Foundation for Offshore Structures
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Module-1
Lecture-4
Basics of Soil Mechanics IV

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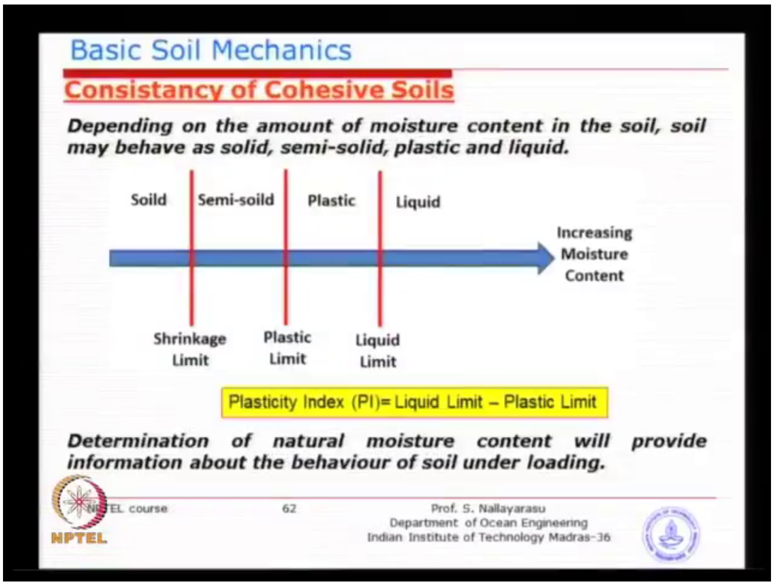

So today we will be looking at cohesive soils and their behaviour under different moisture content. If you look at this picture, you can see the increasing moisture content transform the soil from solid-state to a liquid state. As you can see if you look at you know like coastal areas, many of this, a very soft clay becomes almost like a liquid when you step in, it just goes down.

So you can see the 3 states solid, semisolid, the demarcation is slightly difficult to determine but at least from semisolid to plastic, plastic to liquid, there are 2 immediate you know the demarcation, we can find out one is the liquid limit, beyond which the soil will actually behave almost like a liquid and all the other soil it might become plastic, that is deformation will take place but cannot return back. So basically the plastic limit is the liquid state, almost like a liquid state but not too much of a liquid or fluid added to the soil. It will become plastic state, and on the other side is a key producing the moisture content, it might become semisolid or almost solid-state which will be your know retain the shape irrespective of the small amount of moisture what you have.

So this will tell you when you apply loading to a cohesive soil with different percentages of moisture content, you could see basically how it is going to deform. So that is why we need to determine the percentage of natural moisture content in the soil. So how do we determine and what is these limits, of course finding out the much content in a soil is very easy. You can actually weigh them in a dry state and the natural state and the difference will give you the natural moisture content. But the limits of demarcation whether it is semisolid or solid or plastic state or liquid state, just empirical method of course devised by past researchers.

Several methods are there, we will just discuss one of the methods which will give an idea. So basically we want to do plastic limit and liquid limit determination based on 2 of the methods, one is Cesagrande's method, the other one is Fall cone method. The reason why we need to find out this and why we need to know this, though they are not directly giving us the strength parameters, one of the important idea was the previous literature, the past data, people have tried to relate these 2 limits to the possible determination of classification as well to some of the design parameters. So if you know for your soil this particular limit, then you can go to the literature, find out what kind of strength this will have, what kind of deformation characteristics it might have.

So all these ideas are related to these limits, so that is why we need to find out. One important thing is the differential fluid limit between the plastic to liquid state, so basically is called the plasticity index that gives a very important classification of soil, how much, whether it is behaving as a plastic soil or a semisolid. So that is why we need to find out the plasticity index, the larger it, it will become almost like a fluid. So that is where we want to find out these 2 limits, so we will just quickly look at what it means.

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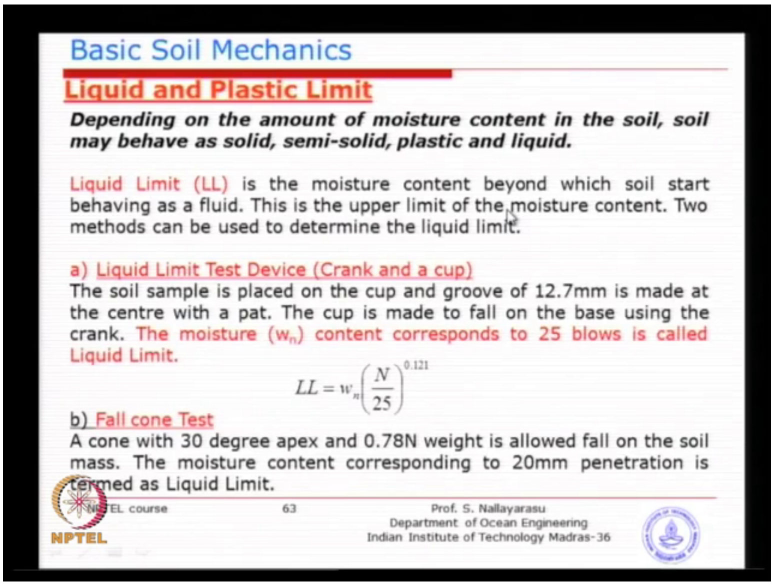

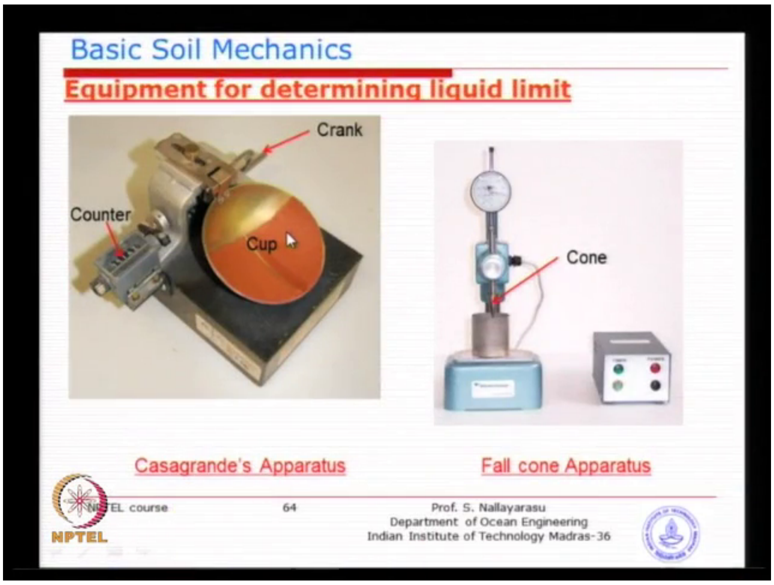

So liquid limit is the moisture content beyond which the soil starts behaving as the fluid, it is just flowing, you know you just pour it or drop it onto the ground, it will become flat almost. You can find out using crank and cup method, I will show you the photograph just little later. So if you look at the photograph of the crank and cup, it is a device I think you might have seen in your laboratory in soil mechanics geotechnical lab. You have a crank and you have a counter which will actually be used to count the number of times you lift and fall down of this cup.

You know in this cup you will fill up the soil, something like this and make a groove, you see that small group of 4.7 millimetres, so several times you rotate it and automatically if the soil is having flow characteristics, it will just try to join at the Centre. So the number of times you rotate the crank will tell you whether it is close to fluid or close to solid. So basically that is that is one of the machines which, I think from olden days people used to use, little bit troublesome but then it is quite good.

The other one is the Fall cone apparatus, you just make a sample of your soil into a cup and then allow this cone to fall down, you can see if it is a very good soil, strong, the cone will not penetrate too much. But if it is like a fluid, it will penetrate larger depth, so that we can understand easily, the fall cone is a direct integration of how soft or how fluid the soil is.

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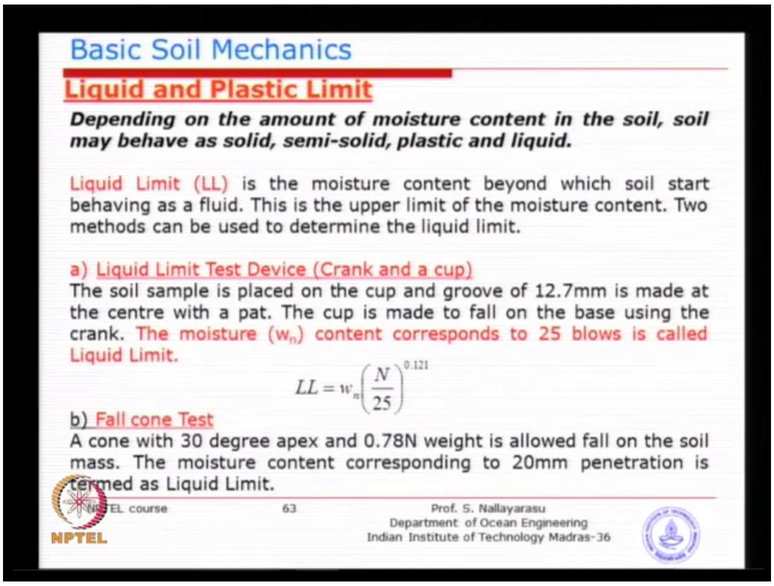

So this method also can be used, so the criteria for crank and cup method is basically the moisture content corresponding to 25 blows, that is the kind of idea they were devising early on, so we still use that. And the formula to calculate the liquid limit, if you do not want to plot in the log log paper, semi-log paper, you can use this formula the number of blows is N and basically the WL is the natural moisture content for the soil. Fall cone test, the cone is having a apex angle of 30 degrees and the weight is 0.78 Newton. So that means it is a very small cone.

And the moisture content that corresponds to 20 MM penetration for the so what you normally do is, you take the soil, change the moisture content several times, that means you will add and then put it into the same you know the cup, allow the cone to penetrate and you do the tests several times, that means with different moisture content. Plot on a graph, in fact I have given you the procedure here.

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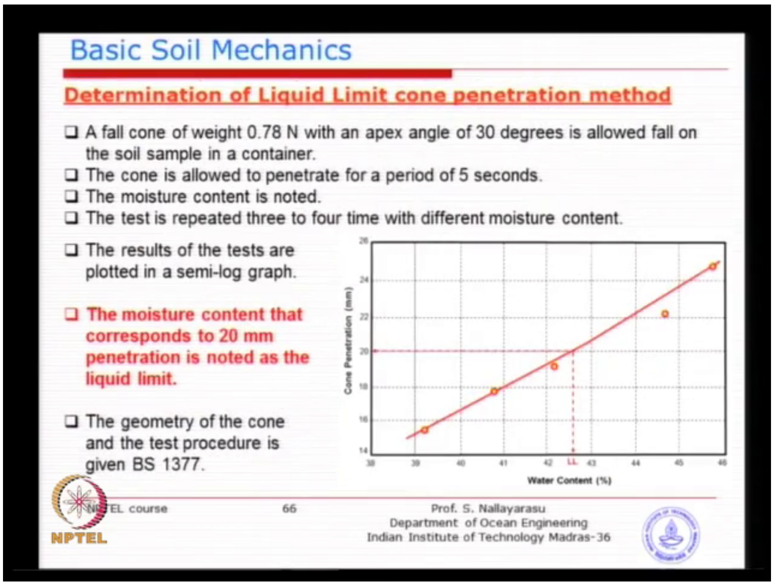

Basically you just repeat the test a few times with different moisture content. So you will have different fall cone penetration and put it in a graph, then you just look at the moisture content corresponding to 20 MM of penetration will be liquid limit. Similarly when you come down to Casagrande method, you will also repeat the test a few times by changing the moisture content, that means you will add water and then you plot in a log semi-log graph and you find out what is the moisture content corresponding to 25 number of blows and basically that will be your liquid limit.

So finding out the liquid limit is very simple idea, you take the original soil sample, do the test and take the sample, reduce the moisture content or increase the moisture content on either side and then do the test also, then you plot it and you find 25 blows corresponding to moisture content will be your liquid limit or if it is a fall cone, 20 MM penetration corresponding moisture content will be your. So these are just very simple idea is to find out how much moisture content corresponding to either 25 blows or 20 millimetres of penetration.

So these procedures are actually given in this ASTM D-4318, of course you will also find in some of the IS codes, I could not pick up the Indian standards but I think it will be there somewhere. But most of the after applications, we use ASTM for marine situations, whereas IS codes does not talk about.

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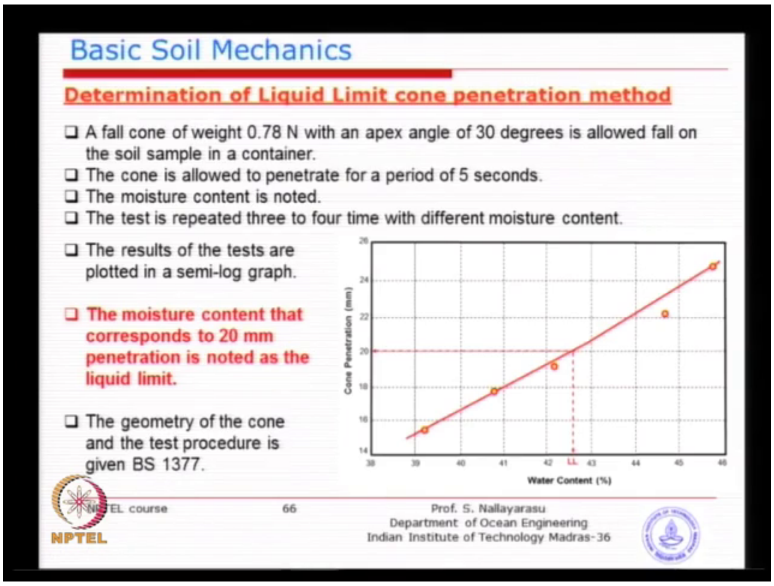

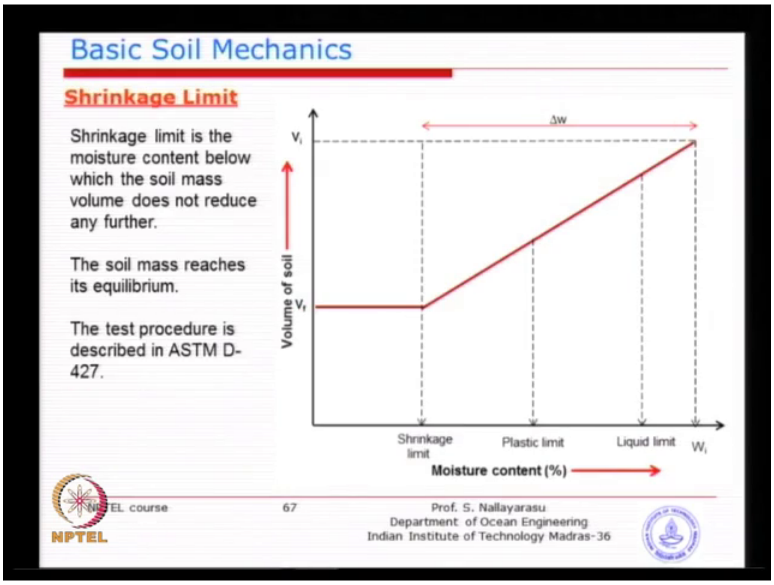

Similarly for the fall cone procedure you have BS 41377, its complete procedure and the fall cone weight and basically the apex angle, number of times to repeat, quite a number of procedures are given, you just strictly follow that. So liquid limit is very straightforward, similarly we can find out the shrinkage limit. I think we saw on the left side of the various states of the soil, as much you keep reducing the water content, beyond certain water content or moisture content, what will happen is the soil volume does not change.

So you can see here from liquid state to a semisolid state and to a solid state, certain moisture content still will be there but the volume will not reduce, that is called a, beyond which the soil's state will not change much, that is called the shrinkage limit. The procedure to find out is given another ASTM code which is basically similar to the liquid limit test. Plastic limit determination, you know historically people have been using this idea of rolling on the finger on the Palm.

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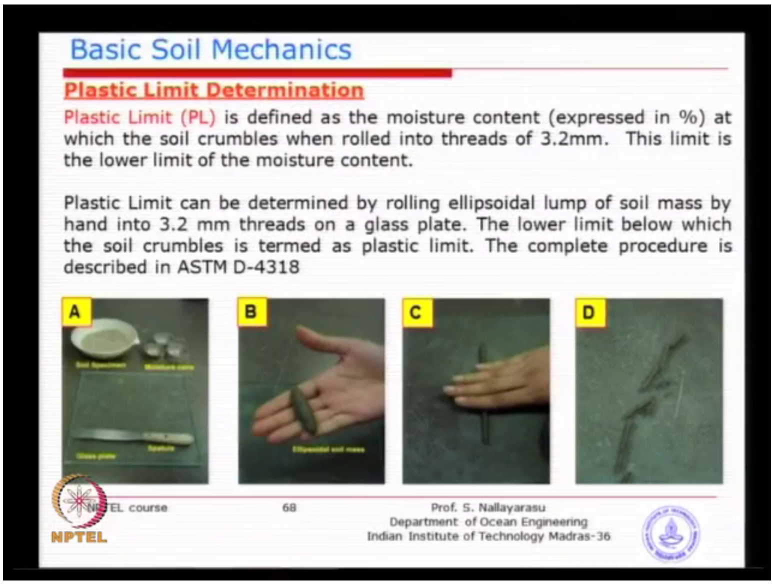

So plastic limit is moisture content which soil crumbles when rolled to a particular diameter of 3.2 MM as a thread, you just keep doing it, beyond which, so if it is a liquid state you cannot roll, if it is too much of a solid state, you just roll, it will just break, it does not have sufficient water content or moisture content. So you just have to repeat it, so until, you can see on the right-hand side, it crumbled. So this is little bit troublesome method because it is not very easy and it is time-consuming. But the procedure is acceptable as the ASTM gives you this also I think you will find in other course.

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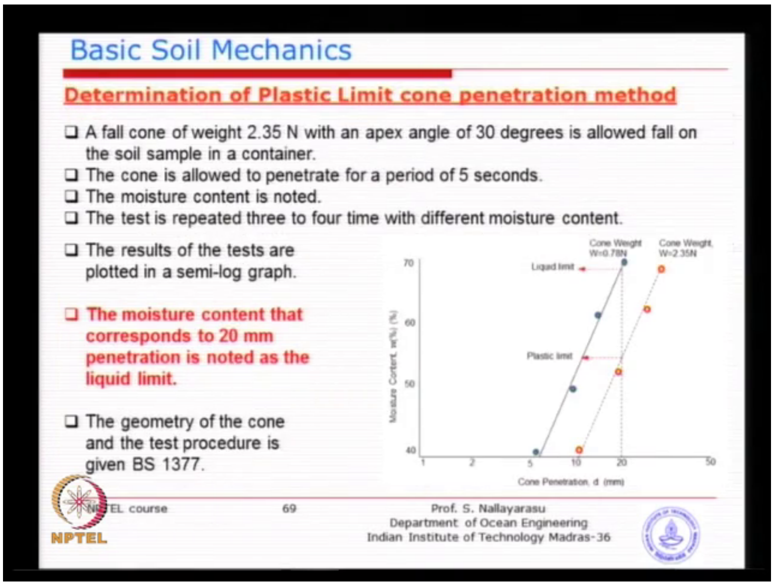

One of the alternate method was, you know this fall cone method was also devised to find out the plastic limit, exactly same procedure as liquid limit, only thing is the weight is slightly bigger. You see here instead of 0.78, I think that is what we were having, you just increase the weight of the fall cone to 2.35 Newton. And basically will repeat the same procedure few times and you can see here there are 2 graphs, one is the black colour one which is cone weight is 0.78 Newton, on the right-hand side you see the cone weight is 2.35 Newton. And basically this 20 MM gives you the liquid limit and the same 20 MM in the other graph gives you the plastic limit.

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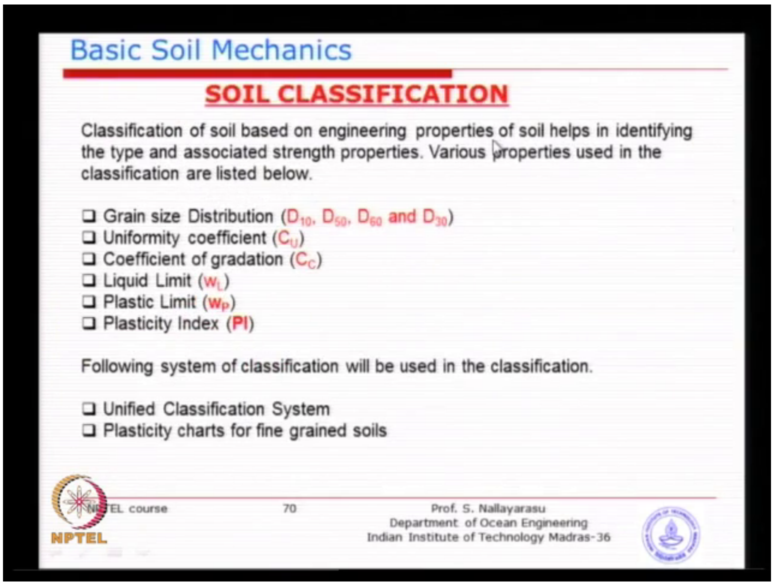

This seems to be a very simple procedure compared to the roll and thread method is basically little bit difficult. But of course if you are experienced enough is not a big deal to do it, basically you can get it done. So why do we needed all these parameters, we started yesterday with all these grain sized distribution, percentage passing through 10 percent, 20 percent, 50 percent, 60 percent using D 10, D 60 and D 30 we were trying to find out uniformity coefficient, coefficient of gradation. So for coarse-grained soils we have few properties which we were able to vitamin very easily.

Similarly for you know the cohesive soil or fine-grained soil we were able to find out liquid limit, plastic limit and plasticity index. With this we can actually find out whether the file is going to behave in which has the predominant way. In natural state you may have sand, clay and mixture, so if it is predominantly sand, you will try to jump to some particular parameter of interest. Whether you want shear strength, we want something other parameters, how do we determine. So basically once you get this information, you can decide what type of test you want to do, whether I want to do a test in situ because the soil is too much of coarse-grained.

Even if I try to take samples from the soil, it is going to be disturbed. It is going to be remoulded, so when I do the test in the laboratory, I am not predicting the right strength because it is already reorganised. As you know very well when the soil particles are repacked, strength will be different, then the foundation soil is in the natural state is going to offer a different strength than what the strength we are arriving at the laboratory. That is why these are some of the very initial tests, quickly do it, then we can get some kind of decision made.

Of course experienced people will be able to make, even at the look, even before you do this, you will be able to decide, I need to do feel test, I cannot take the sample because the sample is going to be getting disturbed. So that is the idea behind getting these parameters, preliminary or primary parameters. We will only look at the soil classification by Unified classification system and the plasticity chart. Though, if you look at the literature, you go to Textbooks, you will find variety of classification ideas, but almost similar, what you see here is almost very close to every one of them.

Even if you look at IS codes, they have followed unified system, so it is not a big change. So these are some of the parameters you will see, some of the tables which I have taken from Unified classification system, we will be using we will be using these parameters to decide whether it is a sand or clay or part of them.

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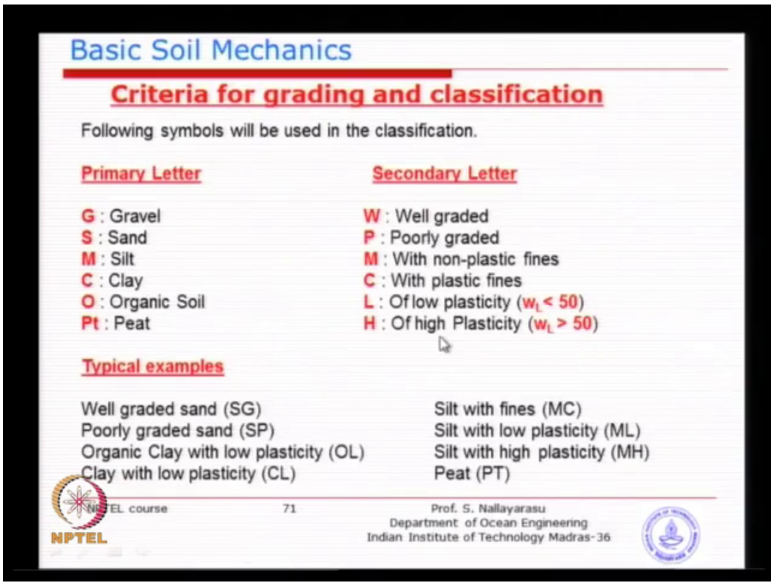

How do we classify is basically a simple idea, noticed this because it is repeated writing, it is not very easy to remember, if you just remember these letters, it is easy to go and find the name of the soil. So you can see here G for gravel, sand, M for silt, little bit because it is repeated, C for clay, organic soil, peat. On the right-hand side the secondary, you know basically grading, the 1st 2 of them are well graded, poorly graded, so W and P, which is very easy, which is what we saw in our several graph in the sieve analysis is well graded throughout the spectrum of particles, you have the percentage passing through.

Poorly graded, some of them are missing or gap graded. And then with respect to how much is fine content, you know basically non-plastic plastic but of course with moisture content. And plasticity, high plasticity or low plasticity, you can see here is the liquid limit less than 50 percent or greater than 50 percent gives an idea whether it is going to be highly plastic or not. So these are some of the parameters which will be added to the primary classification which is sand, clay and silt. Of course you know the gravel, very rarely you get into, it is the natural state of the soil, very rarely, because you will find only very small fraction.

So typical example will be, for example you see here well graded sand, poorly graded sand, organic clay with plasticity, low or high, similarly silt with fine, silt with low plasticity. You can just, so this is what is the description, if you actually have sufficient experience of doing feel studies, you do not even need to actually know all these parameters. Straightaway somebody can write, this is definitely a kind of soil, poorly graded because I can see from there. Sometimes it may go wrong if you not able to do it properly. So that is the idea behind, so if you look at this table, how do we classify, there is a requirement table, you can see here coarse-grained soil, fine-grained soil, I will just take 1 minute to basically explained here how do we determine.

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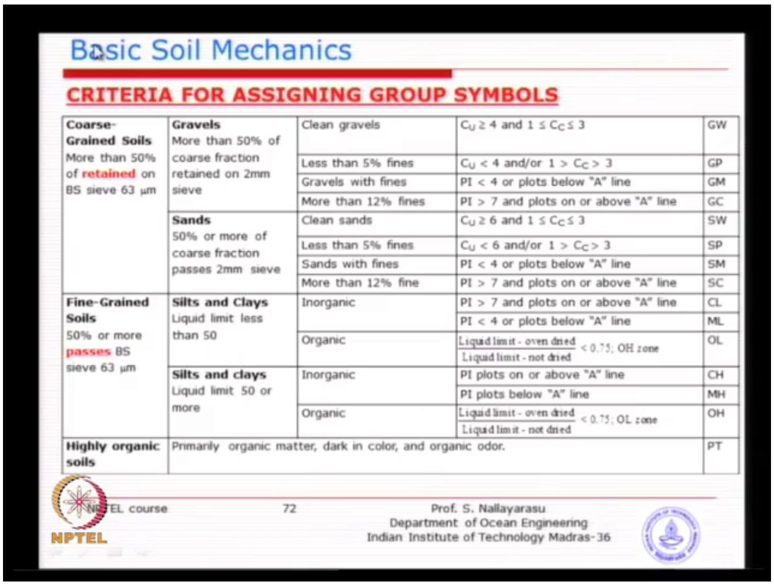

How much percentage, in order to go with the coarse-grained soil, the coarse-grains must be higher than 50 percent. For example you take a natural state of soil, pass through your sieve analysis for a demarcation of to be in coarse-grained soil, we need a more than 50 percent of coarse fraction retained on 2 MM sieve. So you can see this is a, it is not hundred percent we require, so remaining can be any fraction below that particular size. So that is what they have followed, in addition you also have several other parameters like to see here the uniformity coefficient to be in this order, so you can put well graded gravel.

So basically that is the idea behind, so these are some of the parameters set, so when you are doing a soil investigation for your site, you will take this table and just meticulously go through, but beforehand you will have to have these parameters. Do all these sieve analysis and consistency experiments, bring the parameters to this table and try to, you do not have to remember all these numbers because it is anyways available everywhere. But very important thing is to be a coarse-grained soil to be classified in this particular group, you need to have minimum 50 percent or higher coarse-grained particle sizing.

Similarly you see here fine-grained soil, 50 percent or more if it passes through this particular sieve size, then 63 micrometre, then you will be classifying under fine-grained soil because Predominantly fines, predominantly coarse grains. So that is the most important one unit remember, what is the percentage is higher than 50 percent. Whereas all these parameters you see here, one is uniformity coefficient, you have plasticity index and then coefficient of gradation, all these will be used to divide the sub classification of the soils among the coarse-grained or in the fine-grained.

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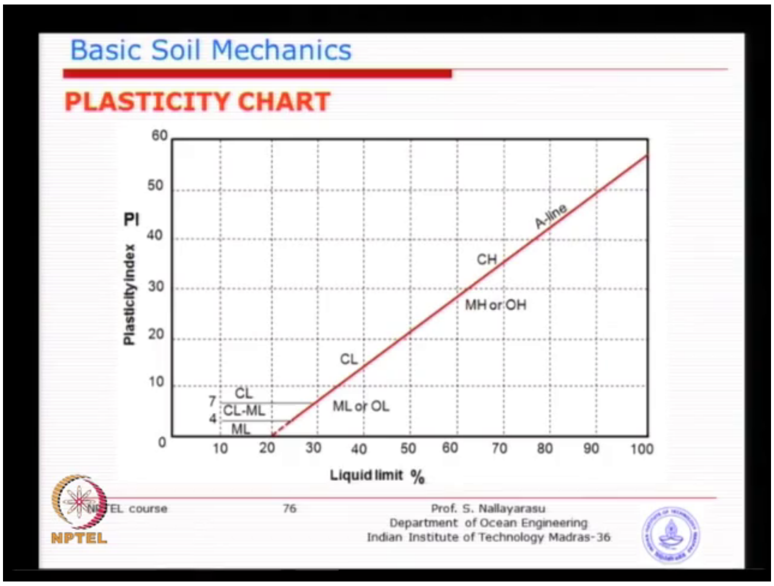

And some cases whenever you actually have plasticity index, you may not be able to directly classify, you may use help from this particular chart which is called plasticity chart, which is giving relationship between the plasticity index on the one side and the liquid limit percentage on the other side, the demarcation is given and the notations are given there. So you will classify the fine-grained soil using this plasticity cart. The idea behind classification have already explained, the reason why we need to classify, I think most of you should remember, the classification does not directly give any strain parameter.

The reason we need to know what type of, where it adhere to, is to use the literature and the past reports and studies so that you can extract some of the design parameters without doing any further field testing or even if you do field testing laboratory testing to your soil, you can always compare with what others have got. Because the uncertainty involved in soil sampling, bringing to the laboratory, carrying out the test is very high. So if you do it yourself, + based on the classification you go to literature and compare where do you stand, whether something reasonable or something unreasonable.

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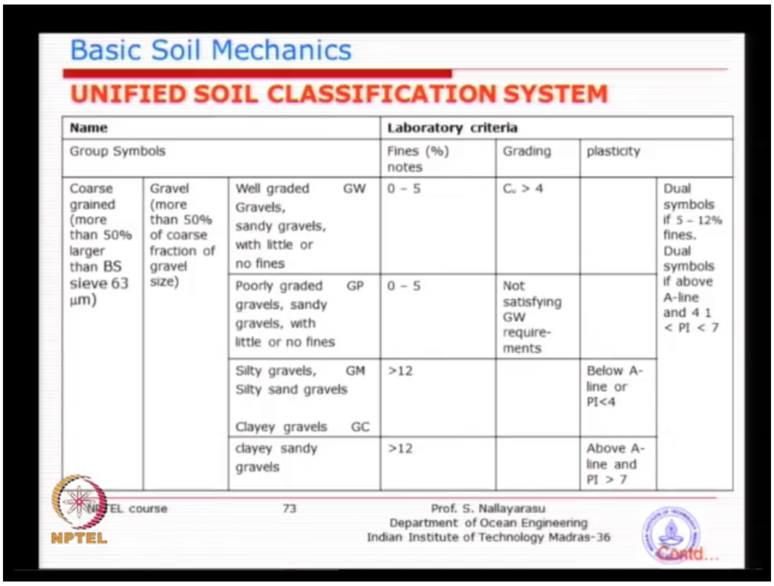

Name			Laboratory criteria			
Group Symbols			Fines (%) notes	Grading	plasticity	
Coarse grained (more than 50% larger than BS sieve 63 μm)	Gravel (more than 50% of coarse fraction of gravel size)	Well graded Gravels, sandy gravels, with little or no fines GW	0 – 5	$C_u > 4$		Dual symbols if 5 – 12% fines. Dual symbols if above A-line and 4 1 < PI < 7
		Poorly graded gravels, sandy gravels, with little or no fines GP	0 – 5	Not satisfying GW require-ments		
		Silty gravels, Silty sand gravels GM Clayey gravels GC	>12		Below A-line or PI<4	
		clayey sandy gravels	>12		Above A-line and PI > 7	

So always you will be doing that comparison that is why this classification helps a lot because we can refer to the past literature. So basically do is, this table is a criteria table by which you will go by one by one and I have elaborated in the next 3 slides, just slightly taken into details, again coarse-grained and fine-grained, with sufficient information on percentages of fines, grading and plasticity. Wherever the plasticity is (())(19:36) you have to go and use the plasticity chart to get the sub classification. So there will be 3 pages, I do not think we need to repeat that, you can just follow through as you want to classify.

So if you are given some of the parameters, for example percentage fines, percentage coarse-grained particles, plasticity index or you know basically CU or CD, CU or CC, you should be able to enter into any one of these tables and try and classify yourself. Now what next we want to do is look at soil mass as three-phase, you know basically solids, you may or may not have water and you have voids with air.

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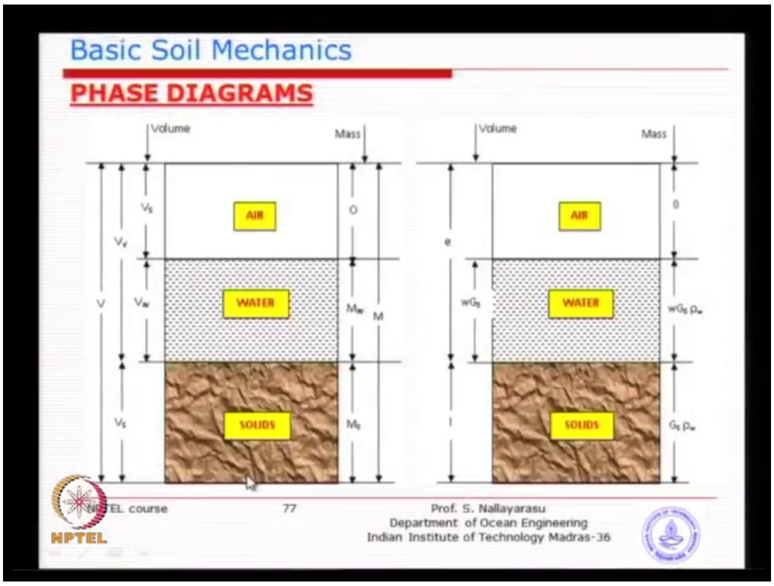

So basically will want to see some of these relationships between, so if you take a soil sample from natural state, you will have solid particles, you might have voids or you might have full of water depending on whether it is fully saturated soil or partly saturated soil. So as we mentioned yesterday most of our subsoil conditions in offshore you will have fully saturated condition. So basic idea is, so this relationship will help us in relating several parameters of interests, especially the bulk density, I think that is what we are looking at, density plays a major role, yesterday we were looking at. 2nd thing is you know the amount of water, out of voids, also going to give us an understanding of how that deformation of the soil is going to happen and that is what we need to know.

You take a soil, bring into the laboratory and do the testing to weigh the weight of solid particles alone, total weight, moisture content and then state of you know the voids inside the soil mass. So this basically, you see this diagram, VV is the volume of voids, basically together with the air and water. So that is where the water is content, so total volume is noted as V and volume of solids, I think this must be VA, this is little trouble there. So VA, VS and V, these are 3 and VW is basically the volume of water. You can express this in terms of weight instead of volume, we also can use that diagram, either way it is going to be same.

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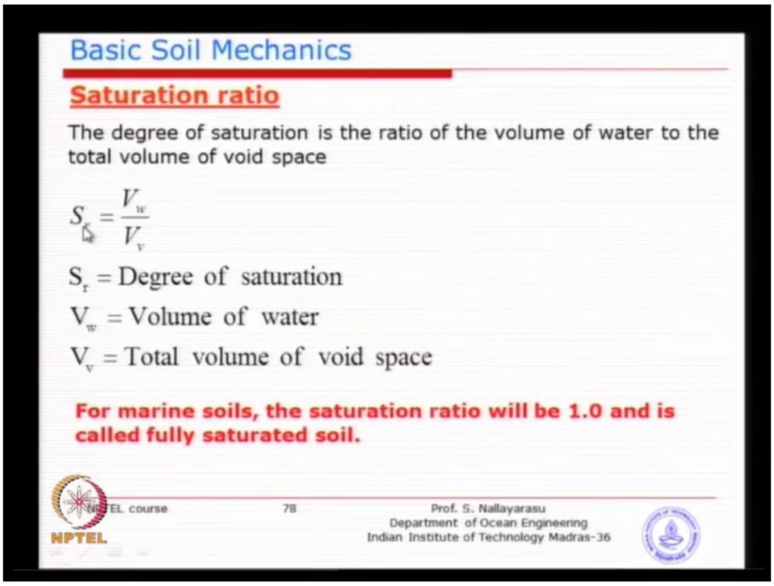

Some of the simplest thing is the saturation ratio, fit is 100 percent saturated the volume of voids is fully filled with water, and we basically, so VW by VV, both of them are equal, that means it is. And partly means volume of water is going to be less than volume of voids somewhere. So it can vary from 0 to 1, so this ratio gives you saturated soil, partly saturated soil or dry soil.

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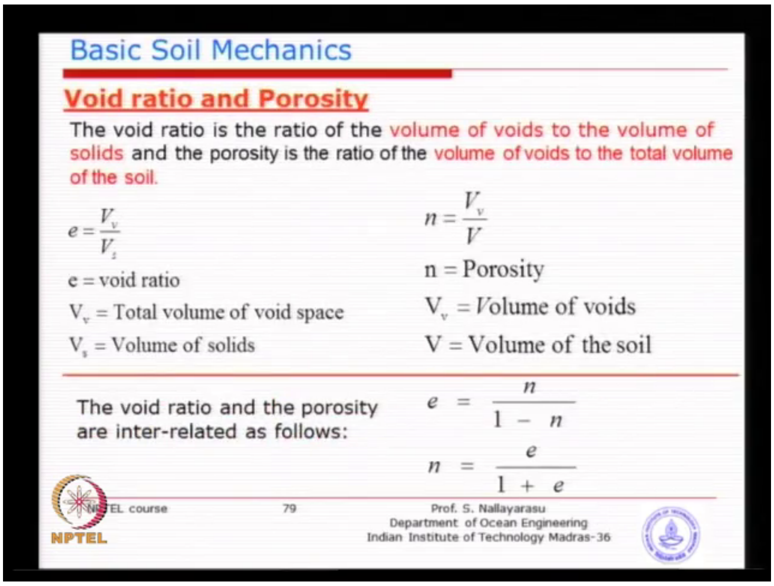

You know, so basically and the next thing what we want to look at is the voids ratio which is basically the volume of voids the volume of solid, honeycomb structure you know basically. And then the porosity is denoted as, I think you should be little bit careful about this n because n is also used elsewhere in some other places but of course you should remember according to the notation wherever it is used. Here we are just using n as volume of voids to total volume will be the porosity. So you can see the ratio of voids total volume here voids to solids, so you get slightly different, you can also combine these 2 to get one from other.

So it is basically the relation between, you can substitute into. So the voids ratio can be calculated once you know the porosity or you can calculate the porosity if you know the voids ratio, it will be very very useful. So what do we gain from here, if the voids ratio is larger, there is no good, is not it, you know that is that is exactly loose soil. If the voids ratio is smaller is better, that means solid particles are more, so that is basically the idea to get the deformation characteristics, later on you will see that. And more the voids, more amount of water will get filled in, you know if it is saturated soil, that means soil will almost like a floating and it may behave very like a fluid flow around when you apply the loading, so that is the idea behind.

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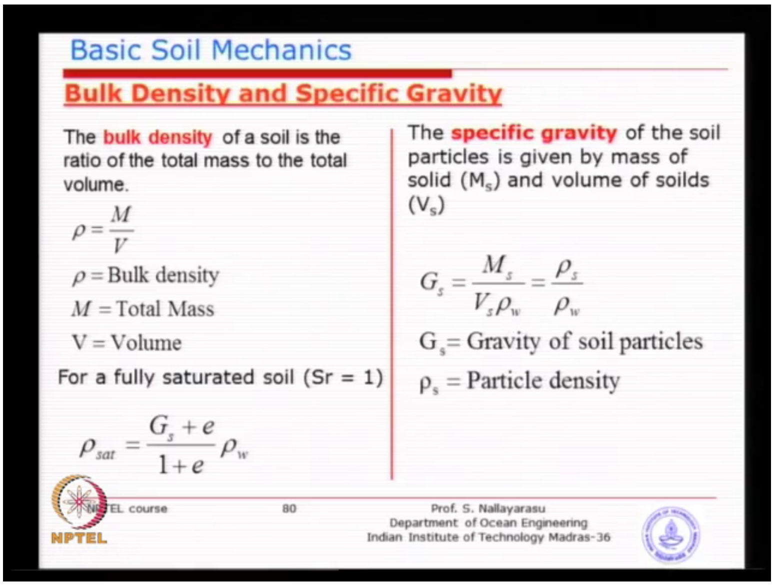

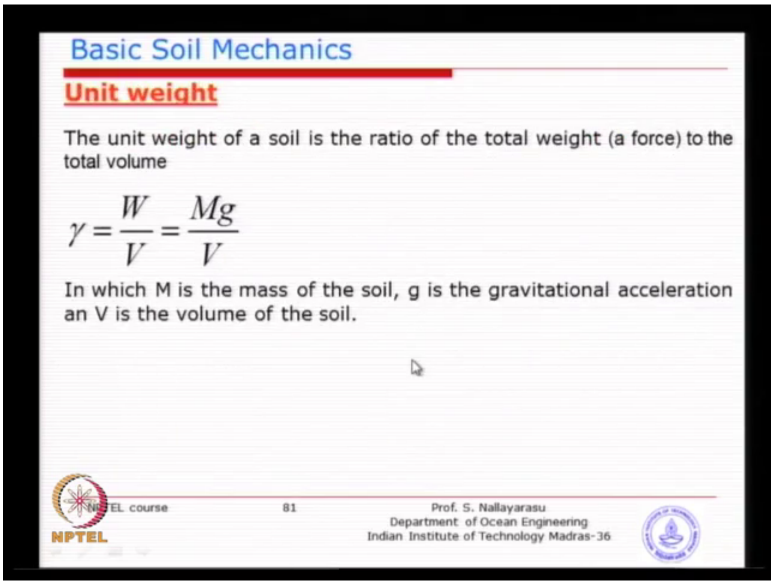

The next parameter we are looking at is the bulk density, total mass divided by total volume which is very easy to find. The next one you can also express that in terms of its gravity, so total mass of solids alone divided by volume of solids into density of water. You can express in several ways, like for example saturated soil is full of water, so basically to get an idea the bulk density. The most interesting or the important one for us for foundation calculations is the weight density, not the mass density or the unit weight.

It is weight by volume which is very easy also to get, bring the soil sample and weigh it in natural state and find out the volume and basically can express in terms of mass times gravitational acceleration if you have mass, or if you have the weight, you can calculate the mass by dividing by 9.81.

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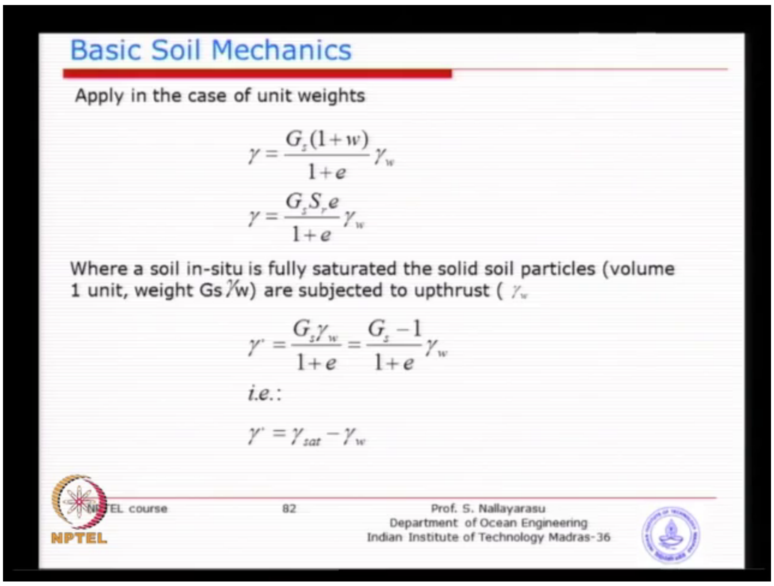

Also you can write in other forms by substitution of specific gravity, which I think most of the times will be very useful, from one you can find out the others. And for us, the most important one is the last the saturated state of soil is always going to be there in offshore conditions. So we want to find out the effective unit weight which is basically - the buoyancy of the particles displaced by. So basically you deduct the density of, weight density of water which will be the net, which will be going downwards.

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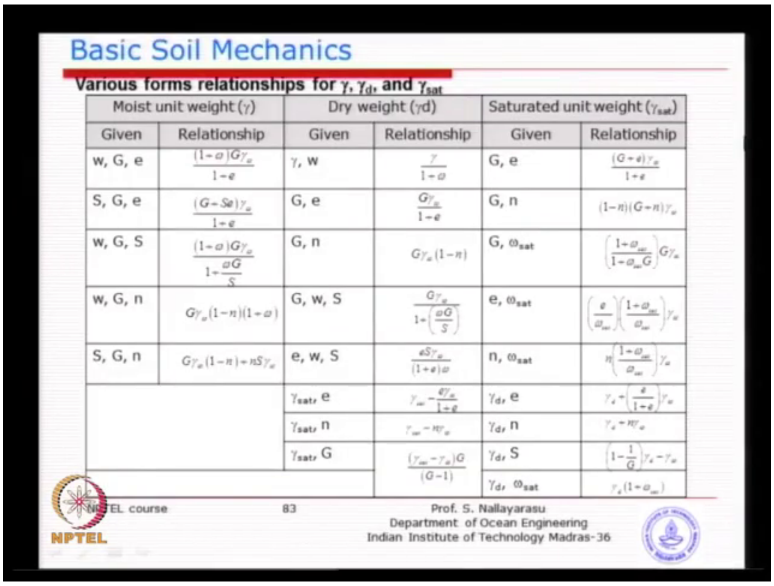
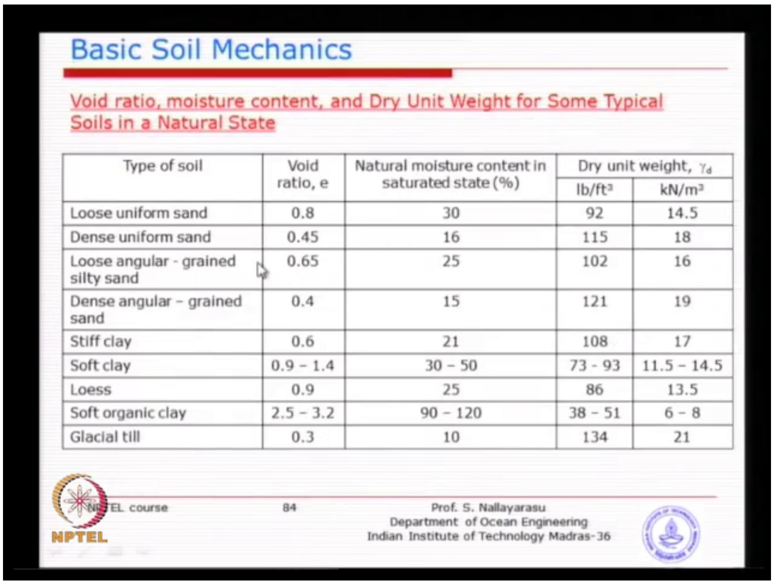


Moist unit weight (γ)		Dry weight (γd)		Saturated unit weight (γ_{sat})	
Given	Relationship	Given	Relationship	Given	Relationship
w, G, e	$\frac{(1+\omega)G\gamma_w}{1+e}$	γ, w	$\frac{\gamma}{1+\omega}$	G, e	$\frac{(G+e)\gamma_w}{1+e}$
S, G, e	$\frac{(G+Se)\gamma_w}{1+e}$	G, e	$\frac{G\gamma_w}{1+e}$	G, n	$(1-n)(G+n)\gamma_w$
w, G, S	$\frac{(1+\omega)G\gamma_w}{1+\frac{\omega G}{S}}$	G, n	$G\gamma_w(1-n)$	G, ω_{sat}	$\left(\frac{1+\omega_{sat}}{1+\omega_{sat}G}\right)G\gamma_w$
w, G, n	$G\gamma_w(1-n)(1+\omega)$	G, w, S	$\frac{G\gamma_w}{1+\left(\frac{\omega G}{S}\right)}$	e, ω_{sat}	$\left(\frac{e}{\omega_{sat}}\right)\left(\frac{1+\omega_{sat}}{1+e}\right)\gamma_w$
S, G, n	$G\gamma_w(1-n)+nS\gamma_w$	e, w, S	$\frac{eS\gamma_w}{(1+e)\omega}$	n, ω_{sat}	$n\left(\frac{1+\omega_{sat}}{\omega_{sat}}\right)\gamma_w$
		γ_{sat}, e	$\gamma_{sat}-\frac{e\gamma_w}{1+e}$	γ_d, e	$\gamma_d+\left(\frac{e}{1+e}\right)\gamma_w$
		γ_{sat}, n	$\gamma_{sat}-n\gamma_w$	γ_d, n	$\gamma_d+n\gamma_w$
		γ_{sat}, G	$\frac{(\gamma_{sat}-\gamma_w)G}{(G-1)}$	γ_d, S	$\left(1-\frac{1}{G}\right)\gamma_d+\gamma_w$
				γ_d, ω_{sat}	$\gamma_d(1+\omega_{sat})$



Type of soil	Void ratio, e	Natural moisture content in saturated state (%)	Dry unit weight, γ_d	
			lb/ft³	kN/m³
Loose uniform sand	0.8	30	92	14.5
Dense uniform sand	0.45	16	115	18
Loose angular - grained silty sand	0.65	25	102	16
Dense angular – grained sand	0.4	15	121	19
Stiff clay	0.6	21	108	17
Soft clay	0.9 – 1.4	30 – 50	73 - 93	11.5 – 14.5
Loess	0.9	25	86	13.5
Soft organic clay	2.5 – 3.2	90 – 120	38 – 51	6 – 8
Glacial till	0.3	10	134	21

I have just summarised from various places, a table containing which parameters can be calculated if you have some of the parameters among these 6 or 7 parameters what we have got, which will be very useful when you do not have something, you can calculate the others. So you just have list of equations. Just to give you an idea what kind of numbers we are looking at, for example if you look at loose sand, wide ratio is as much as 0.8 and if you have stiff clay, soft clay, you can see the parameters also, nearly 1, 1.4. Moisture content, you know when you look for something like this, it is very useful because when we do not have data, you will always, when you have description, loose sand, I want to find out what is the property.

So you search for several places, this type of collected information will be very very useful. And in terms of weight, also you can see almost every one of them is less than 20. And if you look at the dense sand, it goes very close to 18 kilo newtons per metre cube, very close to concrete, concrete is around 20, 22-24. So you could see the dense sand versus loose sand, the major difference in density. Similarly you look at the stiff clay versus soft clay is almost similar, 14, 13, 14, so stiff clay goes almost closed or, so stiff clay means void ratio will be slightly less, for sure well packed, particles are closer and therefore you have the strength wise better, density wise better.

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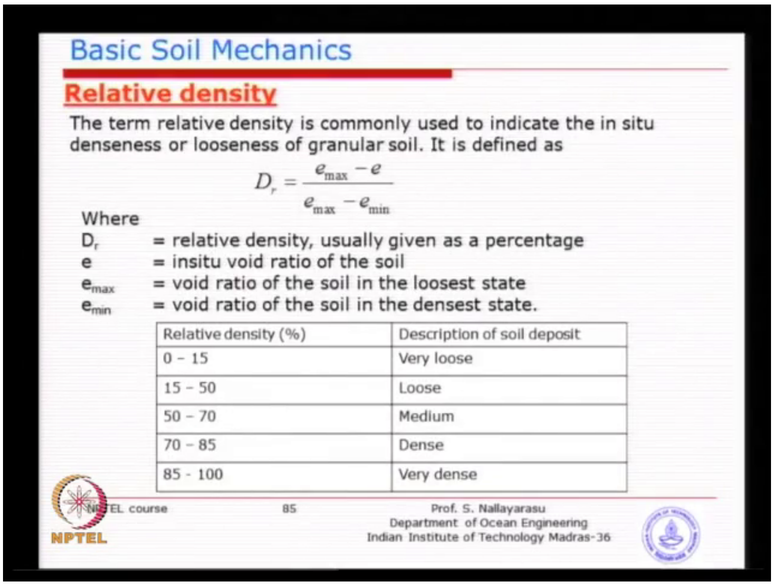

So all these, you know it is indication of the type of characteristics, so either from here you try to assign properties or from the properties you can compare and say this is this type of soil. The next one, basically for coarse-grained soil is the relative density, very commonly used in the foundation design. You know you take a natural state of soil, you find out what is the voids ratio and note down and try to rearrange the particles to a loosest state or the densest state and that will give you an idea of the maximum voids ratio possible. For example you want to take the particles to the loosest state, it has to coexist as the soil mass, you do not want to take the particles separately, that will not be a soil, is not it.

The loosest state means, state will be a particular state of soil which has got largest voids. The densest state is try to pack by means of disturbing it, that means you will neither vibrate or reorganise, that will be the minimum voids ratio. So you can see here, in relation to the maximum and the minimum voids ratio or the state of the soil, we try to find out the relative density in terms of percentage close to lose state or percentage close to dense state, that is called the relative density. How dense in relation to the densest state or how close it is close to the loosest state is called the relative density.

This is very very much, very useful, especially in made-up soils, some places like reclamations or in fact when you are making roads, we will use this terminology because we want to compact it and we want to compact as word is possible to densest state and that we need to specify, say relative density of 100 percent means it is a solid, there is no voids. So you have to take one particle by one particle and organise to get the such a densest state which is practically not feasible. That is why relative density of 70 percent is very good, 80 percent, maybe very good but difficult to achieve, whatever packing you try to do, you will not able to do it.

So that is exactly the idea behind, you will not reach 100 percent relative density, unless if you are able to get all sizes of particles within the soil mass when you actually vibrate, the smallest particle will go into the voids of the biggest particle, almost you will get 90 percent, 99 percent. So that is the idea behind this relative density, predominantly used for coarse-grained soils, especially sandy material where you are trying to do you know compaction, densification, reclamation projects, roads and in some cases even foundations we actually dig out the ground, if the soil is no good, bring in the foreign soil and compact.

So your immediate layer, whenever you find the loose soil, soil replacement projects, you know replace it with a good soil and then you start constructing your foundation. Mostly on open excavated foundations, not on pile foundation because you definitely cannot dig to that depth. So this relative density is an interesting characteristic which you will find it later will be related to several tested parameters. In this case the state of the soil is described and the relative density is given here. So you see this table loose 0 to 15 percent, that means lots of voids, loose, very loose, medium and dense and very dense.

So you can use this and later you relate this, this with density, people have done studies in various locations, loose means density is a 10 to 11, very dense, 18 to 20 and with that 2 information you can also relate that to some of the strength parameters like angle of repose.

Yesterday we were seeing loose soil goes flat, so angle will be less than 20 degrees. Dense sand can go as much as to 30 to 40 degrees, 45 degree. So you can get that table inserted, will be very useful, as soon as you get your density of the state of density, then you can find out the strength parameters. So that relative density is in relation to the densest state of the soil to the closest state of the soil.

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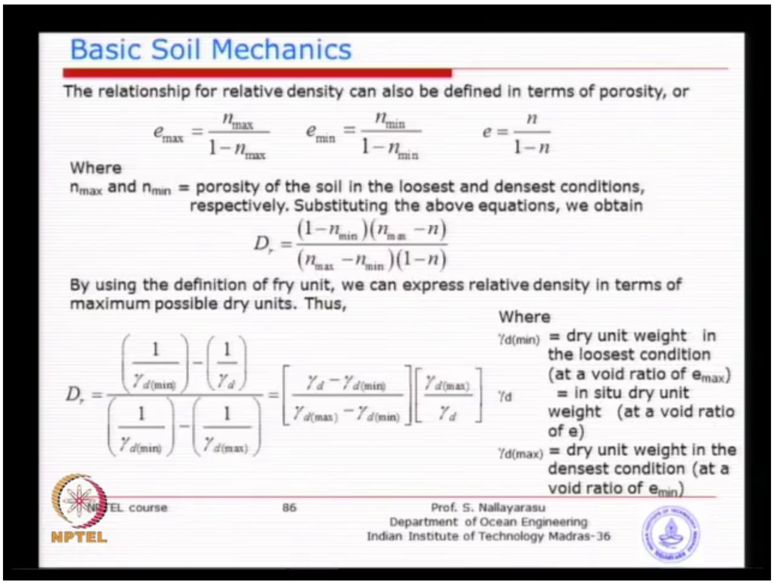

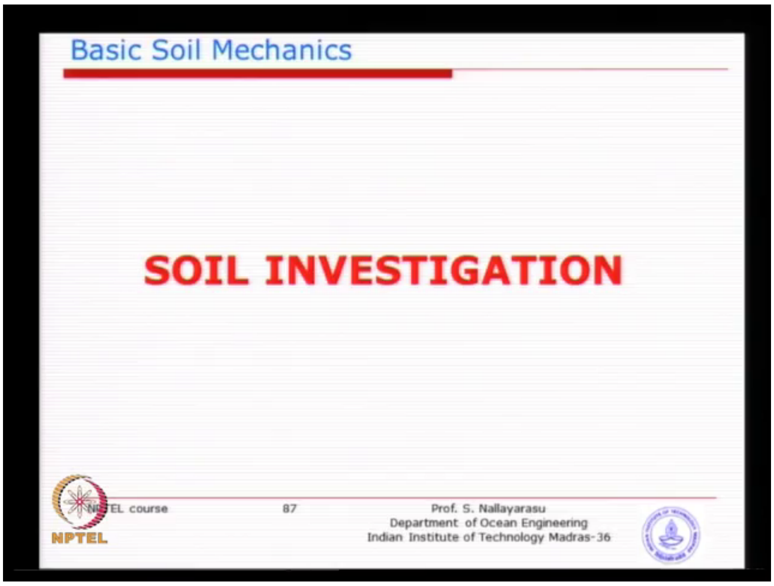

Some of the parameters, you know you can substitute with respect to voids ratio or porosity and relate them so that once you have the parameters you can find out the relative density which is of some use but not very much important. So I think we will try to summarise what we have understood so far is basically from soil particles of shape and size and formation to coarse-grained and fine-grained, properties, we were just picking up see of them. Actually I gave you several of them which were not related to foundation design and basically I identified only some primary parameters like fines, percentages passing through which will describe the particle sizing, sieve analysis, coefficient of gradation and coefficient of uniformity for coarse-grained material.

And we went onto plasticity or so-called plasticity index from liquid limit and plastic limit and the way to determine. So one of the method was crank and cup method, the other one is fall cone method. For plasticity or plastic limit, we will have either the fall cone method or you know basically the 2nd method for plastic limit is the thread you know and then plasticity index. Using these 6 parameters we were able to go into criteria to classify, unify the classification system, coarse-grained, fine-grained. So this gives you an idea soil is that much, what we have not actually gone through is how do we do it and where do we do it is basically is called soil investigation.

So every time you plan a construction of structure either on land or on offshore, the 1st thing is you carryout subsurface investigation, sometimes we call it soil investigation, geotechnical investigation. Trying to find out the strength of the soil as much time you have spent enough time in designing the structure with respect to strength and responses, you also have to investigate to the soil. So we need to basically spend some time so that you can decide the structure type. I think in the design course itself we were looking at, the soil type can change completely the configuration of the structure, whether it is onshore or offshore, does not matter recall ultimately the loads have to go to subsurface.

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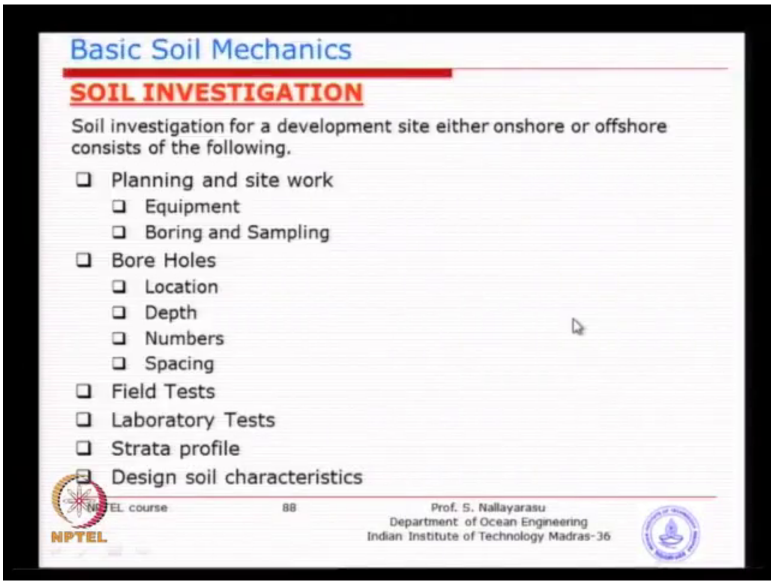

So soil investigation is all about trying to determine the characteristics of soil so that it can be used for load transfer from superstructure to substructure, substructure to soil. So the whole soil investigation you know it requires considerable effort, in fact reasonable effort in planning, you need to determine what type of equipment is required. If it is sandy soil, some type of equipment for picking up the soil, if it is a clay type of soil some other type of equipment, if it is rock, definitely both of them cannot use, you need a core drilling because it is very very hard. And number of samples is very tricky, the more is better always but then the more also expensive and time-consuming.

So we need to determine how many is good to actually profile the soil at the site. How many in one location and how many at the site, for example if you have a site of 1 kilometre by 1 kilometre, 1000 metres by 1000 meter a plant, onshore plant and you have structures spread all over, so many places, so how many of them you need to do, there is no rule book, this is one of the biggest problems. It is left to the engineer's decision because engineers only is the best person to assess how many is required for each structure how many is required for profiling the whole site so that anywhere you can construct.

The best will be for the engineer to make a decision that every structure will have one at least, that will give an idea. But within the structure if the foundation is so large, for example you take one building in the site, 1 kilometre site but one building is 50 metres by 20 metre, whether I will do one bore hole at the centre of the building or I will do 4 of them at the corner or I will do 4 of them one side, 4 of them other side, 2 of them another side, nobody is going to tell us. So which we need to make assessment based on the variability of the soil at the site. If the soil is nightly uniform, you will do one here, you do 1 kilometre away, you will also get the same type of properties, same type of layering, then there is absolutely no reason to go and spend too much of time.

Probably what we do not know is within that like the mall or the Centre, whether it is going to be same size or not, that nobody can say. So unless you have more than 2 or 3 and try to profile, the profile seems to be good, that you may actually take a decision not carry out too many. But if the soil varies, then you really have to spend a lot of time. This planning is the tricky exercise, especially large plants, large construction sites. But offshore projects not a very big problem, at least for platform projects because platforms are not that much longer, you know larger spread, it is going to be a smaller footprint on the seabed.

So normally we plan one at platform, which itself is sufficient. If you have doubt, probably you can do a verification by doing one more in another corner, but typically for offshore projects it is one at each structure location is well represented. But for pipeline projects is a big challenge, I think you might have heard of this subsea pipelines, when you have a pipeline coming from land to offshore platforms, you have several thousand kilometres. Now will you do one or will you do thousands is the biggest question the cause the pipeline is going to sit on seabed. But vulnerability of these pipelines failure due to soil is very less because the loading is quite small, sub is going to be transferring through the surface soil.

So you do not need to go deeper foundation holes or deeper geotechnical investigations, maybe a shallow is good enough. But as much shallow, the number of them will be larger, if you have 1000 kilometre pipeline, imagine how many of them you have to do. Even if you do one per kilometre, is not it, you have to do 1000 bore holes, so then also you have to spend kind of good planning to determine how many of them is required in a stretch. So you need to analyse the variability, in many occasions we do actually a borehole at wider spacing 1^{st}, look at the variability, then determine intermediate bore holes.

So this kind of planning is always, so requirement of equipment in boring has to be determined based on geological formation types. You know if you look at the history of this particular area is belonging to this particular type of you know geological formation full source based on which you will be able to say predominantly clay on 1^{st} layer, predominantly sand on 2^{nd} layer, historical information based on which you will go and provide for type of equipment. Borehole location, depth, number, spacing, I think is a very complex scenario for onshore projects, whereas for offshore and pipeline projects, it is very much well determined.

And you have choice of doing test is a site itself which is called the field test or you bring the soil in an undisturbed state and do a laboratory test which is commonly used. And then you can determine the strength parameters in addition to what we discussed so far, you know the grain sized distribution and the consistency limits and additional density parameters + the strength parameters, all of them can be done in the laboratory. Then use that to profile the soil to a particular layering, you know how the changes happening.

Then from this you can find out what is the design soil parameters advice to the engineers to use that for foundation design. So the whole process is very much essential without which you cannot really design the foundation, we will look into details of each one of them.