# Testing

## A. General Information

Several testing methods can be used to measure soil engineering properties. The advantages, disadvantages, and measured soil properties for each test are summarized below.

## B. Field Testing

1. **Types of In-situ Equipment:**

   a. **Standard Penetration Test (SPT):** SPT test procedures are detailed in ASTM D 1586 and AASHTO T 206. The SPT consists of advancing a standard sampler into the ground, using a 140 pound weight dropped 30 inches. The sampler is advanced in three 6 inch increments, the first increment to seat the sampler. The SPT blow count is the number of blows required to advance the sampler into the final 12 inches of soil.

   Advantages of the Standard Penetration Test are that both a sample and number are obtained; in addition, the test is simple and rugged, is suitable in many soil types, can perform in weak rocks, and is available throughout the U.S. Disadvantages are that index tests result in a disturbed sample, the number for analysis is crude, the test is not applicable in soft clay and silts, and there is high variability and uncertainty.

   b. **Cone Penetration Test (CPT):** The CPT test is an economical in-situ test, providing continuous profiling of geostratigraphy and soil properties evaluation. The steps can follow ASTM D 3441 (mechanical systems) and ASTM D 5778 (electronic system). The CPT consists of a small-diameter, cone-tipped rod that is advanced into the ground at a set rate. Measurements are made of the resistance to ground penetration at both the tip and along the side. These measurements are used to classify soils, estimate the friction angle of sands, and estimate the shear strength of soft clays.

   Advantages of the Cone Penetration Test include fast and continuous profiling, economical and productive operation, non-operator-dependent results, a strong theoretical basis in interpretation, and particular suitability for soft soils. Disadvantages include a high capital investment, a skilled operator to run the test, unavoidable electronic drift noise and calibration, no collection of soil samples, and unsuitability to test gravel or boulder deposits.

   c. **Borehole Shear Test (BST):** BST is performed according to the instructions published by Handy Geotechnical Instruments, Inc.

   Advantages of the Borehole Shear Test include its direct evaluation of soil cohesion (C), and friction angle ($\phi$), at a particular depth, and its yielding of a large amount of soil cohesion and friction angle data in a short time. Disadvantages include difficulty to fix the test rate and the drainage condition of the sample, and no collection of stress-strain data.

**d. Flat Plate Dilatometer Test (DMT):** DMT is performed according to ASTM D 6635, which provides the overview of this device and its operation sequence.

Advantages of the Flat Plate Dilatometer Test are that it is simple and robust, results are repeatable and operator-independent, and it is quick and economical. Disadvantages are that it is difficult to push in dense and hard materials, it primarily relies on correlative relationships, and that it needs calibration for local geologies.

**e. Pressuremeter Test (PMT):** There are several types of pressuremeter procedures, such as Pre-bored-Menard (MPM), Self-boring pressuremeter (SBP), Push-in pressuremeter (PIP), and Full-displacement cone pressuremeter (CPM). Procedures and calibrations are given in ASTM D 4719.

Advantages of the Pressuremeter Test are that it is theoretically sound in determination of soil parameters, it tests a larger zone of soil mass than other in-situ tests, and it develops a complete curve. Disadvantages are that the procedures are complicated, it requires a high level of expertise in the field, it is time consuming and expensive (a good day yields 6 to 8 complete tests), and the equipment is delicate and easily damaged.

**f. Vane Shear Test (VST):** The instructions for the Vane Shear Test are found in ASTM D 2573.

Advantages of the Vane Shear Test are that it provides an assessment of undrained shear strength ($S_u$), the test and equipment are simple; it can measure in-situ clay sensitivity ($S_t$), and there is a long history of use in practice. Disadvantages are that application for soft-to-stiff clays is limited, and it is slow and time consuming. In addition, raw, undrained shear strength needs empirical correction and can be affected by sand lenses and seams.

**2. Correlations with Soil Properties:** Tables 6B-2.01 and 6B-2.02 summarize the measured output values from each in-situ test, the use of the values to evaluate different soil properties, the soil types with which the tests can be used, and correlations used to evaluate soil properties.

**Table 6B-2.01:** In-situ Methods and General Application

| Method | Output | Applicable Soil Properties | Applicable for Soil Properties | Applicable for Soil Types |
|---|---|---|---|---|
| SPT | N | Soil identification | Medium | Sands |
| | | Establish vertical profile | Medium | |
| | | Relative density ($D_r$) | Medium | |
| CPT | Cone resistance ($q_c$), Sleeve friction ($f_s$) | Establish vertical profile | Most | Silts, sands, clays, and peat |
| | | Relative density ($D_r$) | Most | |
| | | Angle of friction (ϕ') | Medium | |
| | | Undrained shear strength ($S_u$) | Medium | |
| | | Pore pressure (U) | Most | |
| | | Modulus (E) | Medium | |
| | | Compressibility | Medium | |
| | | Consolidation | Most | |
| | | Permeability (k) | Medium | |
| BST | σ and τ | Angle of friction (ϕ') | Most | Sands, silts and clays |
| | | Cohesion (C') | Most | |
| DMT | $P_0$, $P_1$, $P_2$, $I_D$, $E_D$, $K_D$ | Establish vertical profile | Most | Silts, sands, clays, and peat |
| | | Soil identification | Medium | |
| | | Relative density ($D_r$) | Medium | |
| | | Undrained shear strength ($S_u$) | Medium | |
| PMT (pre-bored) | $V_0$, V, ΔP, ΔV, $E_p$ | Soil identification | Medium | Clays, silts, and peat; marginal response in some sands and gravels |
| | | Establish vertical profile | Medium | |
| | | Angle of friction (ϕ') | Medium | |
| | | Undrained shear strength ($S_u$) | Medium | |
| | | Modulus (E & G) | Medium | |
| | | Compressibility | Medium | |
| VST | $T_{max}$ | Undrained shear strength ($S_u$) | Most | Clays, some silts, and peat (undrained condition); not for use in granular soils |
| | | Soil identification | Medium | |
| | | Overconsolidation ratio (OCR), $K_0$ | Medium | |
| | | Sensitivity ($S_t$) | Most | |
| | | Pre-consolidation stress ($P_C$') | Medium | |

**Table 6B-2.02:** Correlations Between In-situ Tests and Soil Properties

| Method | Correlations | Applicable Soil Types |
|---|---|---|
| SPT | $\phi=28^o+15^oD_r$ | Granular soils |
| | $\phi=0.45\,N'_{70}+20$ | Granular soils |
| | $q_u = kN_{70}$ | Cohesive soils |
| CPT | $S_u=\frac{q_c - p_0}{N_k}$ ( $P_0=\gamma z$, $N_k$=cone factor, from 5 to 75) | Cohesive soils |
| | $\phi=29^o + \sqrt{q_c}$ | Granular soils |
| BST | $\tau=c+\sigma\tan\phi$ | Cohesive soils |
| DMT | $K_o=(\frac{K_D}{\beta_D})^{\partial} - C_D$ | Granular and cohesive soils |
| PMT (pre-bored) | $K_o=\frac{p_h}{p_0}$ | Cohesive soils |
| VST | $S_u=0.2738\,\frac{T}{d^3}$ | Cohesive soils |

## C. Laboratory Testing

1. **Index Testing and Soil Classification:** AASHTO and ASTM standards for frequently used laboratory index testing of soils are summarized in Table 6B-2.03 below.

**Table 6B-2.03:** Index Testing and Soil Classification

| Test | Test Designation | | Applicable Soil Properties | Applicable Soil Types | Complexity |
|---|---|---|---|---|---|
| | *AASHTO* | *ASTM* | | | |
| Test method for determination of water content | T 265 | D 4959 | Void ratio (e) and unit weight ($\gamma$) | Gravels, sands, Silts, clays, peat | Simple |
| Test method for specific gravity of soils | T 100 | D 854 | Specific gravity ($G_s$) | Sands, silts, Clays, peat | Simple |
| Method for particle-size analysis of soils | T 88 | D 422 | Classification | Gravels, sands, Silts | Simple |
| Test method for amount of material in soils finer than the No. 200 sieve | | D 1140 | Soil classification | Fine sands, Silts, clays | Simple |
| Test method for Liquid Limit, Plastic Limit, and Plasticity Index of soils | T 89 | D 4318 | Soil classification | Clays, silts, peat; silty and clayey sands to determine whether SM or SC | Simple |
| Unit weight, density | | D 1587 | Total density (e.g., wet density) ($\gamma_t$); Dry density ($\gamma_d$) | Undisturbed samples can be taken, i.e., silts, clays, peat | Simple |

2. **Shear Strength Testing:** AASHTO and ASTM standards for frequently used laboratory strength properties testing of soils are shown in Table 6B-2.04.

**Table 6B-2.04:** Shear Strength Tests

| Test | Test Designation | | Applicable Soil Properties | Applicable Soil Types | Complexity |
|---|---|---|---|---|---|
| | ***AASHTO*** | ***ASTM*** | | | |
| Unconfined compressive strength of cohesive soil | T 208 | D 2166 | Undrained shear strength ($S_u$) | Clays and silts | Simple |
| Unconsolidated, undrained compressive strength of clay and silt soils in tri-axial compression | T 296 | D 2850 | Undrained shear strength ($S_u$) | Clays and silts | Simple |
| Consolidated, undrained triaxial compression test on cohesive soils | T 297 | D 4767 | Friction angle ($\phi$), Cohesion (C) | Clays and silts | Medium |
| Direct shear test of soils for consolidated drained conditions | T 236 | D 3080 | Friction angle ($\phi'$) | Compacted fill materials; sands, silts, and clays | Simple |
| Modulus and damping of soils by the resonant-column method (small-strain properties) | | D 4015 | Shear modulus ($G_{max}$), Damping (D) | Gravel, sand, silt, and clay | Complicated |
| Test method for laboratory miniature vane shear test for saturated fine-grained clayey soil | | D 4648 | Undrained shear strength ($S_u$)<br>Clay sensitivity ($S_t$) | Silts and clays | Simple |
| Test method for CBR (California Bearing Ratio) of laboratory-compacted soils | | D 1883 | Bearing capacity of a compacted soil | Gravels, sands, silts, and clays | Complicated |
| Test method for resilient modulus of soils | T 294 | | Relations between applied stress and deformation of pavement materials | Gravels, sands, silts, and clays | Time consuming |
| Method for resistance R-value and expansion pressure of compacted soils | T 190 | D 2844 | Resist lateral deformation resistance | Gravels, sands, silts, and clays | Complicated |

3. **Settlement Testing:** AASHTO and ASTM standards for frequently used laboratory compression properties of soils are summarized in Table 6B-2.05.

**Table 6B-2.05:** Laboratory Test Used to Measure the Compression Properties of Soils

| Test | Test Designation | | Applicable Soil Types | Complexity |
|---|---|---|---|---|
| | ***AASHTO*** | ***ASTM*** | | |
| Method for one-dimensional consolidation properties of soils (oedometer test) | T 216 | D 2435 | Primarily clays and silts | Simple but time consuming |
| Test methods for one-dimensional swell or settlement potential of cohesive soils | T 256 | D 4546 | Clays | Medium |
| Test method for measurement of collapse potential of soils | | D 5333 | Silts | Medium |