TESTING OF MATERIALS AND SOILS

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Summary

The procedures followed in the field and in the laboratory to identify and select materials suitable for the construction of earth- and rock-fill and concrete dams are outlined. Standard testing methods to determine soil properties and strength are described. These are used to determine soil's suitability for construction purposes and to prescribe the optimum moisture content for compaction to maximum density and shear strength. Uniaxial and triaxial shear strength tests are made on compacted samples. Sand and gravel samples are size-graded to design correct proportions for concrete mixes. Porosity and permeability tests are made to determine the suitability of semipervious materials for use in the core of fill dams. Rock and concrete strength determinations are also made by means of uniaxial crushing tests on samples or test specimens.

1. Introduction

Structures built for water collection and storage generally contain large volumes of concrete, earth-fill, and rock-fill, or a combination thereof. The cost of these materials each year adds up to large sums of money, and it is imperative that proper tests be done to ensure that:

- the *quality* of the materials meets the specifications so as to ensure sound structures
- the *engineering properties* of the materials are determined to provide the designers with quantitative figures that would enable them to design structures using the least possible quantities

It is not the intention in this article to describe in detail every test that is done on the various materials, but rather to discuss the kinds of tests that are being done: their purpose, the interpretation of test results, and their application. The three main areas in which tests are performed in the materials laboratory are:

- *soils*, *sands*, and *gravels*, for the construction of earth embankment dams
- *rock-fill*, for the construction of rock-fill embankment dams
- *concrete* and *materials* (*aggregate*), for the making of concrete for construction of concrete dams, concrete structures (such as intake towers that are built with other types of dams), and pumping stations, canals, and so on

In addition, various other materials such as rubber and PVC water stops, sealing and curing compounds, plasticizers, air-entraining agents, and geotextiles are also tested.

2. Testing of Soils Used in Dams

Material deposits near future dam sites are investigated for construction purposes. Sand, soil, and clay are necessary in large quantities and may be relatively close at hand for constructing embankment-type dams, also known as earth-fill dams. Such materials need to have the correct physical properties to permit satisfactory, economical, and sustainable structures of this type to be constructed. Standard tests used to determine the quality of candidate materials are described next (see *Large Dams; Concrete Dam Engineering*; *The Construction of Small Earth-Fill Dams*).

2.3. Overview

The answer to a problem in soil engineering is normally obtained by first determining the properties of the soil in question and then using these properties to work out the solution.

The first step in testing a soil sample should be to look at the material and to compare if what is observed tallies with the description of the material as given in the *trial pit logs*. This step aids the development of a feeling for soil behavior and may aid in the interpretation of the test results that are to be obtained. Simply looking at the material for verification may also detect possible mistakes on the trial pit logs or perhaps the sample numbering. As far as soils for embankment dam construction are concerned, two types of test series are performed in a materials laboratory, as follows.

The first series of tests comprises the grading analyses and the *Atterberg indices*, which are classified as the *indicator tests*. These tests are used in the design of the structure, but provide the designer and technicians with valuable information regarding the nature and characteristics of the material.

The second series of tests comprises the following: compaction tests, determination of specific gravity, permeability, quick shear, and triaxial tests. These tests provide the data that are to be used for the design of the embankments and for the specification of how the materials must be placed during construction.

2.4. Indicator Tests on Soils

A number of standardized test methods for granular construction materials, sand, soil, and clay, have been developed over the decades, and these are strictly adhered to in materials-testing laboratories the world over. These methods are described next.

2.2.2 Grading Analysis

One factor, upon which soil behavior always depends to some degree, is the size and distribution of the individual particles. The grain-size distribution of a soil is also vital data required for the proper design of *filters* in embankment dams and other structures.

The grain-size distribution of a material must, however, never be viewed in isolation, but seen together with the other characteristics of the soil, and serves to provide complete information with regard to its properties and possible uses. Grain-size analyses are performed as routine tests on all soil samples submitted to a materials laboratory.

The test methods followed in the laboratory are basically the same as prescribed by the USBR (United States Bureau of Reclamation) and by the USACE (United States Army Corps of Engineers). The methods have been slightly modified to suit the type of fine-grained soils that the materials laboratory of the Department of Water Affairs and Forestry in South Africa usually deals with.

2.2.7. Atterberg Limits

Depending on the amount of water present, a fine-grained soil can exist in any of several states. When water is added to a dry soil, each particle is covered by a film of adsorbed water. If more water is added, the thickness of the water film around the particle increases, and this acts as a lubricant that permits the particles to slide past one another more easily. The behavior of the soil is therefore related to its moisture content. A. Atterberg defined the boundaries in terms of “limits” as follows:

- *Liquid Limit:* The boundary between the liquid and plastic state of the soil is defined as “that water content, expressed as a percentage of the mass of oven-dried soil, at which two halves of a pat of soil, separated by a groove of standard dimensions, will close at the bottom of the groove along a distance of 12 mm under the impact of 25 blows given in 12.5 seconds in a standard liquid-limit device.”

- *Plastic Limit:* The boundary between the semisolid and solid states is defined as "that water content, expressed as a percentage of the mass of oven-dried soil, at which the soil begins to crumble when rolled into a thread 3 mm in diameter."

The amount of water that must be added to change a soil from its plastic limit to its liquid limit is an indication of the *plasticity* of the material. The plasticity is measured by the "plasticity index," which is equal to the liquid limit minus the plastic limit.

A further limit defined by Atterberg is the *shrinkage limit*. The shrinkage limit is "the water content that is just sufficient to fill the pores when the soil is at the minimum volume it will attain by drying." Determination of this limit involves the submergence of the soil sample in mercury, but for health reasons the test is *not* done by the materials laboratory.

The Atterberg properties are of an empirical nature, but by performing these tests routinely on all soil samples submitted, a valuable feeling can be gained for the character of the soil. These measured properties are also required for the classification of the soil.

A final test that is done instead of the rather unhealthy shrinkage limit determination is the test for the *linear shrinkage*. The results of this test are usually grouped with the Atterberg indices. The linear shrinkage of a soil is defined as "the percentage decrease in one dimension of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state."

The methods for these tests are basically the same as those described by the ASTM (American Society for Testing Materials) for the Atterberg constants.

2.2.8. The Proctor Compaction Test for Determining the Maximum Dry Density and the Optimum Moisture Content of a Material

Earth dams, road and canal fills, and other embankments must be placed with soil in a compacted or dense state if they are to have maximum strength and imperviousness and are to be free of excessive settlement and, in the case of granular soils, free of danger from liquefaction.

Compaction is defined as the "process of bringing soil to a dense state by blows, by passages of a roller, or by some other type of loading."

For any given soil that is to be used in a rolled-fill embankment, there is a certain water content at which a given amount of rolling with the compaction equipment gives the highest density. This value is called the *optimum water content* (see *The Construction of Small Earth-Fill Dams*).

A laboratory test for the determination of the optimum water content was developed by R.R. Proctor, and the test procedure was published in 1933. This test is today known as the Proctor Compaction Test, and it plays an important part in the investigation of materials and the control of construction of rolled-fill embankments.

The Proctor Compaction Test is a laboratory procedure designed to bring soils to approximately the same state of density that is obtained when earth dams are compacted by means of rolling equipment.

With the development of more efficient compacting equipment for the construction of earthworks, several modifications of the Proctor test, each simulating a greater effort to match the increased effort of the new equipment, have been developed.
For embankment dams, however, for which fine-grained materials are generally used, and where plasticity of the core-zone material is especially important, the standard Proctor test has been retained.

The Proctor test procedure followed by the materials laboratory is basically in accordance with the method described by the US Army Corps of Engineers and the USBR test Designation E11.

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Biographical Sketch

Frans Druyts, Pr. Eng., holds the degree B.Sc. (Civil Engineering) from Pretoria University and is a member of the South African Institution of Civil Engineers. He has 27 years' experience in the Department of Water Affairs and Forestry in South Africa. Two years thereof were spent on the construction of a major dam and many years on the design of concrete and earth-fill and rock-fill dams. For 20 years he was Deputy Chief Engineer (Civil Design): Canal Design; Materials Laboratory; Earth- and Rock-fill Dam Design. He is Senior Specialist Engineer in charge of Earth- and Rock-fill Design.
His expertise also covers the supervision of designs for canals, tunnels, and supervising material investigations and concrete-mix design. He was also responsible for the design of flood-damage repairs; and roller-compacted concrete structures. He also lectures at the Technikon, Pretoria, South Africa, on the principles of dam engineering.