Geotechnical Engineering I
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Lecture-09
Soil aggregate and phase relations

Now I will start quantifying the soil matrix or soil aggregate.

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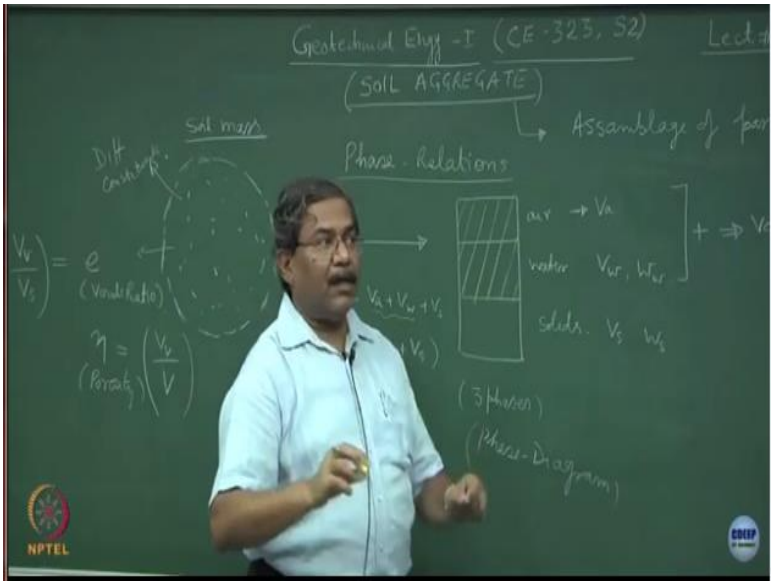

So, this is a new topic soil aggregate basically this defines the description of the assembly of particles. And from this point onwards, the quantification of the soil matrix starts, we also call this as phase relations. Now simple thing is that if you have a soil mass I am sure you must have realized that now I have switched over from discrete particle of the soil to soil mass. As the first time I am using the word soil mass or the matrix of the soil until now I have been dealing with mostly discrete particles, grains.

Now, I am talking about the soil mass, so this file mass contains all the constituents which we have talked about alright different constituents. Now suppose if this soil mass has the volume of V and weight W, capital W. Now this can be depicted as a system of 3 phases and these 3 phases are it is an assumption, simplification. So, this is the air phase, this is the water phase for the sake of the simplicity for third year students of soil mechanics, geotechnical engineering,

I am talking about simple fluid phases water and air, tomorrow if you want to manipulate it to a multi phase system, you can do that air might behaving vapors you know fumes of different chemicals and so on. Water could be in semi frozen form, liquid form, vapor perform of course which constitutes again the air space alright. And the solids we have talked about the air phase, we have talked about the water phase, we have talked about the solid phase, individual particle of the grain is incompressible, clear.

Now, if you do this type of mathematical modeling this becomes district modeling you are considering each and every particle in the continuum. Continuum is the one which is a continuous system containing several millions of particles of the soils clear. However an assemblage of the grains is going to be compressible clear. So, it is a very tricky material, sometimes we talk about the incompressible grains but now the matrix of the soil mass is going to be compressible, is still we assume that this solid phase is not going to be comprehensible as compared to water which is totally incompressible.

And air which is going to be comprehensible at not STP standard temperature pressure. So, this is going to be you know, getting compressed if you elevate the pressures. Under STP, we assume that air phase, water phase, solid phase is the way it is. Now to differentiate these what we will do is, this is what is known as the 3 phases or the phase diagram where the research is. The research is somewhere like if I want to make it a multi phase system.

So, in multi phase system as I said we can take different components and this becomes a very complicated system. So, if I depict volume of air as Va volume of water as Vw and volume of solids as Vs alright. And the weight associated with air Wa will be tending to 0 or equal to 0 is this is ok, we normally do not talk about the weight of the air. So, I will remove this there is no point in writing this.

However the weight of the water component is Ww and the weight of the solids is Ws, solids are basically the skeleton of the soil, minerals. I hope you can realize that capital V would be equal to Va + Vw + Vs. And in this what will be the air and water combined together this would be

equal to volume of voids + volume of solids, so Vv becomes volume of voids is this part ok. Now comes the question what you are asking, the first attribute of the soil mass is it is void ratio.

Most of the net Indian authors write it void but normally I prefer this as voids ratio because there is no one void there are several voids present in the system. Now e is defined as volume of voids divided by volume of solids alright. Porosity is a derivative of the void ratio and the way the porosity is defined is normally we define this porosity as eta you have use this symbol ever eta. So, this is the porosity and this is normally defined as volume of voids divided by total volume is this part clear.

So this is what I feel you are asking is this ok, so now we have defined the porosity and now you can realize that porosity and the void ratios are interlinked with each other. Compute quickly what is the relationship between void ratio and void and porosity. Sir yes how can the water come under voids how can water volume come under voids volume, how come yeah water volume come under voids volume. Because this is the void space, this whole thing is voids, voids are the ones in which the water and air is going to sit.

The voids are the ones in which the air and water will be sitting in the soil matrix is this ok. So when you say voids this is a total volume of the voids divided by volume of the solids. Now when I say porosity, this is the volume of the voids divided by the total volume of the system is this ok now. Let me defend him, the only way to defend you would be suppose if I am dealing with only dry soils, water will not be there, the voids will be only of the air maybe this is what you wanted to say is this ok.

So we have created a subclass is this correct, now you are happy, so you are also correct. I am also correct, but please make sure that the general equations are these. Now my question is can you correlate these 2 quickly do it quickly.

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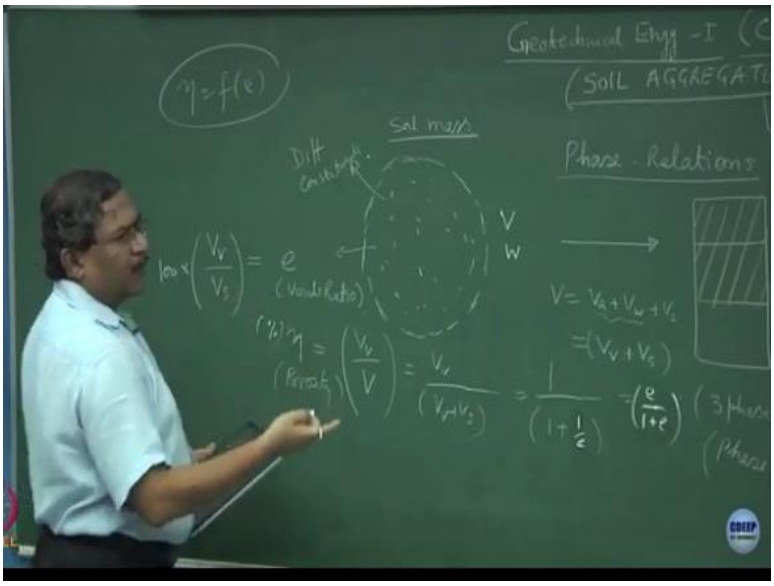

And find out relationship between this f is a function yeah you are right do from the first principle. So I will just quickly tell you how to do it, so your e is Vv upon Vs this will be equal to Vv upon Vv + Vs is this correct. So I can write this as 1 over 1 + Vs upon Vv can you modify it, what is Vv upon Vs, e so this equal to e upon 1 + e why, yeah. So this is Vv and Vv of Vs upon Vv, so this is 1 upon e, so this will be e over 1+e clear.

This is the most fundamental relationship which defines the soil matrix, now come out of this discrete systems now we are talking about the soil matrix. So what we have done is we have define the void ratio, we have define the porosity and we have interlinked porosity with the e upon 1 + e.

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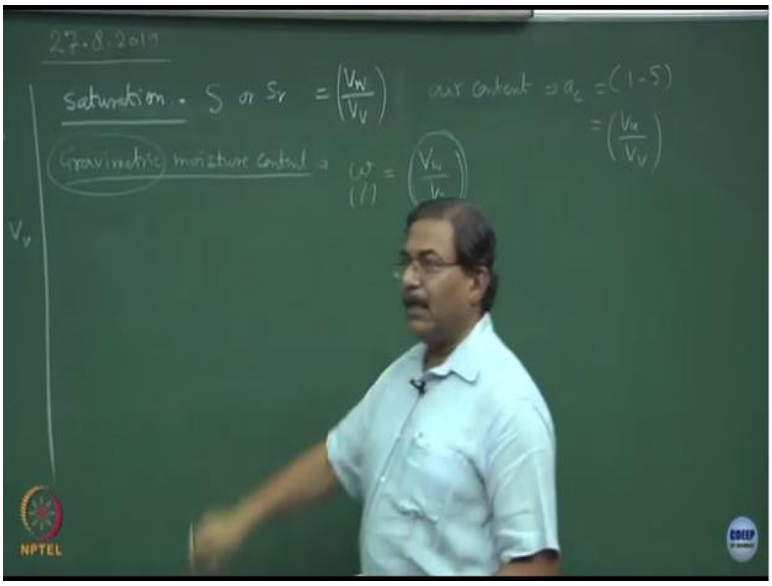

The second fundamental thing would be saturation, normally we define this as S those of few who are more into hydraulics would define this. like Sr both are correct So sometimes they define is as S or Sr I prefer S to avoid the complications of another r you know. This is defined as volume of water divided by volume of voids and remember all these terms are in percentages or you may convert them into factions also.

So, this could be either in percentages alright or I can use fractions also both ways it is used. So, this is the saturation water saturation, the next term is if I am defining as saturation, this is something known as air content, Se and this is equal to 1-S. So basically this can be written as volume of air divided by volume of voids. The next term in the series is gravimetric moisture content. Normally this is defined as a small w again percentage can you guess what will be the definition of the moisture content Vw upon why you are correct.

Because the volume of water divided by volume of solids is the w but normally we do not write like this. We were talking about gravimetric and you brought into it you got it, you got 0, is this clear. This is a fundamental mistake with many people do, so please remember you were talking about the gravimetric analysis or we were talking about the gravimetric things and you have included the volumes is not correct, it will be in the terms of weights.

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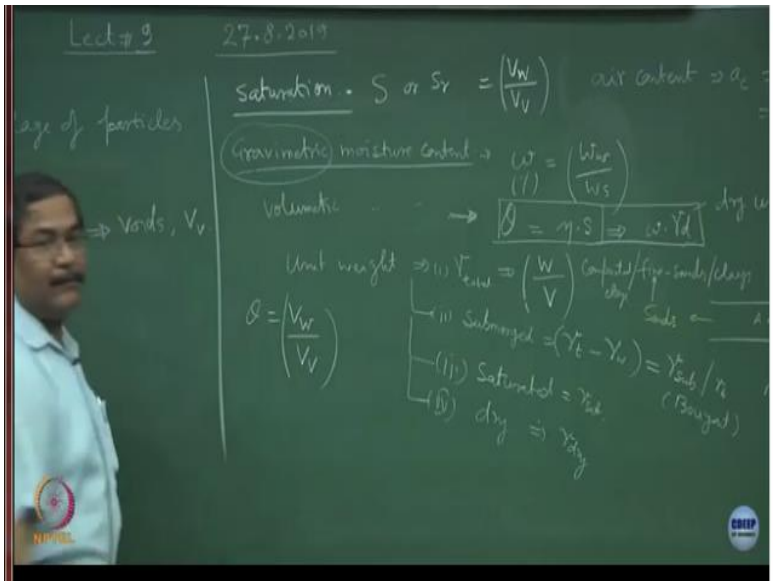

So weight of water divided by weight of solids is this okay, now to confirm your question. Now suppose if I say volumetric moisture content normally this is defined as theta third year students are not suppose to know these things. But I am trying to expose you to these concepts, which is equal to porosity multiplied by saturation or sometimes we can also prove that this is moisture content multiplied by gamma d is this ok.

Now gamma d is that dry unit weight when I say soil it is understood that I am talking about the soil mass alright. We will discuss how to obtain the gamma d value, let me complete first the series then comes the unit weight. Unit weight of the soil mass is normally defined gamma, we defined this as the gamma t, which is corresponding to total very soon we will realize that there are different types of unit weights clear.

So gamma total is the weight of the soil divided by volume of the soil, how it is computed. So let first let me introduce the concepts of the unit weights. These unit weights are number 1 total, number 2 submerged, any idea how would you compute the submerge unit weight, please remember this is not the density these are the unit weights. So density of the material multiplied by g value agreed units are kilonewtons per meter cube especially gravity G is gram per cc ok.

So, submerged any idea how would you obtain this, so let us understand what this concept is. If I take let us say, this is the ground level water table is somewhere here, this is how the water table

is depicted alright. If I take a point somewhere here let us say point number A, there is no direct connection with water table depending upon the material please remember. Depending upon the material at this point, the unit weight could be gamma d provided this layer happens to be sands, I will explain what is the difference clear.

So, we are just talking about the physical attributes of the material coarse grain material it cannot hold water alright. And if there is a water table we will soon study that there cannot be any capillary action and hence water cannot raise in this layer at this point the unit weight is going to be gamma dry. However if I change this sands to the find sands or clays or compacted clays, the story changes simply mugging these equations is not going to help you unless you realize the concepts behind everything.

So, I have created several situations out of it are you getting this point, so if I say large grain granular material water table is not going to influence it ever. But the moment I say fine grain sands, fine grain sands will have a tendency to create capillarity and this water will get lifted up to a certain depth clear or if it is clays very fine particles. And the material has a tendency to suck water because of capillary action fine compacted clays, you were using clays and you compacted them.

So, you have created more and more capillary action, we will discuss all these in details. So now this point is in the dry state however if I consider a point B and if what table remains over here, most of the time this point B is under submerged state clear. And submerged state is nothing but the total unit rate- gamma w. Normally this type of unit rate is depicted as gamma submerged, please be very, very careful with the wordings of the situation.

The material is so notorious, at the same time so obedient, that it wants to understand what the circumstances are clear try not to do these type of mistakes. That means, you have to read very carefully the type of situation which has been created when something is being asked to you. So, I have created several situation material property and the way the deposition is occurring is this quite clear, we will discuss about this much more, these are normal mistake people do ok.

So, I have defined now submerged unit weight and the third one could be saturated, so this I will say as gamma sat. And the fourth one which I will be using is dry unit weight which I will be defining as gamma dry. So first of all 4 types of units weights I am talking about, unit weight of the soil mass, gamma total, gamma, submerged, gamma saturated, gamma dry clear. Now coming to this point, what I said is this is the ground level you have the water level, a point A over here is in the dry state as long as the material is not a fine grain material and not compacted material.

And it is a granular material which cannot hold water for a long time, that means capillarity is not going to be in this region at all. However as long as the water table remains intact over here, any point which is lying over here is in the submerged weight submerged condition. And when we talk about the submerge sometime people also call this as buoyant, buoyancy you have studying here is this part clear now.

So, this is a differentiation the way the layers are placed, the point where it is and the material property and the compaction effect fine. And yes, yeah, because this is submerged so what you have to do is this unit weight is going see you have subtract the unit weight of water because this is submerged. So, this is a sort of a buoyancy which is acting at this point. So, unit weight of this point is going to be gamma submerged gamma buoyant clear.

So either you right gamma b sometimes the write gamma b also, it is a good idea to follow the symbols which I am using in the class, so that there is no confusion between both of us at least alright, you agree is this fine. So this is either gamma b or gamma submerged, gamma total, gamma saturated, gamma dry 4 types of gamma we will talk about, take few minutes to assimilate these thoughts in your mind yes.

This is the volumetric moisture content which is porosity multiplied by saturation correct and this is equal to gravimetric moisture content multiplied by gamma dry, oh theta there is no formula normally what we do is theta is directly measured. So theta ok I will tell you if few are interested in knowing theta would be volume of water present in volume of voids, now try to prove it.

This will be a good homework for you, now I think you are the guy who said clear gravimetric versus volumetric. Now what we have done, this is the girl gravimetric thing weighting of the weights and now you are talking in terms of volume. So look at the volumetric moisture content, this is volume fractions. The moisture content in gravimetric form was the weight fractions, clear. Sir the formula for the saturation in thetas you have written same saturation and theta yeah sir Vw no Abi do one thing you please do this as a exercise.

Like you have define gravimetric moisture content as Ww upon Ws, so theta should be also equal to read Vw upon Vs. That is what I am saying, so please remember the volumetric moisture content is always defined as the volume of water or the moisture which is present in the volume of the voids clear. So, this is volume of water which is present in volume of voids what is gravimetry first of all. In chemistry you have done gravimetric analysis, you weigh everything clear.

So, that is gravimetric weights volume, volumetric moisture content clear. So, volumetric moisture content cannot be weigh what you have to do, you have to measure it, this is the volumetric moisture, so this has to be measured in the volumetric fashion. Now, these are 2 thoughts of schools, one talks about gravimetric one talks about volumetric. Now tell me in today's world in 21st century when you are using these concepts which one you like to use and why.

This is the age of electronic sensing clear, I need not to take a sample from the ground and bring it to the lab by the time I bring it to the lab from Rajasthan everything is lost, it my moisture gets evaporated, agreed. So what I want to do, I want to use a sensor I want to install it there itself what sensor is going to do, it is going to measure volumes clear, this is becoming obsolete.

Because lot of problems first of all take undisturbed sample, bring it all the way to Bombay in your laboratory, there temperature would be 45 degree 50 degree, how would you maintain the moisture sample very big question clear. So nowadays it is good that you are asking this question

I am sure you are getting expose to lot of interesting ideas. So the whole thing is use sensors install them in the field measure this.

Most of the automated sprinkling systems which are working are based on measurement of volumetric moisture. One more thing for gravimetric and volumetric moisture content is if you do the experiment then you will came to know the temperature that we used for gravimetric moisture content and at that temperature most of the organic matter also get vanished ok very good. So explain this again, so what he is trying to tell you is that why gravimetric moisture content should not be used when you are dealing with the soils.

Because you have recently studied that soils have lot of organic matter and if I expose the soils to high temperatures I may lose the organic content and hence the result will be wrong. And this is the reason why people are not adopting the gravimetric methods these days alright.

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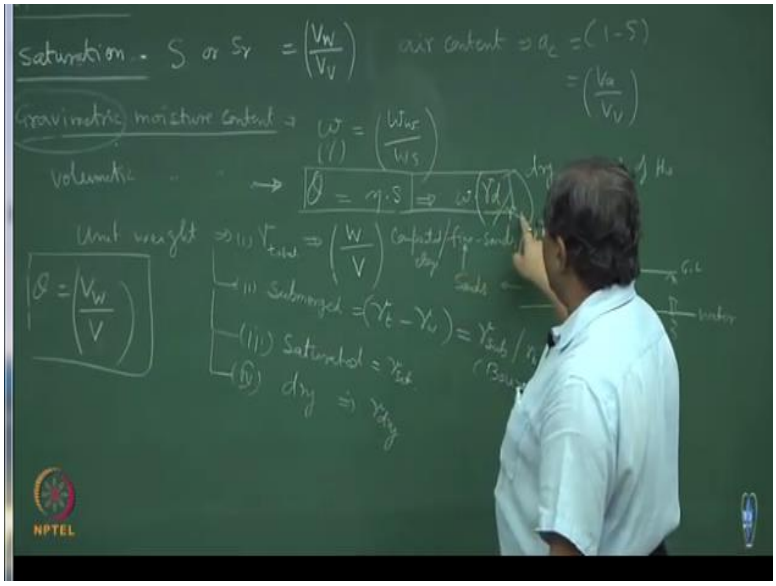

So please make 2 corrections gamma d upon gamma w into moisture content which is gravimetric and Vw upon V. Now let us go into the gammas, what is gamma total.

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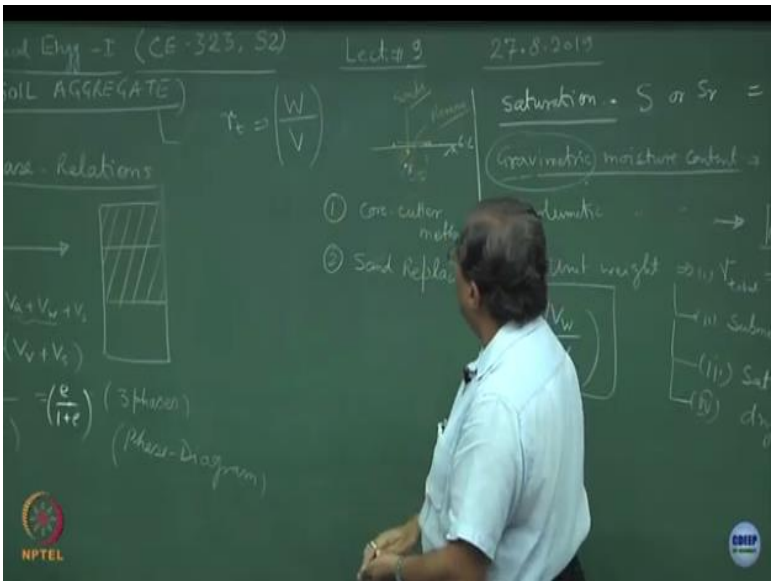

Suppose there is a soil mass like this, this is the ground level and I want to find out what is the total unit weight of the soil at point A there are several techniques. One of these techniques is you know we call it as a core cutter method. I am sure there is a laboratory experiment on this you must have done this, what normally we do is we make a small hole over here on the ground alright scrape out this soil, remove this soil put it in a polythene bag, so that the moisture does not get lost.

And this weight of the soil which you have remove from here and if I measure the volume of the cavity which I have created over here alright this can be done with the help of sand replacement. So core cutter method and sand replacement methods are normally use to obtain gamma t value. The procedure is like this you take a small you know pre punctured sheet of metal keep it over here. There is will be a orifice in this and through this orifice you drop sands clean dry sands.

I can measure the volume of the sands which is filled in this cavity, I know the specific gravity of the sands, I can compute the volume clear, I will tell you how to do this. The soil which you have removed is taken to the lab dry it in the oven, get the weight, obtain the moisture content and that is what is going to help you. Normally core cutter method is done in cohesive soils, you will be surprised to know that despite all this technological advancement when it comes to the payment of the payment of the contractors.

The only method which is use to establish the compaction adequacy of the compaction is by core cutter method there is no other way.

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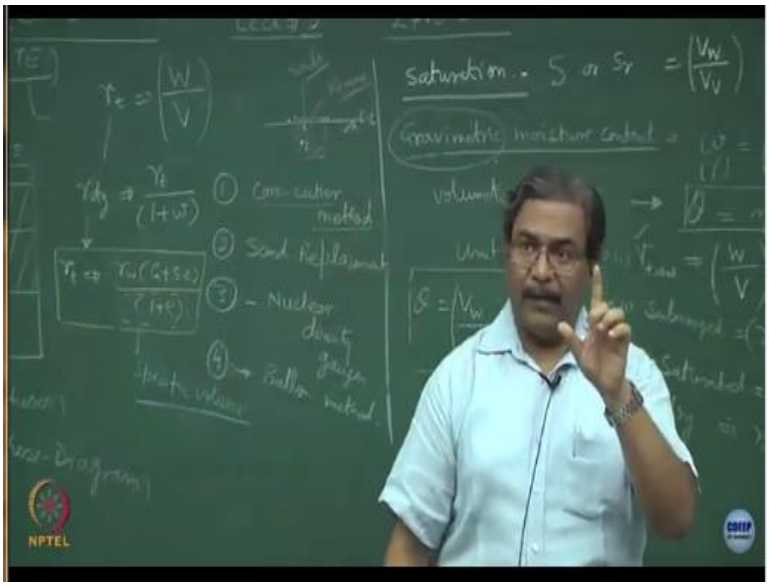

Nowadays what people are doing is, they are also using different type of nuclear density gauges ok. Nuclear density gauge can be utilized to obtain the moisture content and the gamma d directly there is another method which is known as a balloon method. This is the history of geotechnical engineering people use to put a balloon inside and they used to pump air, the balloon use to take the size of the cavity which you have created.

And I can compute what is the volume of the cavity, I have taken out the soil, I know the weight of the soil which is displays from here, I know the volume gamma t is known alright. Those of few who are interested in reading what is the state of the art on moisture content measurement, please go through the papers written by Susha Lakshmi and myself about 2 years back in the journal measurement.

So all the recent techniques of moisture content measurement of the size are listed there, whenever you get time, please read that and that talks about the historic development and what is being practiced right now. So I am now coming to your question slowly alright, so whatever sample you have taken out from here, you weigh it. You know the volume, you get the gamma t, now gamma t and gamma dry they are related to each other.

So if I normalize gamma t with 1 + moisture content this is equal to gamma dry clear, you see in the soil is such a tricky material that everything is possible on paper. But in field nothing of the sort is possible, so I am sure the moment you scrape it out, is not a intact lump, you will be very lucky if you can take out a core intake sample is very difficult. So what you are saying is also possible if you are extremely good experimentalists and a researcher and you value everything up to point third decimal place everything can be done, no doubt about it.

But very difficult do in the field, so what we do is, we measure the volume and weigh the soil clear, you can do other way also, that is not a problem but that is difficult. So this is a relationship between gamma t and gamma dry. So I think we have sorted out now gamma total, we have sorted out gamma dry and submerged is nothing but gamma t-gamma w. Now one thing which is still pending is saturated.

Now so how would you go ahead with this, can you solve this expressions try to derive now, normally I cannot remember these things I have to derive. So this will be gamma w G + s into e over 1 + e try to prove this, is this correct Benny sure. So using these functions try to come to this, this is your homework, I will read out the expressions. Gamma total is gamma w unit weight of water multiplied by G is the specific gravity of the soil if you remember.

Learn the method of finding our specific gravity you might be doing in the laboratory s into e, s is saturation multiplied by void ratio over 1 + e, 1 + e is known as what sorry, you are right, this is what is known as a specific volume, a specific volume of the soil, clear. One of the ways of philosophically looking at these expressions is that you are normalizing the weights with the volume and I will show you how it is done, is this part clear, 1+e is the specific volume of the material.

So truly speaking, this whole term is a weight term divided by the volume, now I can create one more condition out of it.

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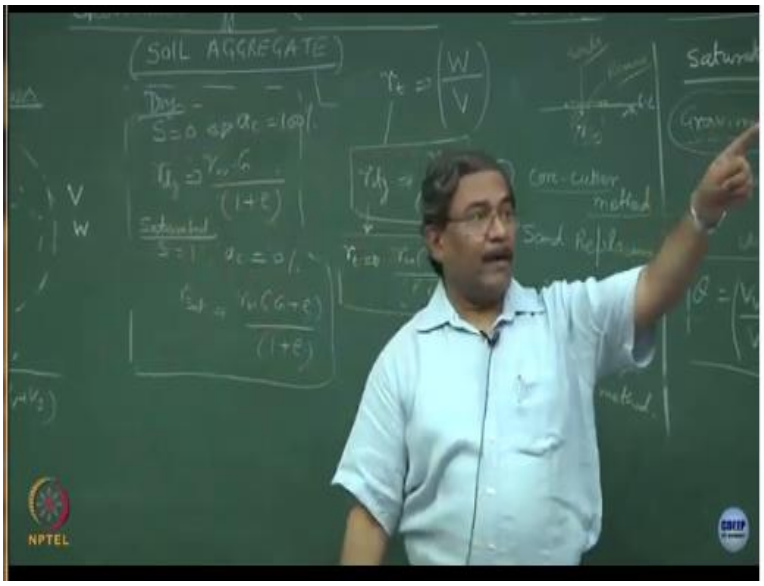

Suppose if the soil is dry, see you are talking about this situation, so when you are dealing with dry soil mass S = 0 what happens to gamma t, mathematically G upon 1 + e I will remove the brackets now. So truly speaking this is G into gamma w over 1 + e fine, one of the conditions when S = 1, this is saturated soils ok, what is going to happen now. So your gamma saturated this will become gamma dry, is this ok gamma t has been replaced with gamma dry.

So this becomes gamma w G + e over 1 + e, I hope you will not have much problem in deriving these, what you have to do is maybe as a rule 30th when I am not here, you treat this as a practice session and it should not take you more than 1 hour get conversion with all these things is so easy alright. So, this matrix is like this, now you can derive this we have talked about gamma dry, one more way of gamma dry was this defining gamma dry was this correct.

This is normally done when you are dealing with the experimental work either laboratory or field. So, the best thing is you take out the sample measure the gamma t we never say we are dividing with 1+w, I call this as a normalization, this is part clear. I am normalizing something which with something and this happens to be your unit a specific volume 1+w is also sort of a specific volume in gravimetric reform.

So, this is how we normally treat gamma d, are you happy, this was your question how to compute gamma d, gamma saturated, gamma submerged, gamma total is this ok, any other

question. This is the state where ac is going to be 100% what is the ac air content, this is the state where ac is equal to 0 clear. Now what you should do is, a start from the first principle keep on substituting these values and see what are the values you are going to get.

Your initial hunch was that you were talking about the porosity if you remember. So now I am giving you lot of homework, what you should be doing is use this function and see whether your hunch was correct or not. But as we discussed earlier, your air component voids will have water also but I am now creating a situation where there are no voids clear, your question of hygroscopic moisture content is a very tricky question.

When I am saying gamma dry, this is a bone fried soil, a gross injustice with the soil which should not be done but it is being done. So this is the shift between the conventional and unconventional new, new geotechnical engineering, so all this G which I am using if you remember in the previous lecture, what I said is normally G is defined as G skeleton or G of minerals clear, but for the sake of simplicity, we do not write G already there are so many times we are using s saturation and all those things just for the sake of simplicity, good question.

So G is meant for the minerals which are present in the soil solid phase, the skeleton clear if a soil is multi mineral soil, then you have to go for a composite of G weighted average of G value, mineral phase number 1, especially gravity multiplied + G1, G2, G3, G4 these divided by total weight God knows it clear, funda clear, now what you should do is try to prove this.

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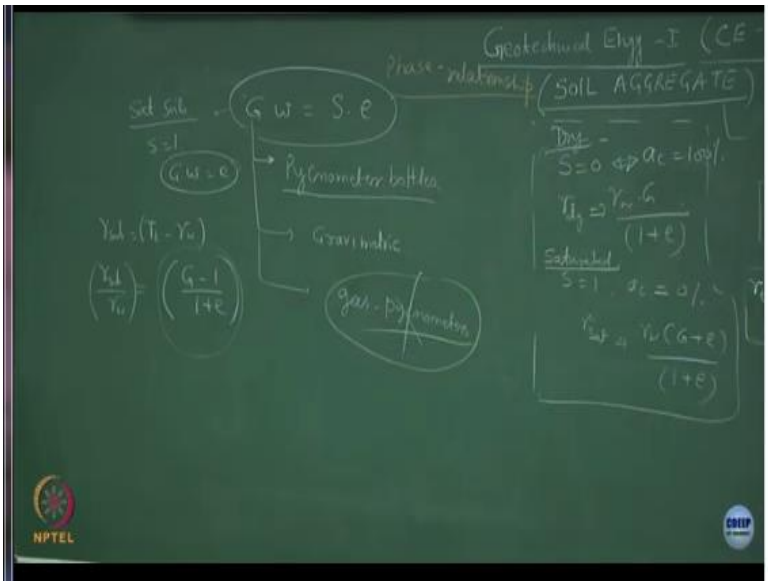

So I will tell you the philosophy part, this is a relationship which is known as phase relationship. Now if you look at the left hand part of the equation, can you recognize what it is and what this part of the equation is, you get the answer. I think we were discussing if you remember this was this, this volumetric versus this, what is G is a volumetric phenomena or gravimetric phenomena, what is G, how do you obtain G, so is the gravity.

Read this, gravimetric phenomena w again gravimetric phenomena clear, weights, volumetric phenomena, biggest flaw in geo mechanics. But this is the starting point what you are doing here unknowingly you are matching gravimetric with correct big question mark. If you answer like this in interview board they will very happy though she is the most state of the artist and then comes all this R and D which is being done, you know, whatever was done in 1930s, 40s and what is happening right now there is a big shift.

But forget about this question off for the timing as far as your third year (()) (42:45) concerned, this is the (()) (42:47) Brahmavakya, we have to follow it, try to prove it. So G is normally obtained by pycnometer bottles, you must be doing it in the lab, go to the website read how G is obtained pycnometer bottles weight displacement. So they take a bottle like this these pycnometer bottles are like this, you weigh this weight of the soil mass put it inside, weigh the whole thing fill it with water, the equal volume of the water has been displaced alright.

You measure that, that is one way, second way would be weight of a material in air and divide by weight of the material in water, 2 methods, third method is more complicated. But what people like researchers use, so this could be gravimetric also, displacement of water, these are known as gas pycnometers. We use these type of equipments in our laboratory where the helium gas is replaced by the material and we measure the volume of the gas replace why.

Because helium is a conservative gas, it would not react with the material and hence the chemical activity of the material remains intact. Another thing could be there are several other methods like thermo gravimetric analysis TGA which chemical engineers do they find out the a specific gravity of raisins and so on. So there are several methods but for the time being, please read this, this and forget about this ok.

So what is going to happen for saturated soils S = 1 that G into w = e it is a interesting relationship but for a very specific case when the soils are saturated alright. Gamma submerged you try to derive as gamma total-gamma water and this you should be getting as gamma w G-1 over 1+e. This expression we will use later on, when we are discussing the seepage theory alright. I am sure you can realize that gamma submerged divided by gamma w alright, this becomes a non dimensional term.

So this is the normalize submerged unit weight of the material, which is G - 1 over 1 + e interesting philosophy behind this. G is the skeleton of the material of the soil, minerals clear and e is the void ratio. So this is a term which can be utilize in defining the stability of the structures the effect of unit weights gets filtered out. So one of the ways of looking at these expressions is how are you normalizing something with what, is this ok. All this expression is used for determining stability of structures, write down this question.

We will discuss this when we start discussing on the seepage theory alright stability of the dams and all, then we will use this as a critical hydraulic gradient correct. So if that is the situation where I am trying to simulate the dancing sands, liquefaction you know the effect of the weight has gone, gravity does not affect this material now, what has happened. The material in itself is

now behaving the way it has to behave in a matrix this subject is more of a philosophy rather than mathematics, is this ok.

So especially gravity of the minerals, the heavier the minerals, this system is going to be more stable organic clays what is going to happen, god knows G is a extremely low we will talk about this void ratios could be very high, marine clays, I said very sensitive material, very high value of this, very low value of this, very susceptible to decay, forget about hydraulic gradients, decay, they just get decayed, alright, is this ok.

So the way to look at this expressions is try to put a lot of physics behind this ok, so I think this we have already done gamma t and gamma dry. So, another interesting thing is you might you should learn how to change gamma t to gamma dry also, so the moment I put S = 0, this system becomes you know, one of the ways to convert this to gamma dry would be I will use now gamma d henceforth is this ok.

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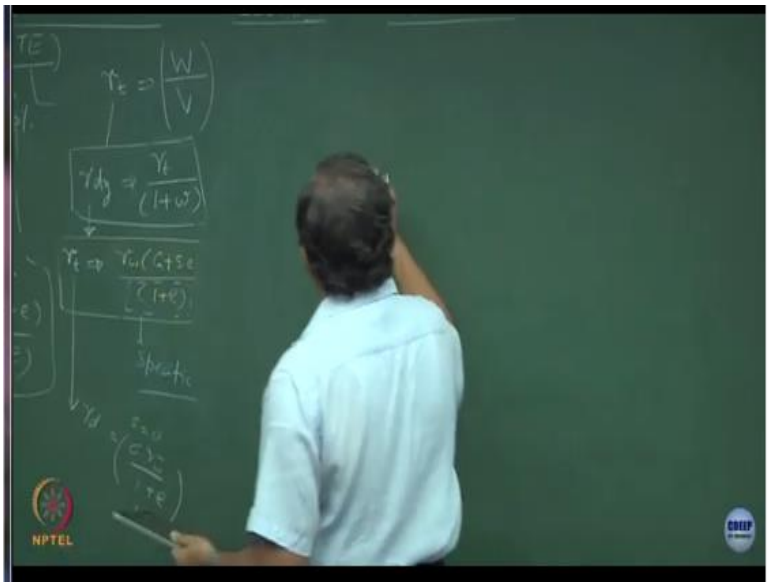

So gamma d would be substitute S = 0, so this becomes G into gamma w over 1 + e until now what I did is you know I was dealing with this 3 phase model like the way I was dealing with it.

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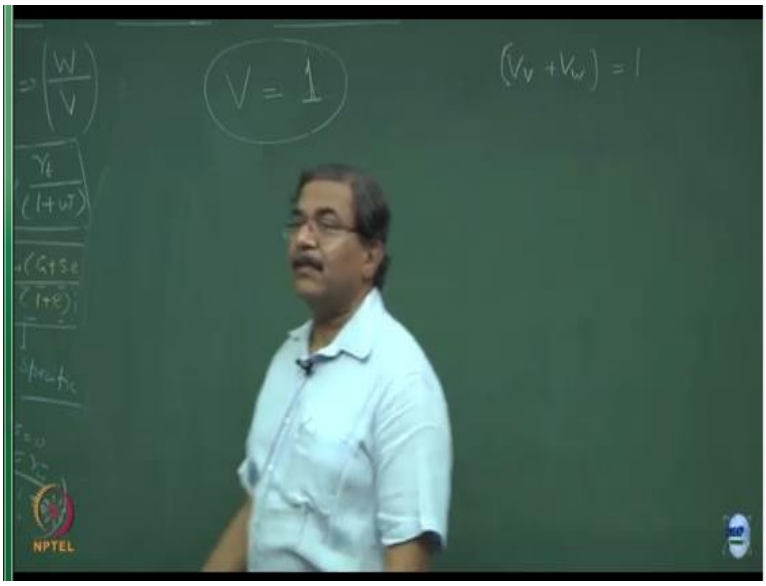

Now suppose if I say, I define V as 1 you think concept will change, until now what we did, we were defining V as Vv + Vw clear. This is another perception of looking at the things the total volume I am assuming to be unity. So that I can get rid of 1+e thing which I use as a specific volume is a cumbersome process you know getting e value w value there are so much discussion, which we did of how to get the water content, how to get the void ratio, how to get the porosity, this, that what not get rid of all this.

You assume that the total volume of the soil is unity and then back compute everything, how will you do this any idea, so what will happen to the porosity now, see or this system is now 1 alight. This is another way of looking at the things yes yeah, you are right this is Vs + Vv = 1 correct, so the total volume is 1, thank you very much, keep correcting. Now what is going to happen the whole story will change, how any guess.

I am talking in terms of now volumetric things earlier we were discussing everything in gravimetric things write on these final expressions and try to prove them.

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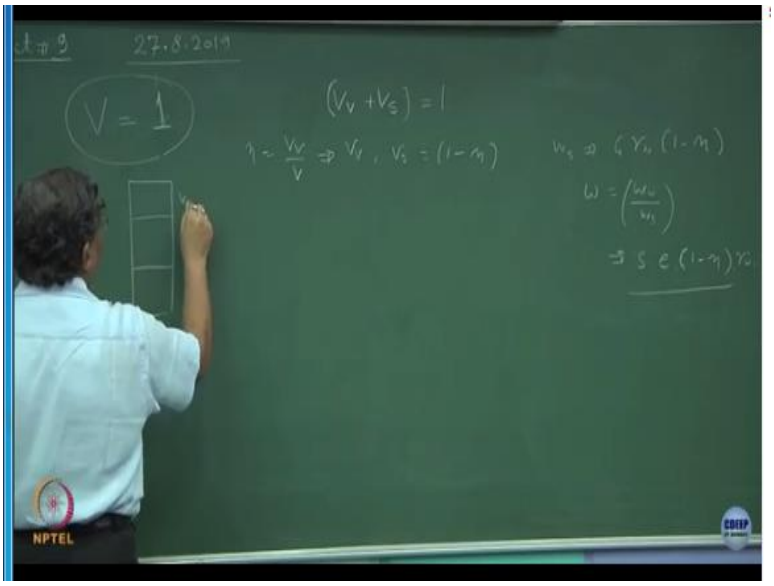

You see your porosity would be Vv upon V this will become Vv and hence Vs will become what, 1-porosity. So your Ws will become G into gamma w 1-porosity, where W is W weight of upon weight of solids. So if you substitute this whole thing, what you will be getting is this will be equal to s into e into 1-eta, try to prove this function and of course gamma W will come.

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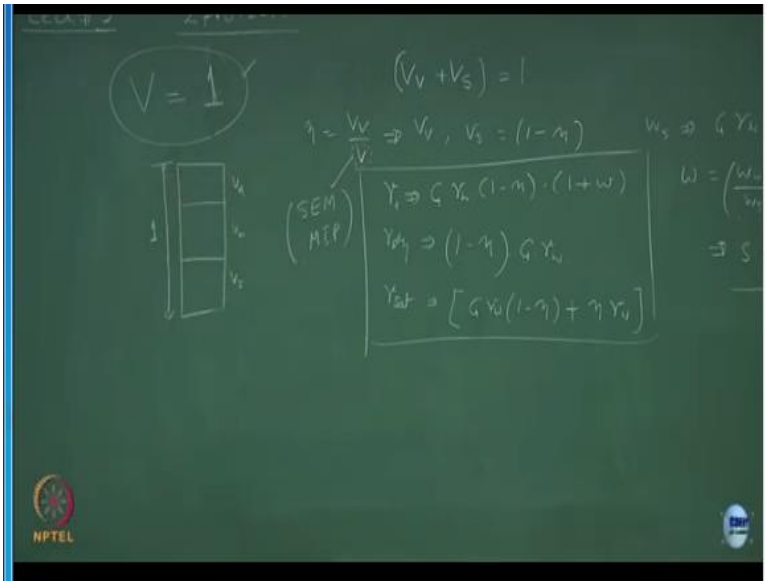

Here what has happened is, this 3 phase system if you remember with which we were working V air, V water, V solids this whole thing has been treated as unity. So I am doing now calculations which are volumetric, volume centric you may say try to prove that gamma = g into gamma w 1 - eta into 1 + w. So gamma dry = 1-eta into G into gamma w and what about the saturated thing G gamma w 1 – eta + eta into gamma w, first one is yeah this is gamma total.

This will be interesting for you to derive I expect all of you to derive these expressions another thing is derivation does not mean that you manipulate with this term and show it equal to gamma t fine . It also does not mean that you substitute the values of some parameters and say that this is equal to gamma t, it should be always starting from first principle. In short what has happened, as I said there are 2 ways of looking at the things.

Look at this function, you know V very conveniently got rid of the volume of the pores which is very difficult to measure. So when you get a chance to do higher studies, then you will realize that the volume of the pores is measured by using lot of sophisticated instruments like SEM, MIP. This is beyond your purview a scanning electron microscopy can be utilized to compute the volume of the pores, you remember the picture which I showed in the last lecture and I showed you that there are cavities between the minerals.

So those cavities can be scanned by using SEM though it is very difficult or you have to use mercury intrusion porocimetry, this equipment is available in our lab. Those of few who are interested are most welcome the entire country uses this equipment in our lab, you intrude mercury at a sudden pressure and get the pore sizes. In short it is a difficult task to measure volume of the whole soil mass but what you are saying is correct, you can take out the soil and put it in a mercury pot and this is what is known as displacement method.

So you find out what is the volume of the mercury which got displaced, that is the volume of the solids and then you can go ahead with this. But again a difficult process clear, what we have done is mathematically we have got rid of the volume by assuming this as unity. This is the beauty of the system and then we are saying that the volume of voids is same as the porosity clear and from here we can compute the volume of solids as 1-porosity.

This has it is own advantages but delicate thing to handle, just for the academic interest, you should be aware of what are the specific gravities of different type of soils.

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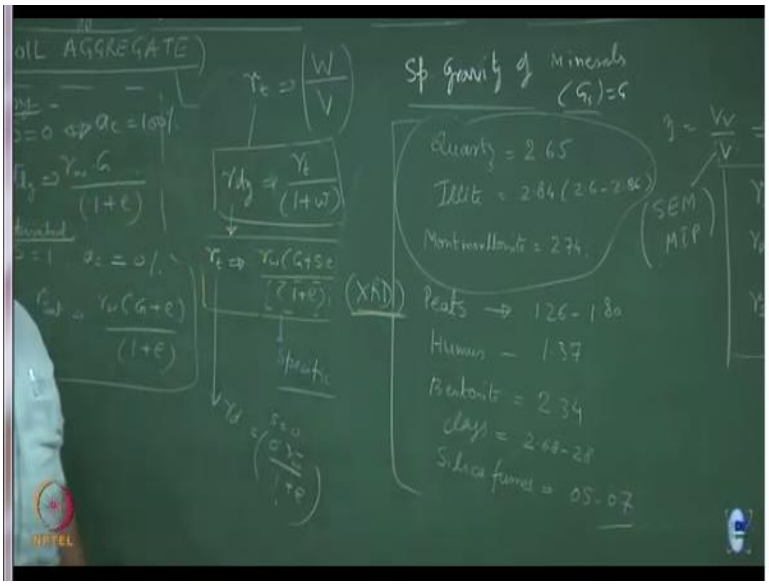

You may say Gs what I have been using all the time as G, quartz is 2.65, Illite 2.84, basically it varies from 2.62 to 2.86 sorry then Montmorillonite 2.74, these are peculiar numbers and these numbers indicate prima facie, what is the soil with which you are dealing, oh in medical profession, this is your diagnostics clear. You need not to do much take the soil, put it beneath XRD and you can quickly get the mineralogical composition and you can establish what type of soil this would be predominantly.

Because later on now you will see what is the art of consulting first to understand the material whether these mechanisms are going to take place in this type of material or not. So I get lot of information from this numbers highly stable system for your information and highly unstable system clear. I have the strategy in my mind, how I have to treat this patient, highly stable, highly unstable, with the poor surface area a very high surface area, very high cation exchange capacity, very high water absorption capacity clear.

Extremely low everything, very poor cation exchange capacity, very poor water absorption, very poor surface area. So the moment you look at the first number in your report of the material, you have a strategy and you can catch the person by the way this profession is becoming more of forensic in nature. Forensic means first thing you have to establish is what are the material which was utilized for creating something and you can prove that this is a fundamental mistake, agree.

So looking at these numbers, I can make out lot of things about it, just to give you a feel of what peats would be, if you remember peats are organic substances a specific gravity is 1.26 to 1.8 Humus 1.37 peculiar numbers, Bentonite 2.34, clays mostly would exhibit 2.68 to 2.8. I am just to give you a feel of silica fume, which is manmade specific gravity would be something of 0.5 to 0.7 alright very good admixture for concretes, it gives you a lot of durability, this is ok.

The best way to analyze this would be take help of XRD which I was discussing the other day in the class, X-ray diffraction you remember or sometimes those who are very good in chemistry, what they will do, they will do stoichiometry to find out what mineral is present. So if you go to the organization where they are dealing with the production of coal they keep a strict vigil on the type of coal which is being produced you know why.

It gets reflected over here and the cost of the coal depends directly on inversely proportional on the specific gravity are you realizing this, go to the steel industry. So when you make sponge iron, when you make different type of irons cast iron a specific gravity is very, very important what is the specific gravity steel, where it would set quick sorry very good 7.8. So steel is somewhere 7.8 at the extreme end alright.

So the blast furnace log which you are using for making different type of concretes and all and suppose if I mix them with the soil what is going to happen. The system is going to become denser and hence I am stabilizing it clear, concrete is nothing but combination of these minerals. So the moment you add GGBFS slogs it becomes denser, it becomes more durable, more strengthful and so on is this ok, do not mug up all these numbers and all ok.

But just keep it in your mind that numbers tell you a lot, let spend some time on now, the grain structure again having done all this particularly the granular soils.

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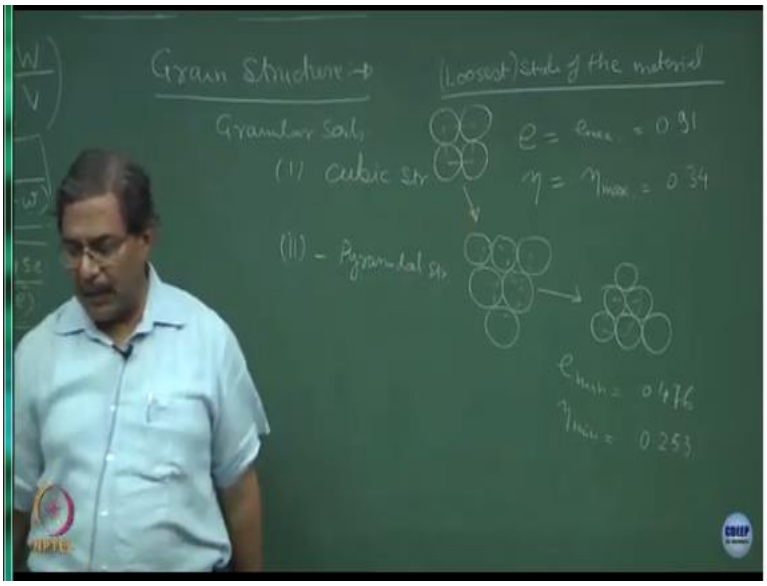

If you remember in the power point presentation, I showed you that most of the granular structures are you know, single grain structures and we normally depict them as perfect spherical entity. But I am sure if you look at you know below a microscope even you will find that they are very distorted. So there is nothing known as a standard sand which normally is used in the practice that this is a standard sand when standard sand is also going to be quite irregular in shape.

But we assume this because this is how these sands are produced, so normally standard sands are used for finding out the insitu gamma t agreed, you remember that core cutter method or soil displacement method you may call it, sand displacement. So you use standard sand, so granular soils are normally depicted as perfect sphere and they have 2 types of structures, one is what is known as cubic.

So a cubic structure would look like this, the front view of the plan it does not matter, can you compute the void ratio of the system compute e and compute porosity, fine keep doing this, this is all homework for you. The second thing is now this is what is going to be the loosest state of the material, where e is corresponding to e max fine and eta is corresponding to what will be eta now porosity max or minimum, max very good say it loudly why.

I am happy that you did not get confused though I try to confuse you, now this is where the concepts are important you getting this point. This material is highly permeable it will allow everything to pass through it very good filters and so on whatever we discuss there, at the same time now what is going to happen earthquake comes ok, is this a stable state of the structure or the structure of the soil or the grain structure soil, no I hope you can understand.

So in case of any lateral motion, lateral stresses shearing of any type, what happens is this gets converted to what will happen, suppose if I depict the plan view like this, please excuse me for my poor art and on the top of this will be the second series of the grains, it will be sitting like this in the void space, can you imagine this. So what is going to happen, in the side view if you see what type of structure is this, ceramic, pyramid yes you are right very good.

So this is a pyramidal sometimes people also call it as a rhombic structure pyramidal correct. Now what is the mechanism of transformation from this state to this state, have you understood. So this is going to be a pyramidal structure, people who are coming from the Gangetic belt parts of northern India you know close to the Bihar, UP and all these places, single grain structure agreed, gravity is predominant.

These particles are coming in sediments all the way from Himalayas, because of the velocity of water, they got grinded enough water is the most abrasive material what it did, all sorts of is irregularity is taken care of the particle becomes spherical, shining particles remember. They would settle down slowly and slowly how they will settle in water body, first layer, second layer, third layer loosest possible for is ok, have you understood this, dangerous situation.

You cannot construct any infrastructure on this, the moment earthquake comes, what is going to happen because this is not a stable state of the material, you can use entropy of the particles to make sure that this is not a stable system because the entropy is going to be more or less here read this. So those of few who are going to master this concept would go into the particulate mechanics by using the concepts of entropy associated with the particle system, particulate mechanics, it is going to be more.

Any system cannot remain at higher entropy, small shaking up is going to cause rearrangement of the particles in this form, which is more stable. So you are very happy with this restructuring or not, life is not so simple. So even if you density the materials from this state to this state, now this is a practice of geotechnical engineering, remember and again earthquake comes on this system also was going to happen, pore pressure is ok, that is fine pore pressure will never develop in coarse grain materials remember.

Please remove this from your mind coarse grain material pore pressures will not come into the picture clear, this earthquake loading is for a few seconds. And within that few seconds the permeability of the system is so high that pore of pressures are not going to build up over there, now what is going to happen is, the moment this type of situation occurs, look at this tomorrow you go to the hostel number, I do not know in which hostel you have a snooker table, try to stack the a snooker balls like this and press them like this.

Look at the hand motion, what tectonic motion does earthquake comes, everything oozes out ice cream scoops are a beautiful example of learning how the state of stress develops in the system alright all type of hollers which you use in civil engineering construction, they go this and they push the soil up ice cream scoop is this like this is not. You push it and then take it out snatch it, so that means if again earthquake comes what is going to happen the rolling starts.

But the intensity of volumetric deformations from this to this are less and from this to this are less, lesser. So the whole concept of modifying the grounds for making infrastructure would be to create a state of the grains particularly in the granular soils which is more stable. Now this concept, we will study in the second course, have you followed this. Now this is going to give you please compute now the porosity and this is going to be a e minimum, minimum possible instead of the void ratios and the porosities are also going to be minimum clear.

I will give you quick numbers, so that but try to prove them analytically, this is the cubicle structure and this is the pyramidal structure, where the balls are coming and sitting over the hollow spaces, this is how it looks like in the side view, it is ok. This is the first layer of the

particles first layer, on the top of this the second layer comes and gets deposited second layer and third and fourth and so on, it is ok.

So, typically for sphericals like this, the e max value is 0.91 and porosity is 0.34, e minimum is 0.476. These are the magic numbers 0.253 try to prove this, very unstable state so called a stable state but still it is under threat because of the dynamic loading. Bore water pressures will never develop is a granular material clear. So understand the material first but yes if you have fines into it, somehow impregnated yes you might think of, we will discuss about that slowly.

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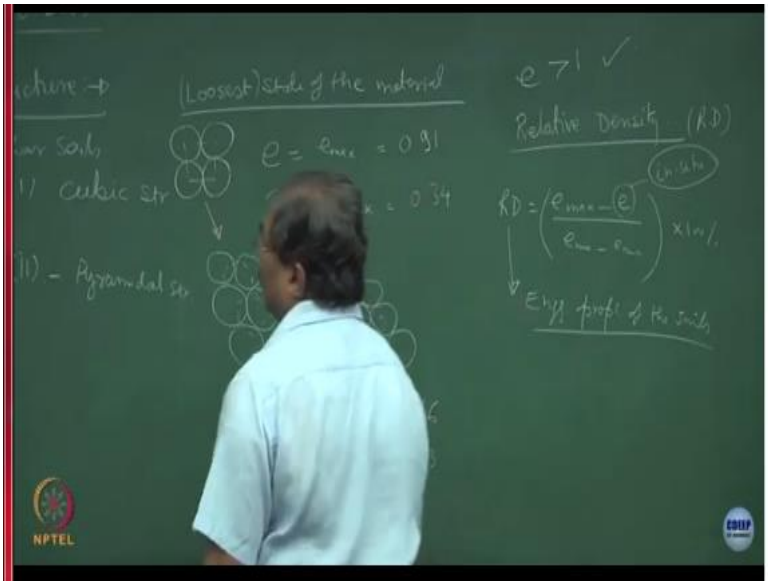

Now there is a concept of somebody may asked you, is it possible that void ratios can be greater than 1, is it possible to have more voids than the solids, are your sure, sure negative marking your answer is correct, it is possible. But only nature do this, remember, we cannot do this. We cannot reconstitute the soils with void ratios more than 1, now nature is a great engineer, what it does slowly is it produces the deposits, where the void ratios could be more than 100%, extremely soft sensitive deposits AXA beach beautiful example.

They put a warning during rains nobody should go there why, the chances of drowning are more not in the water. So imagine this is a state of material, where the voids are more than the solids, you are right absolutely right clear. We define a concept relative density of the metrics of the soil

remember, we call it as RD, now in mathematical terms, RD is defined as e max-e divided by e max-e min and of course multiplied by 100.

Apart from the mathematical expression, the way to understand this would be truly speaking we are trying to find out the deviation of the void ratios in 2 states of the material clear. One is very loose state and one is very dense state, so this becomes a benchmark of the torture which a material can be subjected to, this is a torture clear you have disturbed the whole thing by torturing it.

So e max and e min the difference between the 2 becomes a scale which is use to normalize the state of the material, this e is in situ another new term which I have used today, in situ is as it exists in the nature clear ex situ once you have taken out the sample you have disturbed the as in nature state we call that as ex situ, bring the sample to the lab you can compute e, gamma t is known dry it gamma d is known and gamma d is G into e over 1 + e not G into e, this is G upon 1+e into gamma w clear.

So from there if you know the void if you want to know the void ratio, you know the gamma d you know the value of G do test get the value of e substitute it over here. So this becomes infield, the best way to get e max e min is take a small cylindrical ring pour the samples very gently volume is known, weight of the material can be obtained and from if there you compute e maximum, shake it on a shaker table, let it settle down, compute the volume change which has occurred, measure that volume, weight it is constant, you get the e min value this is how it is done fine.

Now this RD is an indicative of all the engineering properties of the soils and there is the classification system based on this. Sir as you said about the e max how we find the e minimum, no what you have to do is for e max and e min there is a we call it as a standard ring or a cylinder. So, you take a cylindrical unit and in this unit you just pour the dry sand, you know the initial weight of the cylinder.

You pour the sand up to the brim stop the process, you know the weight of the cylinder plus weight of the solid weight of the file, you know the volume of the cylinder internals, you get the gamma d value G can be obtained e is known. So you get e value this is how you are getting the maximum value e max, shake this whole thing on a shaker table you get e min value alright 3 things, so the field sample which you are going to bring is e.

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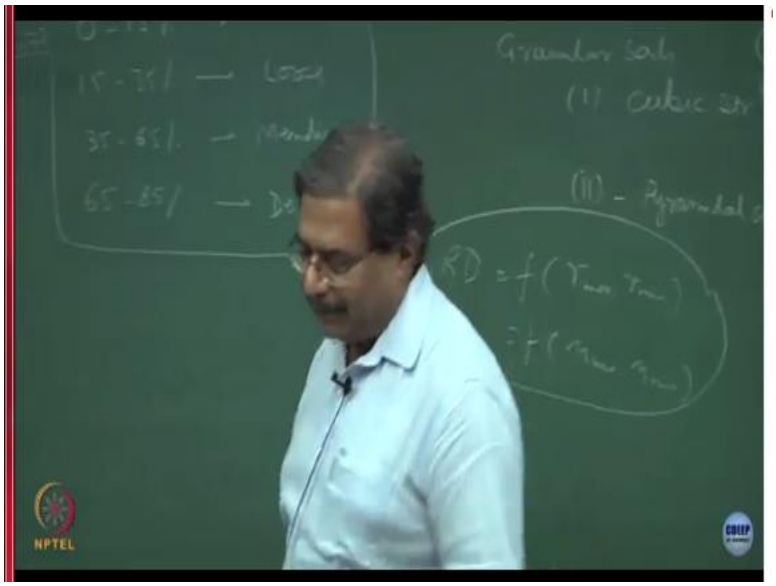

Now try to prove this relationship RD equal to now can you derive RD as a function of let us say gamma max, gamma min and porosity max and porosity minimum, based on the RD of the material 0 to 15, 15 to 35, 35 to 65.

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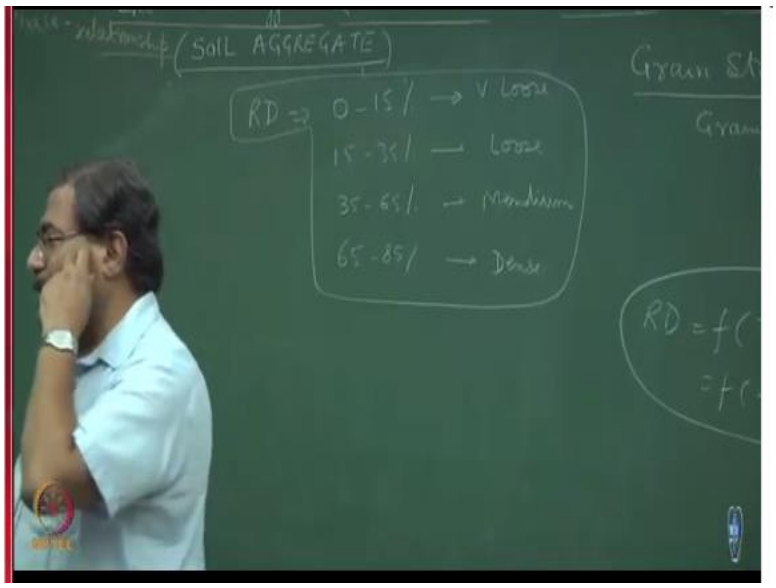

You should try to remember this though I cannot I am sorry for that but this is going to be useful for you. So this is very loose state, this is loose state, this is medium dense sand and this is dense sand. So for the practice of geotechnical engineering these numbers are required, do not bother much all this is available in the course. So when you practice a subject, you have the Bibles with you is it not and the Bibles are nothing but the course.

This is the container, I will keep on pouring the soil very gently from a lower height let it get filled up, I will stop the process I will weigh the soil I know the volume, gamma is known it is a dry material gamma d, G upon 1 + e G is known, e comes from there and that e is corresponding to e maximum because they are looser state clear. So if you do like this, what happened, it gets density I can put on a shaker table that is a better scientific way of doing this.

I can fix amplitude I can fix the number of frequency, whatever, so this is going to drop down in volume. So I know the new volume, I know the weight remains constant, I know the specific gravity, now this is what is going to be your e minimum sure. So this is known and this is you take out the sample from the field and good.