APPENDIX-A

Consistency of Soils as per Atterberg Limits:

Atterberg, a Swedish scientist, considered the consistency of soils in 1911, and proposed a series of tests for defining the properties of cohesive soils. These tests indicate the range of plastic state(plasticity is defines as the property of cohesive soils which possess the ability to undergo changes of shape without rupture) and other states. He showed that if the water content of a thick suspension of clay is gradually reduced, the clay water mixture undergoes changes from liquid state through a plastic state and finally into a solid state. The different states through which the soil sample passes through with the decrease in the moisture content is depicted in Fig (a). The water content corresponding to the transition from one state to another is termed as "***Atterberg Limit***" and the tests required to determine the limits are the ***Atterberg Limit Tests***.The testing procedures of Atterberg were subsequently improved by A.Casagrande.

States	Limit	Consistency	Volume changes
Liquid		Very soft	
...............w_l	Liquid limit..........	soft	
Plastic		stiff	Decrease in volume
................$w_{p,}$	Plastic limit..........	Verystiff	
Semi-solid			
.................w_s ,	Shrinkage limit......	Extremely stiff	
Solid		Hard	Constant volume

Fig (a) : Different states and consistency of soils with Atterberg Limits (64) (from "Text Book of Soil Mechanics and Foundation Engineering" by V.N.S.Murthy)

The transition state from the liquid state to a plastic state is called the ***liquid limit'w_l'***.At this stage all soils possess a certain small shear strength. The arbitrarily chosen shear strength is probably the smallest value that is feasible to measure in a stabdardised procedure.The transition from the plastic state to the semi-solid state is termed as ***plastic limit 'w_p'***. At this state the soil rolled into threads of about 3mm diameter just crumbles.Further decrease of the water contents of the same will lead finally to the point where the sample can decrease in volume no further. At this point the sample begins to dry at the surface,saturation is no longer complete, and further decrease in water in the voids occurs without change in the void volume. The colour of the soil begins to change from dark to light.The water content is called the ***"shrinkage limit' w_s'***. The limits expressed above are all expressed by their percentage of water contents.The renge of water content between the liquid and plastic limits,which is an important measure of plastic behaviour,is called the ***"plasticity index'I_p'*** i.e.$I_P=w_l-w_p$.

There is decrease in the volume of the soil sample as its moisture content decreases.This decrease in volume takes place up to shrinkage limit'w_s'(theoretically)and there will be no further decrease in volume beyond this limit with the decrease in moisture content.The soil remains beyond this limit with the decrease in moisture content. The soil remains saturated up to the shrinkage limit and when once this limit is crossed, the soil becomes partially saturated. The air takes the place of moisture that is lost due to evaporation. At about 105^0 to 110^0C,there will not be any normal water left in pores and soil at this temperature is said to be *Oven-dry*.The decrease in volume of the soil mass with the decrease in moisture content is depicted in the form of a diagram shown in Fig (b). A soil sample of volume V_0 and water content w_0 is represented by point A in the figure.

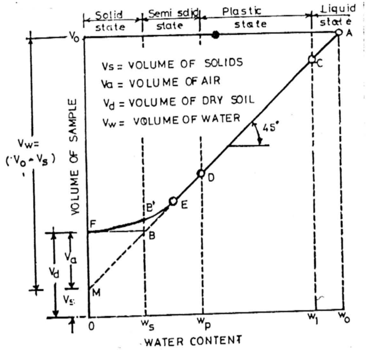


Fig (b) : Curve showing transition stages from the liquid to solid state(64)

(from "Text Book of Soil Mechanics and Foundation Engineering" by V.N.S.Murthy)

As the soil loses moisture content there is a corresponding change in the volume of soils. The straight line, AE, therefore, gives the volume of soil at different water contents.The points C and D represent the transition stages of soil sample at liquid and plastic limits respectively. As the moisture content is reduced further beyond the point D, the decrease in volume of the soil sample will not be linear with the decrease in moisture beyond a point E due to many causes.One possible cause is that air might start entering into the voids of the soils.This can happen only when normal water between particles are removed.If the normal water between particles are removed, the soil particles surrounded by adsorbed water will come into contact with each other.Greater pressure is required to bring these particles closer.As such change in volume is less than the change in moisture content.Therefore,the curve DEB'F depicts the transition from plastic limit to the dry condition of soil represented by point F.However,for all practical purposes, the abscissa of the point of intersection B of the tangents FB and EB when extended meets the ordinate at point M.The ordinate of M gives the volume of the solid particles, V_S.Since the ordinate of F is the dry volume, V_d, of the sample,the volume of air V_a, is given by (V_d-V_s).

<u>Determination of Atterberg Limits:</u>

(a) <u>Liquid Limits</u>

The apparatus shown in Fig.(c) is the Casagrande's Liquid Limit Device used for determining the liquid limits of soils.The device contains a brass cup which could be raised and allowed to fall on a hard rubber base by turning the handle.The cup is raised by 1 cm.The limits are determined on that portion of soil finer than a No.40 sieve(ASTM).About 100 gms of soil is mixed thoroughly with distilled water into a unoform paste.A portion of the paste is placed in the cup and levelled to a maximum depth of 12 mm.A channel of the dimensions of 11mm wide and 8mm depth is cut, as shown ib Fig (a) through the sample along the symmetrical axis of the cup.The grooving tool should always be held normal to the cup at the point of contact.The handle is next turned at a rate of about two revolutions per second and the number of blows necessary to close the groove along the bottom for a distance of 12mm is counted. The groove should be closed by a flow of the soil and not by slippage between the soil and the cup(Fig e).The water content of the soil in the cup is altered and tests repeated.At least four tests should be carried out by adjusting the water contents in such a way that the number of blows required to close the groove may fall within the range of 5 to 40 blows.A plot of water content against the log of blows is made as shown in Fig c. Within the range of 5 to 40 blows,the plotted points lie almost on a straight line.The curve so obtained is known as **"flow curve"**. The water content corresponding to 25 blows is termed as **"liquid limit"**.

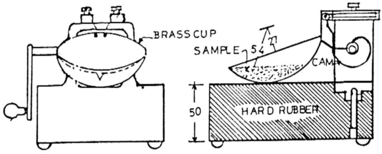
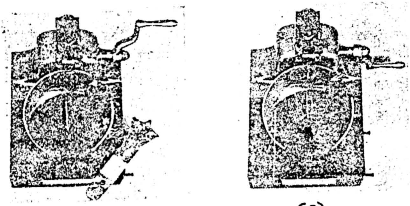
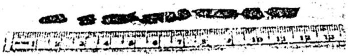


Fig c: Casagrande's Liquid Limit Device (from "Text Book of Soil Mechanics and Foundation Engg." by V.N.S. Murth



(d) (e)



(g)

Figs: Soil sample in Liquid Cup, (d) Cut groove (e) Clo groove and (g) Plastic limit threads (from "Text Book Soil Mechanics and Foundation Engg." by V.N.S. Murthy

The equation of the flow curve can be written as

$$w = -I_f \log N + C$$

where, w= water content

I_f= Slope of the flow curve,termed as *flow index*

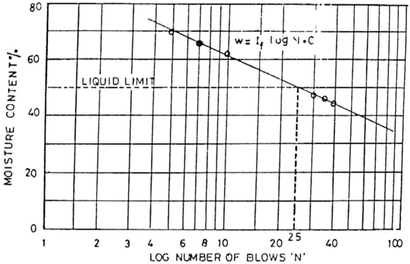
N=Number of blows

C=a constant

Two types of grooving tools are generally in use,one is the Casagrande type and the other ASTM type.The Casagrande type is usually recommended for the cohesive soils and theother for soils with more granular materials in it.

The force that resists the deformation of the sides of the groove,is the shearing resistance of the soil.The number of blows required to close the groove for a specified length is indirectly a relative measure of the shearing resistance of the soil at the corresponding water content.Twenty-five blows has been fixed on the basis,that if the groove closes the specified distance at 25 blows,all plastic soils at liquid limits possess a constant value for shearing resistance.It has been found by means of direct shear tests of different types of clays that the liquid limit corresponds to a shearing strength of about 2.7 kN/m^2. This applies to all plastic soils where the impact forces produce only the deformation of the soil.However, most non-plastic soils are much more pervious than clay and the impact forces tend to cause the pore water to flow towards the groove,thereby, actually softening the soil and reducing the shear strength near the groove.For such soils, the liquid limit no longer represents the water content at which the soil has a certain definite but very small shearing strength.Liquid and other limits have therefore no meaning for cohesionless soils which are non-plastic.

Since the number of blows represent a relative measure of the shear strength of soil,the same semi-log plot can also show a relationship between water content and shearing strength of a soil.If this plot is extended from a semi-liquid stage,through the entire plastic range to the semi-solid stage,the plot is not a straight line.This plot gradually curves and asymptotically approaches the zero water content coordinate.However,the plot iis almost a straight line within the test range of 5 to 40 blows.



Fig(f): Determination of Liquid Limit(64)

(from "Text Book of Soil Mechanics and Foundation Engineering" by V.N.S.Murthy)

(b) Plastic Limit

About 15 gms of soil passing through No.40 sieve(ASTM), is mixed thotoughly.The soil is rolled on a glass plate with the hand,until it is about 3 mm in diameter.The procedure of mixing and rolling is repeated till the soil shows signs of crumbling when the diameter is 3 mm.The water content of the crumbled portion of the thread is determined.This is called as **"plastic limit"**. The broken pieces of plastic limit threads is given in Fig (g).

(c) Shrinkage Limit

Shrinkage limit of a soil can be determined by any one of the following methods:

1. Determination of w_s,when the specific gravity of the soils G is unknown.

2.Determination of w_s when the specific gravity of the soils G is known.

when G is unknown

Three block diagrams of a sample of soil having the same mass of solids M_s are given in Figs (a) and (b) below .Block diagram(a) represents a specimen in the plastic state,which just fills a container of known volume, V_0.The mass of the specimen is M.The specimen is then dried gradually, and as it reaches the shrinkage limit,the specimen is represented by the block diagram(b).The specimen remains saturated up to this limit but reaches a constant volume V_d.When the specimen is completely dried,its mass will be M_S, where as its volume remains as V_a.

These different states are also represented on Fig (h).The shrinkage limit can be written as

$$w_s=M_w/M_s$$

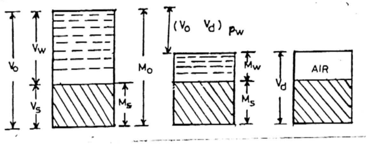


Fig (h) : Determination of Shrinkage Limit (64)

(from "Text Book of Soil Mechanics and Foundation Engineering" by V.N.S.Murthy)

where, $M_w = M_0 - M_s$=Mass of water in the voids at shrinkage limit.

But, $M_w=(M_0-M_S-(V_0-V_d)\rho_w$

Therefore, $w_s=(M_0-M_s)-(V_0-V_d)\rho_w/M_s x100\%$

The volume of the dry specimen can be determined by displacement of mercury as explained below.

<u>**Determination of dry volume V_d of Sample by Displacement in Mercury**</u>

Place a small dish filled with mercury up to the top in a big dish.Cover the dish with a glass plate containing three metal prongs in such a manner that the plate is entrapped.Remove the mercury split over into the big dish and take out the cover plate from the small dish.Place the soil sample on the mercury.Submerge the sample with the pronged glass plate and make the glass plate flush with thew top of the dish.Weigh the mercury that is split over due to displacement.The volume of the sample is obtained by dividing the weight of the mercury by its specific gravity which may be taken as 13.6.Fig (j) shows the apparatus used for the determination of volume.

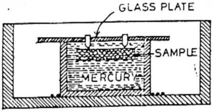


Fig (j) : Determination of dry volume by Mercury displacement method.(64)

(from "Text Book of Soil Mechanics and Foundation Engineering" by V.N.S.Murthy)

<u>when G is known</u>

$w_s=M_w/M_s$ But, $M_w=(V_d-V_s)\rho_w=(V_d-M_s/ G\gamma\rho_0)\rho_0$

Therefore, $w_s=(V_d\rho_w)/M_s - (\rho_w/G\rho_0)$

If $\rho_w \sim \rho_0=1gm/cm^3$,we have $G_w=1$

Hence,$w_s=(V_d/M_s) - (1/G)$

<u>(d) Plasticity index (I_p)</u>

Plasticity index(I_p) indicates the degree of plasticity of a soil.Greater the difference between liquid and plastic limits greater is the plasticity of the soil.A cohesionless soil has zero plasticity index.Such soils are termed as non-pastic.Fat clays are highly plastic and possess a high plasticity index.Soil possessing large values of liquid limit and plasticity index are said to be highgly plastic or fat.Those with low values are described as slightly plastic or lean.Atterberg classifies the soils according to their plasticity indices as in Table below.

Plasticity Index	Plasticity
0	Non-Plastic
<7	Low Plastic
7-17	Medium Plastic
>17	Highly Plastic

TABLE : Soils Classifications according to Plasticity index (64) (from "Text Book of Soil Mechanics and Foundation Engineering" by V.N.S.Murthy)

A liquid limit greater than 100 is uncommon for inorganic clays of non-volcanic origin.However,for clays containing considerable quantities of organic matter and clays of volcanic origin,the liquid limit may considerably exceed 100.Bentonite, a material consisting of chemically disintegrated volcanic ash,has a liquid limit ranging from 400 to 600.It contains approximately 70% of scale like particles of colloidal size as compared with about 30% for ordinary highly plastic clays.Kaolin and mica powder consist partially or entirely of scale like particles of relatively coarse size in comparison with highly colloidal particles in plastic clays.They therefore possess less plasticity than ordinary clays.Organic clays possess liquid limits greater than 50.The plastic limits of such soils are equally higher.Therefore soils with organic content have low plasticity indices corresponding to comparatively high liquid limits.