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SOIL TESTING

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It is the purpose of this Digest to describe engineering soil tests commonly used in site investigations and to indicate their potential use and limitations. It may be regarded as a sequel to CBD 29, "Engineering Site Investigations."

Soil testing is based on the premise that the behaviour of soil masses under imposed conditions can be predicted if certain soil properties can be measured. Because soil is a natural material that is much more variable than man-made building materials, and because it is a multi-phase system composed of solid particles with their intervening void spaces filled with either water or air or a combination of both, the results of soil tests must be interpreted in the light of past experience, climate, and the geology of the site.

One of the most important requirements is that soil tests be conducted on samples that are truly representative of the soil at the site. To be successful, soil sampling, testing and test interpretation must be conducted under the guidance of specially trained and experienced personnel. Proper soil testing has proved to be a reliable basis for the design of foundations and has permitted the design of many notable structures on difficult sites.

The various tests may be divided into four categories: classification or indicator tests, used to identify and describe soils so that they may be compared with other soils of known behaviour; strength, density and compressibility tests which have direct application in determining the bearing capacity of a soil and are used to forecast the probable magnitude of settlement; control tests used in constructing earth structures to ensure that backfill and road bases meet the required specifications for grading and density; and special purpose tests, which include measurement of the swelling or shrinking potential of a clay and determination of the possible corrosivity of a soil.

Classification or Indicator Tests

The first requirement of any soil testing program is the adequate identification and description of soils to supplement the brief visual description supplied by the drilling crew. A number of relatively simple tests are used for this purpose and are outlined below. They provide accurate classification and permit comparison with other soils where behaviour is better known. They are also used as a basis for selecting samples for the more expensive strength tests.

Cohesive or fine-grained soils (clays) and cohesionless or coarse-grained soils (sands) require different tests to assess their probable behaviour. For cohesionless soils the density and grain size distribution or grading are most indicative of behaviour. On the other hand, plasticity gives a better appraisal of the behaviour of cohesive soils. Natural water content is also of vital interest. It is measured by weighing a small sample of soil in its natural state, drying it in an oven at 105°C, and weighing the dried sample. The loss of water upon drying is expressed as a percentage of the weight of dry soil. The natural water content is of most significance when compared with the "Atterberg Limits" or plasticity characteristics of a soil.

Depending on the amount of water present, cohesive soil can exist in three states: as a liquid slurry, a plastic substance or a solid. The tests for Atterberg Limits were developed as a means of distinguishing them. The "liquid limit" is the relatively high water content at which the soil changes from a liquid to a plastic state, and the "plastic limit" designates the relatively low water content at which soil

changes from a plastic to a solid state. The procedures for determining the liquid and plastic limits are well established and are described in detail in publications of the American Society for Testing and Materials and of the British Standards Institution.

The difference in water content between the liquid and plastic limits is defined as the "plasticity index" of the soil. It follows that the greater the plasticity index, the more plastic and compressible and the greater the volume change characteristics of the soil. The plasticity index has proven to be one of the most useful of all soil indices and is essential to the description of a cohesive soil.

As a convenience for comparing a variety of soils, Dr. A. Casagrande devised a plasticity chart (Figure 1), in which an empirical boundary known as the "A" line separates inorganic clays from silty and organic soils. Soils of the same geological origin usually plot on the plasticity chart as straight lines parallel to the A line. The larger the plasticity index the greater will be the volume change characteristics. "Fat" or plastic clays plot above the line. Organic soils, silts and clays containing a large portion of "rock flour" (finely ground non-clay minerals) plot below it.

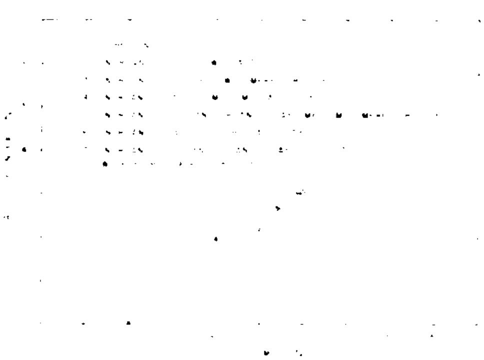

Figure 1. Plasticity chart (after A. Casagrande)

The relation of the natural water content to the liquid and plastic limits is indicative of soil behaviour. If the natural water content is above or close to the liquid limit, the soil may be "sensitive", in which case it suffers a great loss of strength when disturbed. Sensitive soils have a honeycomb or card house structure and overstressing them can lead to disastrous failures. This sensitivity complicates sampling and testing and special procedures often have to be adopted.

Grain size tests are made not only to determine the size of the individual grains in a soil, but also to determine the relative distribution of the sizes. In cohesionless soils the grain size distribution is determined by passing a dried sample of soil through successively smaller sieves down to the 200 sieve. The grain size of fine-grained cohesive soils must be determined by more elaborate methods. One such test, the hydrometer test, involves the measurement of the specific gravity of a soil-water suspension at fixed time intervals. The grain size is calculated using Stokes' Law, which forecasts the terminal velocity of a spherical body falling through a fluid medium. With the hydrometer method it is possible to estimate the grain size of particles ranging from the 200 sieve to colloidal size particles (approximately 0.0005 mm).

The grain size distribution curve indicates the range of the size of particles present in a soil. Its shape can be used in conjunction with boring information to indicate density. A uniform soil, one consisting of particles with a very narrow range in sizes, is liable to be loose. A well graded soil, on the other hand, tends to be dense and can be compacted even more with mechanical equipment. The grain size curve may also be used to determine whether soil is susceptible to frost action, and whether sands and gravels meet specifications for concrete aggregates and road base materials.

Other indicator tests that may be carried out are the determination of the specific gravity of soil particles, the shrinkage limit and the amount of organic matter in a soil. The specific gravity of the soil particles assists in calculations of other more elaborate tests such as consolidation. The amount of organic matter will frequently determine whether or not a soil may be used as road base or backfill.

Strength Density Tests

Cohesionless soils mobilize their strength in direct proportion to the loads applied to them and thus depend upon their confinement and the internal friction or interaction of the individual grains for their strength. The greater the density of a soil, the more internal friction can be mobilized and the greater the bearing capacity. Hence, if the density of a cohesionless soil can be measured, the bearing capacity can be inferred. Unfortunately, a direct measure of density of cohesionless soils is difficult to accomplish. Most sampling methods cause sufficient disturbance to make density measurements on the samples of questionable accuracy. The most common method of assessing density is a penetration test conducted in the field by driving a cone or a split tube sampler into the soil. The number of blows required to drive it one foot has been correlated with the density of the soil. This test must be carried out in accordance with fixed procedures such as those adopted by the Canadian Standards Association. If soils prove to be dense, they provide a competent bearing medium, whereas loose cohesionless soils may require special precautions to guard against settlement under certain loading conditions.

Cohesive soils, which are generally less competent in bearing, lend themselves to more direct measurement of strength and compressibility properties. Their strength is usually determined by axial loading of "undisturbed" samples of cylindrical shape obtained from carefully trimmed blocks or from thin-walled tube samples taken in accordance with the Code of the Canadian Standards Association. The compressive strength of a cylinder of soil may be determined by an unconfined compression test or an undrained triaxial test. The unconfined compression test is conducted in the same manner as the test of a concrete test cylinder. In the undrained triaxial test, the specimen is isolated by a thin rubber membrane and fluid pressures, in addition to the axial stress, are applied to the sample. This allows the test specimen to be subjected to stress conditions simulating those existing in the soil mass.

Although the unconfined compression and the undrained triaxial tests yield the same result, the undrained triaxial test must be used in special circumstances such as for fissured clays. With the triaxial test it is possible to allow the test specimen to change volume under load or to measure the water pressure within the pores generated within the sample at constant volume. This provides a more fundamental understanding of the strength characteristics of the soil and makes possible the forecast of long-term stability conditions where the imposed loads are likely to cause an appreciable change in the water content and hence in the strength of the soil. For bearing capacity computations it is usual to take the shear strength as one half of compressive strengths. Such measurements must be representative of the entire mass of soil affected by the structure – not of a few tests conducted near the foundation level.

For soft clays, the shear strength may be determined *in situ* by means of devices such as the field vane. This is a four bladed vane that is thrust into the soil and the shear strength derived from the torque required to rotate it. This test is more economical than laboratory tests, but its use should be restricted to soft clays.

With highly plastic clay soils it is possible to have an adequate bearing capacity against a sudden shear failure, and yet to have an unsatisfactory foundation because of the large deformations that develop with time from volume changes in the soil. Compressibility characteristics can be predicted within acceptable limits by means of the consolidation or oedometer test, in which an undisturbed sample is confined in a tight fitting metal ring. The top and bottom faces of the sample are covered with porous stones, the sample is subjected to a vertical load, and the time rate of compression measured. A series of such load increments is applied during the test and the time rate of compression measured for each. The following factors may be determined: preconsolidation pressure, compression index, and coefficient of consolidation. From these the amount and rate of settlement under a given load can be predicted. The preconsolidation pressure represents the maximum load to which the soil has been subjected in its geological history and this generally is a safe bearing pressure.

The strength-density-compressibility test results have direct application to design. To treat such results with confidence there must be a background of knowledge of the soil conditions to ensure that the test results are indeed representative of the soil mass affected by the structure.

Control Tests

When specially selected soils are used for bases under slabs on grade, for roads or for backfill against structures, they become an integral part of the structure and must behave in a predictable fashion. To ensure that the earth material meets the required specifications the construction must be controlled by soil tests. The material available should be tested to ensure that it meets the desired grading specifications, and must be placed and compacted in such a manner that the specified density is achieved. CBD 3, "Soil and Buildings," describes the unique relationship between water content and density under a given compactive effort for any soil. Usually it is necessary that the water content be near the "optimum" to achieve the desired density, which is usually specified as 100 per cent Proctor density or 95 per cent of "Modified Proctor." The Proctor test is a method of determining the optimum water content for a soil under a given compactive effort and is described by the American Society for Testing and Materials and other standards organizations.

To ensure that desired densities are achieved field density tests are conducted on the site, the choice of method being dictated by the type of soil involved. All test methods attempt to determine the weight of a known volume of soil, and include the "sand-cone," the "water balloon," or if the soil is cohesive, the direct measurement of a sample of soil. In recent years a radioactive method has been used which in certain circumstances, offers considerable savings in time.

Another type, which might be considered a control test, is an investigation, such as the loading of piles, undertaken to provide a complete foundation report. Because knowledge of the soil is so important in the interpretation of such tests it is essential to have detailed information of its type and condition in each case.

Special Tests

There are many soil tests that may be carried out to determine a single characteristic of a soil, depending upon its intended use. It is proposed to discuss briefly three types of tests here:

Corrosion potential. The problem of soil corrosion is extremely complex. Certain soils may contain chemical constituents that are very aggressive to concrete or steel in contact with them. Ground water also can be aggressive. One of the more common types of corrosion is the deterioration of concrete owing to the presence of soluble sulphate salts in the soil. The problem is acute in semi-arid climates where there is insufficient rainfall to carry away soluble salts, which often cause the rapid disintegration of ordinary concrete. Their presence can in some instances be detected visually or, more conclusively, by a chemical analysis of the soil. If such salts are present, concrete structures may be protected by the use of sulphate resistant cement.

Ground that has been filled with rubbish or industrial wastes, or soil containing appreciable organic matter can present potentially aggressive conditions. Ground waters percolating from such areas may also be potentially corrosive. Again it is necessary to conduct chemical analyses of the soil and ground water to determine the extent of the problem.

The corrosion of steel and other metals in soil is an electro-chemical process. Frequently a small area of the metal may be attacked severely, leaving other parts of the structure unscathed. There are no simple methods of evaluating the potential corrosiveness of a site, but the worst conditions are indicated by the presence of stray electrical currents such as exist near electrified railways or other large direct-current sources, low soil resistivities, and large amounts of dissolved salts in the ground water. Besides chemical analysis on soil samples, indirect methods such as probing with "corrosion sounders" can be used on the site. Expert assistance will always be required in corrosion investigations.

Swelling. Highly plastic soils have the ability to swell if given access to water. The amount of swelling will depend upon the clay minerals present and the initial water content of the clay, but swelling pressures can be high enough to cause serious damage to a structure founded on them. The most serious swelling problems occur in semi-arid climates because the natural water content of the clays may be fairly low. A building stops natural evaporation from the surface and allows water to accumulate under the foundation, thus causing the soil to heave. Tests on swelling soils cannot give definite design criteria, but they serve to point up the potential seriousness of the problem and indicate methods of overcoming it. Soil tests should include the determination of the natural water content, Atterberg Limits and the shrinkage limit. Potential swelling pressure can be measured in a consolidation test where swelling rather than settlement is observed.

Permeability. Because soil is a porous system, water will move through it under hydraulic gradient. Permeability may be defined as the ability of a soil to pass water, and the coefficient of permeability is a measure of the soil's perviousness under a given hydraulic gradient. There are several methods of measuring the coefficient of permeability, all of which measure the quantity of water that flows through the soil sample in a fixed interval of time under known hydraulic pressures. The choice of the test method will depend on the porosity of the soil. Knowledge of the permeability of soils is a vital factor in the design of earth dams and dykes, and is important also in the design of drainage systems.

Conclusions

In this Digest, the various tests that may be used to determine the properties of soil have been discussed. The results of these tests will indicate the suitability of a site and the various design alternatives for a foundation. It is still necessary, however, to evaluate the test results, for the properties of soil are influenced by both the geological and climatic conditions on the site.

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