DISCUSSION OF THE PAPERS REVIEWED BY SUB-COMMITTEE NO. 4 ON "EXPLORATION, SAMPLING AND AREAL DISTRIBUTION OF SOILS" OF THE U.S. NATIONAL COMMITTEE ON SOIL MECHANICS.

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The nine papers submitted through this Sub-Committee for publication by the Second International Conference on Soil Mechanics and Foundation Engineering are considered to correctly reflect the trends that have developed during recent years in the United States in the field of Soil Exploration.

The first and major group of papers is concerned with the methods of regional and areal study of soils.

The paper (no. IIIe 3) by R.E. Frost and K.B. Woods entitled: "Areal Photographs Used For a Regional Evaluation of Soil Materials" outlines the considerable progress which has been made in recent years in this form of study. In this paper the authors have presented the fundamental principles of a method of determination of soil types from examination of aerial photographs which should be of exceptional benefit to the highway and airport engineer. The intelligent application of these principles by a trained observer will allow the selection of the best possible sites and will permit the layout of an economical exploration program for highways or airports. Of equal importance is the use of airphoto interpretation in the selection of areas where granular construction materials may be found.

In certain areas some of the elements used in airphoto interpretation are of importance, whereas other elements are subordinate. For example, in the Mississippi alluvial valley the land form is extremely flat and stereoscopic examination of the photographs provides little information. Identification of soil types is based primarily on current markings, color tones, vegetation, and land use.

As with many new methods which show promise, there may be a tendency for some engineers to adopt airphoto interpretation as a "cure-all" without giving proper thought to its limitations. The method is particularly adapted to highway and airfield work where surface and near surface soils are of primary importance. For heavier structures such as dams or levees, where the sphere of influence extends into the subsoil to depths of 100 feet or so airphoto interpretation has definite limitations in its present state of development. Even in these cases, however, surface soils are a consideration in construction, and the method is of value.

The Mississippi River Commission, Corps of Engineers, Department of the Army has found the use of aerial photographs of great value in its flood control activities on the Mississippi River. By means of aerial photographs the old meandering channels now nearly totally obscure on the ground can be readily located from the air and identified by experienced observers. Since the river under certain conditions will deposit sand, silt and clay in different locations, it is possible, for example, from such photographs to so locate a levee to utilize a clay plug in an old river channel to the best advantage.

The use of aerial photograpns is also being considered as a tool to identify soils quickly over large areas with respect to its trafficability. It is now possible to predict the type of vehicle that can traverse a given area when the general soil type and certain other data, such as rainfall and general topography, are known.

The paper demonstrates clearly the necessity for adequate careful correlation with ground surveys with respect to the subject being studied and the necessity for a thorough knowledge of the geology of the area involved. The accuracy of an interpretation made of an aerial photograph is apparently dependent largely on the skill of the observer in recognizing certain features which identify and distinguish one area from another.

This paper emphasizes the usefulness of a thorough knowledge of the allied sciences of geology and pedology in this type of engineering studies. Three other papers outline special problems arising from attempts to apply these two allied sciences of geology and pedology to all engineering problems of soil exploration.

The paper (no. Ib 3) by W.J. Turnbull and H.N. Fisk entitled: "Geology and Soil Mechanics. Foundation Exploration Lower Mississippi Valley" brings out some of the organizational difficulties which may arise during cooperative efforts of professional groups with different back-grounds The paper further describes how the cooperation of soil engineers and of geologists has been successfully achieved in connection with field projects of major importance, by clearly defining the scope of the activities of each group. It is believed that the organizational principles outlined in that paper can serve as an example for all other work of a similar kind.

The paper (no. Ib 1) by Hans F. Winterkorn entitled: "Engineering Uses and Limitations of Pedology for Regional Exploration of Soils" illustrates how pedology can be of assistance to engineers. The pedologic methods discussed constitute an indirect but valuable approach to engineering problems and emphasize the broad approach that is necessary for soils engineers, particularly those concerned with surface soils. As the paper points out, the results are largely qualitative and must be supplemented by appropriate physical properties of a quantitative nature.

It appears that one of the major advantages of pedologic study is as an aid to organized thought in collection of data regarding soil behavior, and that one of its greatest values is as a stimulant to organized thinking regarding soil properties. From the soil mechanics viewpoint, it is considered that a thorough knowledge of the pedology of a soil or its genesis is in most cases a "must" if the most feasible and economic design is to be attained.

A related paper (No. Ib 4) by Chas. B.Hunt entitled: "Some Geological Aspects of the Problems of Soil Genesis and Soil Classification" although falling within the scope of the Sub-Committee No. 5, should nevertheless be mentioned here in our discussion since it brings out the importance of a pedological approach to the study not only of recent soil deposits, but also in investigations of soils deposited during long-past geological periods.

Mr. Hunt, by specific illustrations of the geology in Utah Valley, has pointed out that only through an accurate knowledge of the geologic history of a soil can its true genesis be known. The geologic history as such must properly integrate the effects of climate, parent material, drainage and erosion, plant and animal life, and the time element. Mr. Hunt states that these five factors are the principle ones in controlling soil formation. The realization that these factors can vary in an infinite number of ways forces the realization that soil genesis can be an exceedingly complex thing.

Three papers discuss direct applications of the methods which form the subject of the preceding four papers.

The paper (No. IIIf 2) by Allen C. Ely entitled: "Areal Studies of Soils in New Jersey" as its name indicates, outlines the related local studies of the New Jersey State Highway Department. Mr. Ely's paper ably points out many of the problems confronting highway engineers in the design and maintenance of road systems under today's heavy traffic loads. The method of approach to the solution of these problems, involving a determination of the engineering properties of soils on an areal basis and correlating pavement behavior with soil characteristics, is one that is coming into more general use and is providing useful information to the design engineer. It is of interest to note that the delineation of soil types in New Jersey by means of airphoto interpretation has been sufficiently accurate to permit an evaluation of pavement performance.

The correlation of soaked bearing ratio values of subgrade soils with pavement distress is certainly of importance so far as soil strength is concerned. However, it is believed that this test should not be the only criterion for determining satisfactory pavement behavior, since it is entirely possible to obtain excessive consolidation of subgrades or bases under traffic, even though the bearing ratio is sufficiently high to prevent shear deformation. This is in part borne out by the statement on page 2 that sands and gravels (normally considered to give adequate bearing ratios when properly placed) have had a tendency to consolidate under traffic, resulting in settlement at joints and cracks in the pavements. It is now commonly known that compaction of granular materials is facilitated in many cases by the use of vibration. The effects of vibratory compaction on other soil types are not too well known at this time, nor are the amount and influence of vibrations transmitted to subgrades and base courses by rubber-tired vehicles too well defined. The proposed project on vibrations as indicated in this paper should provide valuable information for future use in pavement design procedures.

The paper (No. IIIg 1) by Walter K.Wilson Jr., entitled: "Permafrost Investigation in Arctic and Sub-Arctic Regions" and the paper (No. IIIe 2) by K.B. Woods, J.E. Hittle and R. E. Frost, entitled: "Correlation Between Permafrost and Soils as Indicated by Aerial Photographs" give a good account of the special methods which have to be followed during soil engineering studies if these are to meet the unusual difficulties encountered in Arctic regions. The first of these two papers demonstrates very clearly the distinctly different approach to most engineering problems in the arctic regions as compared to these in the more temperate zones. Since different methods of design and construction are required and very little is known concerning them, this article by Colonel Wilson is quite timely in pointing out the need of practical research. The development of Alaska from both military and civil viewpoints is very greatly dependent upon the knowledge gained from such research.

Only three papers are concerned with specific technique of local soil exploration.

The paper by James D. Parsons (No. IIIa 5) entitled: "Sampling Disturbance and Its Effect on Analytical Solutions to Soil Mechanics Problems" emphasizes the importance of the type of sampler employed in connection with the amount of disturbance of the samples extracted. The paper reflects the present trend of up-to-date practicing engineers to accept in their field work the principles brought out by the pioneer research of M. Juul Hvorslev and, specifically, the advisability of using thinwalled samplers. The paper is of value in that it forms a summary of material from several sources. Its greatest value lies in the emphasis which is placed on the influence of sampling disturbances on design. In regard to Mr. Parsons' remarks on the benefits of the stationary piston sampler, it is believed that some very important advantages are not listed. These are: (1) The prevention of the entrance of excess soil into the sampling tube. (2) The pressures immediately over the sample are automatically regulated by the piston and this regulation happens to occur in such sequence as to promote the taking of good undisturbed samples. (3) The stationary piston sampler minimizes to a very great extent the inclusion of any slush and disturbed boring fragments which have accumulated in the bottom of the hole and which have not been expelled by the washing or cleaning.

It is believed that Figure 3-B is not such a good illustration of an undisturbed sample since it shows a distinct convex curvature of the soil layers which may have been caused by failure of the soil at the bottom of the bore holes before sampling, excessive inside friction, entrance of excess soil, or improper removal of the sample from the tubing. Figure 3-C is considered a better example of an undisturbed sample.

The statement that the use of the consolidated quick test results on a sample which has been affected by disturbance is on the unsafe side insofar as most of our analytical solutions are concerned may not be correct for all soils. The dotted extension of the shear envelope to zero (Figure 4) may not correspond to the actual behavior of the soil. It is probable that the strength value at low pressures for consolidated quick remolded samples is smaller than that for undisturbed samples.

In support of Conclusion 6 which is in reference to the effect on laboratory test results of small disturbances due to sampling and testing operations, it would have been better if Mr. Parsons had shown (Figure 7) a comparison between an undisturbed sample and a remolded sample. With respect to Conclusion 2 concerning the probability of evaluating the effect of the change in stress on the strength of a sample when removed from the ground, it is believed this will be very difficult at times especially for soils which contain a considerable amount of absorbed gases in the pore water.

The paper (No. IIIa 6) "Foundation Exploration. A Review of Methods and Requirements" by M. Juul Hvorslev summarizes the findings of his recent research and provides valuable information concerning the selection and the use of specific types of samplers for purposes of exploration under varying field conditions.

The paper (No. IIIb 10) by W.R. Perret, entitled: "Electrical Resistivity Exploration as a Complement to Boring in Deep Alluvial Deposits" gives an account of specific problems encountered with electric resistivity soil exploration and the degree of accuracy of this method as established by control borings.

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DISCUSSION OF THE GENERAL SUBJECTS

IDENTIFICATION, CLASSIFICATION AND PROPERTIES OF SOILS

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INTRODUCTION

It has been suggested that each of the various technical subcomittees of the U.S. National Committee on Soil Mechanics prepare a discussion summarizing the progress that has been made in the one or more subject fields coming within the scope of the Committee's assignment. The subjects: identification, classification and properties of soils come within the province of subject material assigned to Subcommittee No. 5. This committee has reviewed the many papers, submitted for publication in the Proceedings of the Second International Conference on Soil Mechanics with a view not only to making recommendations concerning the suitability of the various papers for such publication, but also with a view to preparing a discussion summarizing the developments in its assigned subject fields as brought to light by these papers.

A total of twenty-three outlines of papers were submitted to this committee for review. Sixteen papers conforming to these outlines were received and reviewed. Of these, one paper bears on the subject of soil identification, two on the subject of soil classification, one on the geologic aspect of soil genesis, and the remainder treat various aspects of the general subject, soil properties. Included in this latter group are papers treating physico-chemical properties, thermal properties, permeability characteristics of anisotropic soils, and stress-deformation, volume change, and strength characteristics of soils under dynamic as well as static loading conditions. Of the 8 papers not received at the time of this writing, two pretain to Soil Classification and the remaining fall into the category of the general subject Soil Properties.

The following discussion is focused upon the subject fields treated in the completed papers and as outlined in the summaries of papers not as yet submitted.

The development in recent years of techniques for identifying surficial soil deposits and for identifying the characteristics of and establishing the drainage features of a given area from aerial photographs has provided the engineer with very useful tools that have many applications in Civil Engineering practice. These developments should be of immediate interest to specialists in the field of soil mechanics.

The development of airphoto interpretation techniques provides an efficient and economical method for the identification and mapping of soil types on an areal basis. Maps thus prepared have been used to good advantage in highway and airport location studies, in prospecting for borrow material in correlating soil factors and highway performance, and in planning locations for detailed subsoil explorations. Drainage maps, showing stream beds in minute detail, can also be prepared directly from aerial photographs. From such maps, the component watershed areas can be easily and accurately delineated. Essential information concerning the runoff characteristics of a given watershed area is depicted by the drainage map and the soil map thus prepared for that area.

In paper No. IIIe 1 entitled "The Determination of Soil Conditions by Aerial Photographic Analysis", by D.J. Belcher, the various elements which are distinguishable on an aerial photograph and which serve as soil identifying feature are enumerated. The author shows by various examples that many soils can be distinguished by characteristic air-photo patterns regardless of the geographic location of the soil. Paper IIIe 3 entitled "Aerial Photographs Used for an Engineering Evaluation of Soil Materials", by R.E. Frost and K.B. Woods, contains an extensive bibliography on the use of aerial photographs in determining drainage features and characteristics of surficial soils within a given area.

SOIL CLASSIFICATION

Noteworthy among the more recent contributions to the subject of soil classification is the paper entitled "Classification and Identification of Soils", by Arthur Casagrande 1). In this paper, the author presents a critical review of soil classification systems proposed for engineering useage and directs attention in particular to the inherent inadequacies of textural classifications according to which all soils are distinguished primarily on the basis of grain size composition. He proposes a system on the basis of which fourteen soil types, which have significantly different physical properties, can be recognized by simple tests that can be made in the field. His proposed system of descriptive classification provides a frame work according to which soils are differentiated so as to reflect performance characteristics under a wide variety of conditions.

Two papers were submitted for publication in the Conference Proceedings bearing on the subject of soil classification. In paper No. XIIa 4 entitled "A Suggested Modern Engineering Classification of Soils," Mr. R.R. Proctor takes issue with purely descriptive soil classification systems and advocates a system of classification based upon quantitative soil test data obtained from "precisely made tests rather than from uncertain visual and other sensorial classification." He suggests that data obtained from compaction-penetration resistance tests serve as classification criteria. In paper VIIIf 5 entitled "Relation of Density and Shear Strength to the Classification of Highway Subgrade and Flexible Base Materials," Mr. C. McDowell proposes a system that distinguishes six different classes of subgrade soils and base materials on the basis of their shear strengths as determined from triaxial compression tests.

Two additional papers on Classification designated as No. 5.1 and 5.2 entitled "Identification. Description and Basic Classification of Soils" by D.M. Burmister and "An Engineering Grouping of New York State Soils" by E.F. Bennett and G.W. McAlpin are not at this writing completed. x)

In paper No. 5.1 Professor Burmister will propose three logical steps to determine detailed and accurate information on the physical properties and the behavior characteristics of soils.

First, relatively simple and reliable methods of identification, based upon the characteristic qualities of each class are given. The author feels that the identification of soils by visual and manual methods would suffice for more than 75% of all work in soil engineering. Needed laboratory identification tests should supplement this information and provide the necessary checks.

Secondly, soils should be given descriptive names which convey a definite meaning. The descriptive names must be expressed in engineering and technical terms. The well established terms gravel, sand, silt and clay used singly or in combination forms the basic element of the soil name. This identifies the predominant soil component. Significant detail may be shown by the addition of descriptive terms as needed.

It is then proposed to group soils according to a basic classification scheme which is based upon physical and behavior characteristics. The characteristics which apply to all classification for practical uses are for example; drainage, plasticity, capillarity, and others. Such a basic classification, if universally accepted, would make available the data from which practitioners in any field could interpret information and draw his own conclusions in terms of his own experience and methods.

It is the feeling of the author, that "the greatest potential field of progress in Soil Mechanics lies in the direction of the accumulation of a body of detailed accurate information and knowledge on the physical properties and behavior characteristics of soils."

In paper 5. 2 E.F. Bennett and G.W. McAlpin, Principal Soils Engineer and Associate Soils Engineer, respectively, in the New York State Department of Public Works, will present a grouping of the soils of New York State according to their geologic origin and mode of deposition. Maps showing the extent of different formations are prepared by utilizing existing geological, pedological, and areal survey information and field reconnaissance. From this information, reports for highway projects that present engineering problems pertinent to each soil group are prepared giving recommendations with regard to location of line, excavation embankments, borrow, sources of gravel, pavement design, top soil and relative agricultural productivity.

It is hoped that both these papers will be completed and that they will appear in the Proceedings. Both will merit careful study.

PHYSICAL PROPERTIES OF SOILS

Many significant papers treating various aspects of the general subject, "Physical Properties of Soils," were presented by U.S. Authors for publication in the Proceedings of the Second International Conference on Soil Mechanics. These papers present fundamental concepts of soil physics and geological aspects of soil genesis. Empirical information is given concerning the dynamic properties, of soils, the thermal properties of soils, the effects of disturbance on the stress-strain and consolidation characteristics of clay-like soils, the shear strength characteristics of varved clays and the stress-strain characteristics of sands as determined from very carefully conducted vacuum type triaxial tests. One paper deals with a theoretical analysis of the permeability characteristics of anisotropic soils. Another deals with the structure of disturbed soils. All of these papers merit careful study.

The six papers which, unfortunately, could not be completed at this writing, deal according to the summary submitted with the effect of cyclic loading on clay, the peculiarities of Lateritic soils, the strength of natural clays, the use of Pocket-Size Piston Sampler and Compression test apparatus for field control tests, further information on the Atterberg Limits and a report on direct shear tests.

It is the earnest hope of the members of Subcommittee 5, that all of these papers will be completed and published in the Proceedings. The Committee has, therefore, taken the liberty of including in the following discussion, information contained in the summaries of these papers.

The concepts presented in paper No. Ic 4, "Some Fundamental Factors Influencing the Properties of Soil Materials," by R.E. Grim, contribute to an understanding of the structure of fine grained soils and in particular to the pronounced influence of the water phase of a soil system due to a postulated oriented configuration of the water molecules. The author enumerates the compositional factors that control soil properties and discusses the effect of each.

Paper No. Ic 3, "Physico-Chemical Properties of Soils," bears on the same subject as that treated by Grim. In this paper, Winterkorn demonstrates how a knowledge of physicochemical phenomena leads to a more basic understanding of the effects of compositional factors on the soil properties that are of interest to the engineer. In a second paper, No. Ic 7, entitled "Dynamic Properties of Soils," Winter-

x) The following papers have not been received by the Editorial Committee: 5.1; 5.2; 5.8; 5.9; 5.11; 5.15; 5.17 (Ed. Comm.)

korn directs attention to the dynamic effects of periodic fluctuations in temperature and moisture conditions in surficial soil deposits. He presents some of the theory and physical consequences relating to the transmission of temperature waves, enumerates the various potentials causing water movement in soils, and comments on the relationship between heat and moisture conduction in soils. Attention is directed to the great need for additional theory and for additional knowledge of the physical properties of soils that relate to these dynamic phenomena.

The influence of geologic factors, which may be considered related to the general subject of soil dynamics, is treated in paper No. Ib 4, "Some Geological Aspects of the Problems of Soil Genesis and Soil Classification," by C.B. Hunt. The author discusses in this paper, the effects of climate, parent material, topography, biologic processes, and time on soil development, and indicates how a knowledge of these geologic factors is useful in soil classification studies.

The need for investigating the thermal characteristics of soils, as suggested by Winterkorn, has also been emphasized by construction experience in Arctic regions subject to perma-frost conditions. Mechanical engineers engaged in studies of various applications of the heat pump cycle are also in need of data on the thermal properties of soils. Three papers on this subject were contributed by M.S. Kersten. In paper IIg 5, "Apparatus for measuring Thermal Conductivity of Soil", the instrumentation for measuring the effects of density, moisture content, temperature, grading, and mineral composition on the thermal conductivity of soils is described. In paper No. IIg 4, "Specific Heat Tests on Soils," the author reports the results of specific heat measurements that were made on a variety of non-plastic, dry soils ranging from crushed rocks to silt loams. It is reported that the specific heat values of such soils are approximately the same at a given temperature but that they decrease with a decrease in temperature. The results of thermal conductivity tests are reported in paper No. Ic 4, "Thermal Conductivity of Soil". In this paper the author presents the results of tests made on thirteen non-plastic soils and one plastic soil. These data show that the thermal conductivity of soil is not only dependent upon the temperature but also upon the grading, the shape of the soil constituents, and the density and the moisture content of the soil.

An analytical discussion of the permeability characteristics of anisotropic soils is presented in paper No. Xa 2, "On the Permeability of Homogeneous Anisotropic Soils," by S.T. Yang. It is shown in this paper how Mohr's stress circle concept can be used in determining the coefficients of permeability in directions normal and parallel to the direction of a flow line.

Investigations of the stress deformation and volume change characteristics of soils are reported in four papers submitted to this Committee. In paper No. IId 11 entitled "An Investigation of Stress-Strain and Strength Characteristics of Cohesionless Soils by Triaxial Compression Tests," L.S. Chen presents the results of carefully conducted investigations on cohesionless soils by means of vacuum type triaxial compression tests. The effects of minor principal stress, density, grain size, and grain shape are reported. Noteworthy improvements in the techniques of preparing test specimens and in the technology of testing are described. The author presents data to show that these improvements in the art of testing have made it possible to determine the entire stress-strain curve of cohesionless materials with a high degree of accuracy and to duplicate results to a degree hitherto unattainable.

The results of pioneering investigations on the "Stress-Deformation and Strength Characteristics of Soils under Dynamic Loads," are presented in paper No. IId 10 by A. Cassagrande and W.L. Shannon. The instrument developed for the purpose of conducting these investigations is described and tentative conclusions are drawn from the results of tests performed on both sand and clay type soils. It is shown that the strength of clay increases very significantly as the time period within which the load is applied decreases and that the increase in transient strength is dependent upon the static strength of such soils but independent of the method of testing. On the other hand, it is indicated that the strength of cohesionless soils is not materially affected by the rate of loading. The information brought to light for the first time by these investigations is of paramount importance in studies of the performance characteristics of soils when subject to the effects of bombing, earthquakes, and the effects of fast moving traffic. This information may also lead to a more fundamental understanding of the stress-deformation and strength characteristics of soils under static loading conditions.

Attention is directed to the shearing strength characteristics of varved clays in paper No. IId 5, "The Determination of the Shearing Strength of Varved Clays and of Their Sensitivity to Remolding" by G.P. Tschebotarioff and J.R. Bayliss. The shearing strength of varved clay as obtained from unconfined compressive strength tests performed on specimens obtained by thin-walled samplers is shown to be in good agreement with values of the shearing strength as computed from data obtained from the failure of a vertical cut in the same type of material. A comparison of strength, as determined from specimens that were obtained by different sampling techniques, indicates the extreme sensitivity of varved clays to disturbance and suggests an explanation for the differences in opinion that are held concerning the usefulness of unconfined compression tests for the determination of the effective shearing strength of varved clays.

The effects of sample disturbance on the stress-strain and volume change characteristics of clay-like soils are indicated by data submitted in paper No. IIIa 3 entitled, "Concerning the Physical Properties of Clays," by R.E. Fadum. In this paper the stress-strain characteristics of a given clay deposit as determined from field loading tests and from unconfined compression tests performed on specimens prepared from test pit and bore hole samples are compared. This comparison indicates the extreme degree to which the stress-strain characteristics of clay-like soils may be affected by sample disturbance. A comparison of the data obtained from numerous consolidation tests, performed on inorganic clay specimens prepared from samples which had been subject to varying degrees of disturbance suggests that the volume change characteristics are influenced to a minor degree by sample disturbance. The results of detailed investigations of the variations in natural water content of a given clay deposit are also reported in this paper.

In paper No. IIa 4, "Structure of Disturbed Soil", E.S. Barber presents data to show that the properties of a given quantity of soil and water compacted in a given volume vary with such factors as method of load application, moisture distribution and exchangeable bases.

The effect of structure is in addition to the effect of moisture and density and can be qualitatively explained by the difference in the dispersion of flaky particles. This concept provides an explanation of thixotrophy, the reduction of swelling by temporary restraint and shows that a change in the dispersion is essential for base exchange to affect the mechanical properties of a soil.

In paper No. 5.9 entitled, "Notes on the Atterberg Limits", Professor A. Casagrande will discuss improvements in the Liquid Limit apparatus and in the technique of determining the liquid limit. He will propose changes in the construction of the Liquid Limit Device, and will show that the shrinkage limit is inherently contained in the liquid and plastic limit values, from which the shrinkage limit can be derived. Therefore, the shrinkage limit does not supplement the liquid and plastic limit values for identification purposes.

In paper No. 5.8 entitled, "Peculiarities of Lateritic Soils", Mr. Bedrich Fruhauf of the U.S. Geological Survey will present data to show that the conventional methods of describing, testing, and classifying ordinary soils when applied to lateritic soils often give results which lead to erroneous conclusions with respect to field behavior. The author will also present the results of routine tests made on Lateritic soils from Hawaii, Virginia and Georgia, together with the results of research indicating the necessary modifications in routine tests to permit the determination of soil constants comparable to those of common soils.

The data will also show that Differential Thermal Analysis of soil specimen can help in determining the influence of moisture, iron oxide, organic content and clay minerals with the loss on ignition, appearance, and behavior of soil. Mineral composition determination may be checked by X-ray photo-patterns. The author will introduce a process of wetting and remoulding and will propose a method of evaluating bearing capacities for various stages of remoulding by a special process of the triaxial compression test. This paper will merit careful study.

Test data which support the following conclusions relative to the Strength of Natural Clays will be presented by Professor P.C. Rutledge in paper No. 5.15

1) Consolidation depends only on the major principal stress and is independent of the magnitudes of other principal stresses.
2) Shearing strength depends only on the density attained at the time of failure, and is independent of total magnitudes of stresses, of pore water pressure and of the source of the stresses that caused the final density.
3) If for a given clay, densities are plotted to an arithmetic scale and stresses to a logarithmic scale, the curve of principal stress difference at failure (twice the shearing strength) vs. density is parallel to the virgin curve of the consolidation curve (curve of major principal stress vs. density). These two parallel curves permit complete evaluation of the shearing strength of the clay for all possible conditions of consolidation and drainage of pore water.

The report of an investigation to determine the effects of cyclic loads, including the effects of amplitude, frequency and number of cycles of load in consolidation and in triaxial compression, as compared with static loading will be presented by Professor P.C. Rutledge and J.O. Osterberg in paper No. 5.17 entitled "Effect of Static Loading on Clays". The equipment built for this study will be described and results obtained will be compared with the effects of repetitive loadings in air field traffic tests. Both this, and the previously mentioned paper will warrent careful study.

In paper 5.11 F.J. Converse will present results of a cooperative investigation to determine the variations in shearing resistance of Ottawa Sand. This study was carried out in nine testing laboratories using different types of equipment and different personnel. Applied normal loads varied from one-quarter to three tons per square foot.

This work was done by the Subcommittee on shear of the American Society for Testing Materials - Committee D-18 on Soils for Engineering Purposes. Professor Converse is Chairman of the Subcommittee and supervised all the work.

In paper No. IIIa 7 M.J. Hvorslev describes two small piston samplers and corresponding apparatus for making unconfined compression tests. This apparatus is very compact and light. Samples - five eighths and one inch in diameter and 2 inches long - of accurate dimensions and constant volume can be obtained. The axial force is measured by means of two calibrated compression springs and the axial stress and strain can be read directly on scales, thus eleminating computations.

The sampling and testing sets are intended for making field control tests on large samples and field tests during the examination of the soil profile in test pits and other accessibel explorations. They may be used in the laboratory for repeating the field control tests and for quickly obtaining values of unit weight, degree of saturation, and the unconfined compressive strength of soil which are sufficiently accurate where the determination of maximum, minimum and average value and the variation in these properties are of more importance than very detailed and accurate tests on soil from specific strata.

REFERENCE

1) Classification and Identification of Soils" by Arthur Casagrande, Proceedings, American Society of Civil Engineers, June 1947.

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DISCUSSION OF SUBJECT OF STRESS DISTRIBUTION

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Subcommittee No. 6 of the U.S. National Committee on Soil Mechanics

The scope of this subject, which was assigned to this subcommittee, is a much broader one than the title would imply. It covers not only the theoretical aspects of the subject of the magnitude and distribution of stresses and displacements in soils and small scale model studies, but also covers the immensely practical problems of observing to full scale and measuring stresses and displacements in the field. The trend of recent development has been in all three of these directions and important progress has been made. These developments fall into five categories. First of all, the trend is to extend theory and to make it conform more closely to the actual physical situations encountered in natural soil deposits and to extend the validity of theory to typical situations most frequently encountered. Second, efforts have been made to make theory more usable in the solution of practical problems of foundation engineering by developing comprehensive tables and diagrams of influence coefficients. Third, the technique of making and analyzing photoelastic models and other types of models has been developed to the point where they not only give a clearer insight into the mechanics of stress distribution but also have important applications in the solution of practical problems of design of earth dams, retaining structures and foundations. Fourth, great progress has been made in the development of devices to accurately and reliably measure stresses and displacements in soil, which is primarily a problem of instrumentation. Fifth, increasingly greater emphasis is being placed upon the measurement of stresses and displacements to full-scale in the field in order to determine the extent of agreement with theory as to magnitude and distribution in an imperfectly elastic non-homogeneous material like soil and to establish the realm of validity or such empirical modification as may be necessary for typical situations.

Eight papers of outstanding merit were submitted to this subcommittee for review. Four papers fall into the first two categories which are considered together. In paper No. Ie 28 entitled "Vertical and Horizontal Shearing Stresses in Earth Masses", D.P. Krynine considers the problem of determining qualitatively the horizontal and vertical shearing stresses which must be set up in a semi-infinite homogeneous mass of soil in order to restore an equilibrium condition of stresses when a fill or an excavation is constructed at the surface and offers approximate solutions of considerable value. The new system of horizontal and vertical shearing stresses play the role of balancing and redistributing the horizontal and vertical stresses, respectively, caused by the construction. In paper Ig 9 entitled "Influence Values for Estimating Stresses in Elastic Foundations", R.E. Fadum presents comprehensive tables and diagrams of influence values derived from the Boussinesq and Westergaard solutions for the cases of loads applied at a point, distributed uniformly along a line of finite length, and distributed uniformly over rectangular and circular areas. These influence values, which are made available in convenient readily usable form, facilitate the making of stress analyses for building foundations. In paper No. VIa 22 entitled "Discussion of Assumptions Pertaining to Stress Analyses for Settlement Computation Purposes", R.E. Fadum examines the basic assumptions made in the theories of stresses and discusses the effects of such conditions as the stiffness of the structure, of a discontinuous surface resulting from constructing the building in an excavation, and of strong and weak layers in the ground upon the stress pattern. Certain refinements in the procedure for making stress analyses are suggested to improve the real accuracy of the results. In paper No. IVb 10 entitled "Deformability of Earth Materials and the Effect on Stability of Earth Dams Following Rapid Drawdown", the authors R.E. Glover, H.J. Gibbs and W.W. Daehn have made an analytical study of the effect of compressibility of the soil structure on stability in order to develop formulas relating stress and strain in soils. A comparison of the possible rigidities of the grain structure with the bulk modulus of water shows the grain structure to be less resistant. The concepts are applied to the case of an earth dam subject to a sudden drawdown and the results are compared with data gathered from actual dams under service conditions. It is concluded that no greater pore pressures than those of the gravity flow system need ordinarily be used in such stability studies.

In the third category is paper No. IIg 14 entitled "A Study of Photoelastic Models of Foundations" in which the authors R.R. Philippe and F.M. Mellinger consider the problems of stress analyses, which first of all involves the model technique, such as the selection of model materials, preparations of the model, methods of loading, and examination and recording of results, and second involves the application of model analyses to the investigation of stress distribution in foundations beneath wall structures and earth embankments for the purpose of design. The techniques are illustrated by presenting the solution to the specific problem of evaluating the boundary stresses for a floodwall with a sloping base and a vertical key.

In the fourth category is Paper No. IIIc 6 entitled "Instrumentation for Field Measurements of Deflections and Pressures for Airport Pavements" in which the authors J.M. Griffith and E.H. Woodman describe the pressure cells and deflection gages developed by the Instrumentation Branch of the Waterways Experiment Station, Vicksburg, Mississippi, for the field measurements of deflections and pressures under heavy airplane wheel loads, which are being made for the development of design procedures for flexible type airport pavements. The paper takes up the general features of instrumentation, typical gage and cell installations and the methods of obtaining measurements. Although this paper deals primarily with installations for airport pavements, the techniques developed have a much broader application to the general field of foundation engineering.

In the fifth category are two papers. In the first of the papers No. VIIIa 2 entitled "Stresses and Displacements in a Homogeneous

Soil" the authors W.J. Turnbull and S.M. Fergus describe the installation of pressure cells and deflection gages for a series of tests to determine the magnitude and distribution of the stresses and displacements imposed in a homogeneous soil beneath loads simulating those of airplane wheels. This is a part of a long-range program for the development of rational methods for the design of pavements and base courses of flexible type airport pavements, but even more important is the possibility of determining the extent of agreement between theoretical and actual measured stresses and displacements and of establishing the realm of validity or the empirical modifications necessary for applying theory to the problems of foundation design. The installation involves the measurement of vertical, horizontal, and diagonal stresses and vertical displacements produced at various depths and offset distances. This paper describes the test section, the comprehensive installation of cells and gages, the recording devices, test equipment and the method of test.

In the second paper No. IIIc 10 entitled "Field Measurements of Soil Pressures in Foundations, in Pavements and on Walls and Conduits, Including Review of Work of the Fact Finding Survey and other Field Investigations of the Corps of Engineers of the U.S. Army", the author D.W. Taylor emphasizes the fact that many questions regarding the soundness of Soil Mechanics theories can be answered only by field measurements of pressures and displacements at major engineering projects. At a number of earth dams and airports measurements of deflections and pressures have been made during recent years. The author presents a brief treatment of the use of pressure cells for measuring pressures in the field, covering theoretical concepts of cell action and requirements relative to cells and installations. Data are given showing results of pressure measurements from cell clusters over a period of months in two earth dams. More of such data is required to supply the important information needed for determining the degree of dependability and correctness of theories and of methods of analysis.

In closing a brief summary of the theoretical development is given. There are a number of important theories of stresses and displacements in soils, which provide the BASIC PICTURES OF STRESSES IN SOILS. These theories have been found to be useful as working hypotheses in the range of materials such as soils, which are imperfectly elastic and non-homogeneous, and have demonstrated their practical value as useful tools. These basic theories of stresses and displacements cover a certain typical condition commonly encountered in practice. It is important to distinguish clearly in these theories two aspects of the problem. First, the realm of validity regarding soil as a material, and second, regarding the set of boundary conditions on the basis of which the theory was developed. In regard to the first, it is clear that the problem of primary concern is to determine the extent of agreement for soil as a material between theoretical and actual measured stresses and displacements and to establish the realm of validity of the law of transmission of stresses in soils and of the law of superposition of stresses and displacements in soils as governing their magnitude and distribution. In regards to the second, four typical cases commonly encountered in foundation work are summarized as BASIC STRESS PICTURES and working hypotheses, which are valid as to the boundary condition noted.

Case 1. A surface loading on a soil deposit, which is homogeneous to a depth equal to twice the average width of the structure. The three-dimensional Boussinesq theory of stresses for a point load applied to the surface of the ground provides the basic picture for this case. A table of influence value for the Boussinesq stress coefficient was presented by Gilboy 1). This theory was extended by Newmark to cover the case of the stresses beneath the corner of a rectangular area with a uniformly distributed load 2). Fadum has presented useful influence diagrams for the solution of this case for facilitating computations in Paper Ig 9 entitled, "Influence Values for Estimating Stresses in Elastic Foundations". Important two-dimensional theories have been developed by Carothers for a number of useful loadings such as for earth dams and embankments, and influence values have been presented by Jurgenson 3).

Case 2. A surface loading on a deposit thinly and uniformly bedded to a depth equal to twice the width of the structure, in which horizontal displacements are restricted.

This second basic stress picture was developed by Westergaard 4). This solution is applicable to a mass of soils that is assumed to be reinforced horizontally in such a manner that the horizontal displacements are entirely prevented. Fadum has presented diagrams of influence curves for the computations of the stresses for this case in paper Ig 9 entitled, "Influence Values for Estimating Stresses in Plastic Foundations".

Case 3. A surface loading on a deposit underlaid by a very strong soil layer or by rock at depths less than twice the average width of the structure.

The third basic picture of stresses was developed by Biot 5) and later more completely by Pickett 6). A few influence curves of stresses at the rock surface have been evaluated by Pickett. The maximum stresses at the rock surface may be 50 percent greater than the values computed by the Boussinesq theory.

Case 4. A surface loading on a thick layered deposit consisting of a strong surface layer underlaid by a weaker underlying layer within a depth equal to twice the average width of the structure.

The fourth basic stress picture was developed by Burmister 7),8). In the layered system case, the upper stronger layer act to reinforce the system and to spread and distribute the stresses over the weaker underlying layer at lower intensities, so that the vertical stresses are considerably less than those computed by the Boussinesq theory. The percent reduction in the stresses depends upon the ratio of the strength properties of the two layers and upon the size of the foundation. Settlements resulting from consolidation in the underlying weaker compressible layer will be materially reduced as a consequence. Influence curves for surface settlements have been presented so far for this case, which indicate the importance of the settlement reducing effect of a strong surface layer. This case is applicable to the solution of problems of flexible airport pavement as well as to problems of building foundations.

These four cases cover a range of conditions which apply reasonably closely to practical problems encountered in foundation work. However, the engineer who uses these theories of stresses and displacements must be prepared to properly evaluate each given situation. Good judgment must be based upon a clear conception of the degree of real accuracy of the computed results and of how important the stresses in the supporting soils may be in any given circumstances. There is always the danger of over-simplification of a problem and of failure to take into account some vital factor. It is the degree to which all vital factors have been recognized and comprehended, and are taken into account in foundation design and construction that determine how satisfactory the foundation is going to be.

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