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Borehole Investigations

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Synonyms

CPT sample; Drill hole study

Definition

Method of study to investigate soils and rocks in the Earth's subsurface by means of long and narrow holes drilled through a variety of specialized methods.

Introduction

Successful engineering works often benefit from a clear and better understanding of the nature of soil and rock below ground. In the absence of extensive trenching and excavation and to complement noninvasive geophysical exploration techniques, borehole investigations can be carried out, including the analysis and characterization of the soil and rock recovered. Such investigations allow the identification of the soils or rocks present, as well as an understanding of their physical properties on the basis of field and laboratory tests.

Borehole investigations allow practitioners to determine the nature and location of the different soil/rock layers, collect samples, carry out in situ tests and permeability tests, and, if necessary, install piezometers and other subsurface monitoring tools. The location of the boreholes is chosen depending on the objective of the project and characteristics of the tests, with due consideration to the type of works planned.

Borehole Systems

Boreholes may be drilled by two primary systems: percussion or rotary techniques. The former relies on the use of a tool that advances with successive hitting movements, driven by a hammer that is dropped, with its energy transmitted by means of rods to a solid tool or hollow tube (sampler) placed at the bottom of the borehole. This system, which has its advantages in unconsolidated soils (silt, sand and gravel), usually takes longer and is more expensive than rotary drilling. The rotary technique (Fig. 1) is the most frequently used method for subsurface exploration. A cutting tool is used to collect samples using a helical auger or drill bit that moves forward by means of a bit crown that is usually widia or diamond tipped.

In the case of auger drilling, alternative methods are needed to obtain samples, which is normally carried out discontinuously. This technique is mainly used in uncemented soft to medium consistency soils or in rocks.

In rotary core drilling, a rock cylinder referred to as "core" may be extracted as the drilling advances and are stored in a pipe screwed to the crown, which is called a "core barrel."

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Borehole Investigations, Fig. 1 Rotary system

This may be a simple tube or a rotating double tube in which the inner tube is mounted on bearings.

In the case of loose or very soft soils, a simple tube must be used, whereas a rotating double tube is preferable in all other cases. A casing pipe is introduced into the borehole to prevent cave-ins or stop water leaks; the casing is telescopic and allows the insertion of the core barrel to continue drilling. The exterior diameter of normalized boreholes ranges between 54 and 143 mm.

Borehole investigations for different civil engineering works must be approved by local state agencies, complying with requirements usually determined by ASTM standards or similar specifications.

Sampling

Samples are representative portions of the soil/rock that are collected to conduct laboratory tests. Depending on the means of collection, they may be classified as disturbed or undisturbed samples (USDA 2012).

Disturbed samples only preserve some of the soil/rock properties in their natural state and are usually stored in bags or as core segments. Undisturbed samples preserve, at least in theory, the same properties as the in situ soil, reflecting the soil/rock characteristics in their natural state at the moment of collection and, consequently, their physical structure.

In order to undertake laboratory tests, it is necessary to collect undisturbed samples, which are obtained by means of core barrels from the boreholes. Once the core barrel has been extracted, the core within is retrieved and placed in a core box. After the collected core is laid out, it is visually inspected and the recovery obtained is measured precisely.

Core samples must be placed in adequate core boxes made of wood or waxed cardboard, maintaining the original position and orientation, and indicating the depth. For this operation to be properly carried out, the same sequence in which the samples were obtained must be followed, introducing separation blocks between the different core runs and defining sampling depths.

As well as the core recovery percentage, the rock-quality designation (RQD) of all the core samples obtained is determined (Deere and Deere 1988). This index, expressed as a percentage, is defined as a quotient between the sum of the length of the core pieces and the total length of the core run.

There are different tools for the collection of samples, and depending on their characteristics, disturbed or undisturbed samples will be obtained. The use of a Shelby tube sampler is preferred in cohesive silty and clayey soils, whereas a split-spoon sampler is used in sandy soils (Small 2016).

A sample extracted by means of a hand or machine-driven auger consists of a short cylinder that is obtained from the combination of rotation and downward force. Samples collected in this manner are regarded as disturbed.

Undisturbed soil samples may be collected by means of thin-wall coring tubes that are pushed into the ground. Thick-wall coring tubes are driven into the soil with a hammer in order to collect soil samples with some cohesion. The sample that is within the tube is a representative sample, but it is not considered undisturbed.

In order to avoid dropping the sample from the tube due to the thrust of water when operating below the water table, a valve is located at the top of the sampler and it is seated on the head of the tube to prevent the water from descending and putting pressure on the sample. It is a simple, robust sampler whose greatest disadvantage is that the sample must be pushed to extract it from the tube, which subjects it to a certain degree of deformation.

The Shelby tube sampler is very simple and widely used. It consists of a thin-wall tube, generally made of steel, with a sharp cutting edge. The disadvantage of this type of sampler is that it is necessary to push the sample out of the tube, which causes some disturbance, occasionally important.

Stationary-piston samplers avoid the penetration of mud or prevent the water pressure from affecting the sample as water enters the tube and raises the ball when discharging the

Borehole Investigations, Fig. 2 Water samples and water table measurement

water towards the rods. They may be used in soft to moderately stiff clayey soils and in loose sands.

A double-tube soil core barrel has a core lifter that protrudes some 4–9 cm from the crown, which ensures that the drilling fluid will not reach the sample and that the crown will not come into contact with the core. It may be used in clayey soils of hard consistency and the quality of the samples obtained is regular to good depending on the ground conditions.

When the soils are cohesive and their resistance is high, the collection of an undisturbed sample is substituted by dipping in paraffin the longest section of the core obtained.

These sections, once they have been superficially cleaned, must be covered in nonabsorbent material and everything must be protected with a paraffin wax seal thick enough to ensure there are no variations in the humidity conditions.

Water samples are collected from boreholes to study the hydrochemical characteristics of the water found in the survey points. It is common to keep a record of the water table level in every borehole (Fig. 2), not only during the drilling but also once it has been completed, at least until the end of the field work.

If bentonite drilling muds or special drilling gels are used during the drilling, the boreholes must be cleaned once they have been completed by means of clean water circulation. Bentonite drilling muds or special gels must be used with caution, especially if the objective is to subsequently carry out permeability tests.

Should it be necessary or convenient, piezometers may be installed so as to isolate the different aquifers intersected by each borehole.

Every sample and core must be appropriately packed to avoid alterations during transport or storage, and must be shipped as soon as possible to the laboratory. Undisturbed samples must be preserved in a laboratory environment with controlled temperature and humidity. Only the packages with the samples that are going to be tested should be opened, and not until the moment when the corresponding tests are going to be carried out.

Borehole Testing

The main tests undertaken in situ in a borehole are as follows:

Standard Penetration Test (SPT)

The SPT is the most common test among those conducted within a borehole (Price 2009). It is a simple test and it may be performed while the borehole is being drilled. It may be applied to any type of soil, including soft or weathered rocks. It is possible to correlate the SPT with the mechanical soil parameters; this correlation, together with the data obtained from laboratory tests, helps define the allowable pressure of a soil for a specific type of grouting.

The SPT is an in situ dynamic penetration test designed to obtain information on the soil properties, while it also collects a disturbed soil sample to analyze grain size and determine soil classification.

The SPT N-value is defined as the number of blows required to achieve a penetration of 45 cm with a sampler placed in the lower portion of the drive rods. It is driven into the ground by means of a 63.5 kg (140 lb) hammer that is dropped in free fall on the top end of the drive rods from a height of 76 cm (30 inches) (Fig. 3).

Usually, the sampler has an outside diameter of 2 inches and an inside diameter of $1\frac{3}{8}$ inches; in the case of gravel, a conical tip with a diameter of 2 inches and an apex angle of 60° is used.

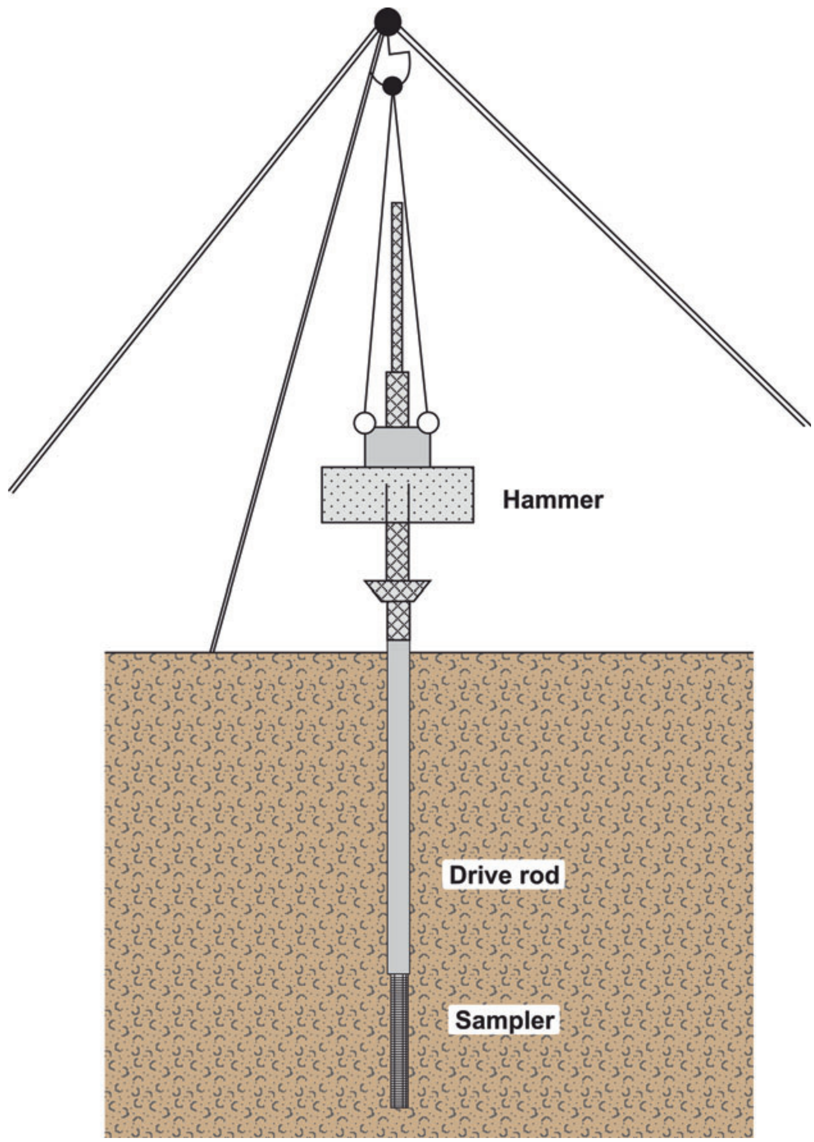
As a hollow tool is used, the test makes it possible to collect a disturbed sample of the soil in which the penetration test was carried out, so as to analyze in the laboratory.

Pressuremeter and Dilatometer Tests

These are stress-strain tests undertaken directly in the soil in order to identify its geotechnical characteristics, regarding its deformability (pressuremeter modulus) and resistance properties (limit pressure).

They are conducted by the expansion with gas of a cylinder cell against the walls of a borehole, measuring the volumetric deformation of the soil in a horizontal plane

Borehole Investigations, Fig. 3 Standard penetration test



corresponding to each pressure until eventually the soil yields.

Regardless of the problem posed by the transformation of the results obtained in the horizontal measurements in the case of the reaction of the foundations, which are usually vertical, and of the fact that soils tend not to be isotropic but stratified, these tests provide isolated and, therefore, discontinuous data as regards the layers encountered. The guidelines to conduct this test are set out in the ASTM D 4719-87 standard.

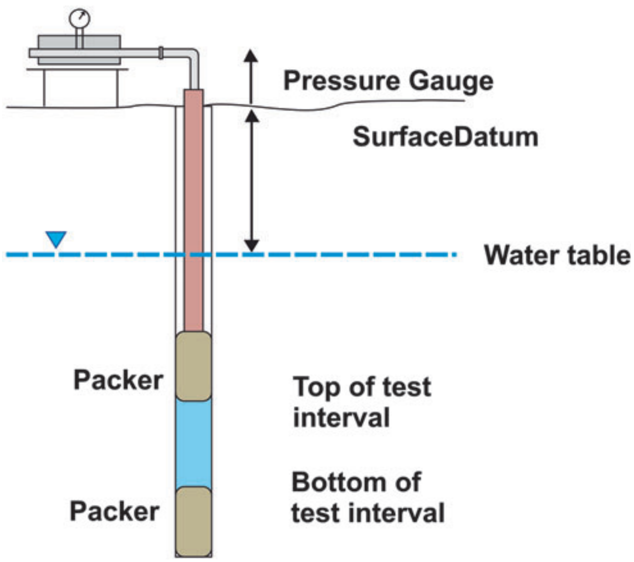
Permeability Tests

In situ permeability tests are conducted in soils and rocks. The most common ones consist of the addition or extraction of water, under a constant or variable hydraulic head.

A reliable estimation of the permeability coefficient is possible in surveys that detect the occurrence of the water table and in boreholes in which this coefficient ranges from 10^{-3} to 10^{-5} cm/s. In the case of lower permeabilities, it is necessary to resort to pumping or laboratory tests.

The most frequent ones are referred to as the Lefranc and Lugeon tests (Monnet 2015).

The Lefranc test is carried out within a borehole, during the drilling or once it has been completed. This test estimates the permeability coefficient k in granular soils (gravel, sand, and silt) or in highly fractured rocks occurring below the water table. It is performed by filling the borehole with water and measuring the necessary flow to maintain a constant level (constant-head) or the fall velocity (variable-head). In the constant-head test, as a general rule, the inflow rate is measured at specific time intervals, keeping a constant level at the borehole head. The k coefficient of the section is the average of all the values obtained. The variable-head test is preferably conducted downward, starting from a maximum head of water and recording the decrease in water level within the pipe at different times.



Borehole Investigations, Fig. 4 Lugeon test

The Lugeon test consists of injecting water under pressure at an isolated section of a borehole bounded by one or two packers and measuring the amount of water that infiltrates into the soil (Fig. 4).

This test can be carried out as the borehole is being drilled or once it is completed. First, the section to be tested is chosen. Once the packers are in place, the injection of water begins, measuring the volume of water injected. The measurement is performed at certain intervals, starting with a minimum pressure and increasing this in stages, all the while measuring the volume of water intake. Starting from the maximum pressure, the same process is repeated but decreasing the pressure at each stage, until the initial pressure is reached. Water is injected by means of a pump, measuring the pressure with a gauge and the volume injected with a flowmeter.

This test is applied to medium to low permeability consolidated soils or rocks ($10^{-6} < K < 10^{-9}$ m/s).

Different tests can be performed in the laboratory, which makes it possible to measure a wide variety of soil properties. Some of these properties are intrinsic to the composition of the soil matrix and they are not affected by the disturbance of the sample, whereas other properties depend on the structure and composition of the soil, and these can only be analyzed effectively in relatively undisturbed samples.

Besides geologic logs from drill holes, a suite of geophysical logs can be collected to provide additional information regarding the nature and distribution of materials below the ground surface. Typical data collected in this manner comprise spontaneous potential (SP), resistivity, gamma ray, gamma-gamma, radioactive neutron, and other methods (acoustic, camera televiewer, etc.)

Summary

The direct study methods used in engineering geology are based on geotechnical surveys, which allow for the sampling of subsurface materials and the undertaking of in situ tests.

Boreholes are drilled by percussion or rotary techniques, with the latter being the most common. Different types of tools are available to obtain disturbed and undisturbed samples. Undisturbed samples are those that best maintain the physical structure and properties of the soil and lead to more reliable laboratory test results.

Tests undertaken in situ in a borehole include penetration tests, pressuremeter and dilatometer tests, and permeability tests. All of these, together with the ones performed in the laboratory on the samples obtained from the boreholes, are essential to understand the characteristics of the soil and to design engineering works to be constructed at the study site.

Cross-References

▶ Atterberg Limits
▶ Bedrock
▶ Borehole
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- ► Rock Laboratory Tests
- ► Soil Field Tests
- ► Soil Laboratory Tests
- ► Water

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