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 (ϕ), 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 (γ)	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) (γ_t) / Dry density (γ_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 (ϕ), Cohesion (C)	Clays and silts	Medium
Direct shear test of soils for consolidated drained conditions	T 236	D 3080	Friction angle (ϕ')	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) 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