SECTION 6

ATTERBERG LIMITS TEST

References

- ASTM D4318 -17 "Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils.
- Bowles, Joseph E., Engineering Properties of Soils and Their Measurement (4th Edition).
- Lambe, T.W., Soil Testing for Engineers.
- U.S. Army Corps of Engineers, Laboratory Soils Testing, EM 110-2-1906.
- ASTM D 6026 - 06 – using Significant Digits in Geotechnical Data

General Discussion

These test methods cover the determination of the liquid limit, plastic limit, and the plasticity index of soils. These test methods are used as an integral part of several engineering classification systems to characterize the fine grained fractions of soils and to specify the fine-grained fraction of construction materials. The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together, with other soil properties to correlate with engineering behavior such as compressibility, hydraulic conductivity (permeability), compactibility, shrink-swell, and shear strength. A fine-gained soil can exist in any of several states; which state depends on the amount of water in the soil system. When water is added to a dry soil, each particle is covered with a film of adsorbed water. If the addition of water is continued, the thickness of the water film on a particle increases. Increasing the thickness of the water films permits the particles to slide past one another more easily. The behavior of the soil, therefore, is related to the amount of water in the system. Approximately sixty years ago, A. Atterberg defined the boundaries of four states in terms of "limits" as follows:

a. **Liquid Limit**: The boundary between the liquid and plastic states.

b. **Plastic Limit**: The boundary between the plastic and semi-solid states.

c. **Shrinkage Limit**: The boundary between the semi-solid and solid states.

These limits have since been more definitely defined by A. Casagrande as the water contents which exist under the following conditions:

a. **Liquid Limit**: The water content at which the soil has such a small shear strength that it flows to close a groove of standard width when jarred in a specified manner.

b. **Plastic Limit**: The water content at which the soil begins to crumble when rolled into threads of specified size.

c. **Shrinkage Limit**: The water content that is just sufficient to fill the pores when the soil is at the minimum volume it will attain by drying.

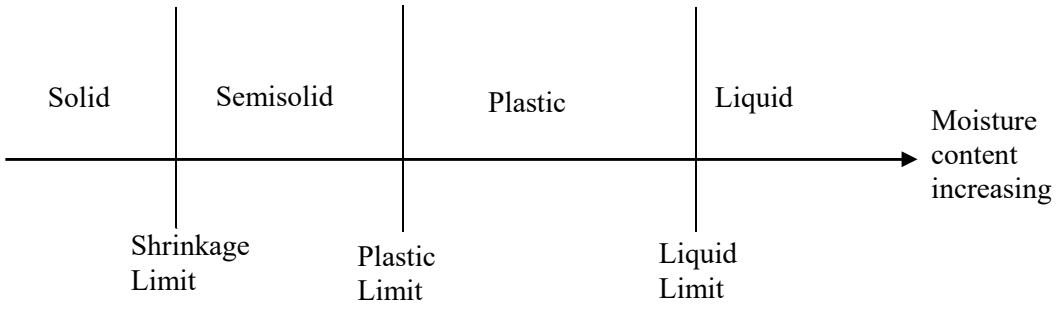


Fig 6-1: Qualitative position of Atterberg Limits on a moisture content scale.

The amount of water which must be added to change a soil from its plastic limit to its liquid limit is an indication of the plasticity of the soil. The plasticity is measured by the "plasticity index", which is equal to the liquid limit minus the plastic limit.

Although the liquid and plastic limits are necessarily determined on soils which have had their natural structure completely destroyed by kneading or "remolding", the shrinkage limit can be obtained on soils in either their undisturbed or their remolded states. The difference between the undisturbed and remolded shrinkage limits may be an indication of the amount of natural "structure" a soil possesses. Also the condition of an in situ soil is often partially revealed by its "water-plasticity ratio", which is the ratio of the difference between the natural water content and the plastic limit to the plasticity index. A high water plasticity ratio, which means that the natural water content is high relative to the liquid limit, indicates a very low remolded strength.

For example, if the ratio is greater than 100%, the soil exists at a water content greater than the liquid limit, and its remolded strength is thus less than that very small amount which it would possess at the liquid limit.

The chemical and mineral composition, size, and shape of the soil particles influence the adsorbed water films on the particles. Because such soil properties as compressibility, permeability, and strength, as well as the limits are dependent on the water films, approximate relationships exist between these properties and the limits.

For a given soil, we can often set up definite semi-empirical relationships between a property and the limits or indices. From such expressions, we can then make predictions of the properties of another sample of the same soil by knowing the limits. Such a procedure is often very helpful because the limits are usually more easily determined than the compressibility, permeability or strength. On construction jobs in which detailed studies of the underlying soil conditions are made, plots of the limits against depth can be made (along with other test results).

The limits furnish an excellent basis for the classification and identification of fine-grained soils. From Plasticity Chart of Aurther Casagrande the soil can be classified using the value of plasticity index and liquid limit and also from PI-LL chart of clay the clay mineral can be identified (see Figure 6 – 2). They are also often used directly in specifications for controlling soil for use in fills, and in semi-empirical methods of design. From the preceding discussion, we can see that even though the limits do not furnish numbers which can be substituted directly into scientifically derived formulas, they are extremely useful to the soil engineer.

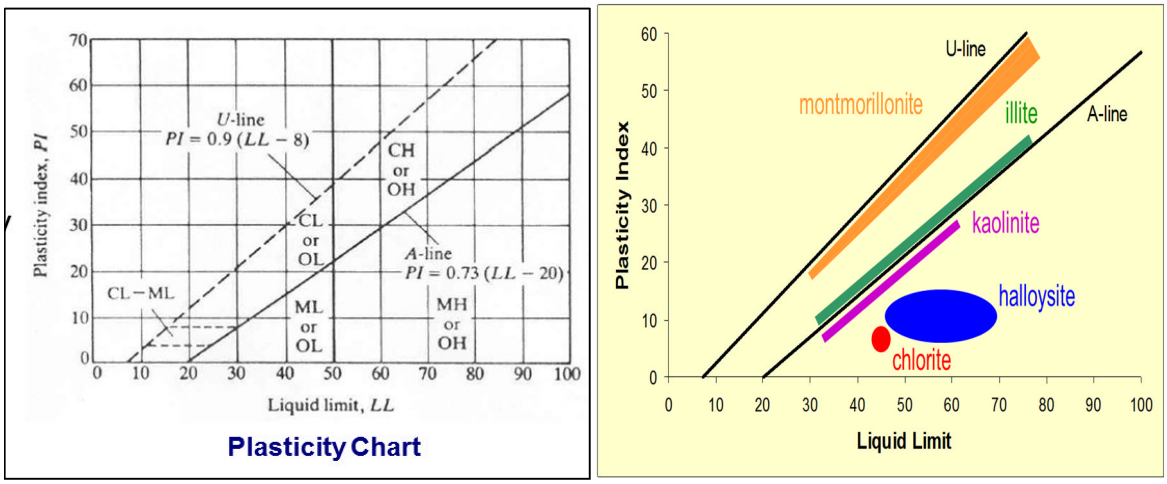


Figure 6 – 2: Aurther Casangrande's Plasticity Chart for Classification of fine-grained soil and Pl-LL chart for identifying Clay mineral by

Equipment

The following equipment are required for the test:

- Liquid limit device and grooving tool
- Mixing bowl
- Drying cans
- Spatula
- Large glass plate
- Drying oven.
- Distilled water
- Evaporating dishes
- Balance (0.01 g sensitivity)
- Large glass plate
- Drying oven



Figure 6 - 3: Equipment used for test.

Soil Preparation

The preparation procedure is as follows:

a. The soil should be dried in air and crushed to sieve through # 40 sieve.

b. Then approximately 200 gm of that soil has to be taken and mixed with water to make Paste

c. The paste should be covered with some container and put some wet cloth around the container to avoid evaporation.

d. The sample should be kept like this for 24 hours to ensure proper mixing of soil particles and water.

Test Procedure

Liquid Limit Test.

a. Each group will pulverize a sufficient quantity of air dried soil to obtain approximately 250 ± 10 g of material passing the #40 sieve. The residue remaining on the sieve should be discarded since it is no longer representative of the sample. It should be made sure that the lumps are broken up before sieving, since many of the fines are in these lumps. The soil must not be oven dried, since this will reduce the liquid and plastic limits of the soil.

b. The height of fall of their liquid-limit device should be checked. The device must be adjusted for a fall of exactly 1 cm (not over ±.0.1 mm). The 1 cm calibration block on the end of the grooving tool must be used for making the adjustment. The adjustment with respect to the worn spot should be made on the base of the cup, not the shortest fall. If the height of the fall is not calibrated within these limits, a water content error of several percent may be introduced, see Figure 6 - 4.

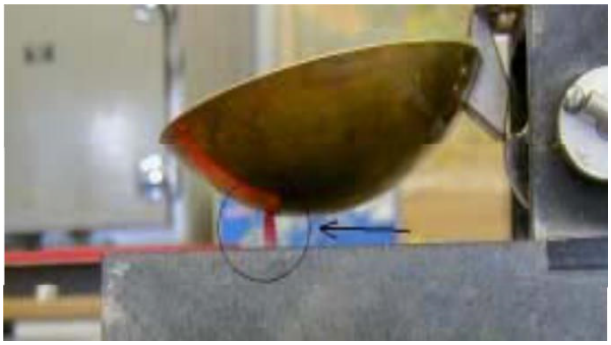


Figure 6 - 4: Use of calibration block. Block can be moved back to ensure a 1 cm drop.

c. The 250 g of soil should be placed in a mixing dish, then a small amount of water should be added, and the soil should be mixed carefully to a uniform color. Another major source of error is poor mixing of the soil-water mixture. When the color is uniform throughout and the mixture has a creamy appearance, proper mixing has generally been achieved. It should be continued to add small amounts of water and should be mixed the mass to a uniform color each time. When the soil reaches to the point of consistency (stickiness) where one can estimate (or by making a trial test) it will take about 50 blows to close the standard groove ½ in., then about 20 g of the thoroughly mixed soil should be removed from the dish. This sample should be set aside for the plastic limit test. Now more water should be added and mixed to a uniform color until the soil reaches to a consistency which will yield a blow count of from 30 to 40 blows to close the standard groove ½ inch.

d. The brass cup should be removed from the liquid-limit machine and a small amount of soil should be placed to the correct depth of the grooving tool, and well centered in the cup with respect to the hinge. The surface of the soil pat must be smoothed carefully, and using the grooving tool, a clean, straight groove should be cut that completely separates the soil pat into two parts. The tool should be held perpendicular to the instantaneous tangent to the cup surface so that the soil pat is not trimmed too shallow in depth. The soil depth should be just barely trimmed with the shoulders of the tool at the deepest part, see Figure 6-5. After making the groove, quickly the cup should be attached to the device and the blow count should be made. The rate of rotation of the crank on the Casagrande device should be about 2 revolutions per second. The test must be stopped after the groove has closed a length of 13 cm, see Figure 6 - 5. Unnecessary delays will affect the blow counts; if the laboratory humidity is low, dry the soil surface. The effect will show when plotting the data by giving an erratic locus of points. Other test errors will also do this, however.



Figure 6 - 5: Groove separating two halves of pat (left); Stop blow counts after this length of groove closes a length of 13 cm (right)

e. Step d should be repeated until 3 consistent blow counts are achieved for the water content. A moisture sample should be taken in the pre-weighed moisture cups (as large as possible and of about 40 grams being sure to take the water content sample from the closed part of the groove. This sample must be weighed immediately and the blow count and wet weight should be recorded on the data sheet. The remainder of the soil from the brass cup should be removed and returned to the mixing dish. Then the cup should be washed and dried up.

f. A small amount of water should be added to the mixing dish of soil, and carefully mixed to a uniform color and consistency to yield a blow count of between 25 and 30 blows. Steps d and e should be repeated.

g. The sequence for two additional tests for blow counts of between 20 and 25, and between 15 to 20, should be repeated for a total of at least four test determinations. It should be made sure to clean and dry the brass cup between tests, and should be tried to maintain a consistent time lapse for each test. The soil should not be allowed to sit in the brass cup for a long period of time before the test. This would allow adhesion to build up, which would result in higher blow counts. The blow count sequence is done in descending order to make sure the sample is well mixed. It is much easier to add water and mix to a uniform consistency (resulting in lower blow counts) than it is to add soil and mix to a uniform consistency. If too much water is added so that the sample is driven to the wet side of 25 blow counts before a sufficient spread of data points is collected on the dry side of 25 blow counts, the sample should be air dried rather than adding dry soil. Mixing or working the sample will help to quicken the drying time. The cups of soil should be placed in the oven (105 to 110°C) and dry 24 hours. When dry, the dry weight of the samples should be weighed and recorded. The water content of the samples should be determined, and a plot of water content versus blow count for this tests should be prepared.

Plastic Limit Test.

a. First 2 to 5 g of the material remaining from the liquid limit test should be taken. The material should be taken at any stage of the drying process at which the mass becomes plastic enough to be shaped into a ball easily without sticking to the fingers when squeezed.

b. Then the specimen should be shaped into an ellipsoidal mass and it should be rolled either under the root of the fingers, under the palm of the fingers, under the palm of the hand, or under the heel of the thumb and against the glass plate. It should be used just enough pressure to roll the soil mass into a thread that is 1/8 in. in diameter. When the diameter of the thread becomes 1/8 in. without crumbling, the thread should be folded and kneaded into a ball again and should be repeated the rolling

process. Kneading and rolling the specimen must be continued until the soil has dried to the point where the rolled thread will break into numerous pieces with a diameter of 1/8 in. and about 1/8 to 3/8 in. in length, see Figure 6 - 6.

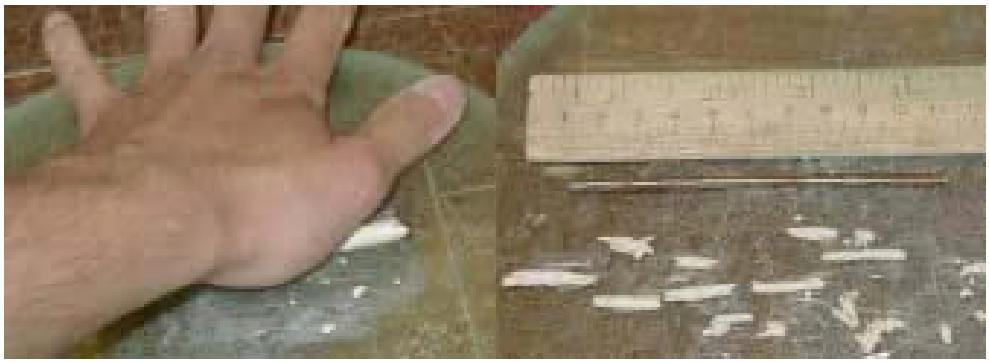


Figure 6 - 6: (a) rolling a thread and (b) rolled threads.

c. The pieces of the crumbled thread should be placed into a specimen container and the water content should be determined. Steps a and b should be repeated three to four times with different portions of the prepared material in order to check the plastic limit.

Both tests should agree within 1/20 of the plastic limit; otherwise the plastic limit test should be repeated.

Shrinkage Limit Test.

a. The shrinkage limit dish should be cleaned and the weigh should be taken. Also the inside diameter and height must be taken to determine the inside volume of the dish.

b. Then the petroleum jelly should be coated inside of the dish and the dish should be filled with wet soil.

c. Excess soil standing above the edge of the dish must be strucked off by a glass plate or straight edge.

d. Weight of the dish with wet soil is noted to record the weight of the wet soil pat.

e. The soil pat in the dish is the oven dried for 24 hours at 110^0C.

f. The oven dried soil should be weighed with container to record the weight of the dry soil pat.

g. The dry soil pat should be taken out of the dish and dipped inside a melted pot of wax and cool it.

h. The wax coated soil pat should be submerged in a measuring jar. Increase of the height of water indicates the volume of dry soil pat.



Figure 6 - 7: Equipment needed for shrinkage limit test.

Discussion of the Procedure

The American Society for Testing Materials and the American Association of State Highway Officials permit the use of the "hand method" of determining the liquid limit in addition to that given in this lab procedure. In the hand method, a tool is used to cut a groove (same size as in the mechanical method) in a soil paste contained in an evaporating dish. The water content is adjusted until the groove is closed by jarring the dish lightly against the heel of the hand ten times. The liquid limit is this adjusted water content.

A simplified procedure for determining the liquid limit has been investigated. The method is based on the assumption that the slope of the plot of blows on log scale against water content on log scale is a straight line with a constant slope. If this assumption were correct, the liquid limit could be obtained from any point on the

curve. Based on 767 liquid limit tests, the discovery was made that for the soils investigated the liquid limit, w_L, could be found from:

$$w_L = w_N(N/25)^{0.121}$$

in which w_N = the water content of the soil which closes in N blows in the standard liquid limit device.

Natural soils used for liquid and plastic limit determinations should not be dried prior to testing because drying may alter the soil by causing the particles to subdivided or agglomerate, by driving off adsorbed water which is not completely regained on rewetting, or by effecting a chemical change in any organic matter in the soil. These effects can significantly change the limits, especially the liquid limit. The liquid limit of oven dried organic soils tends to be lower than that of the undried. On the other hand, the effect of drying on some clays (particularly those composed of minerals of the montmorillonite group) cannot be predicted. For example, the liquid limit of an air-dried sample of a soil was 20% greater than that determined on the soil not previously dried, whereas the liquid limit of an oven-dried sample of the same soil was 24% less than that determined on the undried soil.

Calculations

The limits, expressed as water contents, are obtained as follows:

a. **Liquid Limit**. w_L is read from the flow curve as the water content at 25 blows.

b. **Plastic Limit**. w_p is the water content of the soil which crumbled when 1/8 in. threads were rolled (the average of the consistent determinations made)

c. **Shrinkage Limit** . w_s is found from

$$w_s = \frac{W_i - W_f}{W_f} \text{X } 100 - \frac{V_i - V_f}{W_f} \text{X } 100\, \gamma_w$$

In which γ_w = Unit weight of water,
W_i = Weight of wet soil pat,
V_i = Volume of wet soil pat,
W_f = Weight of dry soil pat,
V_f = Volume of dry soil pat

Atterberg indices can be calculated from the limits as follows:

a. Plasticity index, I_P = Liquid limit – plastic limit
b. Flow index, I_F = Slope of flow curve
c. Toughness index, $I_T = \frac{Plasticity\ Index}{Flow\ Index}$

Water – plasticity ratio, B is found from the equation:

$$B = \frac{w_N - w_P}{w_L - w_P}$$

in which w_N = natural water content

Errors in computing the liquid or plastic limits sometimes can be detected by plotting the values of liquid limit versus plasticity index with reference to the upper limit line on the plasticity chart (shown in Figure 3.2 in Holtz and Kovacs, 1981). The upper limit line starts from a liquid limit of 8 at a plasticity index of 0 and rises toward the right with a slope of 9 vertically on 10 horizontally; the equation of the upper limit line, therefore, is

$$w_i = 0.9\ (w_L - 8).$$

Significant Figures

1. All the Atterberg Limits should be expressed to their nearest whole number.

Possible Errors

General.

a. The specimen is not representative of the soil. The liquid and plastic limits must be determined using the same mixture of soil as that used for determination of natural water content or for other tests.

b. Specimen is improperly prepared. The specimens must be thoroughly mixed and be permitted to cure for a sufficient period before testing. Erroneous results may be caused by the loss of colloidal material when removing particles coarser than the No. 40 sieve or by testing air-dried or oven-dried soils.

c. Inaccurate determination of the water contents would greatly affect the computed liquid and plastic limits because of the small quantities of material available for the water content determinations.

d. Computational mistakes.

Liquid Limit Test.

a. Improperly constructed or adjusted liquid limit device.

b. Worn parts of liquid limit device especially at point of contact between the cup and the base, or worn tip of grooving tool.

c. Soil at the point of contact between the cup and the base. Removing the cup for shaping and grooving the sample will insure that the bottom of the cup and the top of the base are clean. Any soil that has dropped onto the base can be removed with one stroke of the back of the hand before replacing the cup.

d. Loss of moisture during the test. Erratic and erroneous results may be caused by drying of some soil mixtures unless the test is performed in a humid room.

Plastic Limit Test.

a. Rolling thread under fingers will break the thread prematurely.

b. Incorrect final thread diameter. A length of 1/8 in. diameter metal rod close at hand will help in estimating this diameter accurately.

c. Stopping the rolling process too soon. If there is any doubt as to whether the thread has crumbled sufficiently, it is better to roll the thread once more than to stop the process too soon.

Worked Out Example

Atterberg Limits

Test Serial No. **06**

Analyst Name: _____ Date: **04 March 09**

Project Name: **Airport Road – Rokeya Sharoni Link Road Project**

Boring No.: **03** Sample No.: **07** Depth: **1.5 m**

Source: **Shalby Tube from SPT**

Natural Water Content:

Sample No	**1**	**2**	**3**
Container #	**2**	**19**	**95**
Container Wt (gm)	**43.8**	**32.7**	**27.3**
Wet Wt + Container (gm)	**71.2**	**89.5**	**93.2**
Dry Wt + Container (gm)	**68.8**	**84.3**	**87.1**
Wt of Water (gm)	**2..4**	**5.2**	**6.1**
Dry Wt of Soil (gm)	**2.5.0**	**51.6**	**59.8**
Water Content (%)	**9.6**	**10.1**	**10.2**
Average (Natural Water Content)		**9.97**	

Sample Calculations (For Sample No 1)

Weight of container = 43.8 gm

Weight of wet soil + container = 71.2 gm

Weight of dry soil + container = 68.8 gm

Weight of water = (71.2 – 68.8) = 2.4 gm

Weight of dry soil = ((68.8 – 43.8) = 25.0 gm

Natural water content = (2.4 / 25.0) x 100 = 9.6%

Plastic Limit:

Sample No	**1**	**2**	**3**
Container #	**21**	**9**	**59**
Container Wt (gm)	**59.7**	**25.2**	**25.3**
Wet Wt + Container (gm)	**61.1**	**25.9**	**26.8**
Dry Wt + Container (gm)	**60.9**	**25.8**	**26.6**
Wt of Water (gm)	**0.2**	**0.1**	**0.2**
Dry Wt of Soil (gm)	**1.2**	**0.6**	**1.3**
Water Content (%)	**16.7**	**16.7**	**15.4**
Average (Plastic Limit)		**16.3**	

Sample Calculations (For Sample No 1)

Weight of container = 59.7 gm

Weight of wet soil + container = 61.1 gm

Weight of dry soil + container = 60.9 gm

Weight of water = (61.1 – 60.9) = 0.2 gm

Weight of dry soil = ((60.9 – 59.7) = 1.2 gm

Water content (Plastic limit) = (0.2 / 1.2) x 100 = 16.7%

Liquid Limit:

Container No	**4**	**6**	**22**	**1**	**17**
No. of Blows	**20**	**22**	**24**	**28**	**31**
Container Wt (gm)	**59.7**	**59.8**	**59.7**	**58.4**	**58.5**
Wet Wt + Container (gm)	**84.9**	**69.2**	**68.6**	**76.2**	**71.2**
Dry Wt + Container (gm)	**76.8**	**66.2**	**65.9**	**71**	**67.8**
Wt of Water (gm)	**8.1**	**3.0**	**2.7**	**5.2**	**3.4**
Dry Wt of Soil (gm)	**17.1**	**6.4**	**6.2**	**12.6**	**9.3**
Water Content (%)	**47.4**	**46.4**	**43.5**	**41.3**	**36.6**
Liquid Limit (from graph, for 25 blows)			**42.5**		

Sample Calculations (For Container No 4)

Number of blows = 20

Weight of container = 59.7 gm

Weight of wet soil + container = 84.9 gm

Weight of dry soil + container = 76.8 gm

Weight of water = (84.9 – 76.8) = 8.1 gm

Weight of dry soil = ((76.8 – 59.7) = 17.1 gm

Water content (Liquid limit)= (8.1 / 17.1) x 100 = 47.4%

