Soil Mechanics
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Lecture - 8

We have learnt about measures of gradation and also introduced different Atterberg limits for fine-grained soils. We studied about the measure of gradation, practical significance and applications of GSDs.

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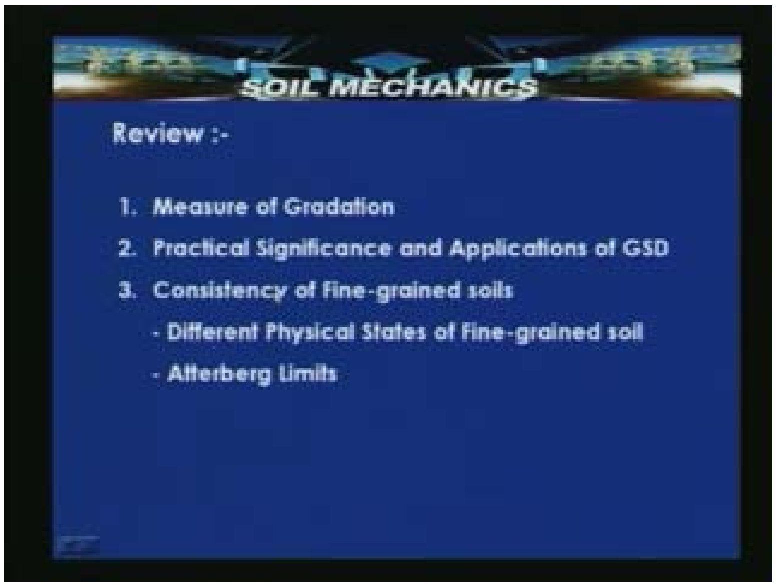

We also discussed about the different physical states of fine-grained soils like solid state, liquid state and plastic state. We have defined different Atterberg limits at the interfaces between different physical states. We have also discussed about the definitions of these Atterberg limits. In this lecture we will be looking into how to determine this Atterberg limits and the shrinkage phenomena involved in the drying of the soil. We will try to look into some classification methods for distinguishing between silt and clay. Slowly this process should lead to classifying both coarse-grained soils and fine-grained soils. This lecture is with title Index Properties and Soil Classification Systems part-3.

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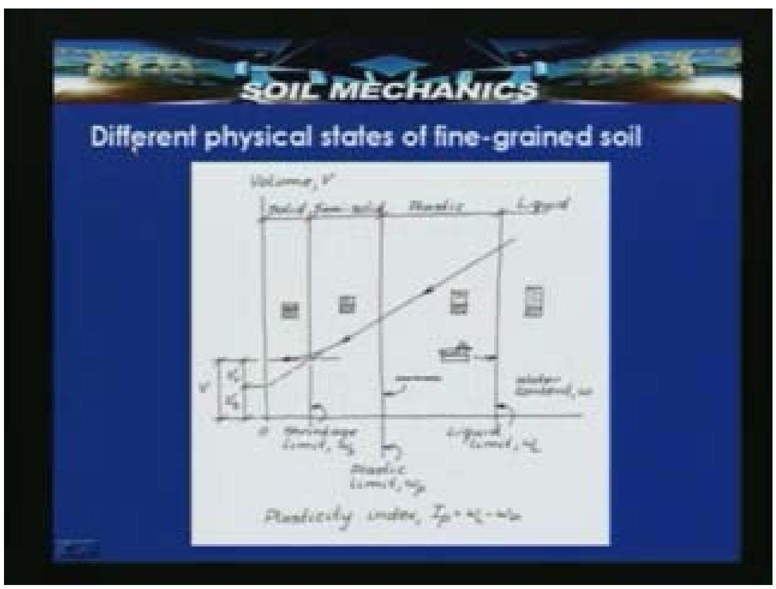

As we have seen different physical states of fine-grained soil, initially when there is high water content and this interface between liquid state and plastic state is called as liquid limit. Interface between plastic state and semisolid state is called as plastic limit. The difference between liquid limit and plastic limit is set as plasticity index. The interface between semisolid and solid state is indicated as a shrinkage limit. And we said, that is the minimum water content at which soil still maintains a complete saturation. After this limit the soil completely changes into a dry state. Gradually in this zone, air starts entering and then complete water in the voids is replaced by air to reach the final volume.

The three limits we defined are liquid limit, plastic limit and shrinkage limit. The difference between the liquid limit and plastic limit is indicated as Plasticity index.

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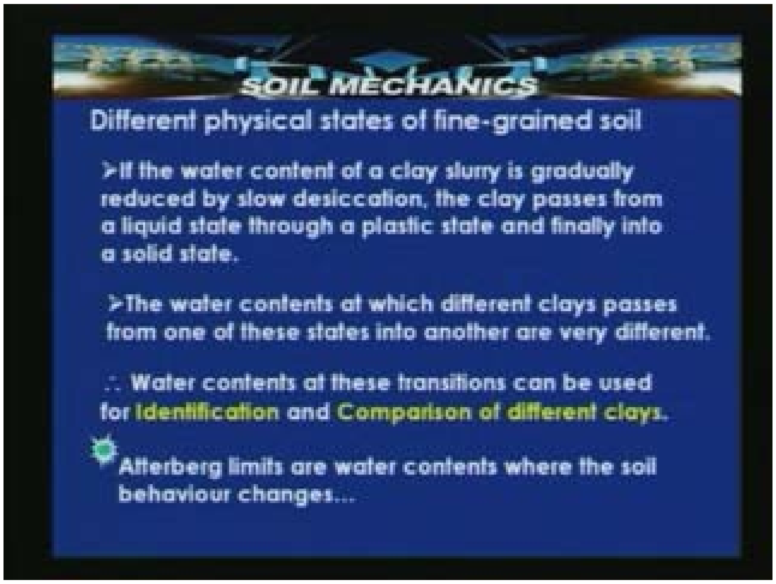

As we have discussed, let us look once again about the different physical states of the fine-grained soils. If the water content of a clay slurry is gradually reduced by slow desiccation that is allowing for drying gradually, the clay passes from a liquid state through a plastic state and finally into a solid state. The water contents at which different clays pass from one of these states into another is very important. These water contents may be unique for particular clay. Water contents at these transitions can be used for identification and comparison of different clays. These water contents like liquid limits, plastic limit are used as a comparison for identifying different types of clays. Atterberg limits are water contents where the soil behavior changes. We can put like as follows: Atterberg limits are water contents, where the soil behavior changes from liquid state to plastic state, and from plastic state to semisolid state, and the semisolid state into a solid state.

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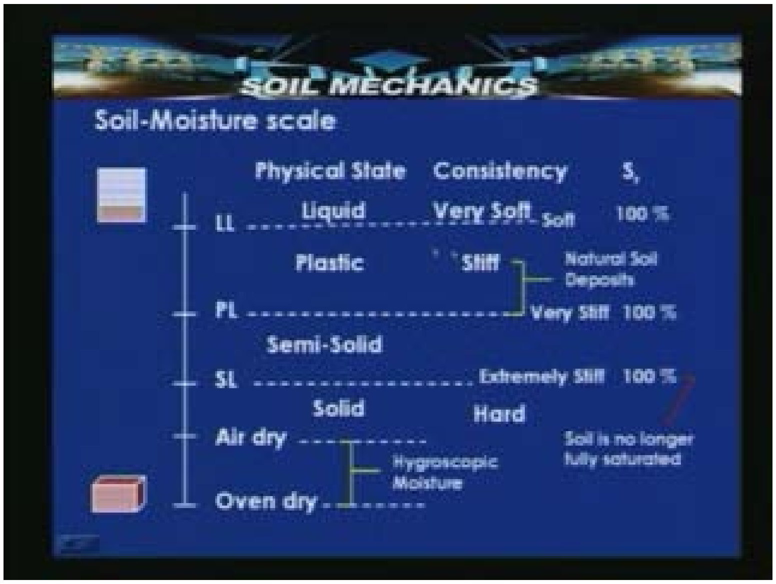

Let us look at this soil moisture scale which is presented in this slide. Here you see, at liquid limit the soil is having most of the voids filled with water. At this liquid limit, the soil is having water as many times the volume of the solids. The state above this limiting line is called liquid limit and the state is called liquid state. At liquid limit, the consistency is said to be very very soft that is at liquid limit the soil is said to have a soft consistency and it is said to have a degree of saturation of about 100 percent. At plastic limit that is interface between plastic to semisolid the soil is said to have very stiff consistency.

In the plastic state most of the soil deposits do exists in the practice. Even at this particular water content that is the plastic limit the soil still maintains 100 percent degree of saturation. From plastic limit to shrinkage limit which is interfaced between semisolid to solid state the air starts replacing the water in the voids and because of the gradual evaporation process the soil tends to become extremely stiff at this particular state. Still, this is the minimum water content in which the soil still maintains 100 percent degree of saturation.

After this, once the soil is allowed to dry then completely the air replaces the water in the voids between the solid grain particles hence this is called air dry where the soil is in a very hard state. From air dry to oven dry, for example if we allow the soil block to dry then whatever hygroscopic moisture content which is there in soil block will actually be lost. Below this shrinkage limit the soil is no longer completely saturated. If soil reaches the shrinkage limit the partial saturation will try to come into picture by losing the complete saturation. Here you see the block which is with more amount of water which has again now become like a solid block where the grains are pushed together to see that the soil grains are placed very close or tightly packed with minimum void ratio. Having seen this and discussed about the shrinking nature of the soil let us try to look at the shrinkage phenomena. We have discussed that at shrinkage limit the soil still maintains 100 percent saturation.

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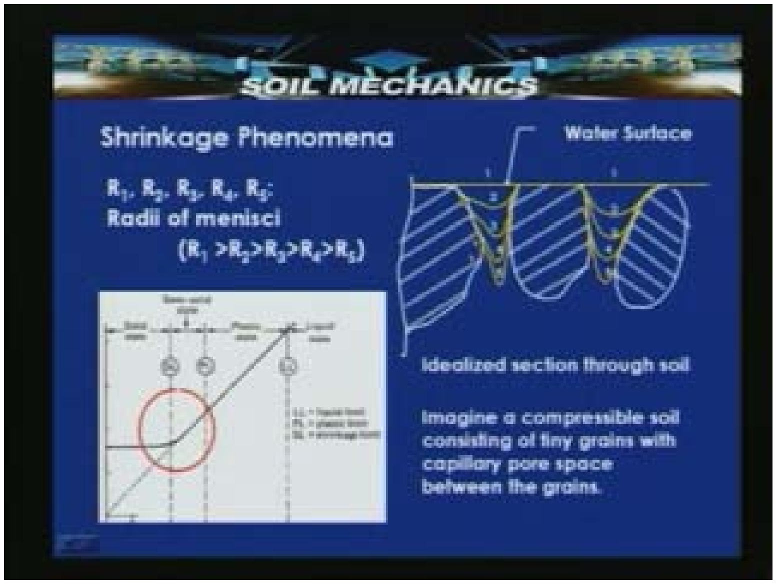

Let us consider the grains which are shown here, an idealized section through the soil, assume that these are the grains and these are the different water surfaces which are shown with different stages 1, 2, 3, 4, 5. When the soil changes from semisolid to solid state in this curvilinear zone the water gradually gets replaced with air. Let us assume that a compressible soil consisting of tiny grains that means grains as small as possible with capillary pore space between the grains.

Let us assume that the menisci radius varies from R_1 to R_5 where R_1, R_2, R_3, R_4, R_5 are the radius of the different meniscus which are forming during the coarse of evaporation. Assume that R_1 is greater than R_2, R_2 is greater than R_3, R_3 is greater than R_4 and R_4 is greater than R_5. With continuous process of drying, the radius of the menisci continuously changes and radius increases. If you look at that gradual process, that water surface which was there at 1 transforms to 2, 3, 4 and 5. Let us try to look into the mechanics behind these particular shrinkage phenomena.

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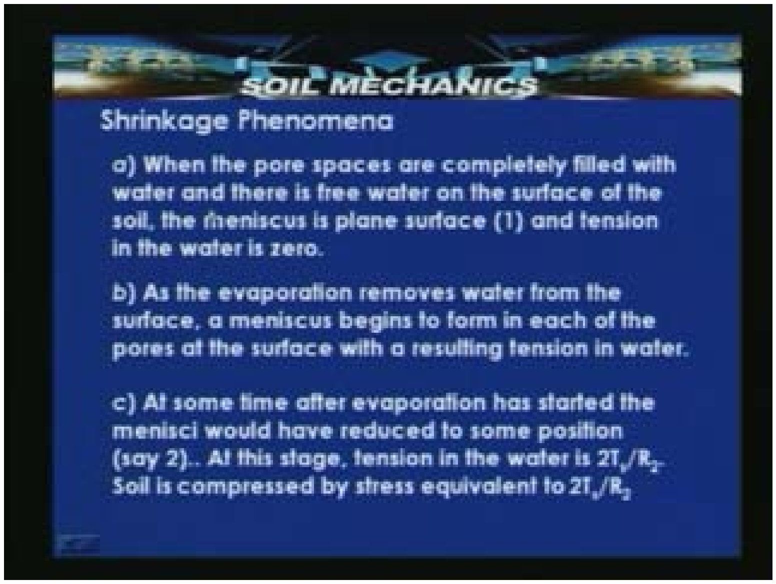

If you look, when the pore spaces are completely filled with water and there is free water in the surface of the soil, the meniscus is plane surface and tension in the water is said to be 0. This is the meniscus surface what we are discussing, that is the tension in the water is 0 and it maintains the free surface. Now, as the evaporation removes water from the surface, a meniscus begins to form in each of the pores at the surface with a resulting tension in the water. So surrounding the grains the meniscus starts forming. At some time after evaporation has started the menisci would have reduced to some position (say 2). That is, we are discussing about at this stage that the menisci has come up to position 2. At this stage, the tension in the water is said to be $2T_s$ by R_2 where T_s is the surface tension of water and R_2 is the radius of meniscus at the particular stage. Soil is compressed by stress equivalent to $2T_s$ by R_2. Let us look at this with a detailed figure that is, between the two grains how this force acts to compress the soil grains.

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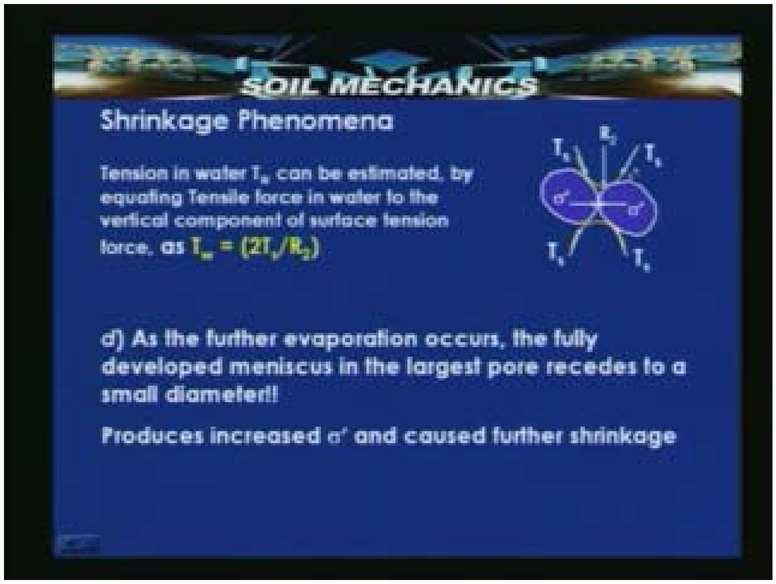

So here consider the same surface tension of water which is acted with a radius of meniscus R_2. Tension in the water T_w can be estimated by equating the tensile force in water to the vertical component of the surface tension force. Let us assume that the water is clean. By assuming water is clean the tension in the water can be calculated as T_w is equal to $2T_s$ by R_2. If you see here, as R_2 radius gets decreases that is it is becoming sharper and sharper then the tension in the water keeps on increasing. As R_2 decreases T_w the tension in the water keeps on decreases. That is what actually happens as the soil starts drying, the water surface or water menisci starts changing from position 1 to 2 and 2 to 3 with decreasing radius. As further evaporation occurs the fully developed meniscus in the largest pore recedes to a small diameter and so it produces increased sigma dash and caused further shrinkage. This stress acting between the grains acts like a compressive stress and it pushes the grains together. So the grains will get compressed up to the maximum extent possible to reach the minimum void ratio. Then soil tries to transform into a very dense packing state.

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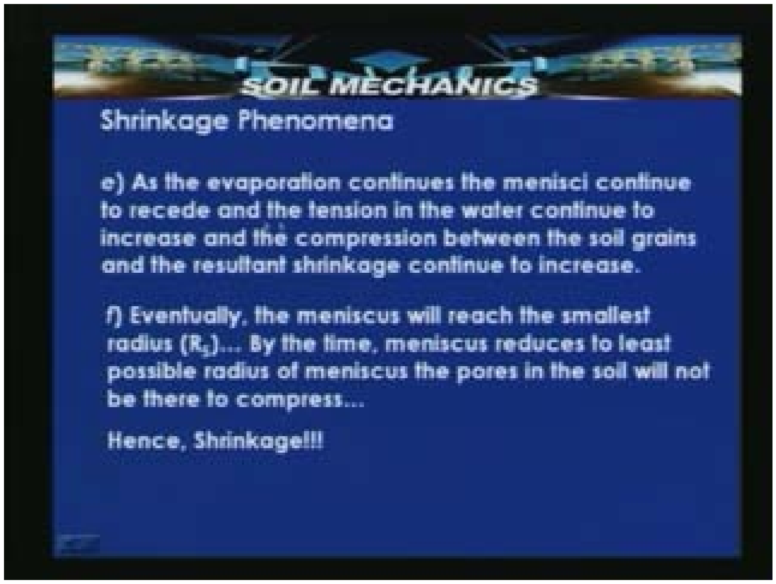

As the evaporation continues the menisci continue to recede and the tension in the water continues to increase. And the compression between the soil grains and the resultant shrinkage continue to increase. Eventually, the meniscus will reach to smallest radius R_S by the time meniscus reduces to least possible radius of meniscus and the pores in the soil will not be there to compress. That means most of the pores in the soil will already get compressed because of the interactive forces at the grain to grain limit, hence the shrinkage phenomenon occurs. What we have seen here is that, as the evaporation process continues the radius of the menisci continues to decrease and when it reaches 5 the inter-granular force is very very high where the grains are pushed closer so the soil undergoes a shrinkage phenomenon. Having seen the shrinkage phenomena, we will go to the determination of these methods once this plasticity index is defined. The plasticity index is nothing but a difference between liquid limit and plastic limit.

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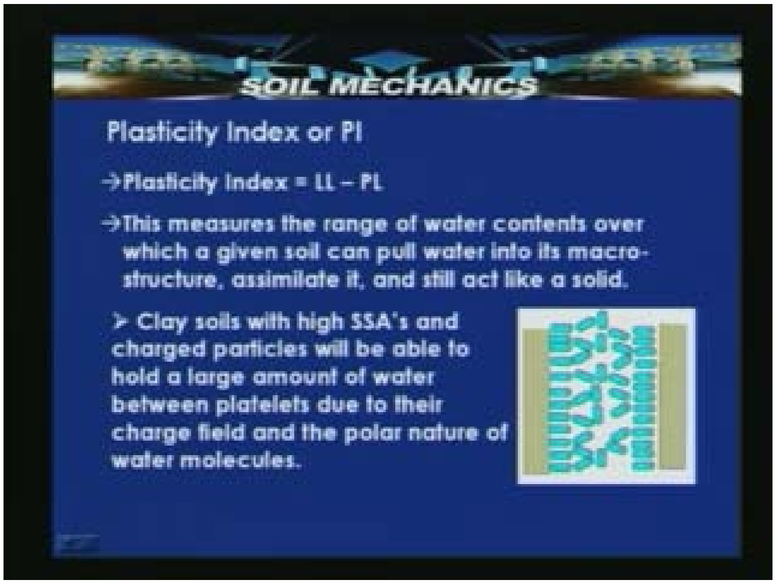

This measures the range of water contents over which a given soil can pull water into its macro-structure, assimilate it and still act like a solid. Clay soils with high specific surface areas and charged particles like this will be able to hold large amount of water between particles due to their charge field and polar nature of water particles. Clay soils with high specific areas tend to exhibit very high plasticity indices. The plasticity index is nothing but the measure of the degree of plasticity.

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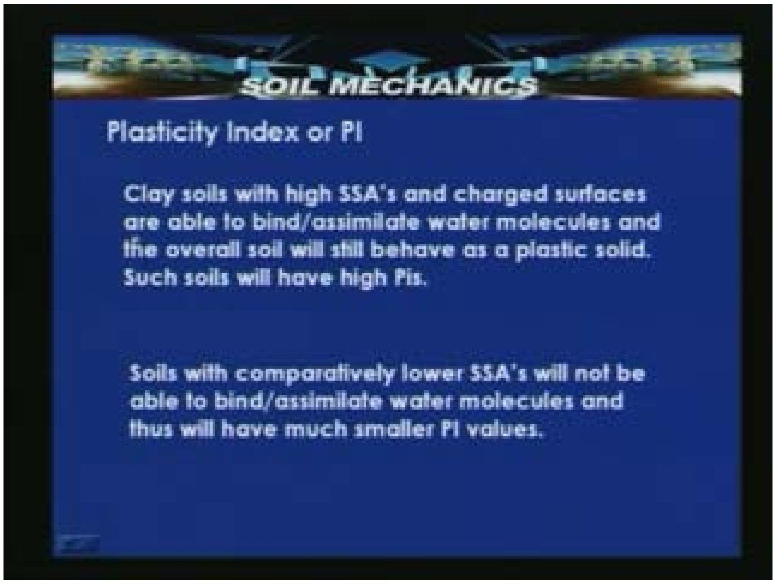

Clay soils with high specific surface area and charged surfaces are able to bind and assimilate water molecules and the overall soil will still behave as a plastic solid. Such soils will have high plasticity indices. Clay soils with high specific surface areas that means finer is the particle, higher is the specific surface area and charged surfaces are able to bind or assimilate water molecules and the overall soil will still behave as a plastic solid. Soils with comparatively lower specific surface areas like sandy grains will not be able to bind or assimilate water molecules and they will have much smaller plasticity values. That means soils like silt or sandy silt will not exhibit higher plasticity because with comparatively lower specific surface area they will not be able to bind or assimilate the water molecules to the grains. So because of this phenomenon they will have smaller plasticity indices values. So while designing an earth and fill for a particular construction for example, for an embankment construction or so then deciding about the plasticity index value is very very important. One classifies the soil based on the plasticity index value. Suppose if the value of the plasticity index value is 0 basically it happens for sandy soils then it is said that it is non-plastic in nature. So, if the plasticity index is 0 then it is said to be non-plastic in nature. If the plasticity value is less than 7 the soil is said to be low plasticity.

For some type of construction like earth and fill materials low plastic soils are recommended because it is easy to compact these particular types of soils. So, if the plasticity index ranges between 7 and 17 they are said to be classified as medium plastic soil and if it is greater than 17 then the soils are said to be very highly plastic soil. If the plasticity index value is more than 17 it indicates a soil with very high plasticity. So having defined about different Atterberg limits at the interfaces of different physical states, now, it is time for us to look for, how to determine these different Atterberg limits like liquid limits, plastic limit and shrinkage limit of the given soil. Let us look the determination methodology for liquid limit.

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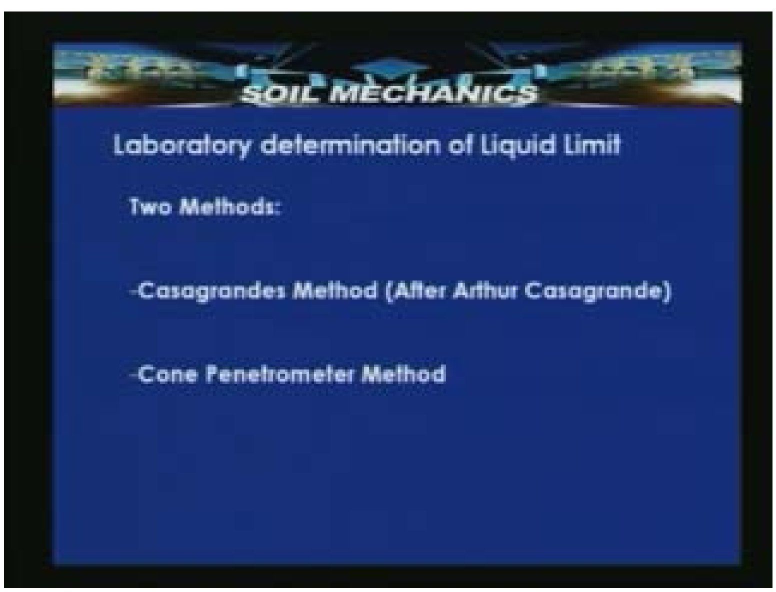

Liquid limit is basically determined in the laboratory by using two widely accepted methods. One is Casagrandes cup method, it is also called Casagrandes method. This is actually postulated after Arthur Casagrande. Other one is the Cone Penetrometer method. Both these methods are widely used. Out of these, Casagrandes liquid limit method is popular.

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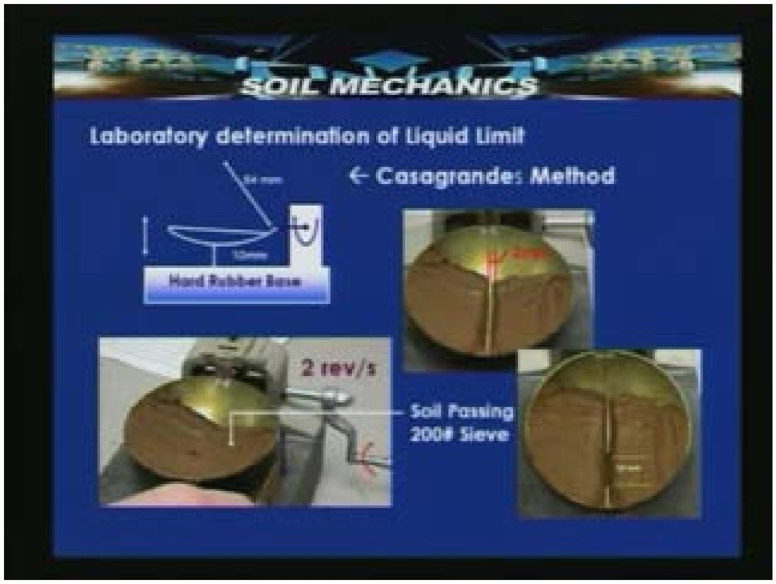

Here in this, the Casagrandes method runs like this. The laboratory determination of the liquid limit by using Casagrandes method is shown. So, here a soil passing through 750 micron and soil passing through 75 micron or 200 number sieve has to be taken in a dry state. It is placed with certain water content in the Casagrandes cup. The Casagrandes cup has got a radius of 54mm. It is attached to a crank mechanism and it is placed on a hard rubber base called Mcarthur rubber base. The soil mass is formed with certain water content.

In this method by using Casagrandes tool or ASTM standard tool, a groove of 2mm is required to be made like this. The groove of the 2mm can be made by using Casagrandes tool which has got a 2mm dent at the bottom of the tool or ASTM tool which has got similar arrangement will also give a 2mm groove in the middle of the sample. Then it is a placed and rotated in this direction as shown here at the rate of 2 revolutions per second gradually.

This particular methodology has been standardized by conducting number of experiments. This is widely accepted standard method where this particular cup is subjected to tamping with a distance of around 10mm to induce movement in the particular soil which is actually separated with this 2mm groove. The number of blows required to close 13mm of this particular portion of the soil is measured along the total length of the group. It is required to be noted that the number of blows which are required to close 13mm length or half inch length of the groove and if you know the corresponding water content we will get a water content at which so many number of blows are required to close 13mm length of the groove. By repeating this particular exercise with increasing water contents one finds variation in water content with number of blows.

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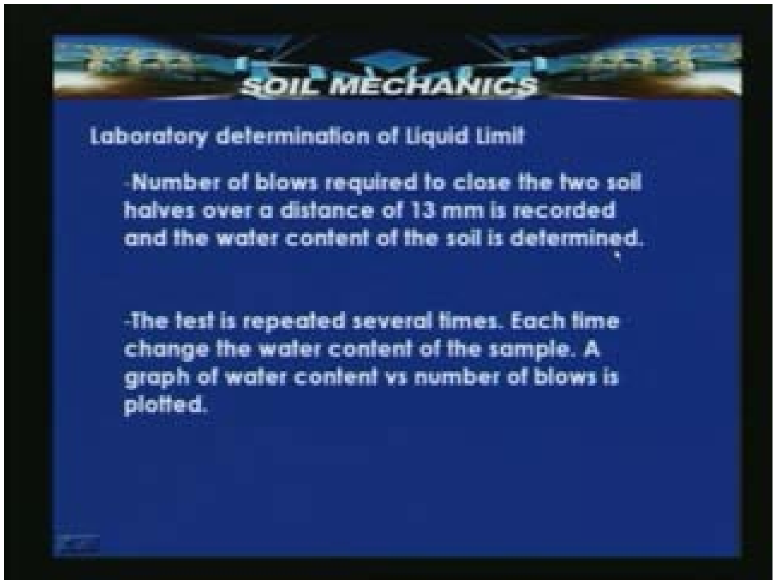

Number of blows required to close the two soil halves over a distance of 13mm is recorded and the water content of the soil is determined. So the test is repeated several times that is what being discussed. The test is required to be repeated at different water contents and the number of blows which are required to close 13mm groove is required to be measured. Each time the change in the water content of the sample is noted the graph of the water content versus the number of blows is plotted.

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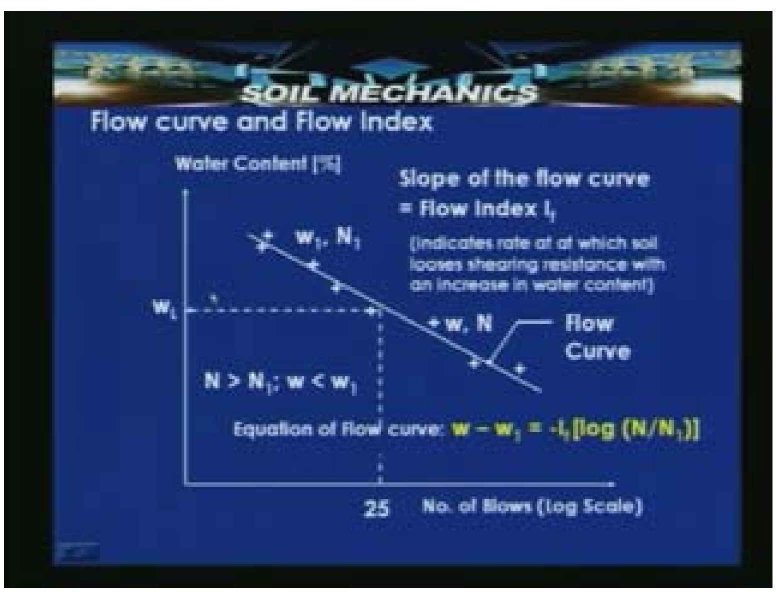

Let us look how the graph looks like? The water content is plotted on the y-axis and the number of blows required is plotted on the x-axis. These are the number of points which we got for the soil which has been tested with number of water contents. So generally soil is tested in dry state with higher water content. The line joining all these points is called the flow curve the line and slope of this flow curve is called flow index which is indicated as I_f. This flow index is nothing but it indicates the rate at which the soil looses shearing resistance with an increase in the water content.

Now, if you plot number of points. Since the number of blows can be 1, 10, 100, 1000 this is actually plotted on the logarithmic scale here. Here, if you consider two points on this axis like W_1 and N_1.where W_1 is the water content at N_1 the number of blows and W is the water content at N number of blows. The equation for the flow curve is written like W minus W_1 is equal to minus I_f log (N by N_1). The slope of this curve is nothing but W minus W_1 is equal to minus I_f log (N by N_1). So, here the water content correspond to 25 number of blows is referred as a liquid limit. This is actually been fixed based on number of correlation on different clays and it has been standardized to determine liquid limit. One tends to do a minimum of three values on the right hand side of this particular 25 number of blows and minimum three values less than 25 number of blows to generate a flow curve for particular soil and determine the flow index and liquid limit of a given soil.

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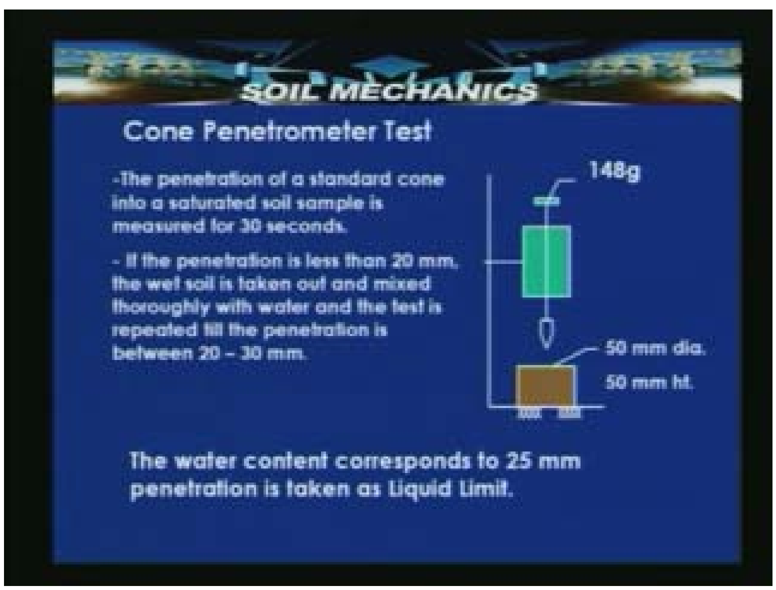

Second method is a Cone Penetrometer method. Before discussing Cone Penetrometer method, one of the demerits which are going to be with liquid limit method is that most of the soils do exists in intact state at a particular level. But what we do in a liquid limit test in Casagrandes cup method is a disturbed condition state where the original disturbed condition or remold state in which the representation of the bonds or soil fabric is not considered or it will not be replicated. So now what we are doing is that, it remains in a certain remold state with a certain soil fabric. The Cone Penetrometer method works out like this. It has got the penetration of a standard cone into the saturated soil sample is measured. The equipment has got a vertically mounted cone and with a standard load of 148g is placed at the cone of this particular size. This particular truncated portion is going to have around 30.5mm length or so.

It is a soil under cushion or a soil which is to be tested is to be placed in 50mm diameter and 50mm height small cylindrical container in which the soil with certain water content is placed. That cone is allowed to penetrate into the soil. So the penetration of the standard cone into a saturated soil sample is measured for 30 seconds. If the penetration is less than 20mm then the wet soil is taken out and mixed thoroughly with water and again the test is repeated till the penetration is between 20 to 30mm. This is required to be carried out. So water content corresponds to 25mm penetration is taken as a liquid limit. So we have discussed about methods to determine the liquid limit. Let us now consider the method to determine plastic limit. This is the second Atterberg limit: The water content at which the soil starts crumbling, when it is rolled into a thread of 3mm diameter basically.

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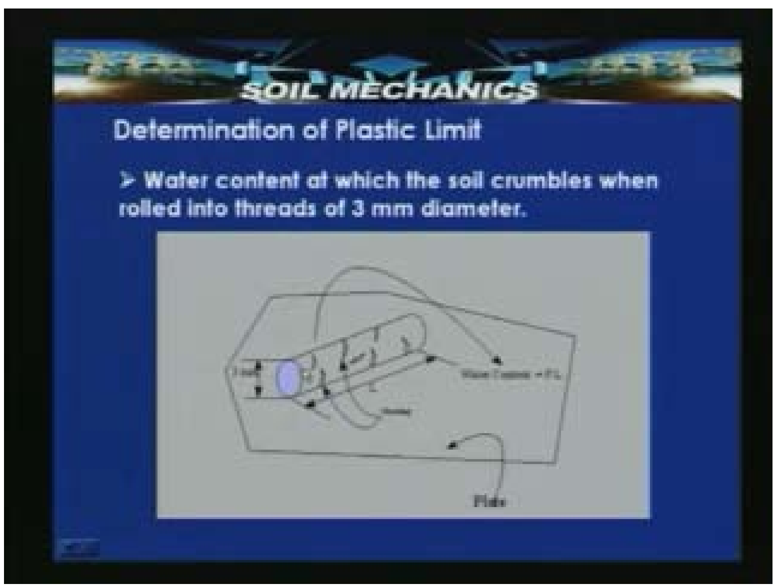

This is the standard method as of today to determine. For determining the plastic limit, the soil is molded like this and made into a small thread of 3mm diameter. When it starts rolling, the water content at which the soil starts crumbling is actually measured as a plastic content. This is required to be done with repeated trails. The average value of the number of the trails has to be taken into record as a plastic limit. This crumbled portion has to be kept in oven-dried for about 105 degree C or so to determine plastic limit. The typical Atterberg limits for sandy soil is said to be in non-plastic. Though a fine sandy soil under certain moist states can exhibit some liquid limit but they are basically with plasticity index 0, where it is called non-plastic. Silt is the particle with low surface area and because of the limited capacity to simulate water to the particles, they exhibit low

Atterberg limits. Basically liquid limit will be in the range of 30 to 40 and plasticity index will be in the range around 10 to 15 and they are actually medium plastic soils.

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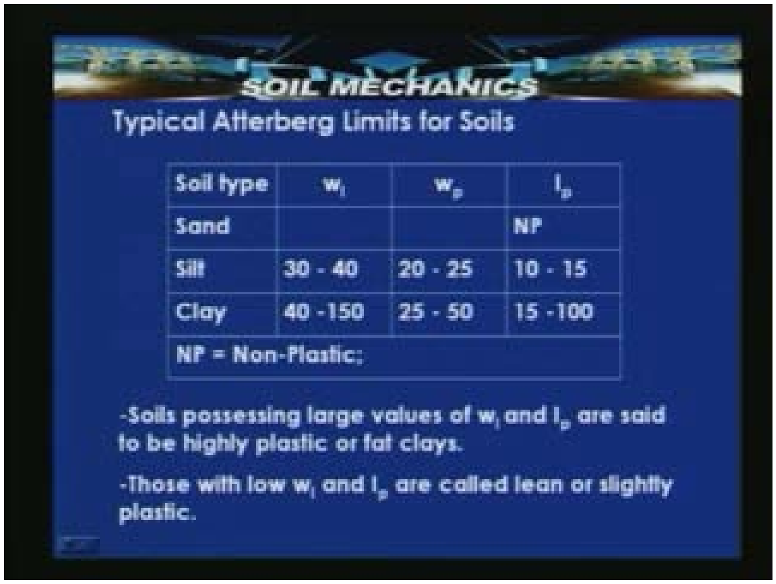

Clays will exhibit from 40 to 150 and plasticity index up to 15 to 100. The clays possessing very high plasticity index values are called fat clays and the clays possessing low plasticity index values are called lean clays. A fat clay and lean clay is actually the terminology which is used generally in the practice. Soils possessing large values of liquid limit and plasticity index are said to be highly plastic or fat clays. Those with low liquid limit and plasticity index are called lean or slightly plastic soils. Depending upon the type of the mineral and adsorbed cations the soil can have various liquid limits.

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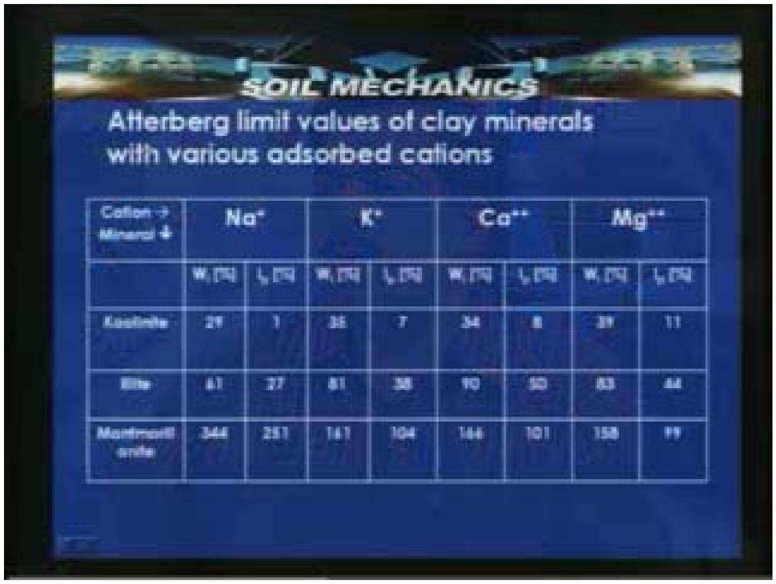

Cation → Mineral ↓	Na^+		K^+		Ca^{++}		Mg^{++}	
	W_L (%)	I_P (%)	W_L (%)	I_P (%)	W_L (%)	I_P (%)	W_L (%)	I_P (%)
Kaolinite	29	1	35	7	34	8	39	11
Illite	61	27	81	38	90	50	83	44
Montmorillonite	344	251	161	104	166	101	158	99

That is what it is being shown here in this particular table. Atterberg limit values of clay minerals with various adsorbed cations. If you see here, different adsorbed cations Na to the power plus, K power plus, Calcium power plus plus and Mg power plus plus is shown and because of higher replacing power the thinning of the adsorbed layer occurs. And because of that the liquid limit and plastic limit decreases.

For example, sodium based Montmorillonite clay can have a liquid limit of 344 percent and plasticity index of around 251 percent. The calcium based Montmorillonite can have a liquid limit about 166 and plasticity index of about 100. Sodium based Kaolinite is said to have a very low liquid limit. With magnesium or calcium, it will have a liquid limit in the range of 34 to 39 percent. Illite is falling in between kaolinite and Montmorillonite. Here in this particular table Atterberg limit values of clay minerals with various adsorbed cations are shown. As we can seen here, with Na to the power plus, K power plus, Calcium power plus plus and Mg power plus plus there is a gradual decrease in the liquid limit and the plasticity index values.

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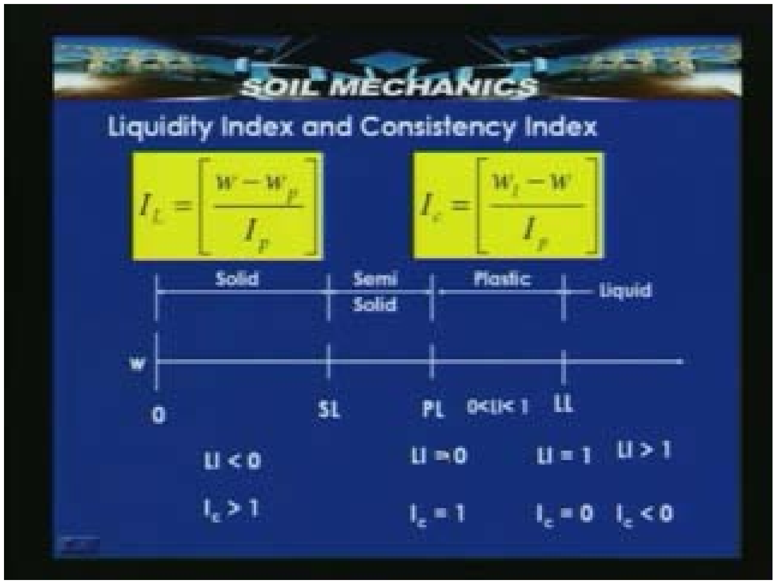

So, once we have determined liquid limit, plastic limit and plasticity index basically. Now we are interested in accessing the soils consistency. These are basically carried out by using two indices called liquidity index and consistency index. Liquidity index is defined like this (W minus W_p) by I_p, where W is nothing but the water content in its natural state, W_p is the plastic limit of a given soil and I_p is the plasticity index. I_c the consistency index is nothing but difference of liquid limit and water content in natural state to plasticity index.

If you consider here in this line, this is the solid state that is between shrinkage limit to 0 water content, semisolid state that is from plastic limit to shrinkage limit and plastic state between liquid limit to plastic limit. Above this is a liquid state. In the solid state, the liquidity index value is said to be less than 0, contrary to this in the solid state the consistency index will be greater than 1 because I_c is equal to (W_L minus W) by I_p. Because of this I_c is greater than 1. In each and every state if you compare I_c plus I_L is said to be equivalent to unity. So at plastic limit, liquidity index value is 0 because the water content at plastic state W is equal to W_p and consistency index is equal to 1. That is at this particular point the difference W_1 minus W_p is nothing but a plasticity index which is actually called I_c. I_c is equal to 1 at plastic limit.

Liquidity index is equal to 1 at liquid limit and at liquid limit consistency index value is 0. At liquid limit, liquidity index is equal to 1. Above liquid limit that is in the liquid state the liquidity index value is greater than 1 and I_c is less than 0. The I_c that is consistency index value is less than 0 indicates that the soil is in very very soft state. In a liquid state, if liquidity index value greater than 1 then the soil state is again said to be in the very very soft state. So the two indices we explained is basically to define the consistency of the soil. One is the consistency index which is nothing but (W_L minus W) by I_p, where W_L is nothing but the liquid limit minus water content in natural state to plasticity index of a given soil. Similarly liquidity index IL or LI is indicated like (W minus W_p) by I_p, where W is the water content in natural state to W_p is the plastic limit and I_p is the plasticity index. Basically we have a standard soil classification methodology based on the soil consistency particularly with different ranges of liquidity index values and consistency index values.

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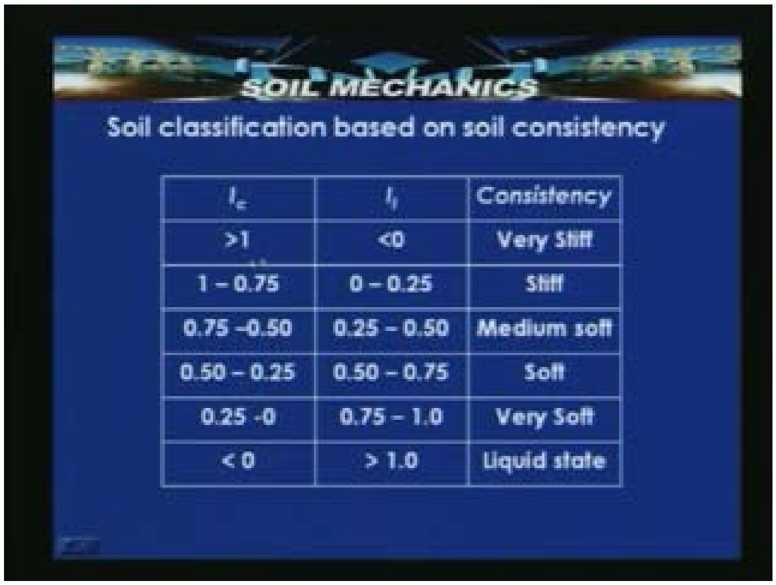

I_c	I_l	Consistency
>1	<0	Very Stiff
1 – 0.75	0 – 0.25	Stiff
0.75 –0.50	0.25 – 0.50	Medium soft
0.50 – 0.25	0.50 – 0.75	Soft
0.25 -0	0.75 – 1.0	Very Soft
< 0	> 1.0	Liquid state

As we discussed, if I_c greater than 1 or I_l less than 0, the soil is said to be in a very stiff state. When I_c is in between 1 to 0.75 and 0 to 0.25, the soil is said to be in stiff and in between 0.75 to 0.5 or 0.25 to 0.5, it is said to be in the medium soft. Similarly, when the I_c value is less than 0 and I_l value is greater than 1, the soil is said to be in the liquid state consistency. This is the standard soil classification based on the soil consistency where the soil is said to be very stiff. If I_c is greater than 1 that means that most of the voids in the water is removed and if the value of I_l is less than 0, then it is called a very stiff consistency.

Here, if I_c is greater than 1 then it is said to be in the liquid state. So two extremities are defined with these two indices that is liquidity index and consistency index. Another index is called toughness index. The toughness index I_t indicates the rate of loss of shear strength upon increase in water content. Suppose, for a given soil if the water content gradually increase then this toughness indicates the rate of loss of Shear strength upon increase in the water content. So with the assumption that the flow line is a straight line between liquid limit and plastic limit the shearing resistance is proportional to number of blows. The flow line is assumed to be linear between liquid limit and plastic limit, and shearing resistance is proportional to number of blows. At liquid limit, number of blows required N_l is equal to $KS_{l,}$ where S_l is the shear strength of a soil at the liquid limit. So N_l is equal to $KS_{l.}$ where K is a constant and similarly for the same soil in same slopes, then N_p is equal to KS_p that is number of blows at plastic limit is equal to K times shearing resistance at S_p.

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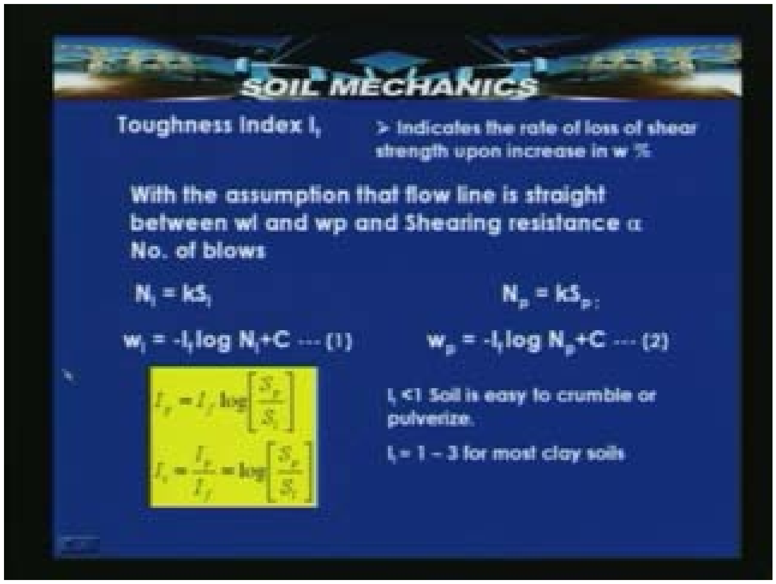

From this, if you substitute this in the equation of the flow curve where W_1 is equal to minus I_f log N_1 plus C then substituting for N_l, KS_l and substituting N_p, KS_p we get by subtracting W_l minus W_p converting and writing as I_p is equal to I_f into log S_p by S_l. This is nothing but I_p by I_f is equal to log (S_p by S_l). This ratio of plasticity index to the flow index I_f is nothing but the slope of the flow curve called I_t is equal to I_p by I_f.

Generally for most of the clay soils I_t value varies from 1 to 3 and I_t is less than 1 then soil is said to be easy to pulverize. Basically this happens with silt soils and clay soils. Silt soil is easy to pulverize and break where the clay soil is very very difficult to break because the toughness index value will be greater than 1. So having seen different methods for determining liquid limit and plastic limit, once we know the liquid limit and plastic limit we will be able to estimate the plasticity index, then show that we will be able to assess the soils plasticity. When the soil is transforming from semisolid to solid state one more interface limiting water content arises which is termed as shrinkage limit and the methodology which is required to determine the shrinkage limit is like this.

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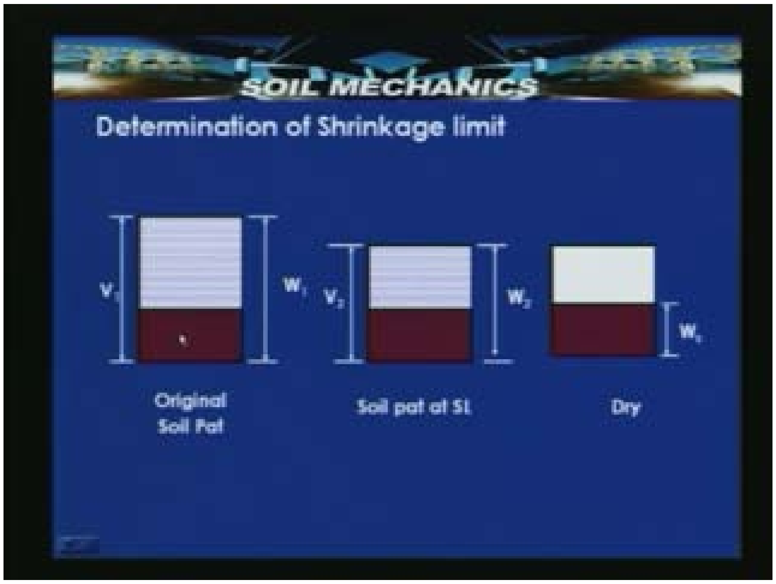

For example, if you consider a original soil pack with solids and very high water content, here when this particular soils pat is allowed to dry, the water which is evaporated is nothing but V_1 minus V_2. This V_1 minus V_2 is the amount of water which is evaporated and then transforms into a dry state once it allowed to dry. This is the soil pat at shrinkage limit and this is the soil pat at the dry state. Let us look at the methodologies for arriving at shrinkage limit. Once if you know the specific gravity of the soil or if you do not know the specific gravity of the soil then what is the methodology is available for determining the shrinkage limit? There are two approaches; one is by knowing the specific gravity or without knowing the specific gravity.

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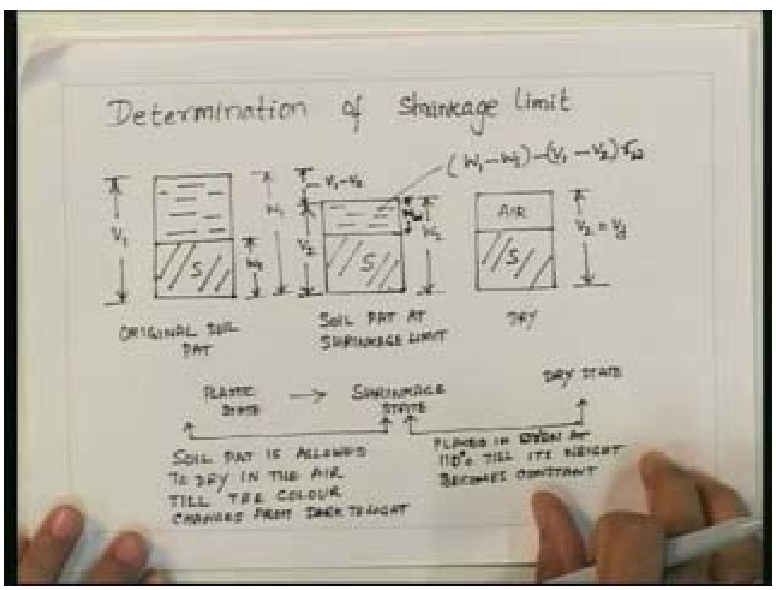

Consider a soil sample which has been shown here with original soil pat and with volume of water. All the voids in the soils are filled with water so it is a 2-phase system. W_s is the weight of the solids,W_1 is the initial weight of the soil pat and $V_1$is the initial volume of the soil. Once it is allowed to drying soil pat at shrinkage limit is V_2 the volume and W_s is the solids again. The weight of the water is remaining at the shrinkage limit and W_2 is wet weight of the soil pat at shrinkage limit. So V_1 minus V_2 is the volume of the water which is lost during the process of evaporation. Now, weight of water is nothing but the difference of W_1 and W_s that is weight of soil mass minus weight of water minus volume of water, W_1 minusW_s is nothing but the water which has been evaporated. That is (V_1 minusV_2) into gamma w, this much weight of water has been evaporated. Once the soil pat is allowed to dry because of the phenomena we have discussed there will not be any volume change. So $V_2$is equal to V_d . Here, from this process to this process the air gradually replaces the water. That is, water gets gradually replaced by air so it is transformed into a dry state. Here what we see is a plastic state, initially we took a plastic state and once you allow it to dry it is transformed to a shrinkage state that is at the shrinkage limit and from there into dry state. Here the soil pat is allowed to dry in the air till the color changes from the dark color to light color and placed in the oven at 110°C till its weight becomes constant. Basically we take glass containers in which the inner surface of the glass containers is required to be lubricated to prevent any cracking of the soil pats upon rain and allowed for drying gradually in the laboratory. So with these assumptions let us try to determine shrinkage limit. Two approaches are there.

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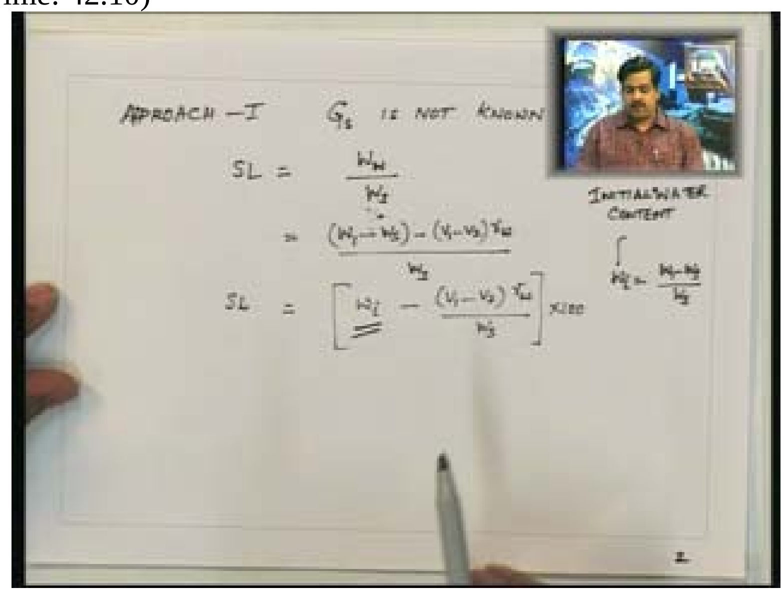

The first approach is that the specific gravity of the soil solids is not known. In that case shrinkage limit is nothing but a water content which is the weight of water to weight of solids. So weight of the water is nothing but (W_1 minus W_s minusV_1 minusV_2) into gamma w. That is what we have been discussed (W_1 minus W_s minus V_1 minus V_2) into gamma w is actually the volume lost equal amount of water which has been lost because of the evaporation. By rewriting this particular expression, we can write shrinkage limit as is equal to W_i that is initial water content is (W_1 minus W_s) by (W_s minus V_1 minus V_2) by gamma into (gamma w by W_s). So shrinkage limit is equal to [W_i minus (V_1

minus V_2) into (gamma w) by W_s] into 100. So this is actually a process where in you are required to know the initial water content. V_2 is the volume at the end of the shrinkage limit or in the oven state. So this V_2 is required to be determined by a mercury displacement method. We have a standard method in the laboratory where we immerse the dry soil pat in the mercury. The volume of mercury being placed is calculated and the weight of the mercury which has been replaced by mercury by the specific gravity that is going to give the volume of the soil pat.

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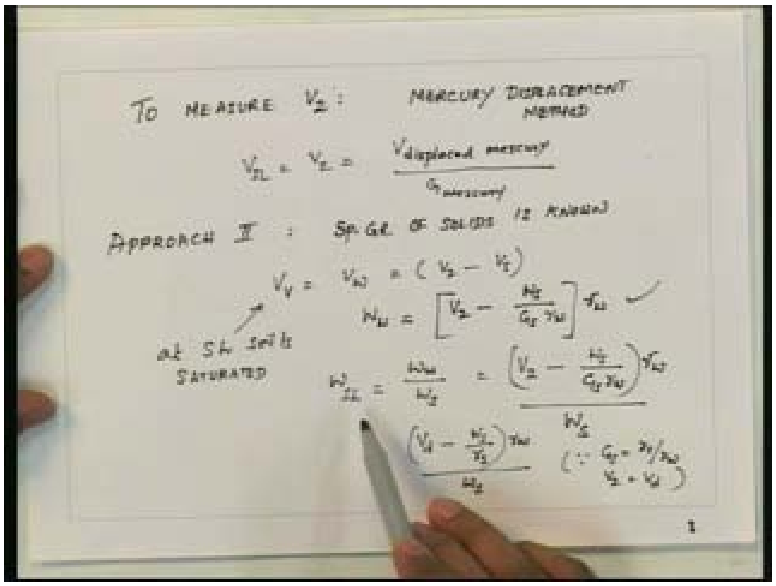

In this approach, to measure the volume of the soil pat at the end of the drying is said that there is a mercury displacement method. At the shrinkage limit or at the dry state V_2 is equal to volume of the displaced mercury by $G_{mercury}$ which is nothing but 13.6. With that we will be able to get V_2. Once we know the V_2 that is once you know initial volume of the soil pat without even knowing the specific gravity of the solids we will be able to estimate shrinkage limit of a given soil. Another approach is that, the specific gravity of the solids is known to us. Then let us assume that volume of voids is equal to volume of water is equal to V_2 minus V_s. At the shrinkage limit as the soil is still completely saturated. So all the voids are filled with water, volume of voids is equal to V_2 minus V_s. So we can write weight of water as V_2 minus W_s by ($G_s$gamma w). That is W_s is equal to G_s V_s gamma w. From there by writing V_s is equal to W_s by ($G_s$gamma w). We can write this particular expression. By seeing this, W_{sL} is equal to weight of water to weight of solids. So weight of water is estimated like as [V_2 minus W_s by ($G_s$gamma w)] into gamma w. by W_s gives us the shrinkage limit. By rearranging and simplifying we can write V_2 as V_d and G_s as gamma s by gamma w. [(V_d minus W_s by gamma w) into gamma w] by W_s is shrinkage limit where here G_s is equal to gamma s by gamma w which has been replaced.

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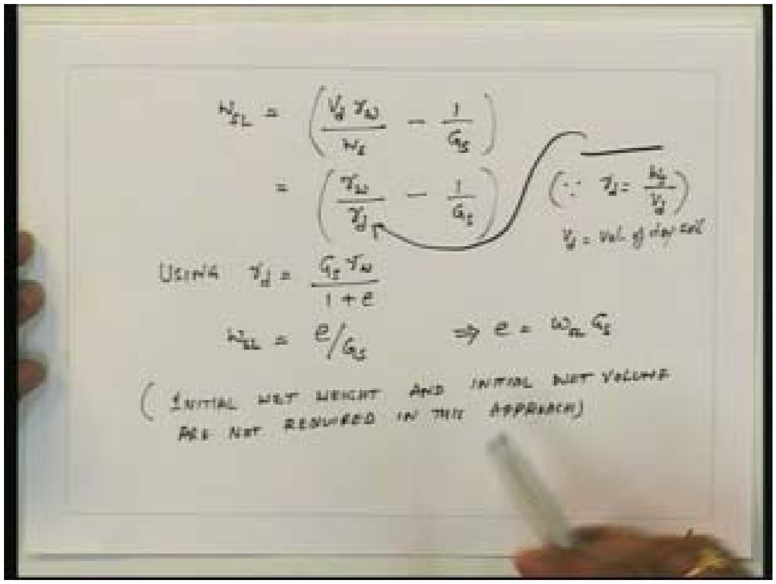

Simplifying further we get shrinkage limit W_{sL} is equal to (V_d gamma w by W_s) minus 1 by G_s. So now writing this gamma d is equal to W_s by V_d. That is W_s by V_d is substituted here as gamma d that is gamma w by gamma d minus 1 by G_s For a dry soil gamma d is equal to ($G_s$gamma w) by (1 plus e). So using soil gamma d is equal to ($G_s$gamma w) by (1 plus e) and simplifying this particular expression will get shrinkage limit is equal to e by G_s.e is the void ratio at the shrinkage limit that is the minimum void ratio for a given soil. So e is equal to W_{sL} G_s. So initial wet weight and initial wet volume is not required in this approach. If you know the specific gravity of the solids, sometimes it is also required;, the specific gravity of the solids can be determined by knowing the other values. So in this approach we have seen the two methods. One method is determined by not knowing the specific gravity and another one is by knowing specific gravity. Now let us define shrinkage ratio.

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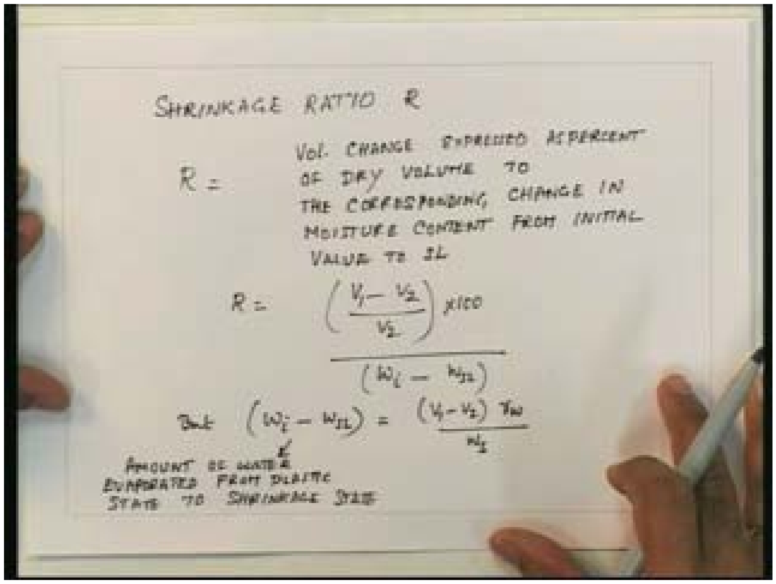

Shrinkage ratio is nothing but is a ratio of volume change expressed as percentage of a dry volume to the corresponding change in the moisture content from initial value to shrinkage limit. So shrinkage ratio is indicated by r. So r is equal to [(V_1 minus V_2) into 100 by (W_i minus W_{sL}). But W_i minus W_{sL}) can be written as ((V_1 minus V_2) into (gamma w)) by W_s] The W_i minus W_{sL} is nothing but amount of water evaporated from the plastic state to shrinkage state.

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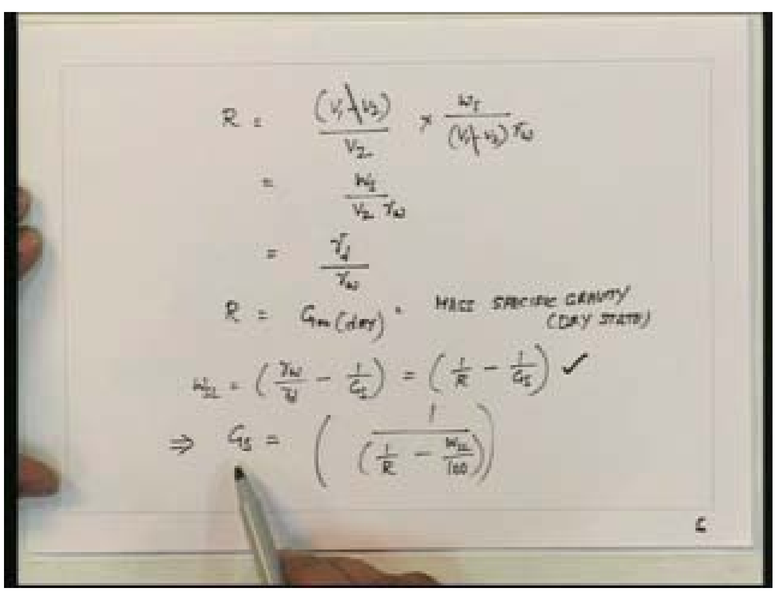

So simplifying further we can write shrinkage ratio as r is equal to [(V_1 minus V_2) by V_2] into [W_s by (V_1 minus V_2)gamma w]. Simplifying further by canceling V_1 minus V_2, we get W_s by (V_2 gamma w). This can be again simplifies like by writing W_s by V_2 that is nothing but dry unit weight of soil mass W_s by V_d. The volume of the soil mass with solids and air gamma d by gamma w which is nothing but R_w is equal to G_{mdry} that is nothing but mass specific gravity of a given soil mass in dry state. So the shrinkage ratio is equal to mass specific gravity of the given soil in dry state. So substituting in the previous expression what we have derived W_{sL} is equal to (gamma w by gamma d) minus 1 by G_s is equal to (1 by R) minus (1 by G_s) so this is the expression what we derived. So G_s can be determined by back calculating from the shrinkage ratio and shrinkage limit. So by knowing the shrinkage limit and shrinkage ratio we will be able to cross check the specific gravity of the solids. This is actually the procedure for determining the shrinkage limit. So having seen, there is one more very important parameter called activity number.

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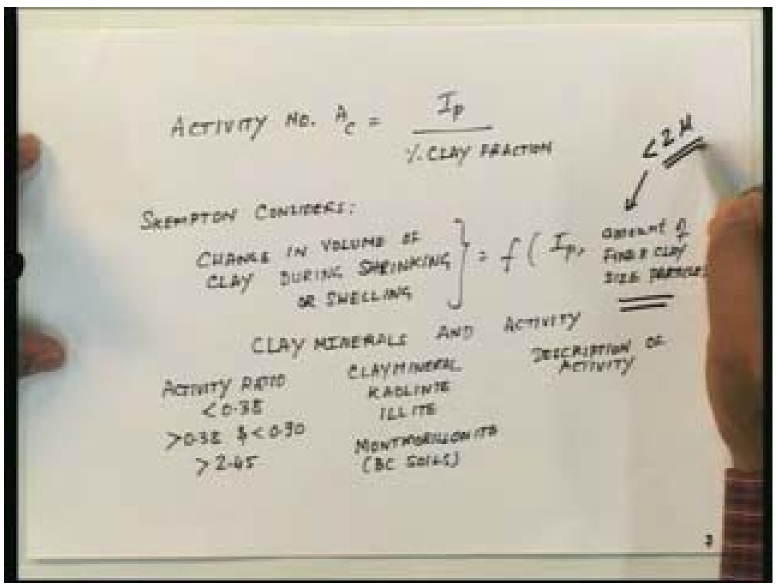

Activity number is nothing but the ratio of plasticity index to percentage clay fraction. So activity number is basically is used to define the swelling potential of the clays basically for fine-grained soils. The skemton considers the change in the volume of the clay during shrinking or swelling which is a function of plasticity index and amount of the finer clay size particles. That is amount of clay particle size is finer than that is less than 2 micron size. That is, the amount of the finer particles is finer than 2 micron size. If you see the clay minerals and activity ratio, activity ratio is less than 0.38 for kaolinite and in between greater than 0.38 and 0.9 for illite and greater than 2.45 for montmorillonite or BC soils that is block cotton soils. Montmorillonite soils are liable to have very high activity ratio.

Once the activity number is determined we will be able to estimate the swelling potential of the particular clays whether the clay is used to identifying this particular soil is having the swelling nature or not, this activity number can be assertine. Actually this is basically obtained by the percentage clay fraction finer than 2 micron and by knowing the plasticity index. The activity number which is defined as ratio of plasticity index to percentage clay fraction which is finer than 2 microns.

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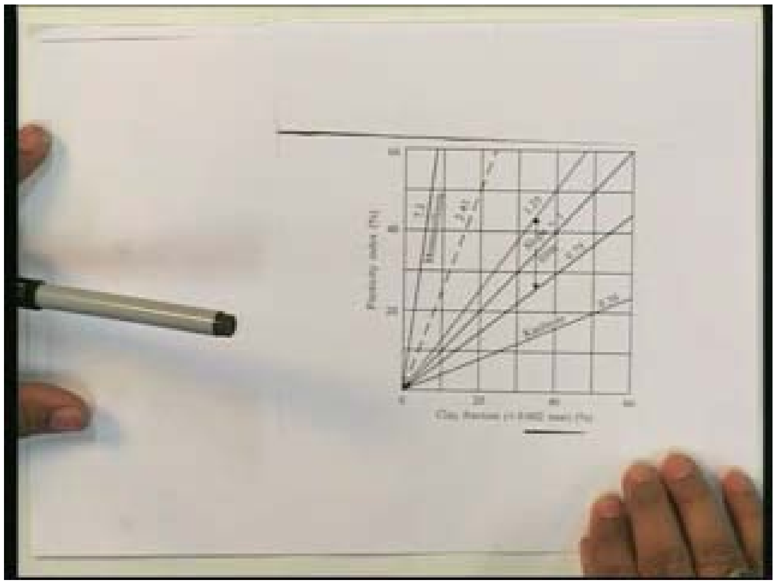

This particular graph is shown here. The clay fraction is less than 0.002mm expressed in percentage which is shown here on the x axis. Plasticity index graph is shown on the y axis. So here, if you see the kaolinite is exhibiting the value of 0.38 and illite has the value in between 0.38 and 0.9. So this is actually the illite line. Somewhere here the montmorillonite is actually having very high activity number which is 7.2. That is what we have discussed that montmorillonite clays are known for swelling or a shrinkage or swelling in nature. There are different slopes which are dictated if the soil falls in this range then they are said to be inactive and if it is in between 0.75 to 1.25, if there are more than 1.25 and that the soil is above 2.45 then it is actually said to be very active.

Very active in the sense, the particular soil is prone for higher degree of swelling. So we have seen different methods about determination of the liquid limit, plastic limit and shrinkage limit. Now we have also studied about different methods which are available for determining the size of the soils. Now it is time for us to classify the soil basically by knowing different particle size distribution of coarse-grained soils as well as some information about on the physical states of the fine-grained soils. With that we will be able to classify these soils. So basically this classification methodology is to group the particular soils which are having identical properties. So that for an engineer, once this particular group is known, it is easy to identify and get first hand information about the soil behavior.