Soil Mechanics
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Lecture - 7

We have studied about index properties particularly soil grain properties and their Grain Size Distribution. In the Grain Size Distribution we have introduced two methods; one is coarse-grained soils based on the sieve analysis and other one is for fine-grained soils where we have introduced a method called hydrometer analysis. In this class we try to learn about the measures of gradation and we will try to classify the soil based on the gradation. If this procedure is not adequate for classifying the fine-grained soils then we will introduce a method for classifying the fine-grained soils based on its consistency.

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This lecture is with title Index Properties and Soil Classification part 2.

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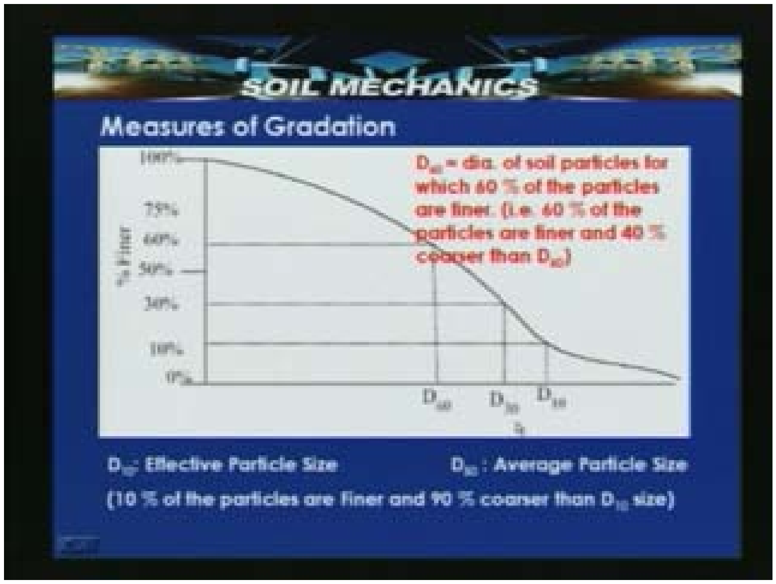

The measures of gradation as we discussed in the previous class, the percentage finer is plotted on the y axis and particle size is plotted on the x axis on the logarithmic scale. Basically different sizes are used for analyzing the Grain Size Distribution curve. This is a typical Grain Size Distribution curve shown here and different particle sizes are represented here D_{10}, D_{30}, and D_{60}. D_{50} is known as the average particle size and D_{10} is termed as the effective particle size it means that 10 percent of the particles are finer and 90 percent of the particles are coarser than that particular particle size D_{10}. Similarly, D_{60} means diameter of the soil particles for which 60 percent of the particles are finer and 40 percent of the particles are coarser than D_{60}. So, typically we use D_{10}, D_{60} and D_{30} in arriving at measures of gradation.

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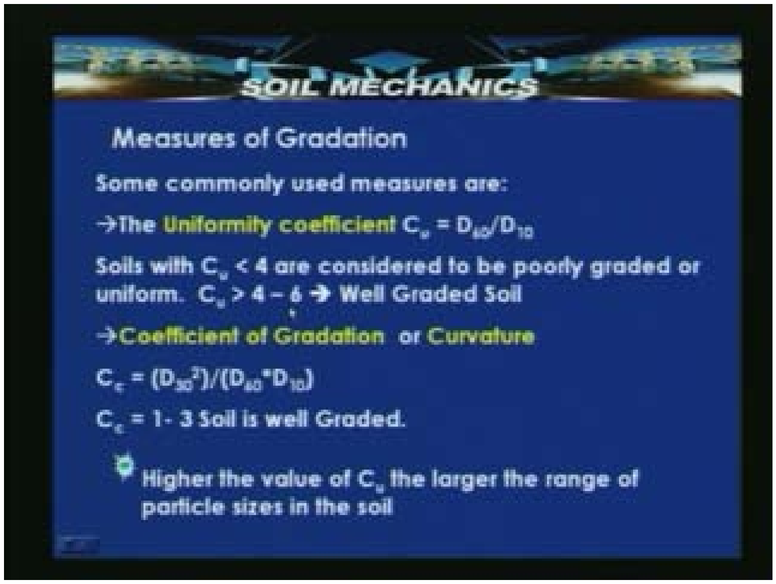

Some commonly used measures are the uniformity coefficient. The uniformity coefficient C_u is defined as the ratio of D_{60} by $D_{10.}$ So when C_u is greater than 4 to 6, it is understood as a well graded soil and when the C_u is less than 4, they are considered to be poorly graded or uniformly graded. Uniformly graded in the sense, the soils have got identical size of the particles. For example for desert sands C_u will be approximately is equal to 1. Another coefficient to measure gradation is: C_c is equal to (D_{30} square) by (D_{60} into D_{10}) where coefficient of gradation or coefficient of curvature is (D_{30} square) by (D_{60} into D_{10}). For the soil to be well graded the value of coefficient of uniformity C_u has to be greater than 4 and C_c should be in the range of 1 to 3. So higher the value of Cu the larger the range of the particle sizes in the soil. So if the C_u value is high it indicates that the soil mass consists of different ranges of particle sizes.

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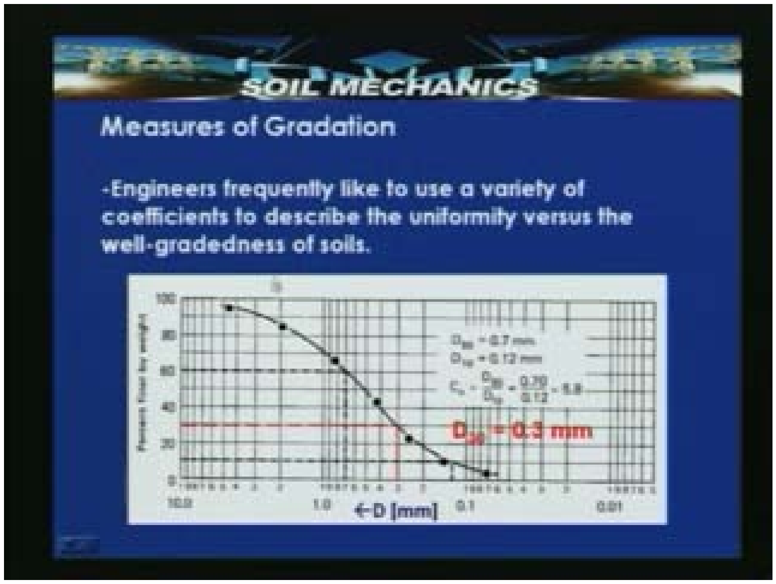

Engineers frequently like to use a variety of coefficients to describe the uniformity versus well-gradedness of the soils. Let us consider a Grain Size Distribution curve which is shown in this slide. Percentage finer by weight on y axis and particle size D represented on the logarithmic scale on x axis. This is a typical curve shown here. These different points are obtained by performing sieve analysis.

Here as we said D_{60}, D_{10}, and D_{30} can be worked out like this. For example D_{60} is read from the curve as 0.7mm. Similarly D_{10} is read from this curve as 0.12mm and D_{60} is equal to 0.7mm. From here we can find out that D_{30} as around 0.3mm. If you find out coefficient of uniformity here that is the ratio of (D_{60} by D_{10}) works out to be 5.8 and coefficient of curvature (D_{30} square) by (D_{60} into D_{10}) gives around 1.07. So this particular Grain Size Distribution curve represents a well graded soil. In that case, it represents the particles with different ranges. Particularly the Grain Size Distribution curves are typically plotted on the semi logarithmic scale by keeping in view the different ranges of the soil particles. The soil particle size can range from 20mm down to less than 0.002mm.

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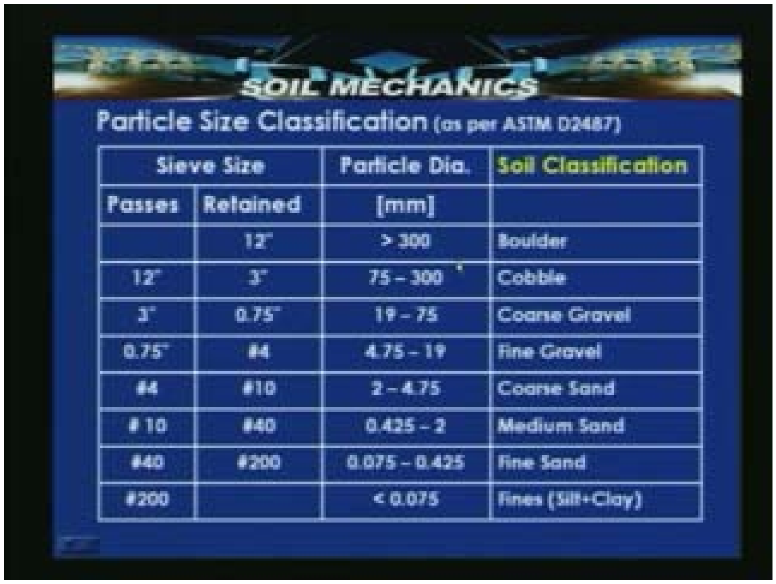

Sieve Size		Particle Dia.	Soil Classification
Passes	Retained	[mm]	
	12"	> 300	Boulder
12"	3"	75 – 300	Cobble
3"	0.75"	19 – 75	Coarse Gravel
0.75"	#4	4.75 – 19	Fine Gravel
#4	#10	2 – 4.75	Coarse Sand
# 10	#40	0.425 – 2	Medium Sand
#40	#200	0.075 – 0.425	Fine Sand
#200		< 0.075	Fines (Silt+Clay)

Let us look at the particle size classification. Based on the grain size, once we get the different gradation of different particles then we will be able to classify the soil based on their particle size. This is the table which shows the particle size classification as per ASTM D2487. This is the code in ASTM which talks about the particle size classification. So here in this column a sieve size is given and particle diameter and the soil classification are also shown in this table.

Different types of the sieves are indicated, for example here it is retained in the 12 inch sieve that means the particle diameter is greater than 300mm it represents boulder which passes 12 inch sieve and retained in 3 inch sieve which indicates the particle diameter ranges from 75 to 300mm which represents cobble. The sieve size which passes 3 inch and retained in 0.75 inch represents that particle diameter ranges from 19 to 75mm which is a Coarse Gravel type.

Similarly, when you come down you can see it which is passing through number 40 sieve and retained in 200 sieves that means that the particle size ranges from 0.075mm to 0.42mm which represents the fine sand. Below this, passing to number 200 sieves which means less than 0.075mm particle size represents the fines that is silt and clay fraction. If you look into this here, the sizes from 19 down to fine sand, they are treated as coarse-grained soils. These soils which are fines are treated as the fine-grained soil that means that from soil particle size at the size ranging from 0.075mm to 975mm diameter. Basically it is consider up to 19mm treated as coarse-grained soils. Fines are passing 75 micron sieve or number 200 sieve, they represent fine-grained soils which consists of silt and clay fractions.

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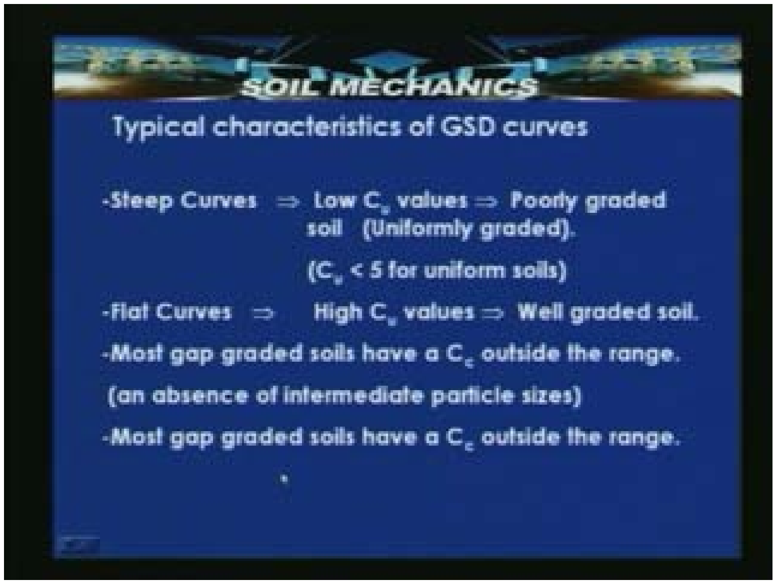

Next we are going to see the typical characteristics of the GSD curves. If you look into it, suppose it is possible to get different types of the curves with different steep with inclinations or slopes of the Grain Size Distribution curves. So if the curve is steep that is steep Grain Size Distribution curve it indicates that the value of the C_u is low and it is a poorly graded soil. It indicates that the soil mass consists of identical sizes of the particles.

As we discussed earlier it is very difficult to compact identical sizes of the particles. So the steep curves indicate low coefficient of uniformity or uniformity coefficient values. Poorly graded soil, which is also known as uniformly, graded soil. C_u is less than 5 for uniform graded soils. Flat curves in the sense which is extending from the larger particle size to finer most particle size indicates that higher C_u values which indicates that it is a well graded soil. So flat curves generally indicate well graded soils. Most gap graded soils have a coefficient of curvature outside the range. If we have introduced like a gap graded soil, some times an absence of intermediate particle sizes exists. So with this what happens is that, you know that particular type of soil is called gap graded soil or bimodal soil. Most gap graded soils such as a C_c outside the range.

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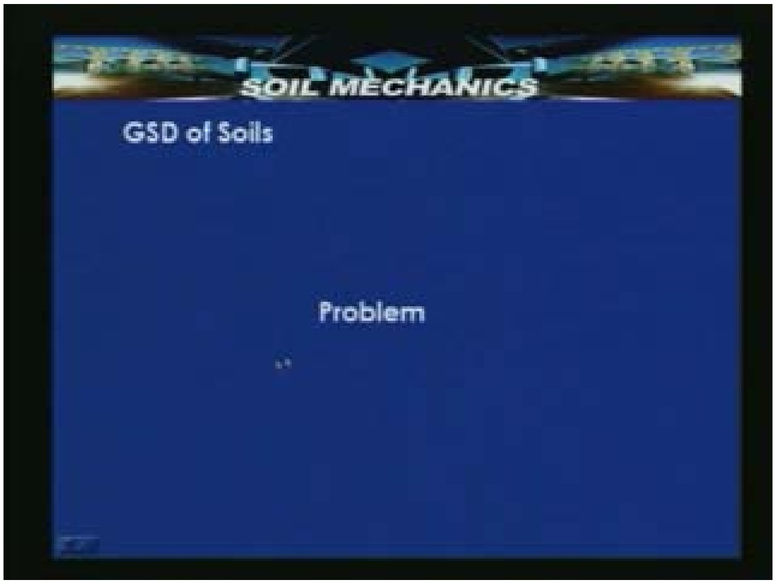

Let us look at a problem now in terms of GSD of soils.

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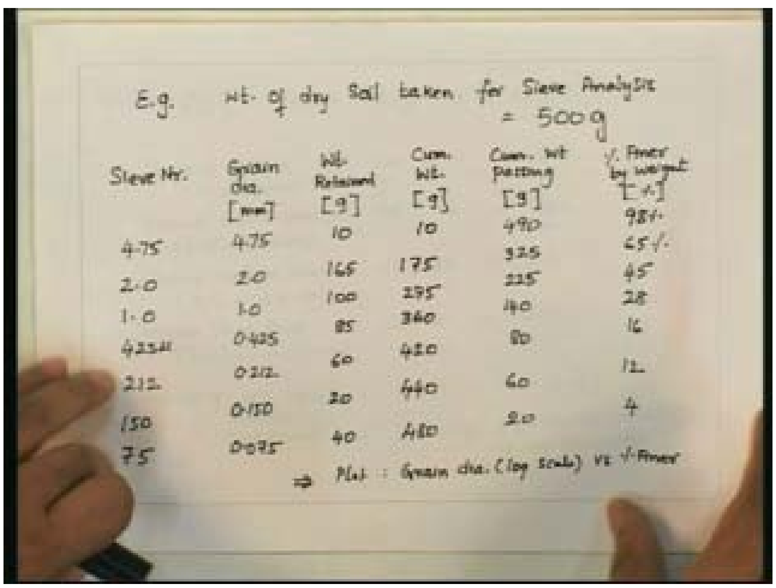

E.g. wt. of dry soil taken for Sieve Analysis = 500g

Sieve Nr.	Grain dia. [mm]	Wt. Retained [g]	Cum. Wt. [g]	Cum. Wt passing [g]	% Finer by weight [%]
4.75	4.75	10	10	490	98%
2.0	2.0	165	175	325	65%
1.0	1.0	100	275	225	45
425μ	0.425	85	360	140	28
212	0.212	60	420	80	16
150	0.150	20	440	60	12
75	0.075	40	480	20	4

⇒ Plot : Grain dia. (log scale) vs %Finer

In the previous class we have introduced a problem, where in we took a weight of dry soil for the sieve analysis as 500g. It sieved through different sieves of sizes 4.75 to 75 micron sieve and it represents the grain diameter here in this column. Weight retained in the each sieve and this is the cumulative weight retained in the each sieve is calculated. The cumulative weight passing is given by 490g is passed through this sieve only 10g is retained here. So (490 by 500) into 100, it gives you 98 percent. That is the percentage finer by weight which is actually the first point on the Grain Size Distribution curve with ordinate y equivalent to 98 percent and x in the terms of particle size has 4.75mm on the logarithmic scale. Similarly once we get, this we will get as a percentage finer by weight. Once we plot percentage finer by weight on y axis on arithmetic scale and the particle diameter on x axis on a logarithmic scale we will get a typical Grain Size Distribution curve. In this case, once we plot then we will get the typical Grain Size Distribution curve.

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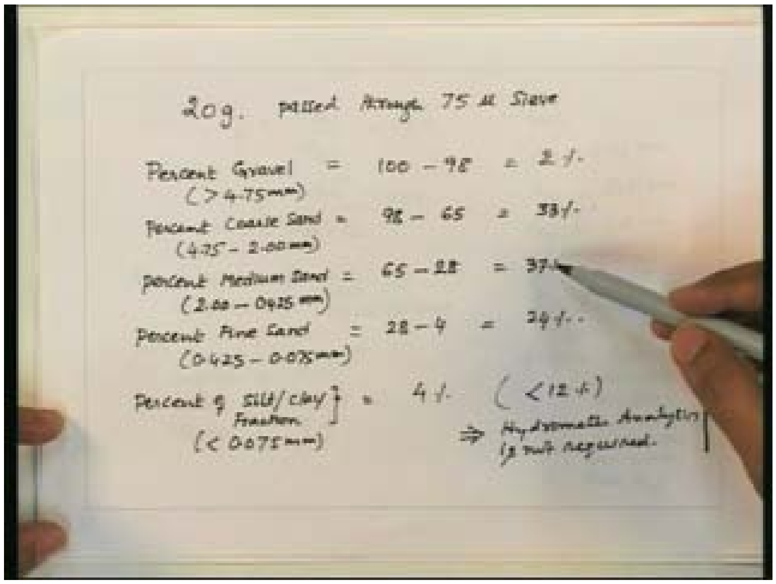

Let us look now; we noticed that only 20g of soil passed through 75 micron sieve. To calculate the percentage gravel the gravel size particles which are greater than 4.75mm, the percentage gravel is calculated in a soil mass. Let us take the particle size greater than 4.75mm, so 100 minus 98 gives you 2 percent. It indicates that 2 percent of the soil mass has got a gravel size particle that is greater than 4.75mm. Similarly percentage coarse sand range from 2mm to 4.75, percentage medium sand 0.425 to 2mm, percentage fine sand range from 0.075mm to 0.425mm which gives us percentage coarse sand as 33 percent, percentage medium sand as 37 percent and percentage fine sand as 24 percent. So in a percentage silt clay fraction, a particle having size less than 0.075mm is 4 percent and it is less than 12 percent. As we discussed the hydrometric analysis is not generally recommended if the percentage of the silt clay fraction is less than 12 percent. If it is more then it is required to be determined and then incorporated in the Grain Size Distribution curve. So having obtained this percentage gravel and percentage sand and percentage silt and clay fraction we can determine different coefficients which are used for measuring the gradation.

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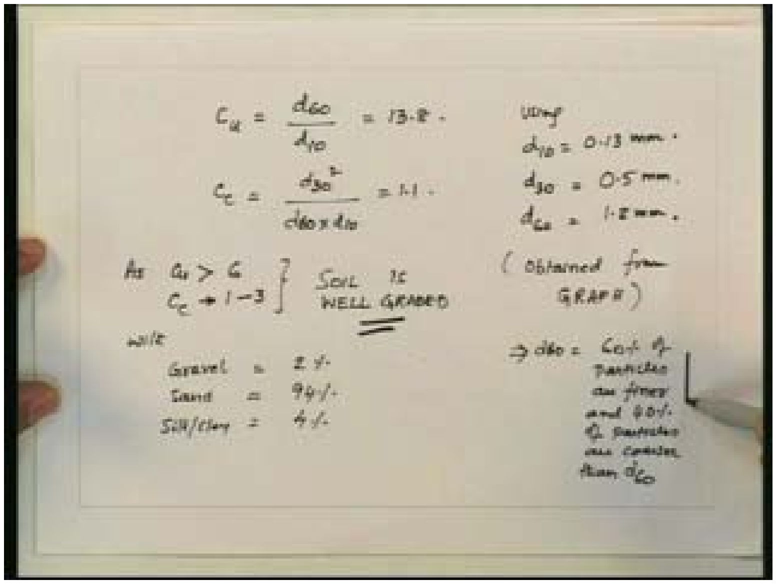

Coefficient of uniformity can be obtained by D_{60} by D_{10}. So here the D_{10} is determined from the Grain Size Distribution curve as 0.13mm, D_{30} as 0.5mm and D_{60} as 1.8mm. So by determining now, C_u works out to be 13.8 and C_c which is (D_{30} square) by (D_{60} into D_{10}) works out to be 1.1. As C_u is greater than 6 and C_c in the range of 1 to 3, the soil is said to be a well graded soil. These particle sizes are obtained from the graph and this soil is well graded. Once we complete this analysis we say that soil is well graded with percentage gravel 2 percent, percentage sand 94 percent and percentage silt clay as 4 percent. Revise once again, D_{60} is nothing but 60 percent of the particles are finer and 40 percent of the particles are coarser than D_{60}. So this is required to be remembering while determining these particle sizes from the Grain Size Distribution curve. So this is how we solve typical problems or analyze the Grain Size Distribution curves. Now let us look into another example, something that we have not seen so far.

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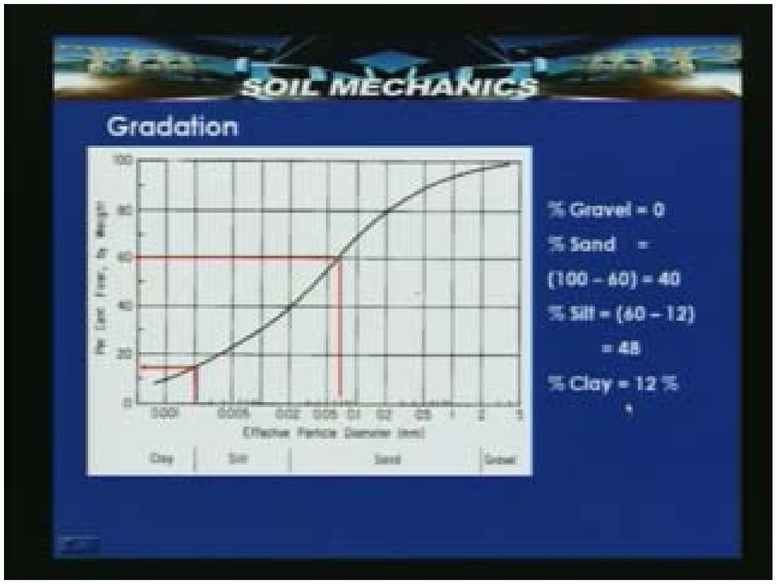

This is another example in which a typical Grain Size Distribution curve is shown where the particles ranging from sand, silt and clay is plotted with effective particle diameter on x axis and percentage finer weight on y axis. If you determine here, the percentage gravel is 100 minus 100 is 0, the percentage sand is 100 minus 60 that is around 40 percent, silt is around 60 minus 12 which is 48 percent and clay is around 12 percent. Basically here the major amount of the soil is with fines and then some sandy soil that is something like a silty sand type. So sandy silt where the sand is less compared to composition of the silt and clay. Time to time these Grain Size Distribution curves also can provide indication about soil’s history. As we have studied from the origin of soils, soil can be a residual soil or a transported soil.

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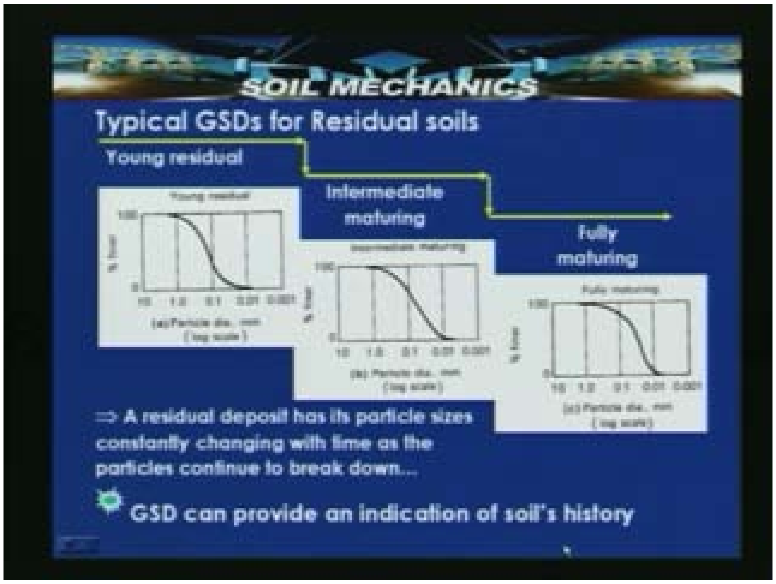

In the case of a residual soil let us consider typical Grain Size Distributions of residual soils collected at different ages of the soil. So here, this particular particle size distribution curve represents for the young residual soil and this one is a intermediate maturing soil and this curve represents the fully maturing soil. As you can see from the young residual soil type to intermediate maturing to fully maturing, gradual changes in the particle sizes can be noted.

A residual deposit has its particle sizes constantly changing with time as the particles continue to breakdown because of certain process of weathering. So a residual deposit has its particle sizes constantly changing with time as the particles continue to breakdown. So these are the typical Grain Size Distribution curves for the residual soils where we have seen as young residual soil deposit, intermediately maturing soil deposit and fully maturing soil deposit. As we run down we see that a residual deposit has its particle sizes constantly changing with time as the particle continuous to breakdown. So we can say that the GSD can provide an indication of soils history. This can give a conclusion about the soil's history in the past.

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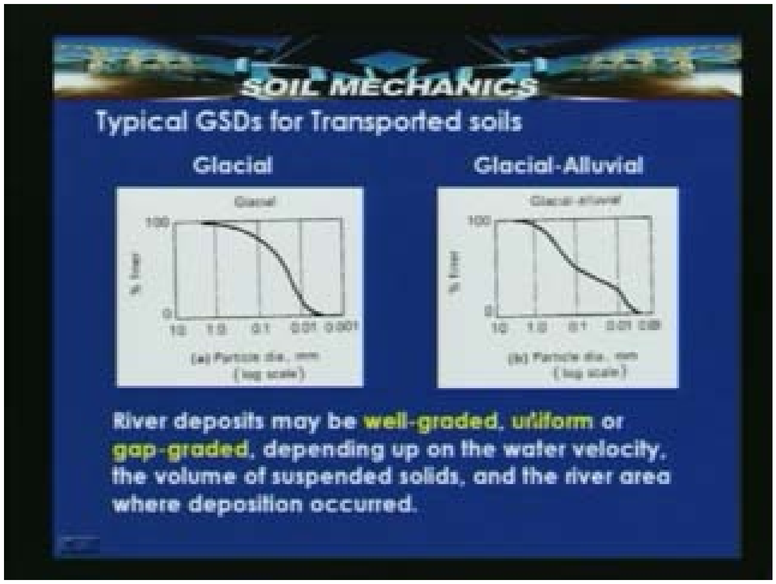

Let consider a typical Grain Size Distribution curve for transported soils. Here, a Grain Size Distribution curve for a glacial type soil and glacial-alluvial soil can be seen. River deposits may be well-graded, uniform or gap-graded depending upon the water velocity, the velocity with which the particles are being drifted and the volume of the suspended solids, and the river area where the deposition occurred. So as we can see with glacial to glacial-alluvial, the particle size distribution of the particular soil is getting changed. This is also a typical example of the Grain Size Distribution curve for the transported soils.

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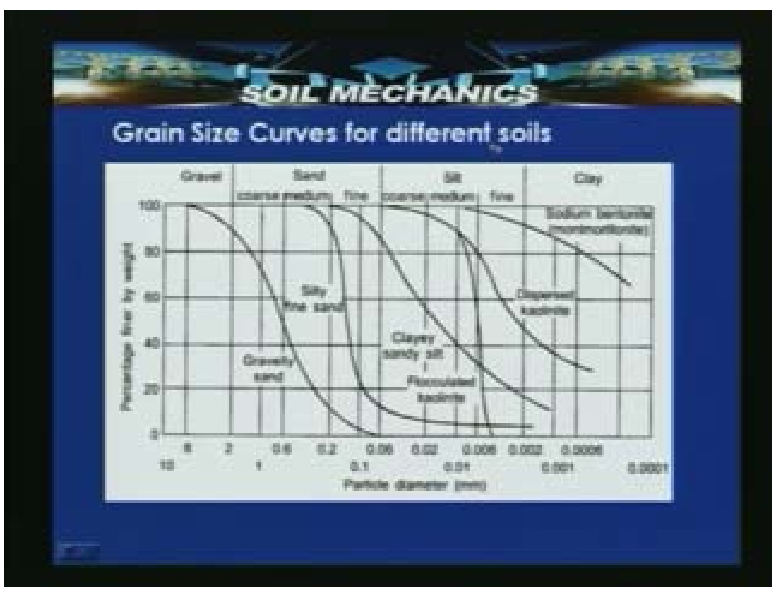

This particular slide shows typical Grain Size Distributions of different soils. Let us see different soils have been represented here present as finer by weight on y axis and particle diameter on the x axis. You can see here, this curve indicates a typical Grain Size Distribution for gravelly sand. If you see here, the large amount of the particle size which is more than 4.75mm is gravel and then followed by sand. So we can say that, a composition of soil mass is gravel in certain percentage, and predominantly sand, then we call it as gravelly sand. This particular Grain Size Distribution curve is shown for silty fine sand.

We can see here there are fine sand particles and the composition also has some silt particles in it so this particular curve represents silty fine sand. This particular curve represents clayey sandy silt because silt is predominant over the clayey and sandy soils. So, major portion of the soil here is silt and these two curves s how a different Grain Size Distribution of the flocculent and dispersed kaolinite. So dispersed kaolinite is finer and flocculated kaolinite is in the silt size. This is the typical Grain Size Distribution curve of sodium bentonite that is Montmorillonite. The Montmorillonite has got the finest particle size, that is what we have learnt while introducing the structures of the soil minerals. We said that the bentonite has got the finest of the finest particles with highest specific area and highest cation exchange capacity. So this slide represents typical grain size curves for the different soils.

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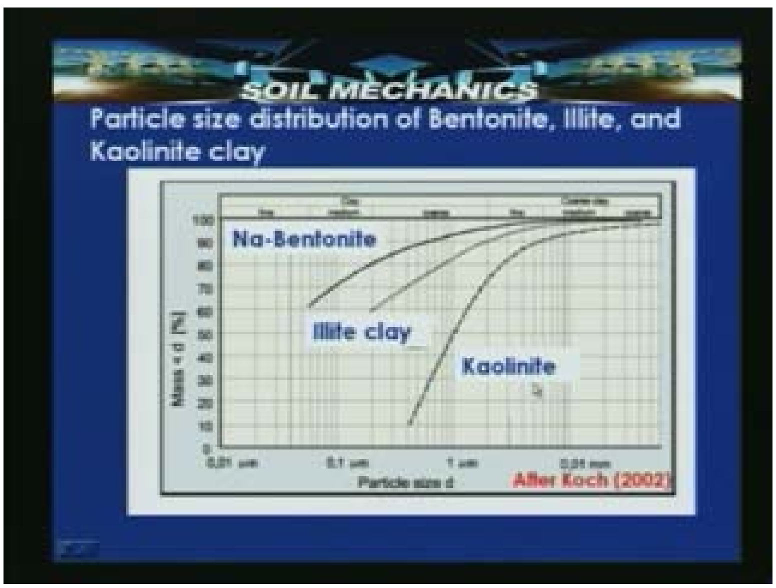

In this slide, particle size distribution of the bentonite, illite and kaolinite are shown. So as we learnt in the previous lectures, kaolinite is supposed to have large particle sizes compared to illite and bentonite. The similar thing can be seen here which is represented after Koch 2002. This is the kaolinite particle size distribution curve and this represents illite clay and this is the sodium bentonite. Sodium bentonite is observed to be the finest among bentonite, illite and kaolinite family.

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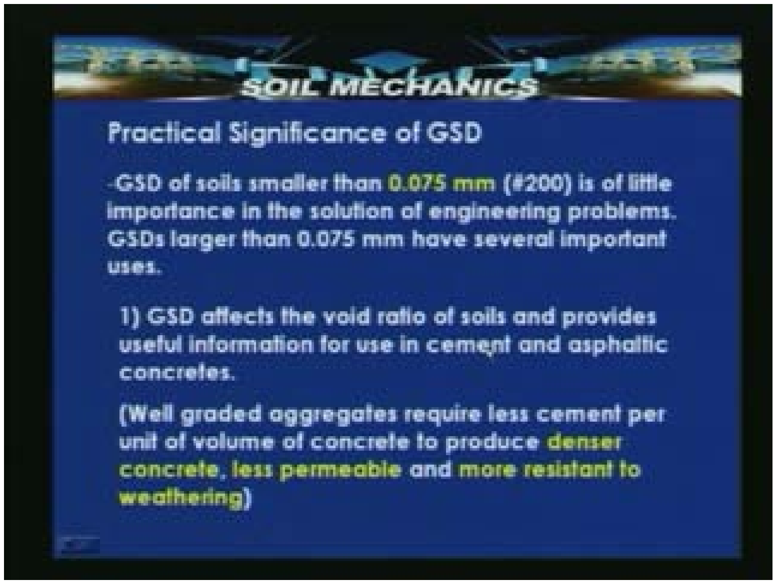

So having learnt about the measures of gradation let us try to understand or see the significance of this Grain Size Distribution curve. That is, the practical significance and why we it is required to determine the gradation of soils. This is the practical significance of GSD that is Grain Size Distribution. So GSD of soils smaller than 75 micron that is passing 200 number sieves is of little importance in the solution of engineering problems. GSDs larger than 0.075mm (75 micron sieve) have several important uses. So GSD affects the void ratio of soils and provides useful information for use in cement and asphaltic concretes. So the Grain Size Distribution curve affects the void ratio of soils. We have seen that, if the soil is well-graded, the void ratio is supposed to be less and if the soil is uniformly-graded, the void ratio is supposed to be very high. Well graded aggregates require less cement per unit of volume of concrete to produce denser concrete and less permeable and more resistant to weathering. So this is one of the practical significance with the Grain Size Distribution analysis.

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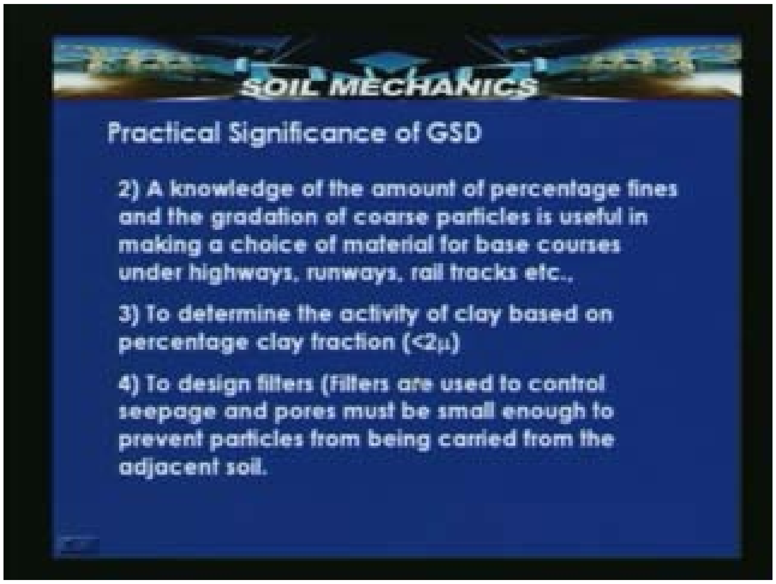

The second significance is knowledge about the amount of the percentage fines and the gradation of coarse particles is useful in making a choice of material for base materials under highways, runways and rail tracks. Basically in highways and runways, it is utmost requirement to give a mechanically stable foundation to support the loads which are coming on to the pavement. So for that we are required to have the matrix with certain amount of the fines. So, knowledge of the amount of the percentage fines and the gradation of the coarse particles is useful in making a choice of material for base courses under highways, runways and rail tracks. Another practical significance which we will be discussing later is to determine the activity of the clay based on the percentage clay fraction. That means based on the percentage clay fraction we can say whether that particular clay soil with particles finer than 2 microns is active or inactive or in what extent it is active.

All these things can be said by determining the activity which is possible with percentage clay fraction. To design filters, basically number of filters are required either to provide drainage in case of parking lots or road sub bases, etc. In case of retaining walls basically the filters are designed or along the canal banks the filters are designed. Basically the criteria for designing the filter is to see that to control the seepage and the pores must be small of to prevent the particles from being carried from the soil. Let us look into this particular requirement for the practical significance of the Grain Size Distribution curve with reference to retaining wall.

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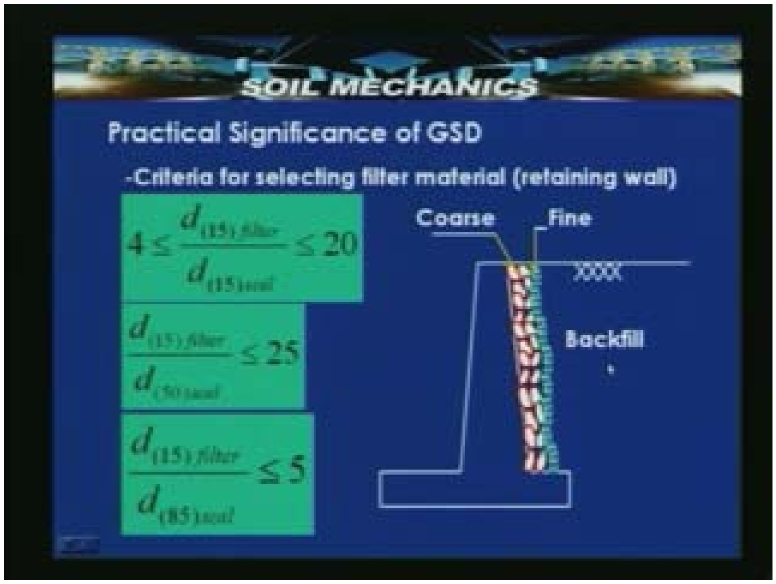

That is, a filter material extends to a retaining wall. Basically a filter is required to be provided behind the retaining wall to get rid of the water pressure. Once the wall is getting the effect of the water pressure then the lateral pressure exerted on the wall increases. To get rid of the pressure from the water which is collected behind the wall it is required to provide different ranges of filters such as a coarse filter or a fine filter and a backfill soil. Then to drain the water from here either collection pipes can be kept here or it can be kept with poles which are called as dipoles. There are certain criteria for selecting the filter material basically for retaining wall: the ratio of D_{15} of the filter to D_{15} of soil should be with in 4 and 20.

Another criteria which is required to be satisfied is D_{15} of filter to D_{50} of soil should be less than or equal to 25 and D_{15} of filter to D_{85} of soil shall be less than or equal to 5. By fulfilling these criteria, one can design different types of filter materials. The filters can be designed basically to see that the backfill material, the fine particles in the back fill materials are not required to be washed out. Only the water which is there within the back fill soil is required to be drained. So that the wall is free from the lateral pressure exerted from the water. Similarly this criteria for selecting the drainage material is followed in Indian Roads Congress 37-2001.

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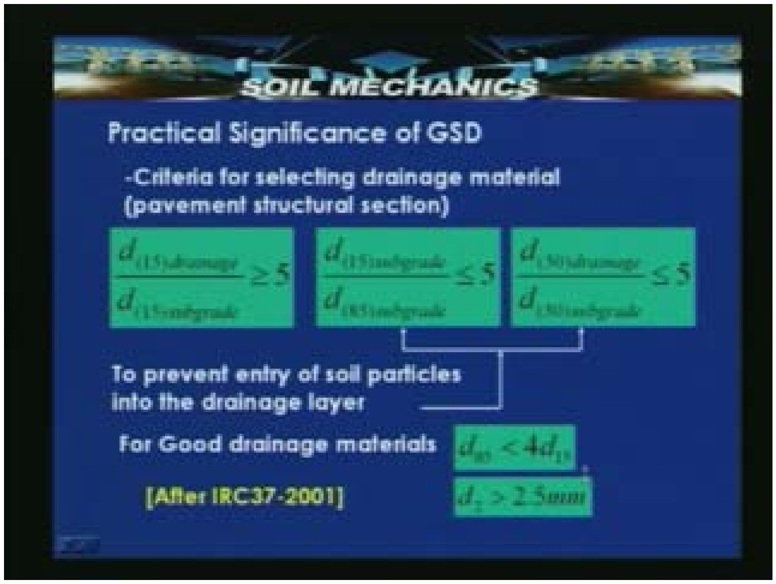

The criteria works out as follows: For the pavement structural section, as the functional performance of the pavement depends upon the drainage of the water the life of the pavement depends upon the drainage which is there at the sub grade level. For that it is required to provide the drainage material. So to design the drainage material it should be seen that ratio of D_{15} of drainage material to D_{15} of sub grade should be greater than or equal to 5 and the ratio of D_{15} of sub grade to D_{85} of sub grade should less than or equal to 5.

One more criteria is there that the ratio of D_{50} of drainage to D_{50} of sub grade shall be less than or equal to 5. So these two criteria are basically selected or required to be fulfilled to prevent entry of soil particles into the drainage layer. For good drainage materials, basically it is required to be seen that D_{85} of a drainage material is less than 4 times the D_{15} of a drainage material and D_2 of a drainage material shall be greater than or equal to 2.5mm. Then we can select this particular material as a qualified drainage material in the case of a pavement structural section.

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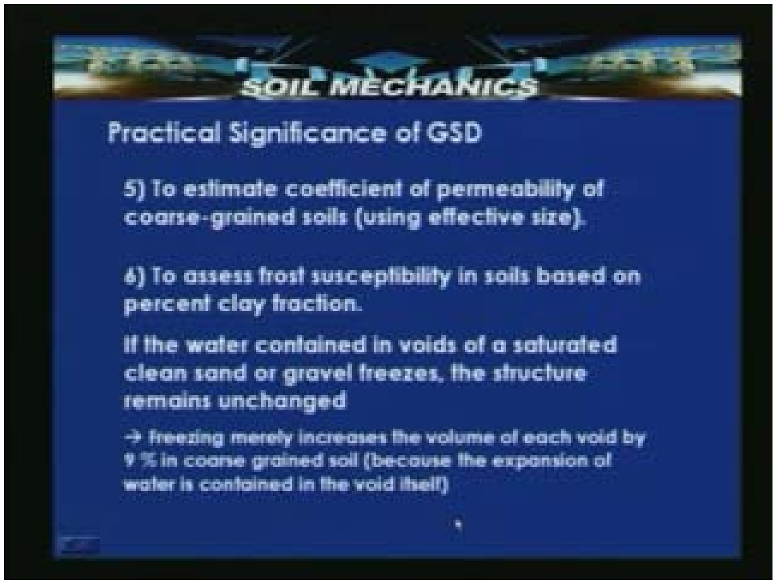

Another practical significance is that, to estimate the coefficient of permeability of the coarse-gained soils. Hazen has tried to find out coefficient permeability of the coarse-grained soils basically using the effective particle size $D_{10,}$ number of collisions has been found out and it has been documented that for determining the coarse-grained soils, basically sandy soils which has the particle size D_{10} that is effective particle size is used to determine the coefficient of permeability of soils. That is the permeability is nothing but ease with which the water can pass through the soil matrix.

Also, the other significance is to assess the frost susceptibility in soils based on the percentage clay fraction. Basically this frost susceptibility is required to be high for the fine-grained soils that are particles passing 75 microns sieve also or particles having less than 2 micron size. So to determine that, the reason for this particular phenomena is that whenever the water in the voids of a saturated clean sand or the gravel freezes then what happens is that the structure remains unchanged because there will not be much expansion as freezing nearly increases the volume of each void by 9 percent in coarse-grained soil (because the expansion of water is contained with in the void itself). So because of that they are not more susceptible, whereas in case of a fine-graded soils the water which is prevalent in the void increases and it causes a sieve called as frost sieve in case of a clay soils which is because of this particular nature. To assess the frost susceptibility of given fine-graded soils we are required to determine the percentage clay fraction. By assessing that we can find out how much frost susceptible the soil is. Some applications of the GSA Grain Size Analysis in Geotechnology and construction is the selection of fill material.

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So we wanted to select a fill material for constructing embankment or constructing earth dams. In the case of earth dam, different gradations are required in the different zones. So the selection of fill material is important where the gradation will come into the picture because for certain type of constructions we are required to have well graded materials to contribute to the strength.

Road sub base material: As we said, to provide a mechanically stable foundation we are required to have good knowledge about the grain size analysis of the particular material under consideration. Next one is drainage filters, basically it is required to know the drainage characteristics of the filter material with the edges and soil characteristics and then ground water drainage and grouting and chemical injection. This is a phenomenon to strengthen the ground or to fill the voids in the ground or to fill the voids or cavities in the ground.

This grouting is a phenomenon which is used by a chemical injection or cement sand grouts are inserted into the ground. To workout these, it is required to know the knowledge about the grain size analysis. The concreting materials we have seen that, in order to produce a denser concrete unity we need to have well graded materials so that less amount of cement or asphalt can be consumed. Denser the concrete more resistant it is to weathering. Dynamic compaction is another phenomenon to compact the soils. For this also the knowledge of the grain size analysis is required.

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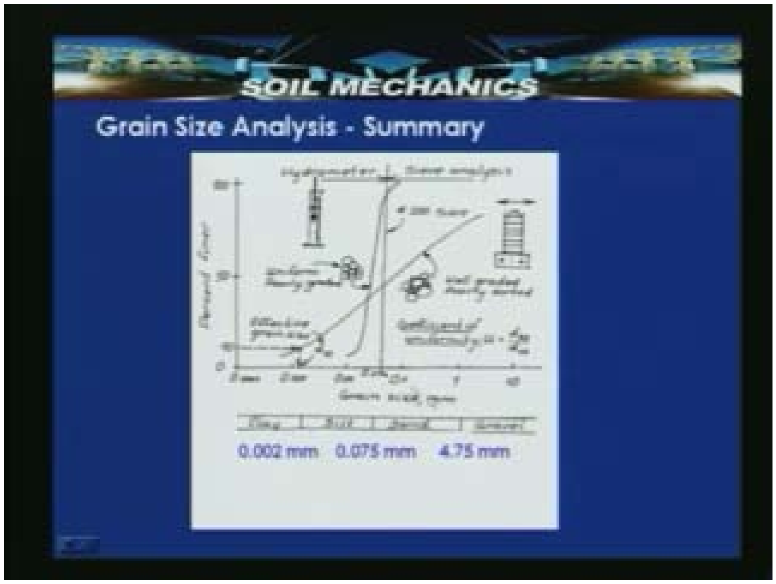

Now let us look into the summary of grain size analysis. We have seen that coarse-grained soils which is greater than 75 micron is analyzed by using the sieve analysis. Then it is subjected to the soil mass which is placed in the series of seals and subjected to shaking. While measuring the percentage retain and calculating the percentage stimulate weight of the soil retain in each sieve, percentage finer weight can be calculated which is plotted here. Based on that we can say that the different coefficients of soils can be found out and then we can say that it is well graded or a uniformly graded.

Uniformly graded looks like the particles are of equivalent size and you can see that this curve is a steeper curve that represents uniformly graded or a uniform fully graded soil. This represents a well-graded soil because the finer particles are filling the voids within the large particle sizes. So this is a well-graded purely sorted soil tank. So coefficient of uniformity here we said is that C_u is equal to D_{60} by D_{10} and coefficient of curvature as (D_{30} square) by (D_{60} into D_{10}). We also said that this effective particle size is indicated as D_{10} which indicates that 10 percent of the particles are finer and 90 percent of the particles are coarser than this size.

We also said that the D_{50} is the average particle size. So, for the particles which are finer than 75 micron, it is required to find the particles by using the hydrometer analysis. Depending upon the sizes of the particles, they settle and then hydrometer is required to be worked out with different corrections to get the fine particle size percentages. Once it is corrected it can be joined with the original Grain Size Distribution curve to get the complete curve. So this hydrometer analysis is required to be carried out if the percentage fines are more than 12 percent.

Now, basically having determined the particle size of a coarse-grained soil, to some extend we are able to classify the soil. But we also have the soils with major amount of soils or major portions of soils with passing 75 micron sieve that is very very fine soils. In that case, we need further information to classify these fine-graded soils.

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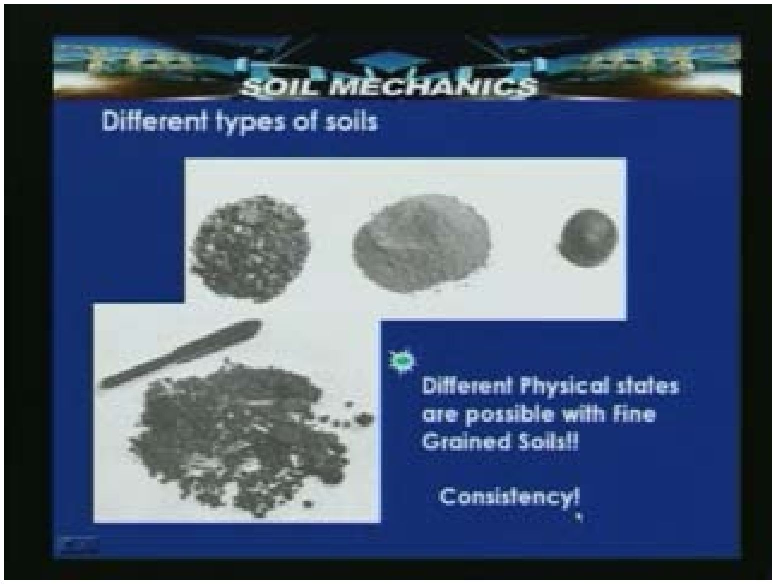

So for that we consider the physical states of the soil that means if you look into this slide different types of soils are shown. A gravelly soil with different particle sizes and a sandy type soil is shown here And a clay type soil is shown here. As you can see here, this particular shape can be attained with less amount of water. By adding more amount of water, this particular lump of soil may lose its shape. So different physical shapes are possible with fine-grained soils and that is what leads to consistency of a given soil. Before classifying the fine-grained soils or before introducing the classification of fine-grained soils let us introduce a term called consistency.

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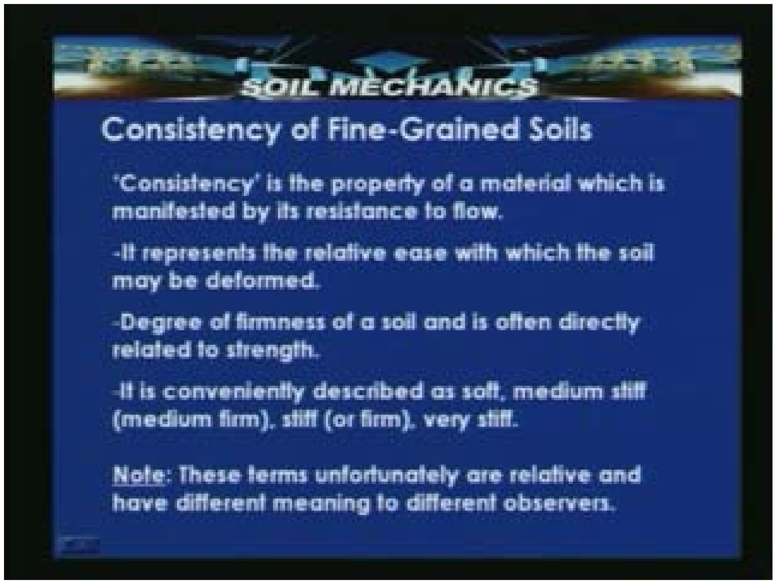

The consistency of the fine-grained soil is generally defined as a property of a material which is manifested by its resistance to flow. It represents the relative ease with which the soil may be deformed. So degree of the firmness of the soil and is often directly related to strength. Generally it is conveniently represented like this: We say that fine-grained soils of soft consistency or medium consistency or medium stiff consistency or medium firm consistency all are alike, stiff or firm or very stiff. These terms are unfortunately relative, higher and also have different meaning to different observers. But this is a relative explanation of the different physical states with different consistencies like soft that is said to be soil and it may be having very low strength and medium stiff, stiff and very stiff soils. In soil mechanics, it is a need to determine the range of the potential behavior of the given soil based on very few simple tests.

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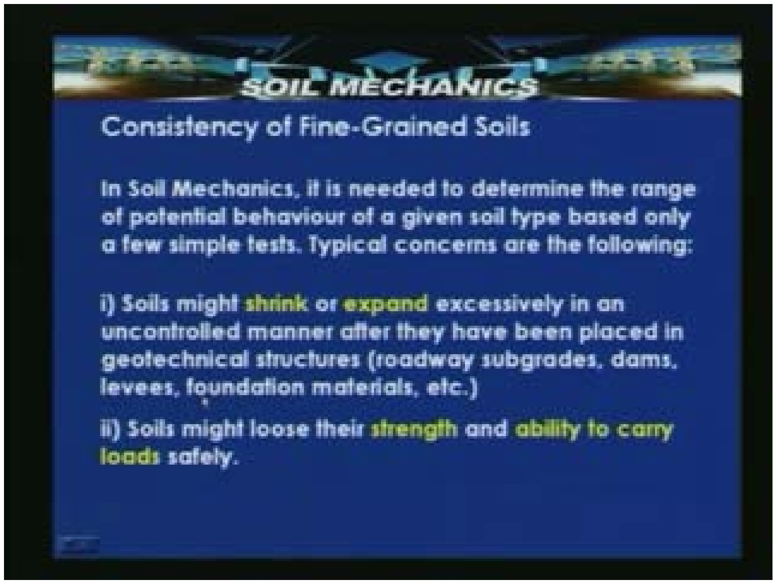

Typical concerns are the following: You know what will happen when the soil is having less amount of water or more amount of water, that is, basically we are referring either coarse-grained soils or fine-grained soils. So in case of different states, typical concerns for the geotechnical engineers are that soil might shrink or expand excessively in an uncontrollable manner after they have been placed in geotechnical structures (roadway sub grades, dams, levees, foundation materials). Soil might lose their strength and the ability to carry loads safely.

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Test used to detect the potential problems for coarse-grained soils basically gravel and sands are different from those used to detect the potential problems for the fine-grained soils basically silts and clays. So if you see the coarse-grained soils, basically water content is generally not a major factor; Major factor leading to shrinkage is the structure of the soil skeleton. That means that the arrangement of the soil particles or soil fabric can change from the loose state to the dense state. That is only in the case of a coarse-grained soils is possible. Major factor leading to the shrinkage in the sense of coarse-grained soil which indicates that a loose fabric can change to a dense fabric or very dense fabric.

In the fine-grained soils the water content is a major factor. If you see here as water content increases from left to right soil expand and loose in strength. As water content decreases from right to left soils shrink and gain in strength. So if you look into this, fine-grained soils are proved to get affected with the presence of water. So that is an interesting phenomena and A. Atterberg a Swedish scientist basically for agriculture purposes has come out with certain limits of water content at which the soil changes its physical states. So that is being currently used to determine these limiting water contents at which the soil undergoes the physical states. These limits are used for determining or classifying the fine grained soils.

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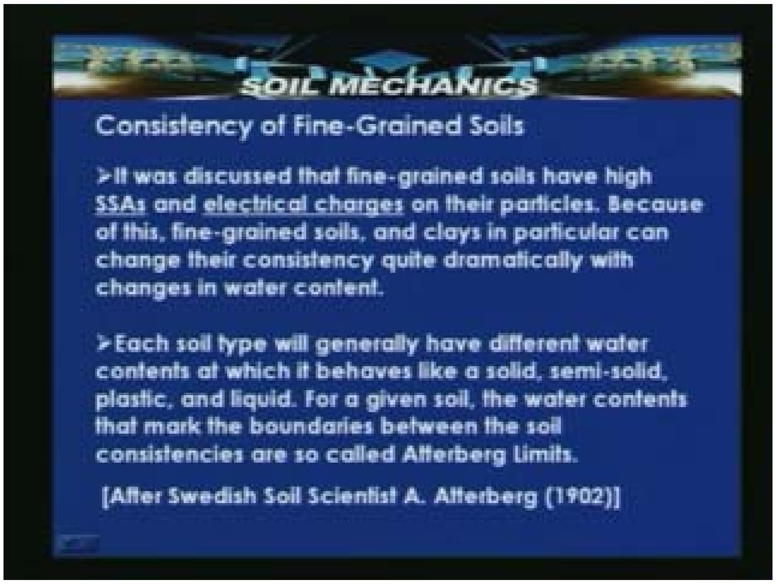

As we have studied earlier it was discussed that fine-grained soils have higher SSA, because finer is the particle size whereas higher is the specific surface area and electrical charges on their particles. They are supposed to have higher electrical charges around the surfaces because of these fine-graded soils and clays in particular can change their consistency quite dramatically with changes in water content. With the availability of water, the consistency of the soil can be changed from the firm to soft state or very stiff to soft state. So each soil type will generally have different water content at which it behaves like a solid, semi-solid, plastic and liquid. Different states have been introduced like solid, a solid state which is like a brick tile and semisolid, plastic and liquid state. For a given soil, the water contents that mark the boundaries between the soil consistencies are called as Atterberg limits [After Swedish Soil scientist A. Atterberg (1902)]. Here onwards we will see about how the Atterberg limits are defined, how they are deduced and how they are determined. So that and all we will be looking into the further course of the lecture. The consistency of the fine graded soils is mentioned here.

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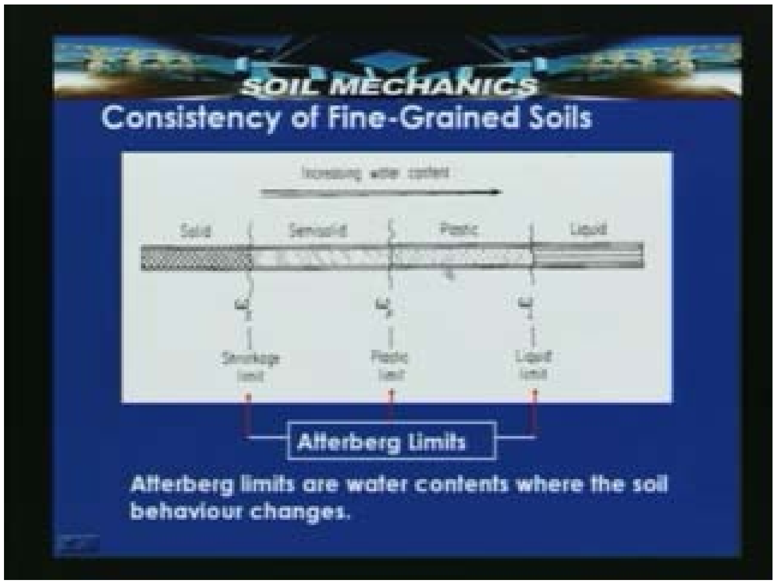

The soil with the solid state is referred as the limiting water content. The limiting water content, in between solid state and semisolid state is indicated or termed as shrinkage limit. Then the limiting water content between semi-solid state and plastic state is indicated as a plastic limit and limiting water content between plastic state and liquid state is indicated as a liquid limit. So these liquid limit, plastic limit, shrinkage limit are known as Atterberg limits. So Atterberg limits are nothing but water contents where the soil behavior changes. So here, there is a changing behavior in solid to semisolid state, semisolid to plastic state and the plastic to liquid state. Mostly the natural soil deposits occur in this range very close to plastic limits.

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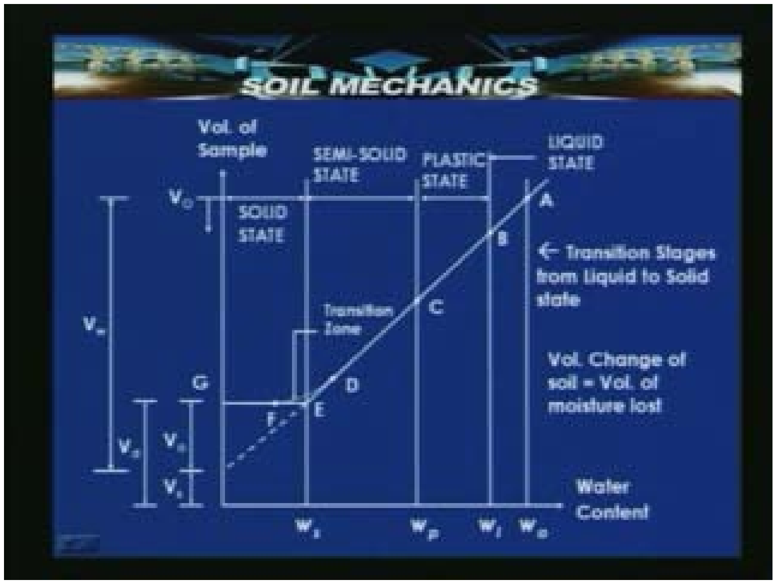

Let us consider this particular curve which is plotted with water content on the x axis and volume of sample on the y axis. This shows a different transition stages from liquid to solid state. Let us consider a different transition point like A, B, C, D, E and F. Here V_0 is the initial volume of the soil mass, V_s is the volume of the solids and V_w is the water. That means, here the volume of water is many times more than the volume of the solids. V_0 is the initial volume of the soil mass that is above the liquid state. If the soil is allowed to dry, then it undergoes changes from liquid state to plastic state, plastic state to semi-solid state and semi-solid state to solid state.

You can see here, the limiting water content between the liquid state to plastic state is indicated as a liquid limit which is indicated as W_L (liquid limit). If you are indicating the liquid limit in percentage, it is indicated as W_L or if you writing the value of the liquid limit, then it is indicated as LL (liquid limit). Similarly at point C, interface between the semisolid state and plastic state is known as the plastic limit. So the difference between liquid limit and plastic limit gives the range of the plasticity of the soil. That is liquid limit minus plastic limit will give you the plasticity index.

Once you allow the soil to dry up to point D, then you can see that upon further drying, soil mass will not experience any change in the volume. From point D to F, the curve undergoes that is this particular zone is said to be a transition zone. When it is changing from semi-solid state to a solid state the curve is not linear, it is in the curvy linear shape. So it is said that one of the possible reasons for this phenomena is because air starts entering from this point. So this is the point where entry starts, then it comes up to this point and then here by this time, mostly the water is replaced by air.

The soil grains are pressed so close that there will not be further reduction in the volume. Even up on further drying if you keep it in the oven, the soil mass will not further reduce in volume because the particles have been pulled close in such a way that there will not be any further reduction in the void ratio. So at different levels, for example at the initial volume is represented here, here it represents the volume of the soil mass at point B and this corresponding point represents the water content corresponding to this state. Here this curve is supposed to be inclined at 45 degrees because if the gamma W is around 10 kilometer per meter cube.

The volume change of the soil at any point during this process will allow you to drain from A to D. The volume change of the soil is equivalent to the volume of the moisture lost. So this point B is the limiting water content between the liquid state and the plastic state and it is said to be a liquid limit. At point c, the limiting water content between plastic state and semisolid state is said to be a plastic limit.

The difference between liquid limit and plastic limit is indicated as plastic index and limiting water content at point E is indicated as shrinkage limit. Shrinkage limit is the minimum water content at which still the soil is completely saturated. Afterwards the soil transforms or undergoes change in colour. It indicates that drying is taking place or the change of the colour indicates that the water is being replaced by air. Here the evaporation of the soil is where air starts entering. This is the entry point and here completely it enters and it replaces all the water in the voids.

If you extend this curve further down, here this point gives the volume of the solids. The volume of the solids is constant throughout in this process of drying. This slide shows the different states of the physical states of the fine grade soil. That is interface between liquid state and plastic state is defined as a liquid limit and interface between semisolid state and solid state is defined as shrinkage limit. Interface between plastic state and semisolid state is defined as a plastic limit. So as we defined, let us look into the definitions of Atterberg limits.

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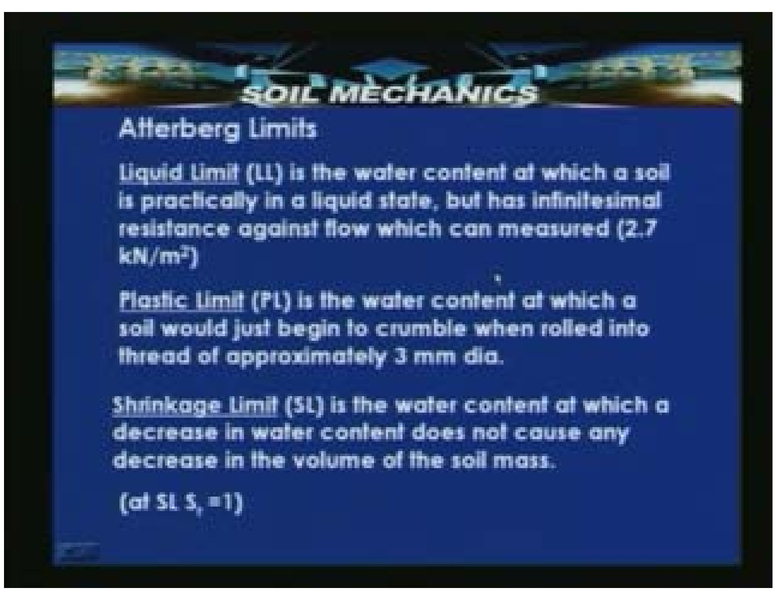

Liquid limit is a water content at which a soil is practically in a liquid state, but it has infinitesimal resistance against flow which can measure. So at liquid limit the soil has practically a small shear strength which can be measured. So most of the soils have a shear strength at liquid limit is around 2.7 kN by m square. Above liquid limit the soil state changes into stationary state. Plastic limit is the water content at which the soil would just begin to crumble when rolled into the thread of approximately 3mm diameter. The plastic limit is thus with the same definition or the same phenomena we determine the plastic limit of a given soil. The plastic limit is the water content at which the soil would just begin to crumble when rolled into thread of approximately 3mm diameter.

Shrinkage limit is the water content at which a decrease in water content does not cause any decrease in the volume of the soil mass. Even at the shrinkage limit, the degree of saturation is said to be 100 percent. If you wanted a domain void ratio at the shrinkage limit we can say e shrinkage limit. The void ratio shrinkage limit is equal to water content of shrinkage limit which is nothing but the shrinkage limit times specific gravity to the solids. Similarly for void ratio of a given soil at liquid limit E_l is equal to W_l into G_s. The volume void ratio of the soil at the plastic limit is indicated as E_p is equal to W_p into G_s. So Atterberg limits provide a good deal of information on the range of the potential behavior of the given soil might show in the field and variations in the water content.

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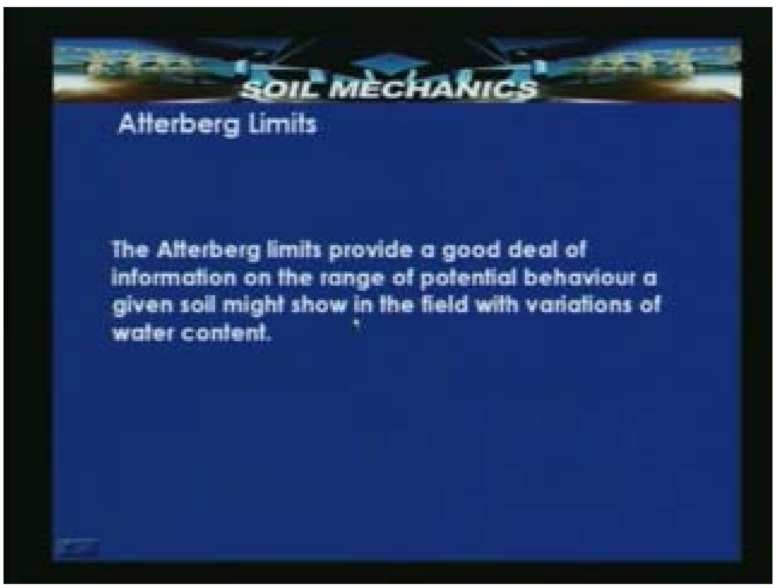

This particular behavior is shown here.

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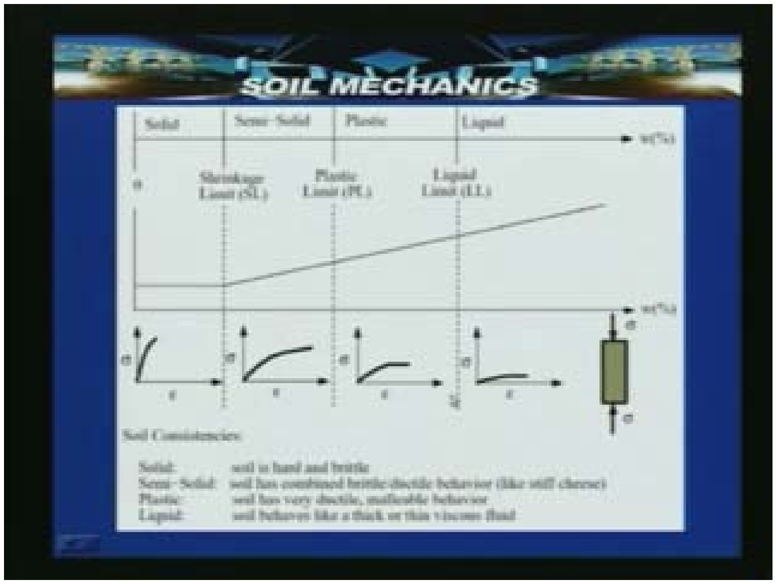

When the soil is solid that is stiff or very stiff, semisolid, plastic and liquid. This interface limiting water contents here is given as shrinkage limit, plastic limit and liquid limit. Here it shows that a solid soil is hard and brittle in the stress strain behavior. Suppose if you take a sample which is pressed with a certain stress sigma and with a strain axial strain epsilon, the soil experience or exhibits a brittle behavior when it is hard. During the semisolid state, the soil has combined brittle and ductile behavior like a stiff cease material. And when the soil is in the plastic state, soil e has very ductile and malleable behavior. If the liquid state that is soil behavior is like a thick or a thin viscous fluid, almost the soil is having a juristic. So here liquid limit is the point where the soil still possesses an infinitesimal shear strength which can be measured. Normally this shear strength of the soil at liquid limit is said to be around 22.7 kN by m square.

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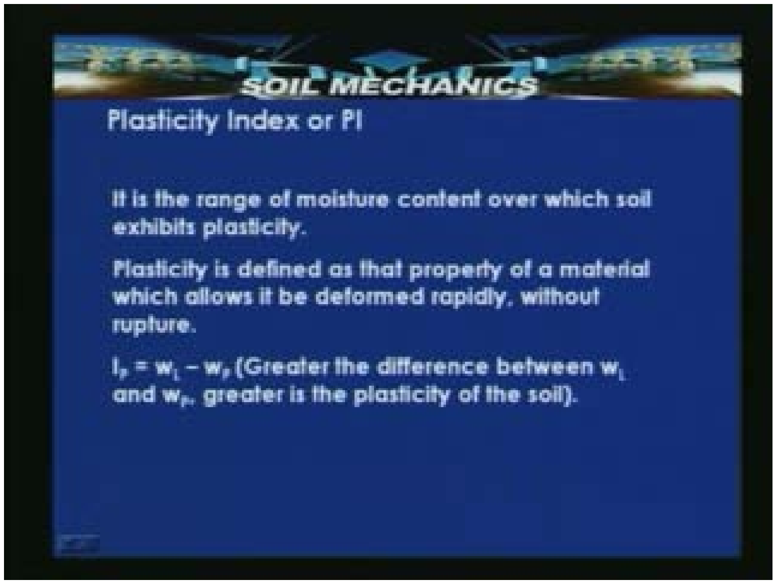

We also define the plasticity index is the range of the moisture content over which soil exhibits plasticity. Plasticity is defined as the property of a material which allows it to be deformed rapidly without rupture. So plasticity is very important for the fine graded soils which are defined as the property of material and which allows it to be deform rapidly without rupture or without breaking. I_p the plasticity index, if it is indicated in percentage or if it is indicated in values, it is indicated as PI the liquid limit minus plastic limit. The greater the difference between W_l and W_p, greater is the plasticity of the soil. This is an important parameter while selecting different materials for construction. In this lecture, we have studied about the measures of the gradation.

Also, we have been introduced to the consistency of fine-graded soils and different physical states of fine-grained soils. We introduced the Atterberg limits and we defined them as liquid limit, plastic limit and shrinkage limit. These Atterberg limits are used further to classify fine-grained soils. In the next class, we will try to look into different classifications based on the plasticity index that is Atterberg limits and their integrated details pertinent to Atterberg limits and their determination.