APPLIED SOIL MECHANICS

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Soil mechanics is essentially the study of the behavior of soil masses under the forces which act upon them. The study includes the determination of stress distribution from the loads through the soil and the corresponding deformations in the soil, together with the factors which determine the resistance of the soil to failure.

The object of the study is to help the Engineer solve problems of construction. In its present state of development, soil mechanics can not provide all of the answers, but it may be of very great value when properly used by one familiar with its limitations. The backbone of practical soil mechanics is adequate field investigation and correct sampling. The natural underground is seldom uniform either horizontally or with depth. The extent of the variations must be known before any correct stability analysis can be made. One who has not made detailed studies of soil conditions naturally thinks of the soil as uniform over wide areas. Nothing could be farther from the facts. Deep, moderately uniform strata are the exception rather than the rule. This may be illustrated by an experience on the Tech campus in the early days of soil research here. A study of the effect of the size of a footing on the bearing capacity of soil was being undertaken. A strip of soil near the present Athenaeum garages was selected as the site for the studies. When excavations had been made and load was applied, a plate 1 sq. ft. in area settled only 0.1 inch under a load of 30,000 pounds. Search for a more suitable location indicated much softer material on the southwest corner of the campus: At this location only 1,000 lb. was required for 0.1″ settlement, and at a load of 3000 lb. the settlement exceeded 1 inch. Investigations of foundations under school buildings after the earthquakes of 1933 indicated an astonishing amount of variation throughout almost every site. In one case (by no means unique) one wall was resting on firm sand capable of sustaining a safe load of four tons per square foot, and the opposite wall, 50 feet away, was on soft clay good for 1 ton per square foot.

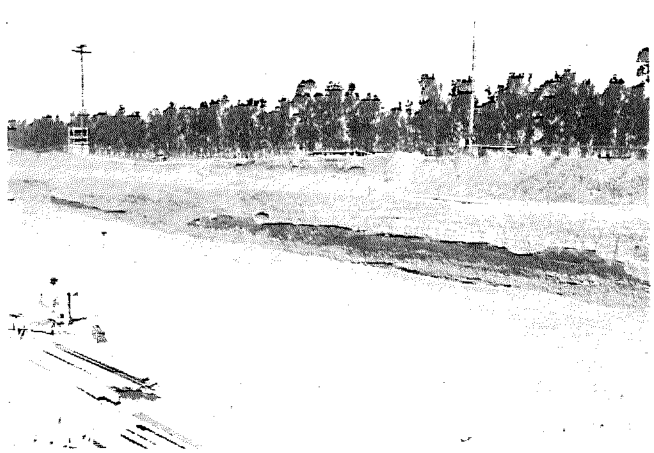

Fig. 1. Silt lense in dense gravel.

Figure 1 shows a cut for the foundations of the soaking pits at the Kaiser Steel Mill. Most of the material is good sand and gravel, but the dark material in the center is soft silt into which one could easily push a pencil. This is typical of this area and of Pasadena soil also. Former stream beds, filled in either by nature or by man, are a frequent source of striking and unexpected variations. A good example is the situation disclosed by the investigations at the Roosevelt Fleet Base on Terminal Island. The Island at this location is composed mainly of fine sand and silt, but at one point a channel 800 feet wide had evidently been cut clear through the Island and later filled with soft black mud. The mud deposit is up to 28 feet thick and is still soft and unconsolidated, although buried under at least 30 feet of sand.

The necessary depth of an investigation depends on the type of the structure as well as the character of the soil. For relatively light structures, a depth below the footing equal to 2½ times the width of the footing is adequate, providing the soil is not so soft as to require piles. Where piles are necessary the investigation should extend far enough below the pile tips to insure stability against excessive settlements. This requires that either a thick firm strata has been reached or that a depth at least equal to 2 times the least width of the pile group has been explored without locating excessively soft material.

SAMPLING

In order to determine the strength and physical characteristics of soil by means of laboratory tests, it is necessary to obtain samples in as nearly natural field conditions as possible, without disturbance of grains, swelling, compaction, or change of moisture content. A committee of the American Society of Civil Engineers has been working on the problem of sampling for the past three years. Intensive study by a full time research staff, and extensive co-operation by the U.S. Army Engineers, has resulted in the development of some important principles of sampling. The usual method of sampling frequently results in excessive disturbance, especially in soft clay and silt, or loose, fine sand. The usual method of sampling consists in driving a tube into the soil at the bottom of an open hole to a penetration of from 1 to 3 feet. The soil within the tube is brought to the surface, extracted from the tube, transferred to the laboratory and prepared for test. The process of driving the tube is a frequent source of error. A thick tube may compact the soil ahead of it so that the sample is denser than the soil in place. Long cores may have a similar effect, due to friction on the inside of the tube. Driving a thick tube into dense sand causes the sand to flow into the tube in a loosened condition, due to the fact that dense sand may expand before it can be displaced.

The thinnest, sharpest tube possible takes the best cores, other conditions being equal. The minimum thickness that can be used is dependent upon practical conditions. The tube must be strong enough to withstand driving and keep its shape. Pebbles easily damage a thin cutting edge, and distort the tube. It is frequently impossible to bring up a sample in a simple tube, because it slips out due to its weight and to suction from the bottom. A retaining device, or core catcher, is necessary in this case, but requires a thick point to enclose the mechanism. Extraction of the sample from the tube may cause disturbance if the soil adheres to the tube. Split tubes are used to overcome this difficulty, and these are of necessity moderately thick. Thin liners within the drive tubes are very desirable, since they permit the sample to be extracted from the tube, transferred to the laboratory, and tested, without disturbance other than that of the original driving. The proper thickness of tube is a compromise between necessity and desire, the practical requirements of sampling modifying the desire for a small thickness—diameter ratio.

The manner of driving has an important effect on the sample. A few heavy blows are better than many light ones, because the vibrations set up by driving tend to split or shatter the specimen, especially if the blow is at the top of a long length of pipe or drill rod. Drill jars apply the blow at the top of the sampling tube and eliminate much of the vibration. Continuous steady forcing of the sampling tube into the soil by means of jacks gives excellent results.

Figure 2 shows how sampling may disturb the material sampled.

LABORATORY TESTS

The most important laboratory tests are for the determination of the shearing strength, the relative density, and the time consolidation characteristics of the soil. An accurate knowledge of the shearing strength of the soil is essential to the determination of allowable bearing values for foundations, safe pile loads, stability of slopes and any problem involving failure of the soil. There has been a great deal of careful research in an attempt to establish the true relationship between shearing resistance as determined by various methods in the laboratory, and the strength of the soil under field conditions. Direct shear tests are the simplest to perform and have been used extensively in soil laboratories. They operate by sliding one portion of the soil relative to another in much the same way that a rivet connecting two plates is sheared by pulling the plates in opposite directions.

From a number of shear tests at different normal loads, the values of the cohesion and the angle of internal friction are established, thereby providing information from which the shearing strength may be determined for any stress condition within the soil. Considerable variation in the shearing values may result from different ways of performing the test especially in the case of clay. This has lead some investigators to abandon the direct shear method in favor of the "Triaxial Compression Test." In this test, a cylinder of soil is placed under lateral hydrostatic pressure at the same time that longitudinal compression is applied. By this scheme the principal stresses at any point in the soil can be duplicated, and the load to produce failure determined. Since failure is in shear, the shearing stress and angle of friction may be found from one test. Time effects are very important, especially in the case of saturated clay. The increase of load develops hydrostatic pressure within the pores of the soil. Clay being relatively impermeable, this pressure may persist for some time before drainage permits equalization of stress. The rate of loading, therefore, has an important effect on the resulting shearing strength. Knowledge of the conditions to be met in the field should determine the rate of loading of the test sample. The triaxial compression test requires a much larger specimen than the direct shear test, takes longer to prepare and run, and is subject to uncertainties such as end effects and internal pore pressure. It undoubtedly gives more accurate results than the direct shear, when properly in-

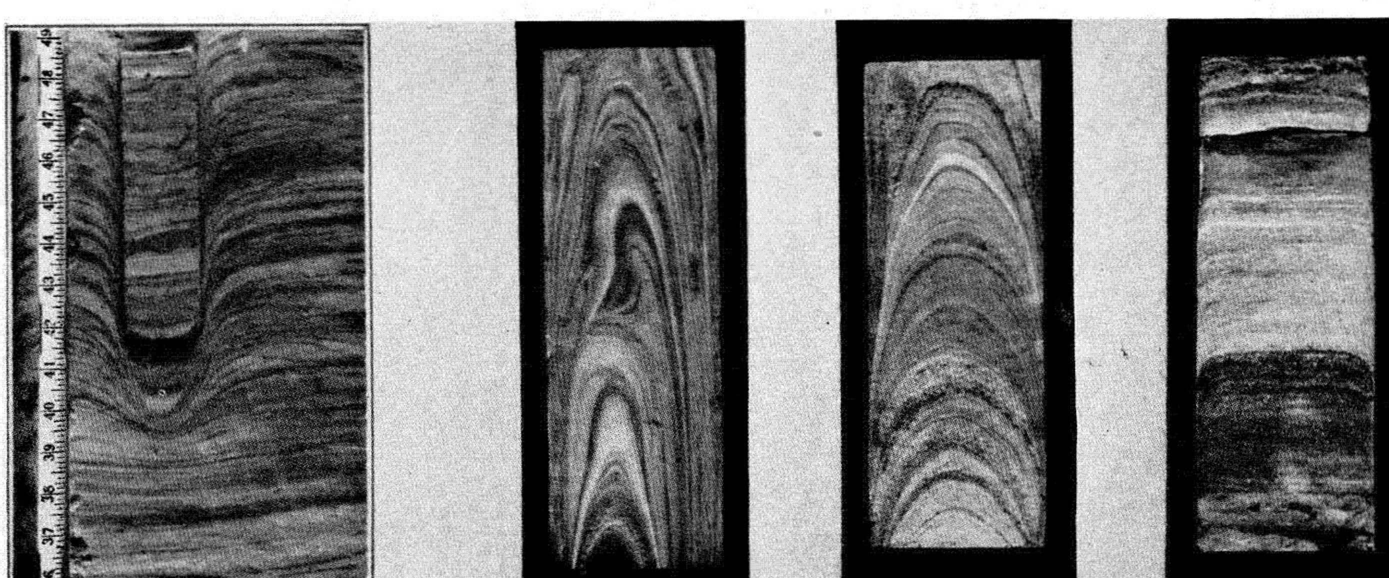

Fig. 2. Soil disturbed in sampling.

terpreted, and is particularly desirable for research work. The direct shear however gives values which are sufficiently accurate for most construction problems and if in error are on the safe side. The fact that the direct shear test requires only a small sample of undisturbed soil is very much in its favor. Figure 3 shows a shear testing machine at Caltech.

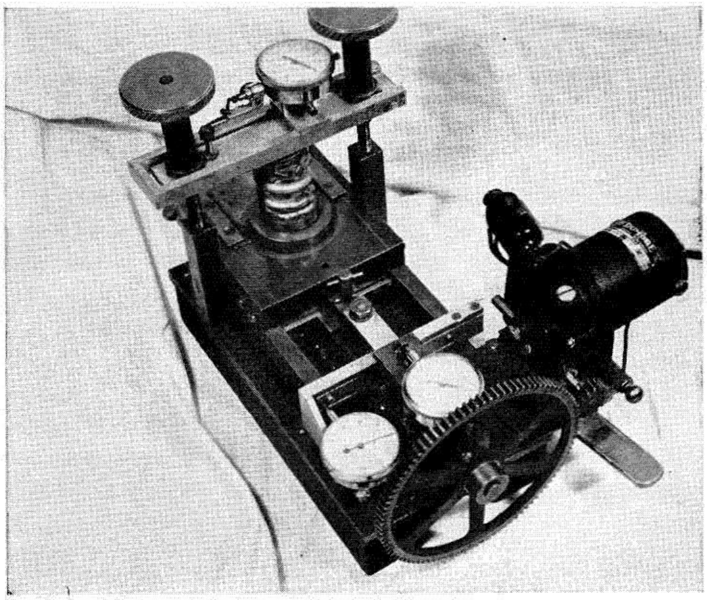

Fig. 3. Shear testing machine.

The consolidation test determines the load-deformation and the time-deformation characteristics of the soil. It is performed by placing a thin slice of the soil in a tube or cylinder, and applying load through a piston. Porous stones are placed on each side of the specimen in order to permit the water to drain out. Data from the consolidation tests may be used in calculating the settlement of the structures. In most cases the values will be only approximate but in certain types of soil, such as thick uniform beds of clay, very accurate time-settlement determinations may be made. Figure 4 shows a consolidation machine.

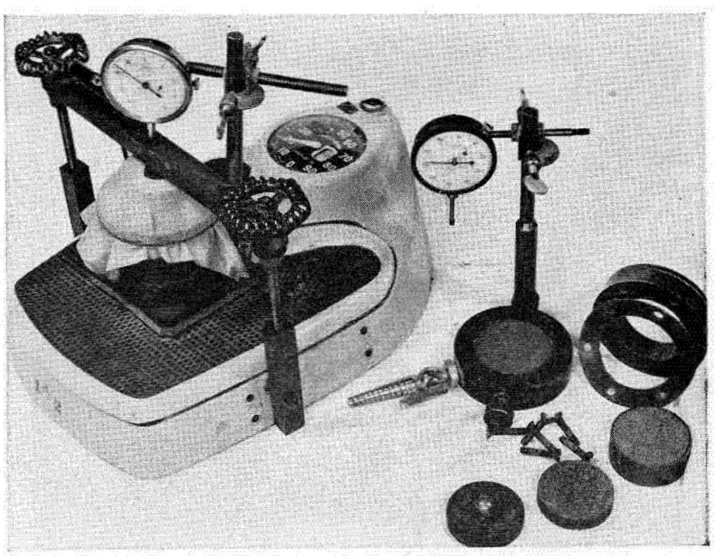

Fig. 4. Consolidation testing machine.

CONSTRUCTION PROBLEMS

One of the main problems of building construction is the determination of bearing values for spread footings of buildings. Soil mechanics investigations can usually provide reasonably close values of safe loads and corresponding settlements, but frequently conditions exist which make exact solutions impossible. In such cases the correctness of the result depends on the skill with which assumptions and approximations are made. One assumption involves the stress distribution from the footing through the soil. In some simple cases, this can be calculated accurately by means of the equations of elasticity, but many soils are not completely elastic, and frequently the boundary conditions are such that no solutions to the intricate mathematics have been obtained, even for the elastic theory. Many soils become disturbed for some distance below the footing, and adjust their internal structure by flow or plastic action. Formulas similar to those of the elastic theory have been proposed for such cases. They give values close to test results and are adequate for construction work.

Another uncertainty is the stress distribution from one layer or strata of soil to another of radically different type, as from sand to soft clay. This becomes very important in the case of highways and airport runways, and no satisfactory method of analysis has been developed which stands the tests of time in the field. At present most highway and airport design is empirical, being based on certain soil bearing tests which are compared with a standard established by experience. Extensive research in this field is in progress by a number of agencies including the Army Air Corps, the National Public Roads Administration, some state highway departments, and the A.S.C.E.

Formulas for the determination of the ultimate bearing capacity of spread footings are available, but they should be used with caution. Most of them include some approximations which must be recognized before the formulas are applied to a problem. Nearly all of them assume (without mentioning it) that the density of the soil is greater than a certain critical value. If the density is less than critical, the formulas do not apply, and failure occurs at a much lower value. This value can be easily calculated if the shearing resistance of the soil is known.

Settlement rather than ultimate strength is frequently the determining factor in establishing allowable bearing capacity. For the case of saturated clay and silt, the time-settlement relations may be determined with accuracy by calculations based on the results of the consolidation test. Where the soil consists of sand or loam, the calculations are approximate, the degree of accuracy depending on available empirical data. Frequently field load tests on different sized plates will furnish the required information. This latter process, however, is expensive and time consuming, and is little used except on large jobs. Much experimental and analytical work is still necessary before settlement calculations from laboratory tests can be made with accuracy and confidence from laboratory tests alone, for the case of granular soils. Fortunately the strength of such soil in shear is usually the controlling factor, rather than the amount of settlement.

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conditions, let us not act too hastily or drastically. Certainly, no such long-range revision of the patent laws should be undertaken until the National Patent Planning Commission, established by the President for this very purpose and composed of men of unquestioned ability and integrity, has had an opportunity to complete its studies and submit its recommendations.

SOIL MECHANICS

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The calculation of safe pile loads from laboratory tests of disturbed samples has taken a great deal of the "guess" out of pile driving. This method is now replacing the former method of driving test piles and estimating the bearing capacity by a dynamic formula based on the penetration per blow of the pile driving hammer. This latter method has been found to be very unreliable and frequently calls for unnecessarily long piles. At the plant of the California Shipbuilding Corporation, 54,000 piles were driven to a predetermined length calculated from field investigations and laboratory analysis. It is estimated that at least $250,000 was saved by this procedure. At an aviation gasoline plant near Houston, Texas, calculations indicated a safe bearing value of 20 tons on a 35 ft. pile with a factor of safety of 2. When the piles were driven, the usual dynamic formula indicated an allowable value of only 4 to 8 tons. The piles were tested by loading them for several days with 30 tons. Upon removel of the load, the permanent settlement was found to be less than 1/16 inch.

The problem of safe slopes for earth fills and cuts in such structures as highways, dams, levees, canals and ship channels, has been solved in a very satisfactory manner. The construction of firm, dense fills of known characteristics is now accomplished by a standard procedure, developed in California and carrying the name of Mr. R. R. Proctor of the Los Angeles Department of Water and Power.

Research into the basic principles of soil mechanics is proceeding at an unprecedented pace in spite of war conditions. In fact, war problems have intensified the necessity for such work in connection with the construction of airports, harbor facilities and war production plants. Studies in the field of the colodial chemistry of clay are leading to new conceptions regarding the behavior of soil containing such clay. Based on this work, new processes for the stabilization of highways and airports are being developed, and a better understanding of the action of clay under load is assured. Studies of the pressure developed in the water confined within the pores of the soil, in dams and in laboratory test specimens, is producing some illuminating information which will undoubtedly have an effect on design and construction procedure as well as laboratory test methods.

An understanding of the fundamentals of soil mechanics is an asset to any Engineer. It is part of the stock in trade of a Civil or Structural Engineer, and provides him with an interesting and illuminating field of study and experimentation.