Lab Testing for Soils and Rock

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Module 7: Laboratory Testing for Soils

Learning Objectives

By the end of this section, you will be able to:

- **Identify** fundamental soil weight-volume relationships and their direct applications in geotechnical pressure and volume computations.
- **Evaluate** the load-deformation process, specifically the consolidation mechanism in saturated soils, to predict behavioral changes under stress.
- **Calculate** total, hydrostatic, and effective overburden stresses to re-establish in-situ conditions for accurate laboratory modeling.
- **Select** appropriate laboratory tests based on project type, site-specific soil peculiarities, and required design parameters.

Executive Summary: Laboratory testing is a critical geotechnical element used to model in-situ conditions and determine parameters for design. Effective stress—the difference between total stress and porewater pressure—is the controlling factor in soil shear strength, consolidation, and stiffness. Engineers must strategically optimize testing programs by understanding load-deformation processes and re-establishing accurate overburden stress profiles during laboratory evaluation.

Design Fundamentals

Laboratory testing ranges from basic moisture content determination to specialized strength and stiffness evaluations. Because testing is resource-intensive, you must recognize project issues early to optimize the program, particularly for strength and consolidation.

Weight-Volume Concepts

Soil samples generally consist of soil grains, water, and air. The weight and volume depend on the specific gravity of the solids, the size of the voids, and the degree of water saturation.

Void Ratio (e) is a primary indicator of relative strength and compressibility:

- **Low Void Ratio:** Generally indicates strong soils with low compressibility.
- **High Void Ratio:** Often indicates weak and highly compressible soils.

Table 7-1. Terms In Weight-Volume Relations (After Cheney and Chassie, 1993)

Property	Symbol	Units[1]	How obtained (AASHTO/ASTM)	Direct Applications
Moisture Content	w	D	By measurement (T 265/ D 4959)	Classification and in weight-volume relations
Specific Gravity	G_s	D	By measurement (T 100/D 854)	Volume computations
Unit weight	(	FL^{-3}	By measurement or from weight-volume relations	Classification and for pressure computations
Porosity	n	D	From weight-volume relations	Defines relative volume of solids to total volume of soil
Void Ratio	e	D	From weight-volume relations	Defines relative volume of voids to volume of solids

[1] F = Force or weight; L = Length; D = Dimensionless. Although by definition, moisture content is a dimensionless fraction (ratio of weight of water to weight of solids), it is commonly reported in percent by multiplying the fraction by 100.

Table 7-2. Unit Weight-Volume Relationships

Case	*Relationship*	*Applicable Geomaterials*
Soil Identities:	1. $G_s w = S e$ 2. Total Unit Weight: $\gamma_T = \frac{(1+w)}{(1+e)} G_s \gamma_w$	All types of soils & rocks
Limiting Unit Weight	Solid phase only: w = e = 0: $\gamma_{rock} = G_s \gamma_w$	Maximum expected value for solid silica is 27 kN/m^3
Dry Unit Weight	For w = 0 (all air in void space): $\gamma_d = G_s \gamma_w/(1+e)$	Use for clean sands and dry soils above groundwater table
Moist Unit Weight (Total Unit Weight)	Variable amounts of air & water: $\gamma_t = G_s \gamma_w (1+w)/(1+e)$ with $e = G_s w/S$	Partially-saturated soils above water table; depends on degree of saturation (S, as decimal).
Saturated Unit Weight	Set S = 1 (all voids with water): $\gamma_{sat} = \gamma_w (G_s+e)/(1+e)$	All soils below water table; Saturated clays & silts above water table with full capillarity.
Hierarchy:	γ_d # γ_t # $\gamma_{sat} < \gamma_{rock}$	Check on relative values

Note: $\gamma_w = 9.8\ kN/m^3$ (62.4 pcf) for fresh water

Load-Deformation Process in Soils

Deformation depends on grain-to-grain (intergranular) forces and pore water volume.

- **Dry Soils:** Deformation occurs primarily through the sliding and rearrangement of grains.
- **Saturated Soils:** Water must be squeezed out before grain readjustment can occur.
- **Consolidation:** The process where load is transferred from pore water to soil grains as excess pore pressure dissipates. This results in a higher unit weight and decreased void ratio.

💡 **Design Tip:** Soil permeability dictates the speed of deformation; highly permeable soils deform rapidly under load compared to low-permeability clays.

Principle of Effective Stress

Total stress in saturated soil consists of intergranular stress and porewater pressure. Only the intergranular stress is effective in resisting shear.

The Effective Stress Principle: Effective stress (F') = Total stress (F) - Porewater pressure (u).

Consolidation increases effective stress, which directly increases the soil's shear strength. In the field, staged construction allows foundation soils to gain strength before adding subsequent fill loads.

Overburden Stress

Soil at depth is affected by the weight of the material above it, known as **overburden stress**. Because sampling relieves this stress, laboratory tests must re-establish in-situ conditions.

Equation 7-1: Total Vertical Overburden Stress

$$\sigma_{\mathrm{vo}} = \sum(\gamma_t \cdot dz)$$

Where:

- **σ_{vo}** = Total vertical stress at depth z
- **γ_t** = Total unit weight of soil strata
- **z** = Depth

Equation 7-2: Hydrostatic Pressure (u0)

$$u_0 = \begin{cases} 0 & \text{Above water table (Dry)} \\ \gamma_w \cdot (z - z_w) & \text{Above water table (Capillarity)} \\ \gamma_w \cdot (z - z_w) & \text{Below water table} \end{cases}$$

Where:

- **u0** = Hydrostatic pressure
- **γw** = Unit weight of water
- **z** = Depth of soil element
- **zw** = Depth to groundwater table

Equation 7-3: Effective Vertical Stress

$$\sigma_v' = \sigma_{\text{vo}} - u_0$$

Where:

- **σ'v** = Effective vertical stress
- **σvo** = Total vertical stress
- **u0** = Porewater pressure

🧮 **Calculation Note:** Profiles of effective overburden stress with depth (F' diagrams) are essential for foundation analysis and testing assignments.

Selection and Assignment of Tests

Determine the laboratory scope based on project size, loading types (static/dynamic), and settlement limitations.

Table 7-3. AASHTO and ASTM Standards for Frequently-Used Laboratory Testing of Soils

Test Category	Name of Test	Test Designation	
		AASHTO	ASTM
Visual Identification	Practice for Description and Identification of Soils (Visual-Manual Procedure)	-	D 2488
	Practice for Description of Frozen Soils (Visual-Manual Procedure)	-	D 4083
Index Properties	Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating Method	T 265	D 4959
	Test Method for Specific Gravity of Soils	T 100	D 854
	Method for Particle-Size Analysis of Soils	T 88	D 422
	Test Method for Amount of Material in Soils Finer than the No. 200 (75-:m) Sieve		D 1140
	Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils	T 89 T 90	D 4318
	Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (600 kN-m/m^3)	T 99	D 698
	Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (2,700 kN-m/m^3)	T 180	D 1557
Corrosivity	Test Method for pH of Peat Materials	-	D 2976
	Test Method for pH of Soils	-	D 4972
	Test Method for pH of Soil for Use in Corrosion Testing	T 289	G 51
	Test Method for Sulfate Content	T 290	D 4230
	Test Method for Resistivity	T 288	D 1125 G 57
	Test Method for Chloride Content	T 291	D 512
	Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils	T 194	D 2974
	Test Method for Classification of Soils for Engineering Purposes	M 145	D 2487 D 3282

Purchase this course to see the remainder of the technical materials.