1. Laboratory Test

1.1 Atterberg Limits (Liquid Limit and Plastic Limit)

☸ Classification of soils (cohesive soils) based on behavioral difference by their water contents

Water content increase ↓

- Cohesion limit : Generally not in use
- Sticky limit : Generally not in use
- Shrinkage limit: Moisture content below, which no further soil volume reduction occurs.
- Plastic limit (PL): Lower limit for plastic behavior of soils.
- Liquid limit (LL): Upper limit for plastic behavior of soils.

- Plasticity Index (PI): Range of water content for plastic behavior of soils.

$$PI = LL - PL$$

☸ Purpose and usage

- Soil identification and classification (Simple method without difficulty in finding out mineral compositions)
- Quick referencing and most commonly used method for soil characteristics

1) Settlement or volume change :

ex) $C_c = 0.009(LL-10)$ for undisturbed clays of low to medium sensitivity. (Terzaghi and Peck)

2) Undrained strength : $s_u/\sigma_v' = 0.1 + 0.0037PI$ for NC clay deposits (Skempton)

3) Friction angle : empirical correlations between PI and ϕ

(increase of PI ➡ decrease of ϕ')

4) $K_o = 0.44 + 0.42(PI/100)$ (Massarsch, 1979)

❅ Testing methods for liquid limit

1) Conventional Method

- Determine water content at which a pat of soil in a brace cup, cut with a standard groove, and then dropped from a height of 10mm will undergo a groove closure of 12.7mm when the cup of soil is dropped 25times(=N) at the rate of 120 drops/min. (Need at least 4-5 reasonably well spaced points from about N=15 to 35.)
- Several variables
    1) Size of soil pat
    2) Rate of blows
    3) Length of time that soil is in cup
    4) Laboratory humidity and speed of performing test
    5) Degree of care for soil mixing
    6) Type of material for LL device base.
    7) Accuracy of height of fall
    8) Type of grooving tool.
    9) Condition of liquid limit device
- Use the soil fraction passing the No. 40 sieve (0.425mm opening)

    → For air dry soil (pulverizing and sieving , need curing time of 24-48 hours after remixing with water.

    → Minimal-to-no drying soil (wet sieving), can induce substantial problem of segregation and require a very careful mixing and long mixing time.

- One-Point Liquid Limit Method

  Based on regression analysis of 767 soils,

  $$LL = w_n(N/25)^{\tan\beta}$$
  $$= w_n(N/25)^{0.121}$$

  Error is negligible if N is between 20 and 30.

2) Fall cone

- Alternative method for determining the liquid limit and maybe more reproducible.
- Liquid limit is defined as that water content at which 20mm of cone penetration with a 30^{o} apex angle and a total mass of 80g into soil in the 55mm diameter and 40mm depth occurs in the 5s test time.
- LL is generally defined in a semilog plot made of penetration depth and water content.

☸ Testing Method for Plastic Limit

- PL has been defined as that water content at which a soil thread just crumbles when it is rolled down to a diameter of 3mm.
- Somewhat more operator-dependent but can be reproduced within 1-3%.

1.2 Specific Gravity of Soil Solids

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* Specific gravity can be computed using any ratio of mass of substance to mass of water for equal volume.

$$G_s = \frac{M_s / V}{M_w / V}$$

- With any given mass of soil (M_s), measure the mass of flask and water (M_{bw}) and the mass of flask, water and soil (M_{bws}) with measurement of temperature.
- Mass of water with same volume of soil (M_w) can be given as

$$M_w = M_{bw} + M_s - M_{bws}$$

- Specific Gravity can be obtained as

$$G_s = M_s / (M_{bw} + M_s - M_{bws})$$

- Correction for temperature

$$G_s = \alpha M_s / (M_{bw} + M_s - M_{bws})$$

(α is given in Table in page 73, based on 20°C)

* Major point of testing approach

- Deaerating the soil water mixture and water itself in flask.

  ⇒ Accomplished by applying a vacuum and/or heating.
- Checking the efficiency of air removal
- Any temperature error (deviation of volume of flash and density variation) and error due to the use of tap water is negligible, if 18°C ~22°C and no visible mineral in a flask.

1.3 Particle-Size Analysis

- Mechanical Sieving Method
- Hydrometer Test

1.3.1 Mechanical Method

- Particle size distribution is the most elementary and indispensable measurment of soils.
- It is one of suitability criteria of soils for any kind artificial application such as road, backfill of retaining structure, airfield, dam….
- Stacking a series of sieves (the size bracketing and not determination of individual particle sizes) does the test. (No reproducible analysis => a deviation of ±2.0% for (-)No.4)
- Standard sieve sizes (Table 5-1).

  ⇒ The No.200 sieve (0.075mm) is the smallest practical sieve size.

  (Hydrometer method is used to estimate particle size < the No.200 sieve size.)

1) Key Point of Testing Method

boundary between gravels and sands

boundary between sands and silts

- Typical set of sieves: 4 – 7 sieves including No.4, 10, 40 and 200.
- Most important factors: **How to obtain a representative sample and how to break down soil lumps into individual soil particles.**
- Soaking (2 to 24hrs) and washing. (Pulverizing process is not enough to

break down soils to individual soil particles especially in fine particles.)

⇒ Can be omitted for soils with less than 5% of (-) 200 material.

- The result is presented as a semilog plot of percent finer versus particle size.
- Oven-dry soil or air-dry soil?

⇒ For air dry, must determine water content to compute dry sample mass.

⇒ Seem to be no significant difference.

- How to determine adequate quantity of soils.

⇒ The more, the better result. But it depends on the maximum grain size. ⇒

D_{max}	M_{min}(g)
No. 10	200
No. 4	500
3/4 in.	1500

⇒

2) Problems and Limitations

- Obtaining a statistically representative sample.
- The presence of soil lumps.
- The practical limitations of using square sieve mesh openings for irregularly soil particles.
- The limit on the number of sieves used in a stack for the analysis.

1.3.2 Hydrometer Method

1) Principle and Key Points of Hydrometer Method

- The larger the diameter of particle, the higher the velocity of fall of particles.

  ➡ Stokes' law

  Velocity of fall of the spheres, $v = \frac{2}{9}\frac{G_s - G_f}{\eta}(\frac{D}{2})^2$

  The range of soil particles in which the equation is valid,

  ⇒ (Brown movements) 0.0002mm ≤ D ≤ 0.2mm (Turbulence of fluid)

- Specific gravity of soil-water suspension is changed (decreased) with time, because soil particles continue to fall down and be sedimented at bottom.
- A dispersing agent is used to neutralize the particles to prevent soils from adhering together. ⇒ Sodium metaphosphate ($NaPO_3$) and Sodium Silicate (A 125mL quantity of 4% solution of Sodium metaphosphate in the 1000mL of soil water suspension.)

2) Hydrometer

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- The hydrometer displays the specific gravity of the soil-water suspension at the center of the bulb. (➡percent finer)

- The velocity of fall of the particles (from time reading +L)

  $v = L/t$ (➡particle size)

- Generally used type hydrometer: H152 (Calibrated to read 0 to 60grams of soils in the 1000mL soil water mixtures. (G_s=2.65))

3) Corrections and Calibrations

- The immersion correction :

  Correction of *L* (=the distance particles fall) for rising the surface of suspension due to inserting the hydrometer.

$$L = L_1 + \frac{1}{2}L_2 - \frac{1}{2}\frac{V_b}{A}$$ ← Figure 6-2

  It depends on shape of hydrometer. For 152H, *L=16.3 - .1641R* (*R*= reading of hydrometer) or Table 6-7

- Meniscus correction ← Figure 6-2

- Temperature correction and corrections for water impurities and for the use of a dispersal agent :

$$R_c = R_{actual} - zero \quad correction + C_T$$

where C_T is presented in Table 6.3.

- Correction for specific gravity of soils

$$a = \frac{1.65G_s}{2.65(G_s - 1)}$$

$$Percent \quad finer = \frac{aR_c}{M_s}100\%$$

4) How to obtain the relation between % finer and particle size.

1. Taking hydrometer reading (R_{actual}) and temperature at various elapsed times (t).
2. Making corrections and calibrations as necessary.
3. Computing particle size with elapsed time and percent finer with hydrometer reading.

$$D = \sqrt{\frac{30\eta}{980(G_s - G_w)}\frac{L}{t}} = K\sqrt{\frac{L}{t}}$$

(L in cm, t in min and D in mm)

where K (Table 6-4) can be computed with temperature and G_s.

$$Percent \quad finer = \frac{aR_c}{M_s}100\%$$