

Geotechnical Engineering

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2. Subject Introduction

2.1. Components of Soil

- **Solid**
- **Air**
- **Water**

2.2. Examples in Geotechnical Engineering

- Landslide and ground subsidence
- Earth retaining structures
 - Gravity
 - Cantilever
 - Semi-gravity
- Ground improvement
- Foundations
- Excavations
- Land reclamation
- Dams
- Tunnels and underground space
- Mining
- Environmental geotechnics

3. Laboratory Testing: Soil and Rock (AS 1289.0)

Laboratory testing may be required if **in-situ tests** are **insufficient** or **not possible** or the importance of the project deems the additional testing necessary (relying on empirical relationships may not be feasible)

3.1. Basic concepts

3.1.1.1. Soil phase relationships

The **weight** and **volume** of a soil sample will **depend** on the

- Specific gravity of soil grains (solids)
- Size and space between soil grains (voids and pores)
- Volume of void space filled with water

Soil **properties** include

- Moisture content (w)
- Specific gravity (G_s)
- Unit weight (γ)
- Porosity (n)
- Void ratio (e)

•

- **Weight-volume relationships**

•

- Soil identities

$$G_s w_n = S e$$

$$\gamma_T = G_s \gamma_w \left(\frac{1 + w_n}{1 + e} \right)$$

•

- **Limiting unit weight** (solid phase only, $w=e=0$)

•

$$\gamma_{solid} = G_s \gamma_w$$

•

- **Dry Unit weight** ($w = 0$, all air in void space)

$$\gamma_d = \frac{G_s \gamma_w}{1 + e}$$

- **Moist unit weight** (variable amounts of air and water)

$$\gamma_T = G_s \gamma_w \left(\frac{1 + w_n}{1 + e} \right)$$

•

- **Saturated unit weight** (all voids with water, $S = 1$)

$$\gamma_{sat} = \gamma_w \left(\frac{G_s + e}{1 + e} \right)$$

3.1.1.2. Load-deformation process

As the amount of **water** in the voids **increases**, the **pore water pressures** on the soil grains will **increase** and the **intergranular** contact **forces** will be **reduced**

→ if the sample is **saturated**, the **water** filling the voids will be **forced out** and the **soil particles** will **consolidate** (if saturated and low permeability, deformation is slow and there will be an increase in pore water pressure initially before deformation)

Deformation will **depend on** the

- **Intergranular forces** (grain to grain contact)
- The **volume of water** in the voids (higher void ratio increases possibility of deformation)

3.1.1.3. Principles of effective stress

For **partially saturated** soils **effective stress** will be **influenced** by the **soil structure** and **degree of saturation**

For soils **below** the **water table** (soil is saturated)

$$\text{Total stress } (\sigma) = \gamma_{sat} z$$

$$\text{Pore water pressure } (u) = \gamma_w z_w$$

$$\text{Effective stress } (\sigma') = \sigma - u$$

3.1.1.4. Overburden pressure

Soils are **affected** by the **weight** of the **soil above** (overburden stress)

→ when a **sample** is removed the **overburden stress** is **relieved** (need to re-establish in-situ stress conditions)

→ **unit weight** is **determined/estimated** from density tests, shear wave velocity, SPT/CPT or other in-situ test

$$\text{Total overburden stress } (\sigma_{v0}) = \int \gamma_T dz \approx \Sigma \gamma_T \Delta z_i$$

$$\text{Effective overburden stress } (\sigma'_{v0}) = \sigma_{v0} - u_0$$

Effective horizontal

Soil elements **above** the **water table**

Completely Dry: $u_0 = 0$

Full capillarity: $u_0 = \gamma_w (z - z_w)$

Soil elements **below** the **water table**

$$u_0 = \gamma_w (z - z_w)$$

3.2. Index properties

Several **index properties** are **obtained** from **laboratory tests**

- Moisture content
- Specific gravity
- Unit weight
- Sieve analysis
- Atterberg limits
- Moisture-density relationship
- pH of soils
- **Organic content** (important to know as properties of soil can change over time - may give desirable engineering properties now but this can change, e.g. additional settlement following decomposition)

3.2.1.1. Sieve analysis

Used to determine the **particle size distribution** which is useful in evaluating engineering characteristics (permeability, susceptibility to frost action)

3.2.1.2. Hydrometer analysis

Use to determine the **distribution** of **particles** that are **smaller** than the **no. 200 sieve** (75µm)

→ Identifies silt, clay and colloids percentages

3.2.1.3. Atterberg limits – AS 1289.3

Used to describe the **consistency** and **plasticity** of **fine-grained** soils with **varying** degrees of **moisture content**

→ portion of the soil **passing no. 40 sieve** is considered to identify **3 stages** of soil behaviour.

1. **Liquid Limit (LL)**
 2. **Plastic Limit (PL)**
 3. **Shrinkage Limit (SL)**
- Plasticity Index (PI) = LL – PL**

3.2.1.4. Moisture-density relationships

Used to determine **moisture content** and **max. dry density** for a given soil and specific **compactive effort** (used for the design and construction of earth structures – embankments, dams, structural foundations and fills)

→ a dry density vs. moisture content plot is obtained and the relationship is determined from performing tests on a given soil at varying water contents

3.3. Strength tests

The **selection of strength parameters** will depend on the **context** (construction type, foundation design, intensity type and duration of loads, soil materials)

The **strength parameters include**

- Effective strength envelope: assumed to be constant for a particular soil
- c' : cohesion
- ϕ' : angle of shear resistance
- Effective shear strength: $\tau_{max} = c' + \sigma_N \tan(\phi')$
- Total or undrained shear strength: S_u or c_u

3.3.1.1. Unconfined compressive strength (q_u)

Can find the **undrained shear strength** from the unconfined compressive stress and axial strain relationship

$$\rightarrow q_u = 2c_u = 2S_u$$

3.3.1.2. Triaxial Tests

A 38mm diameter **soil sample** is placed in a **rubber membrane** that sits in a **cell** with a given **confining pressure** where the confining pressure should approximately simulate in-situ state of effective stresses (e.g. original overburden pressure σ'_{v0} , anticipated max. vertical pressure in future, an intermediate pressure)

→ a **deviator stress** is applied vertically to the soil sample until the sample fails

→ the **pore water pressure (u)** is **controlled** by a **drainage connection**

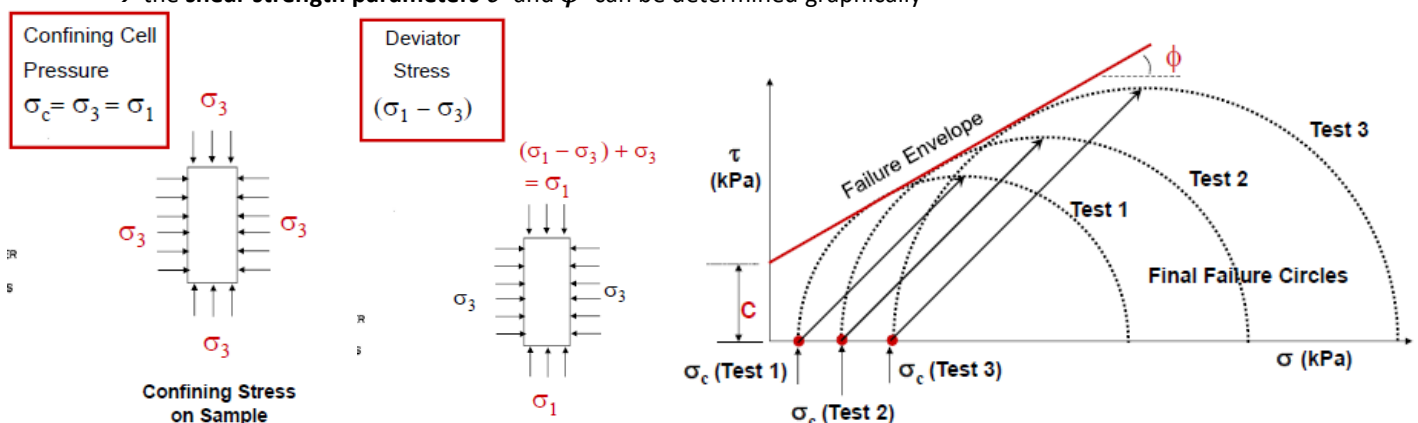
Drainage: $\Delta u = 0$

No Drainage: $\Delta u > 0$

→ σ_3 is held constant while σ_1 is increased through the deviator stress until failure (considered to have failed when the deviator stress reaches its peak)

→ **final failure Mohr circle** and the **failure envelope** can be found by **repeating** the test for **different σ_c**

→ the **shear strength parameters c' and ϕ'** can be determined graphically



There are **several types of triaxial tests**

→ CU, CUPP and CD tests are used to develop strength envelopes by the use of Mohr circles

1. **Unconsolidated Undrained (UU):** Samples not allowed to drain or consolidate prior or during testing, results will depend on degree of saturation ($s = 0 \rightarrow \phi' = 0$)
→ does not produce reliable results for saturated granular soils
2. **Consolidated Undrained (CU):** Specimen allowed to consolidate but drainage is blocked when axial stress is applied (pore water pressure will increase)
→ used on lower permeability soils