drainage; various loading tests discussed and results presented in charts.

47. Mather, J.R., "Determination of evapotranspiration by empirical methods", Am Soc Agric Engrs--Trans 2: n 1, 1959, p 35-8, 43.

Evapotranspiration is difficult to measure; empirical formula yielding satisfactory calculations for potential evapotranspiration requires aid of tables and nomograms; calculation of actual evapotranspiration requires precipitation data, potential evapotranspiration, and conversion tables; irrigation schedules can be worked out on basis of data derived.

48. Matta, Gabriel, "A new method for studying seepage through porous media", Civil Engineering 56: n 662, pp 1183-1185, September 1961.

Based on the relaxation method and depending on the similarity between the flow through the capillary tubes and the flow through porous media, the author presents an experimental and automatic relaxation representing the porous medium by a network of capillary tubes interconnected.

The method of the hydraulic network combined all the advantages of the sand models, those of the electrical analogy and those of the relaxation. General solutions are obtainable even in the case of complex boundary conditions; the seepage line is given without any trial; the potential at any point is given by simple reading; and the capillary effect is fixed at will by the choice of the liquid to be used.

This method can replace with advantage the relaxation method whenever the latter is usable: homogeneous and isotropic, or hetergeneous and anisotropic porous media. It can be used more generally to solve problems of irrotational flows or for flows having a very small Reynolds number.

The problems of varying flow, for which the existing methods are very long, are solved rapidly and with sufficient accuracy by means of the capillary tubes.

Besides problems of seepage, we may finally note that this theoretical and experimental method can be conveniently arranged to solve many problems of partial derivatives such as the Laplacian (frequently encountered in the analysis of fluid flow), the Poisson, and the biharmonic.

49. Means, R.E., "Buildings on expansive clay," Theoretical and Practical Treatment of Expansive Soils: <u>Colorado School of Mines Quarterly</u> 54: n 4, pp 1-3, October 1959.

Cohesive soils and clays differ from noncohesive soils in the properties of their constituent minerals and differences in shape of the mineral grains. Swelling of clays is due to addition of water in capillary tubes between the particles; shrinkage is caused by removal of this water, either by evaporation or by compression. During a drought evaporation from the surface lowers the top of the capillary fringe toward the water table; the dry clay above this fringe is then subjected to maximum shrinkage. After a rain, free surface water is pulled downward, and the capillary zone above the water table rises. When the two saturated zones meet, the capillary tension in the pore water is relieved, and the clay can begin to swell against the reduced pressure. Swelling can take place only after saturation, and saturation is a very slow process, hence clays in some climates never reach maximum swell because wet periods are too short.

When a building is erected on clay, evaporation is retarded, but the soil can become saturated with capillary water drawn up from below. Expansion can thus occur even during dry periods. Around the periphery of a building which loads the soil to pressures less than the maximum capillary pressure, changes in climate and application of water to the surface may cause periodic swelling and shrinking of clay, with consequent damage to the building. The paper contains numerous examples of damage to buildings from expanding clays with suggested or actual methods of prevention or control of damage. All examples have to do with the highly overconsolidated Permian clays of Oklahoma.

50. Merkel, Eller and Dick, "Untersuchungen ueber Grundwasserstroemung", Gas - u Wasserfach 90: n 9, May 15 1949, p 238-42.

Investigations of groundwater flow; theory; observations on change in groundwater level; curves indicating flow in sand; lowering of groundwater in well with and without consideration of capillary forces; diagrams.

51. Meyerhof, G.G., "Influence of roughness of base and groundwater conditions on the ultimate bearing capacity of foundations", Geotechnique (England) 5: n 3, p 227-242, September 1955.

Previous theories of the ultimate bearing capacity of perfectly rough and perfectly smooth strip footings have been reviewed and combined to suggest a method for estimating the bearing capacity of a foundation with any degree of roughness of the base. While the bearing capacity of a weightless material is independent of base friction, the bearing capacity of a material with weight increases with roughness of the base. For a material with weight, approximate bearing capacity factors have been derived which are less than those commonly used, even for a rough foundation. Some loading tests have been carried out on model footings with different base frictions on sand, and the results are consistent with the proposed analysis.

Flow-net analysis shows that under upward seepage the bearing capacity of submerged material is somewhat less than estimated from the average hydraulic gradient on account of local piping around the foundation edges and a greater seepage pressure on the theoretical failure surface. An analysis has been made of the bearing capacity of partly submerged cohesionless material. The theoretical bearing capacity increases almost linearly with depth of water-table below ground level up to a depth below base level of ½ to twice the foundation width, depending on Φ and foundation shape.

Loading tests on model footings at various depths in fully-submerged sand below a stationary water-table are consistent with the bearing capacity being directly proportional to the effective unit weight of the material. Under upward flow of water the bearing capacity was reduced practically linearly with increasing average hydraulic gradient, the divergence from theory at larger gradients being due to considerable local piping around the base. The observed bearing capacity of footings on partly submerged sand was largely due to apparent cohesion on

account of the small scale of the experiments. Nevertheless, the test results provide a useful check of bearing capacity theory applied to a cohesive material with large internal friction.

52. Mickley, A.S., "Thermal movement of moisture in soil," Am Inst Elec Engrs--Trans 68: pt 1, 1949, p 330-3 (discussion) 333-5.

When moist soil is subjected to temperature gradient, moisture will have tendency to move in direction of heat flow; phenomenon concerns cable heating studies because thermal conductivity of earth in heat field involved will decrease as moisture is lost; it is also of interest in heat pump using buried ground coil, where migration has also been observed.

53. Mielenz, Richard C. and Myrle E. King, "Physical-chemical properties and engineering performance of clays", Clays and Clay Technology Bul 169, July 1955.

Fabric (texture and structure) and mineralogic composition determine the response of clays and shales to events occurring during construction and operation of engineering works. A new system of classification of the fabric of earth materials is proposed. Characteristic mineralogic composition of clays and shales, especially in the western United States, is described. Fabric and composition are correlated with soil mechanics properties and engineering performance. Needed research on clays and shales as a basis for design, construction, and maintenance of engineering structures is emphasized.

54. Muguiro, L. Aldaz, "La Impermeabilizacion por Inyecciones del Embalse del Tranco", Revista de Obras Publicas 93: n 2762, June 1945, p 254-9.

Impermeabilizing Tranco dam by grouting; dam on Guadalquiuir River, below confluence with Hornos River is 90 mi high and has impounding capacity of 550 million cu m; seepages through fissures in limestone, particularly in faulted area, tend to increase as limestone dissolves; unless grouted before reservoir fills, flow of water may wash out cement before it sets; illustrated description of practice, including test borings.

55. Newstead, G. and J. C. Jaeger, "Study of underground water movements by measurements in drill holes", Engineer 202: n 5243, July 20 1956, p 76-8.

Instrument for measuring small flows of water along or across drill holes at depths up to some hundreds of feet developed in connection with experiments on determination of thermal conductivity of rocks by measurements in drill holes.

56. Orlob, G.T. and G. N. Radhakrishna, "Effects of entrapped gases on hydraulic characteristics of porous media", Am Geophysical Union--Trans 39: n 4, Aug 1958, p 648-59.

Importance of changes of permeability by gas entrapment in ground water hydrology; increase of air content in voids of prepared media by 10% is capable of producing 15% reduction in'effective porosity', 35% decrease in permeability, and about 50% reduction in hydraulic dispersion; of interest in ground water recharge, sewage spreading, water pollution, and underground movement of radioactive wastes.

57. Philip, J.R. and D. A. deVries, "Moisture movement in porous materials under temperature gradients", Trans/American Geophysical Union 38: n 2, pp 222-232, April 1957.

A theory of moisture movement in porous materials under temperature gradients is developed which explains apparently discordant experimental information, including (a) the large value of the apparent vapor transfer, (b) effect of moisture content on net moisture transfer, and (c) the transfer of latent heat by distillation.

The previous simple theory of water vapor diffusion is porous media under temperature gradients neglected the interaction of vapor, liquid and solid phases, and the difference between average temperature gradient in the air-filled pores and in the soil as a whole. With these factors taken into account, and (admittedly approximate) analysis is developed which predicts orders of magnitude and general behavior in satisfactory agreement with the experimental facts.

An important implication of the present approach is that experimental methods used to distinguish between liquid and vapor transfer have not done so, since what has been supposed to be vapor transfer has actually been series-parallel flow through liquid "islands" located in a vapor continuum.

Equations describing moisture and heat transfer in porous materials under combined moisture and temperature gradients are developed. Four moisture-dependent diffusivities arising in this connection are discussed briefly.

58. Pilatovskii, V.P., "K zadache o neustanovivshemsya pritoke gruntovykh vod k drene v sloe beskonechnoi glubiny", Akademiya Nauk SSSR, Izvestiya, Otdelenie Teknicheskikh Nauk n 7, July 1958, p 70-3.

Problem of non-stabilized inflow of underground waters into drain within infinitely deep stratum; differential and integral equation giving shift of limits between two incompressible liquids in sloped thin stratum.

59. Poluboyarinov-Kochin, P. Ya., "K Teorii Neustanovivshikhsya Dvizhniy v Mnogosloynoy Sreda," PrikladnayaMatematika i Mekhanika 15: n4, July-Aug 1951, p 511-4.

Theory of indeterminate flows in multilayer medium; analysis of theory on established hydraulic flows in soil consisting of two layers; problem of indeterminate flow of underground water in medium consisting of two layers.

60. Ranganatham, B.V. and A.W. Hendy, "Permeability of black cotton clay as related to void ratio and adsorbed water," Sols-Soils, Revue Internationale de Mecanique des Sols No 4, pp 22-29, March 1963.

Existing hydraulic theories of flow through porous media take no account of diffusion phenomena. But is is well known to researchers in the field of soil mechanics and colloid science that clay flakes are generally negatively charged and that a diffuse type of electric double layer is formed in the presence of water. Hence a slight modification is suggested to the well-known low of Poiseuille in order to incorporate the retarding effect of the ionic field. Furthermore, flow in soils is sinuous, winding around soil particles and leading to a difference between the true hydraulic gradient and that arbitrarily used in analysis. A simple functional relationship between this tortuosity factor and void ratio is suggested from a consideration of the limiting values. It has thus been possible to postulate that the coefficient of permeability for clays,

$$k = \frac{c_s \gamma_w D^3{}_s}{216 \mu B} \quad \frac{e^5}{(1 + e)^2}$$

By conducting a series of consolidation tests on black cotton clay with different electrochemical environment, the permeability is correlated to void ratio and adsorbed water. An approximate method of analysis is advanced to estimate the thickness of the oriented non-liquid water. Test results agree quite favorably with the concept reported.

61. Rao, K.S. and S. K. Wadhawan, "Studies in soil permeability; effect of heating soil on permeability under prolonged submergence of soil in water", Irrigation & Power J of Central Board of Irrigation & Power (India) 10: n 4, Oct 1953, p 460-9.

Studies carried out on Gangetic alluvial soil of Delhi, India; soil was heated to 60, 150, 225, 360, 600, 650, 800, and 1000C and subjected to permeability measurements; soil shows shrinkage in low humid atmosphere of winter and swelling in high humid atmosphere of autumn.

62. Reeve, R.C. and M. C. Jensen, "Piezometers for ground-water studies and measurement of subsoil permeability", Agric Eng 30: n 9, Sept 1949, p 435-8.

Studies made in Gem County, Idaho; small diameter piezometers were used to investigate flow of groundwater in area of open drain and for making permeability measurements of subsoil materials; permeability determinations are based on theory developed by Kirkham for flow from open pipe into soil below water table; some of basic laws governing flow of water through soils.

63. Remson, Irwin and J. R. Randolph, "Review of some elements of soil-moisture theory", Fluid Movement in Earth Materials, U. S. Geological Survey, Professional Paper 411-D, 1962, 38pp.

This review was assembled from the existing literature to make available a convenient introduction to this subject.

Surface tension at the liquid-vapor interfaces largely controls the occurrence and movement of moisture in unsaturated soils. Surface tension is defined as the amount of work or energy required to produce a unit increase in the area of a liquid surface. The pressure on the concave side of a liquid-vapor surface in a round capillary tube exceeds the pressure on the convex side by an amount equal to twice the surface tension divided by the tube radius. The rise of liquid in a round capillary tube, if the angle of contact is assumed to be zero, is predicted by the capillary-rise equation $\rho g \zeta = \frac{2\sigma}{r}$; where ρ is the density of the liquid, g is the acceleration of gravity, ζ is the height of capillary rise, σ is surface tension, and r is the radius of the tube.

Important soil-moisture phenomena result from the transfer of water molecules across liquid-vapor surfaces and from the diffusion of water vapor within the system. Vapor pressure decreases with increasing height above a free water surface according to the barometric equation.

The total potential of soil water is the minimum energy per gram needed to transport a test body of water from a water-table datum to any point within the liquid phase of a soil-water system at equilibrium.

The hydraulic conductivity of a wet soil decreases very rapidly as the moisture content decreases from its saturation value. Field capacity and wetting-front phenomena are largely a result of this decrease of hydraulic conductivity with moisture content.

The differential equation for unsaturated flow is derived from the equation of continuity and Darcy's law.

64. Richards, L.A. and D. C. Moore, "Influence of capillary conductivity and depth of wetting on moisture retention in soil", Am Geophysical Union--Trans 33: n 4, Aug 1952, p 531-40.

Storage of moisture in soil depends on dynamic moisture transmitting properties of soil; field capacity condition corresponds to moisture content and moisture tension at which capillary conductivity of soil becomes small; changes thereafter depend on hydraulic gradient and low residual values for conductivity.

65. Richards, L.A., "Laws of soil moisture", Am Geophysical Union--Trans 31: n 5, pt 1, Oct 1950, p 750-3.

Study relating to observed regularities in processes connected with flow and distribution of water in soils; Darcy equation which expresses proportionality between transmission velocity and driving force for water in saturated soils; discussion and application of outflow law.

66. Robins, J.S., "Some thermodynamic properties of soil moisture", Soil Science 74: n 2, pp 127-139, August 1952.

This investigation was undertaken to obtain a more complete understanding of the energetics of soil moisture and to establish more clearly the nature of the forces involved in soil moisture retention. The methods employed were chosen primarily because of their thermodynamic rigidity;

other deficiencies in the methods were considered of secondary importance.

Each of the three thermodynamic properties investigated (the specific free energy, the specific heat content, and the specific entropy) was found to be reduced at all moisture contents studied. The specific free energy and specific heat content each exhibited the characteristic hysteresis effect, thus supporting its reality in the soil moisture system. The methods employed in obtaining the specific entropy, however, prevent any conclusive statement concerning the hysteresis effect in this property.

The specific free energy, the specific heat content, and the specific entropy were found to be affected somewhat by temperature for the temperature range studies. The specific free energy was found to increase numerically with increasing temperature, but the change was neither large nor consistent. The specific heat content and specific entropy were found to decrease numerically with increasing temperature.

The negative specific entropy values show that the randomness of the soil moisture is reduced over the range of moisture contents studied. This reduced randomness indicates that the major contributor to soil moisture retention for moisture contents, at least up to the permanent wilting percentage, is the electric force fields surrounding the soil particles.

67. Russam, K., "The distribution of moisture in soils at overseas airfields", <u>Gt. Brit. Road Research Laboratory Road Research Tech Paper No.</u> 58, 1962, 107pp.

The performance of a road or airfield pavement is influenced by the strength and hence by the moisture condition of the subgrade. Knowledge of any changes that might take place in the moisture condition of the subgrade after construction of the pavement has been completed is therefore, required by the engineer. Information relating to the moisture conditions at ten overseas airfields, which cover a range of climate and soil type, has been analyzed.

It has been found that under the pavement the ultimate moisture distribution was greatly influenced by the position of the water-table relative to the surface. A theoretical method for estimating the ultimate moisture distribution from the results of laboratory tests can thus be used and it has been shown to apply where the water-table was at a depth of 30 ft in clay and at a depth of 10 ft in sand. This is of particular importance in arid climates where a

water-table is at a great depth, the moisture condition of both the subgrade and the unpaved soil appeared to be determined by the humidity of the atmosphere.

Vapor movement of soil water did not appear to be a major factor in controlling subgrade moisture except where a fall in temperature occurred at the end of the rainy season and the soil was an unsaturated silty or sandy clay.

68. Sanwal, K.D., "Ground-water flow", India Central Board of Irrigation--J 5: n 1, Jan 1948, p 67-72.

Factors affecting ground water increment and decrement are: rainfall penetration, natural influent seepage from streams, lakes and ponds, artificial influent seepage from irrigation reservoirs, inflow of free or confined ground water, natural effluent seepage and discharge by evaporation, and artificial discharge by drainage and pumping; attempt is made to clarify ground water inflow, and rainfall penetration to water table.

69. Schiff, L. and F. R. Dreibelbis, "Infiltration, soil moisture, and land-use relationships with reference to surface runoff", Am Geophysical Union--Trans 30: n 1, 3 Feb 1949, p 75-88, June p 401-11.

Method for determining rates of water movement within soil uses rainfall rates and field measurements of moisture changes; major objective is determination of relationships between infiltration, soil moisture, and surface runoff on watersheds representing two soil types of different hydrologic characteristics and in three vegetal covers.

70. Scott, V. H., "Relative infiltration rates of burned and unburned upland soils", Am Geophysical Union--Trans 37: n 1, Feb 1956, p 67-9.

Practices followed to increase value of range land densely covered by brush; one practice, clearing by use of fire, has raised question as to its effect on infiltration capacity of soil; results of study by means of single ring infiltrometers; applicability to conditions in California.

71. Sedgley, R. H., "Effects of disruption and flocculation on pore-space changes in beds of clay aggregates", Soil Science 94: n 6, pp 357-365, Dec 1962.

The changes in pore space which occur when air-dry aggregates of clay soil are flooded and then allowed to dry were examined in the laboratory. Oven-dry porosities of beds of aggregates after flooding and drying depended on the initial size of the units composing the beds and the content of electrolyte in the wetting solution. The shape of individual aggregates and structural pore space separating them could be distinguished on polished blocks of flocculated samples, whereas in the controls the arrangement of aggregates was compact and pore space visible at low magnifications was confined mainly to large cracks formed by shrinkage.

The preparation and rapid wetting of the soil involved processes of disruption which increased the amount of structural pore space present by more than 12 cc per 100 cc of soil. The tendency for thisstructural pore space to be lost by consolidation during drying was apposed by forces associated with flocculation, and, in beds containing aggregates 1 to 2 mm in diameter which had been flooded with solution containing 5 me. per liter of dissolved salt, only a small proportion of newly created structural pore space was consolidated.

The roles of disruption and compression in producing the pore space changes described are discussed in relation to conditions in the field.

72. Shockley, D. R., "Capacity of soil to hold moisture", Agric Eng 36: n 2, Feb 1955, p 109-12.

Method for estimating total readily available moisture to maintain rapid drop growth; tables are based on available moisture in inches per foot for each soil texture and percentage of total moisture plant extracts from each 6, 12, or 24-in. (approximately 25%) layer of root zone profile.

73. Slater, C. S., "Flow of water through soil", Agric Eng 29: n 3, Mar 1948, p 119-22 (discussion) 122-4.

General conditions of gravitational flow; velocity and tension in frictionless system, and in friction system; Darcy's law and terminal velocity; character of flow in open and sealed soil columns; effect of capillarity on gravitational flow; saturation and gravitational flow; tension in static system; limit of tensions produced by drainage; effect of additive tension on gravitational flow.

74. Smith, S.W., "Determination of soil moisture under permanent grass cover", J Geophysical Research 64: n 4, Apr 1958, p 477-83.

Calculations taking into account decreasing evapotranspiration with decreasing soil moisture; discussion of other methods for calculation of moisture status, with particular emphasis on C. W. Thornthwaite's method.

75. Stearns, F.W. and C. A. Carlson, "Correlations between soil-moisture depletion, solar radiation, and other environmental factors", J Geophysical Research 65: n 11, Nov 1960, p 3727-32.

Data were obtained in upland meadow on [illegible]. highest correlations of single factors with moisture loss were obtained with soil temperature and evaporation-pan data and with solar radiation; values for air temperature, vapor pressure deficit, humidity, and wind were progressively lower.

76. Swartzendruber, D., "Water flow through soil prifle as affected by least permeable layer", J Geophysical Research 65: n 12, Dec 1960 p 4037-42.

Water movement through water saturated soil profile is analyzed on basis of Darcy's law for sectionally continuous hydraulic conductivity along one-dimensional, downward flow path; resulting relationships are used to assess effect of least permeable layer on flow through profile; hydraulic conductivity of least permeable layer does not of itself control flow.

77. "Symposium on permeability of soils", Am Soc Testing Matls--Special Tech Publ No. 163, 1955, 136p.

Papers presented at 57th Annual Meeting, Chicago, June 15, 1954.

78. Thirion, C., "Etude sur le pouvoir filtrant des sols", Genie Civil 127: n 19, Oct 1, 1950, p 367-70.

Study of infiltration of soils with aid of improved method by A. Muentz, applied to perimeter of preliminary scheme of Trebes irrigation canal at Lezignan-Corbieres, France; geographical and geological conditions; measurement of infiltration capacity; causes of variation; map, charts.

79. Todd, D. K. and J. Bear, "Seepage through layered anisotropic porous media," ASCE--Proc 87: (J Hydraulics Div) n HY3, May 1961, pt 1, paper 2810, p 31-57.

Study of seepage from leveed rivers into adjoining agricultural lands; flow nets in idealized cross sections were determined by electric analogy model; boundaries represented channel bed and bank, levee base, lower impermeable stratum, and water table in adjoining drained agricultural land; variables included 2 layers of different permeabilities and anisotropies, layer arrangements and thicknesses, channel depth and width, levee base width, and water table slope.

80. van Rossum, F. and A. Zanen, "Onderloopsheid. Onderzoek naar de aard van het verschijnsel en methode ter bepaling van de veiligheidscoefficient", Ingeniuer 71: n 20, May 15, 1959, p B87-91.

Investigation of phenomenon of under-seepage in flow of groundwater under structures; attempt made to provide method by which rate of safety can be calculated for designed construction.

81 Veihmeyer, F. J. and F. A. Brooks, "Measurements of cumulative evaporation from bare soil", Am Geophysical Union--Trans 35: n 4, Aug 1954, p 601-7.

Measurements were made of evaporation of soil water during 1921 in California at Davis, Delhi, Mountain View and Whittier; soil surface was kept free of vegetation and no rain fell for periods of eight to twelve weeks; other studies of soil in tanks reveal that evaporation rate from bare soil without water table is extremely slow.

82. Veihmeyer, F. J. and A. H. Hendrickson, "Permanent wilting percentage as reference for measurement of soil moisture", Am Geophysical Union--Trans 29: n 6, Dec 1948, p 887-91 (discussion) 891-5.

Permanent wilting percentage is constant; in rainless summers this moisture condition is reached below surface layer which is affected by evaporation; moisture is slowly reduced to minimum which is slightly below permanent wilting percentage; latter is satisfactory reference point from which available water may be calculated.

83. Waldmeyer, T., "Rates of flow of underground water and choice of tracers to determine them," Instn Water Engrs--J 12: n 6, Oct 1958, p 389-408.

Review of British literature on rate of travel of underground water, which varies from 0.04 ft per hr in sand to about 750 ft per hr in highly fissured formations; borehole observations in Maidstone, Kent, show that rates of flow in fissured racks may be much higher than reported and that there is very free flow of water in wide area around main boreholes; use of potassium salts, especially acetate as tracer, together with flame photometer.

84. "Water and its conduction in soils", Nat Research Council--Highway Research Board Special Report n 40, 1958, 338p.

International symposium on Physico-Chemical Phenomena in Soils presented at 37th Annual Meeting, Washington D.C., Jan 6-10, 1958.

85. Woodruff, C.M., "The movement and evaporation of soil water in relation to moisture potential", Soil Sci Soc Amer Proc 6: 1941, pp 120-125, illus. 5.

Moisture movement phenomena were studied in short columns of soil when drying in air. Evaporation curves reveal a limited moisture content where soil moisture movement as the liquid phase does not take place. Water movement takes place only through thevapor phase when soil moisture is below the limiting content, and thus is lost at a slower rate than when movement through the liquid phase ceases when the surface of a short column of soil becomes dry. Water loss may then occur only by evaporation beneath the surface, and the rate of evaporation is related inversely to the square of the thickness of the dry layer of soil through which the vapor diffuses. Practically, this means that it will require four times as long to dry out the second inch of soil as it does to dry out the first inch. The limiting moisture content corresponds to the field capacity. It may occur at any moisture potential. In coarse-textured soils and in very fine-textured structureless soils it corresponds to the moisture potential required to empty the pores. This moisture potential is a function of the size of the dominant group of pores. In soils of medium texture, such as in fine sandy loams, in silt loams, and in granulated clay loams, the limiting moisture content is determined by the instability of water in the liquid phase at a moisture potential of pF 3. Consequently, most

agricultural soils which fall in this range of textures exhibit a moisture potential of pF 3 at field capacity.

86. Woodside, W. and J. M. Kuzmak, "Effect of temperature distribution on moisture flow in porous materials", Am Geophysical Union-Trans 39: n 4, Aug 1958, p 676-88.

Application of temperature gradient across enlarged model of particular, high-quartz wet sand and measurement of temperature distribution within pore spaces; flow mechanism consists of multiple vapor diffusion and liquid flow steps in series, resistance to flow in liquid phase being negligible, so that flow rate is determined by vapor pressure gradients in pore spaces.

87. Woodside, W. and C.M.A. deBruyn, "Heat transfer in a moist clay", Soil Science 87: n 3, pp 166-173, March 1959.

Results of experiments on heat transfer in remolded clay samples at various moisture contents are reported.

The thermal conductivity of remolded Leda Clay appeared to increase markedly with increasing moisture content and density, Values ranging from 1 to 4 B.t.u. in./hr ft^2 deg F were found.

Thermal conductivity values for the dry material obtained by means of a conductivity probe were in agreement with the result of one test carried out with a 12-in. guarded hot plate apparatus. Conductivities ranged from 1.0 to 1.3 B.t.u. in/hr ft^2 deg F for dry densities varying from 58 to 71 lb/ft^3.

Conductivity values for the same material, calculated from the conductivity of the grains and the dry density by means of a formula proposed by De Vries, were somewhat lower than the measured values and ranged from about 0.8 to 1.0.

Measurements of the conductivity of Leda Clay at various moisture contents up to about 20 percent were seriously hampered by thermal migration of moisture (thermo-osmosis) during the tests.

Tests carried out on clay at 10 and 18 percent moisture contents with the conductivity probe showed the instrument in its present form to be unsuitable for determining the conductivity of moist soils. Because of thermal migration of soil moisture during the tests, the measured conductivity decreased continuously, and extrapolation towards a value representative of the initial uniform moisture content appeared to be impossible. Better results might be obtained using a probe with a somewhat larger diameter in order to decrease the disturbing effect of thermal moisture redistribution in the soil by reducing the temperature gradient at the surface of the probe.

88. Zangar, C. N., "Theory and problems of water percolation", U. S. Bur Reclamation--Eng Monographs n 8, Apr 1953, 76p.

Flow of water through dams and their foundations; effects of this "percolating" water and methods for correcting them; methods for determining permeability of soils by field tests.

89. Zunker, F., "Bedeutung und Bestimmung der spezifischen Oberflaeche und der Durchlaessigkeit von Boeden", Dresden Technische Hochschule--Wissenschaftliche Zeit 1: n 2, 1951-52, p 131-6.

Significance and determination of specific surface and permeability of soils and other dispersoids; tests carried out on different soils, with both air and water permeation. Bibliography of author's works.