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NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

CDEEP
IIT BOMBAY

ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 02

Module-1
Three Phase Soil System, Volumetric ratios and Basic relationships

Welcome to lecture 2 of module 1 for the course advanced geotechnical engineering in the previous lecture we have understood about origin of soils and their type of soils in this lecture we would like to understand about phase properties phase relationships using phase diagrams and we will try to solve some couple of problems so as we discuss soil is a three phase material where you have a soil composition which consists of solids which consists.

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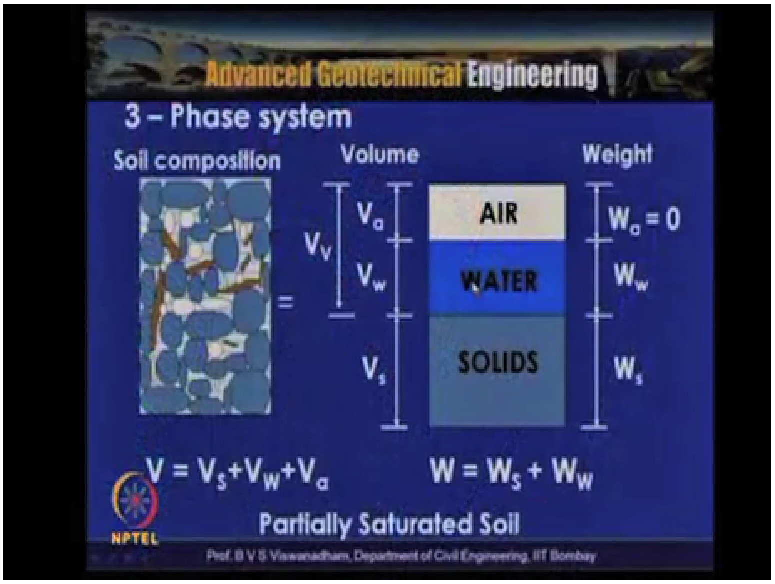

Of air water and solids so if you separate the soil composition into three predominant phases they are a water and solids and if you put weights on the left hand side as on the weights on the right hand side where weight of air is equal to zero and weight of water and weight of solids and if you put volume on left hand side the volume occupied by voids which comprises of volume of a and volume of water and volume of solid.

So volume of voids plus volume of solids is total volume so V = VA +V S+ V W +VA and weight total weight is equal to weight of solids plus weight of water so this is this is a case for a partially saturated soil.

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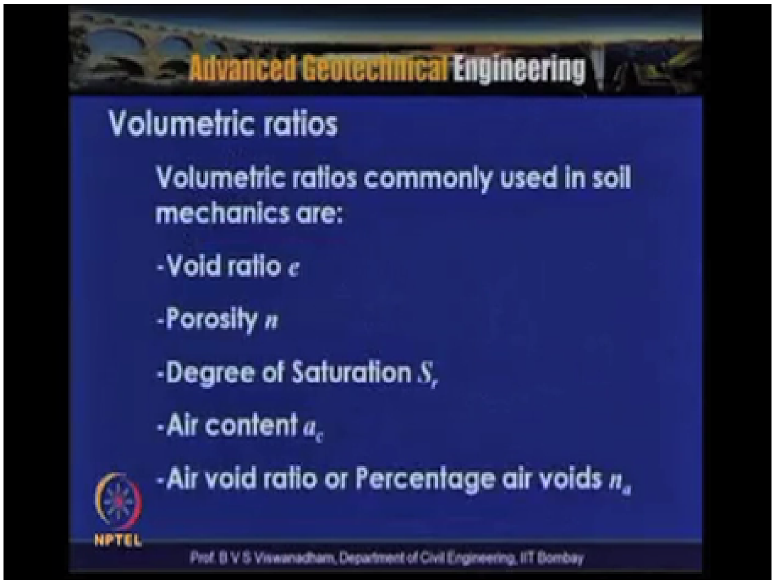

Now based on the phase diagram whatever we have discussed we can deduce number of volumetric ratios and these are used in soil mechanics and geotechnical engineering particularly they are known as wide ratio II porosity n degree of saturations SR air content AC air void ratio or percentage void percentage air voids n a so from the subsequent slides we will try to understand about these definitions of these and inter relations among these properties.

So void ratio is defined as the ratio of the volume of voids to the volume of solids which can be written.

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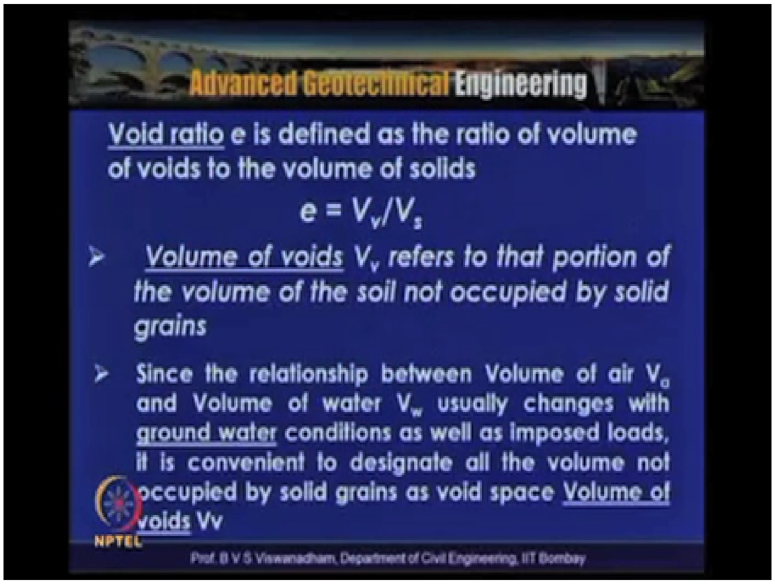

As e is equal to V V by VS as it can be seen here E is equal to V, V by VS so volume of voids v suffix refers to that portion of the volume of the soil not occupied by the solid grains since the relationship between volume of air and volume of voids volume of water usually changes with around with groundwater conditions as well as imposing loads suppose if the groundwater table changes or fluctuates or because of the imposed loads.

If the soil undergoes some compression are some expulsion of water there is a possibility that volume of air and volume of water can change it is convenient to designate all the volume not occupied by the solid grains as wide space that is volume of whites so the volumes which are not occupied by the solid grains is indicated as the volume of whites so white ratio is defined as VB by V s now if you look into for any solid material a is equal to zero that means this absence of whites.

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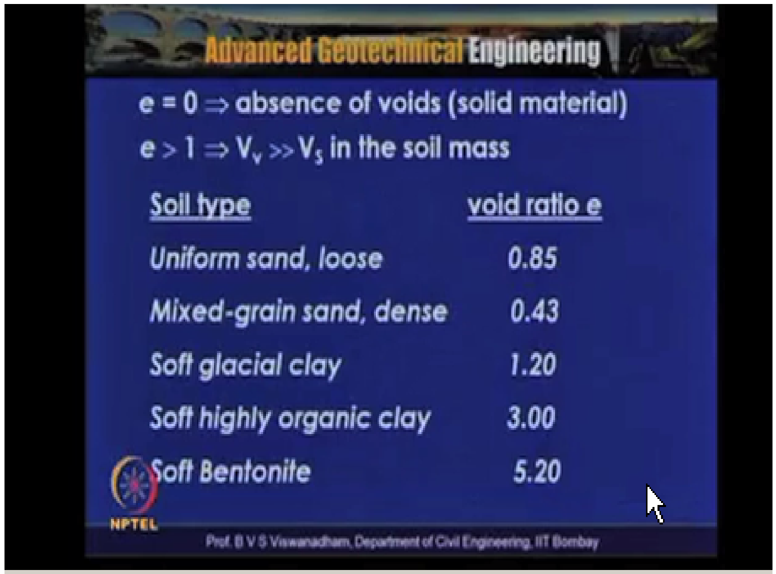

And e greater than one that means that the volume of voids is militants more than the volume of solids for a typical soil the void ratio ranges from say 0.8 to or 0.4 to around five point two in this case in the table here the typical soils are even say for example you know what is uniform sand and which is in the loose state which we are going to discuss in subsequent lectures so if you have got a uniformly graded sand particles the void ratio is about 0.85.

If you have got mix it grain sand that means that and it is in dense condition in that case the void ratio can be as low as 0.43 if you have got a glacial clay the void ratio can be up to 1.2 and soft highly organic clay that that means the soil which actually has got organic matter the clay which actually has got organic matter can have void ratio up to3.0 in the case of soft Bentonite the void ratio can be as high as 5 .2 so the void ratio for sandy or a sandy soils is relatively low and a clay soils is relatively high.

So if you make this observation here the void ratio of sandy soils is on the lower side compared to wide ratio of the clay soil so in subsequent lectures we will understand why this you know particular observations.

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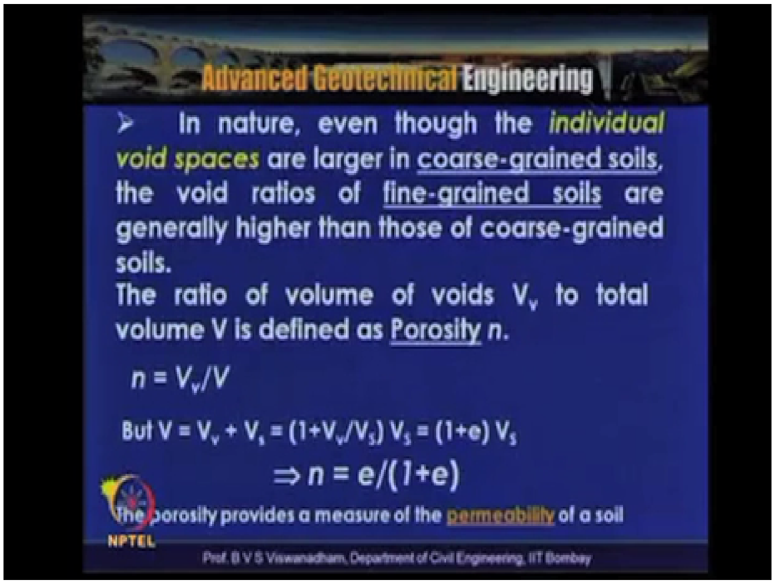

So in nature even though the individual wide spaces are larger in coarse granular soils that that means that in nature if you look into this even though the individual wide spaces are larger in coarse-grained soils the void ratios offline grade soils are generally higher than those of coarse grained soils so in the previous slide we observed that the void ratio of sandy soils are relatively lower compared to clay soils that means that if you put as the coarse grained soil.

The void ratios are of the individual grains the pore spaces in nature even though the individual void spaces are pore spaces are larger in coarse-grained soils the void ratio offline-grained soils are generally higher than those of coarse grain soils then we define one more parameter called porosity this is nothing but is a ratio of volume of voids to total volume this is generally expressed as a person in a percentage so if you take VV + VS is equal to total volume if you write V is equal to 1 + V V by V s into V.

So you can write that as 1 + V into VS that means that you can actually get an interrelation between N porosity and void ratio which is nothing but n is equal to e by 1 + e if you look into this the porosity provides a measurement measure of the permeability of a soil if the soil is more porous the permeability is high that means that the porosity provides a measure of the permeability of a soil permeability is a property of a soil which is defined as it is ease with which the water can flow through the soil
The porosity indicates here a large porosity provides a measure of the permeability of a side so this porosity N of soil.

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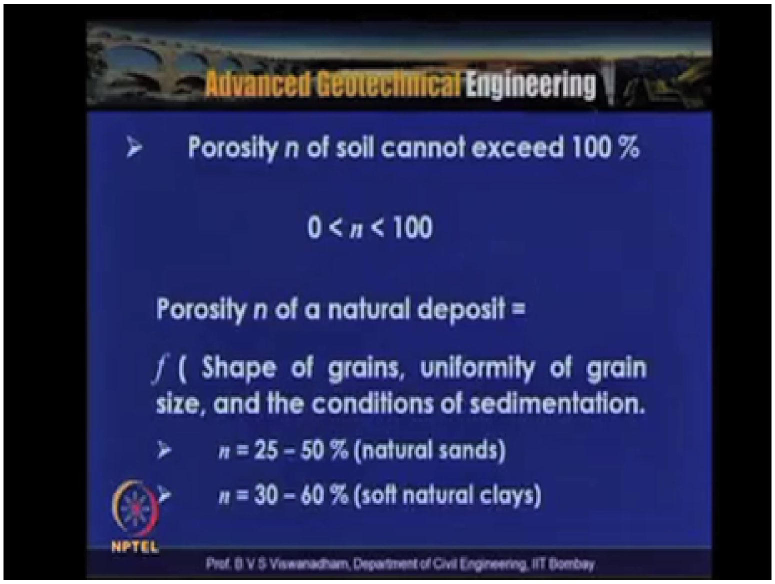

Cannot exceed 100 percent that means that it ranges between 0 and 100 porosity n of a natural deposit can be a function of the shape of grains that means that the type shape of the grain uniformity of grain size whether it is same size or different sizes and the conditions of sedimentation so for natural sands the porosity is in the range of n is equal to 25 to 50 percent and for a soft natural clays the porosity can be in the range of 30 to 60 percent.

So we have defined porosity and porosity we said that which is ratio of V V by V that is volume of voids to the total volume and the porosity n of a natural deposit is a function of shape of the grain uniformity of grains and the conditions of sedimentation now if you look into this in soil mechanics or in geotechnical we use wide ratio the reason is out of the void ratio E and porosity what ratios used frequently in soil engineering because of the particular region.

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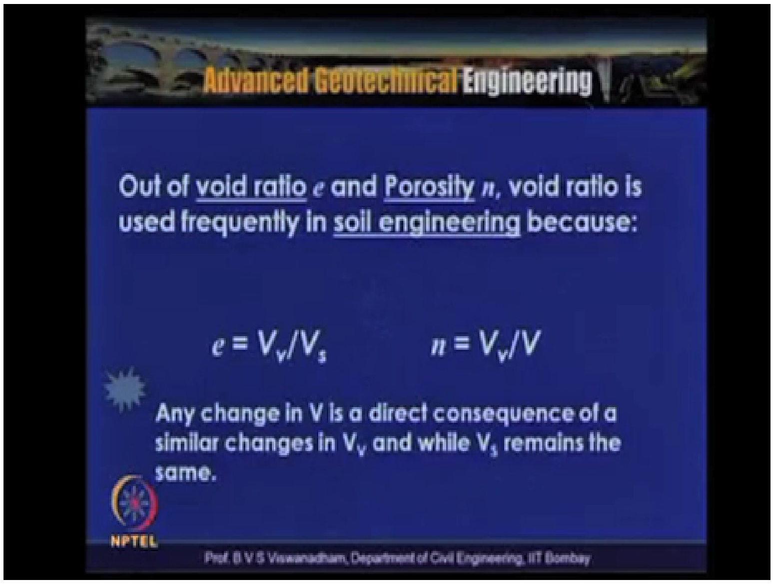

If you see the definition here E is equal to V ,V by VSN is equal to V, V by capital V so any change in a volume is a direct consequence of a similar change in volume of voids and while V s remains constant so because of this if you see the numerator and denominator V s which is actually remains constant in case of void ratio but in case of porosity both numerator and denominator undergoes changes.

So hence Wight ratio E is frequently used in soil engineering now another definition which is actually called as water content which is very much important the water current water content of a soil is defined as a weight of water - weight of the solids.

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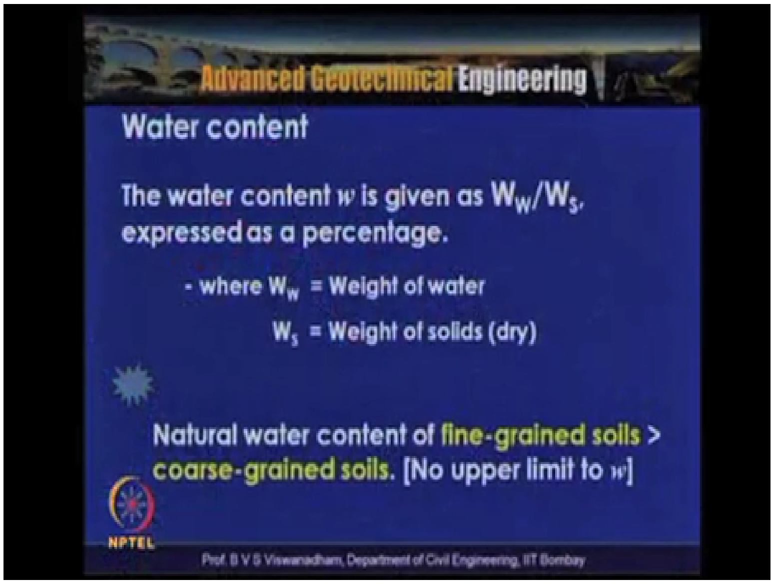

Expressed as a percentage so W, W that is w suffix W is nothing but weight of water WS is nothing but the weight of the solids in dry state so natural water content of fine-grained soils is greater. Than coarse grained soils and there is no upper limit for the water content so this water content is also called as moisture content or in case if it is in natural state it is called natural moisture content or in-situ moisture content so the water content W.

Which is defined as weight of water - weight of solids and which is actually not having any upper limit and for some soft soil deposits the water content that can be up to 500 percent and we also said that the natural water content offline-grained soils is high greater than coarse grained soils then there is another one important term.

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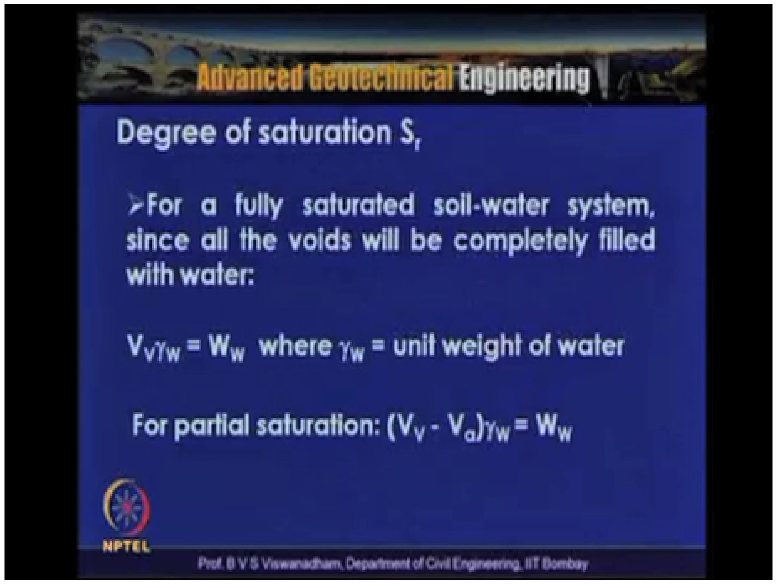

Which indicates the degree of saturation of SI so which is defined as volume of water to volume of whites that means that volume of water within volume of whites so this how it can be deduced let us see-through this slide for a fully saturated soil water system since all the voids will be completely filled with water we can write V suffix V γ W as weight of water that means that weight of water is nothing but γ W that is the unit weight of water.

Which is in SI units can be taken as nine point eight one kilo Newton per meter cube so W ,W is equal to V ,V γ W so for partial saturation we can write V ,V - V a γ W is equal to weight of water that means that what we did is that we have taken that weight of that volume of voids which is Comfort completely saturated soil volume of voids is equal to volume of water now for partial saturation.

We can write V ,V _ VA into γ W now the relationship between s are the degree of saturation can be obtained as SR is equal to V V _VA by γ W.

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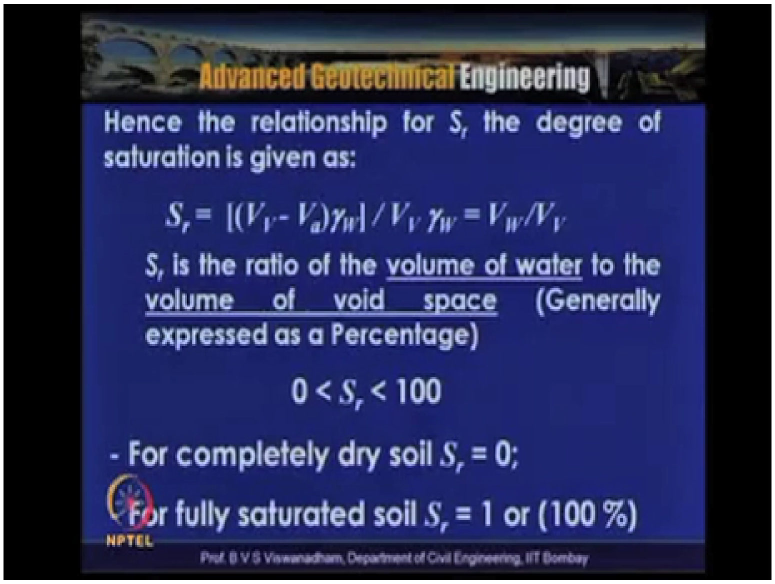

Divided by V, V γ W so if you simplify this you will get V suffix W by V suffix V so S R is the ratio of volume of water tote volume of white-spaces this generally expressed as percentage if this it ranges from 0 to 100 if s our degree of saturation is equal 100 that means that the soil is completely saturated if you have a soil with the 80 percent saturation then we can say that the soil is partially saturated so for fully saturated soil SR that S suffix R or degree of saturation is equal to 100percent.

So soil can be partially saturated and if you look into this diagram if this is the ground surface what you see is the ground surface.

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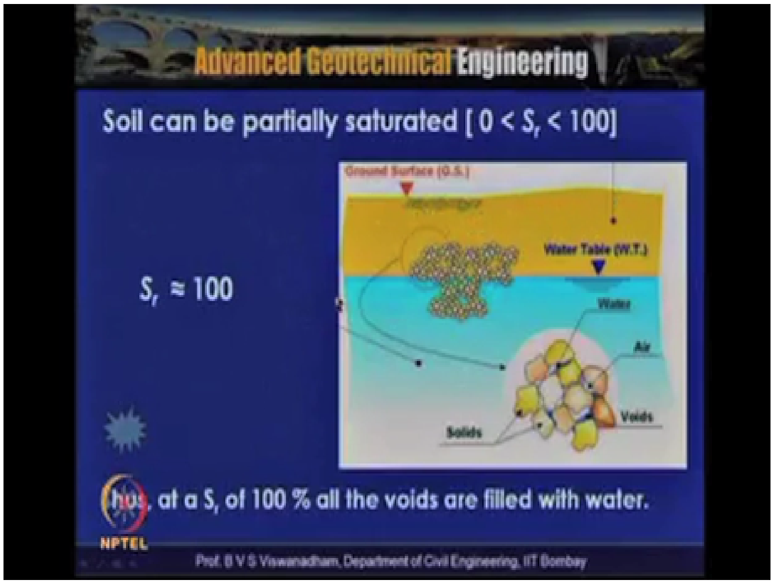

And this is the water table location the hydrostatic groundwater location the soil above this is the mains in partially saturated this is because of the temperature fluctuations as well as the partial the water evaporation which takes place in this Joel the soil below ,the water table is said to be completely saturated except some minor occurrence of air bubbles otherwise you can say that the soil is completely saturated it means that all the wines.

Which are actually filled with water so at SR is equal 100% all voids are completely filled with the water so below the water table we can say that the soil is completely saturated above the water table unless the type of soil is different you actually have a partially saturated soil occurs.

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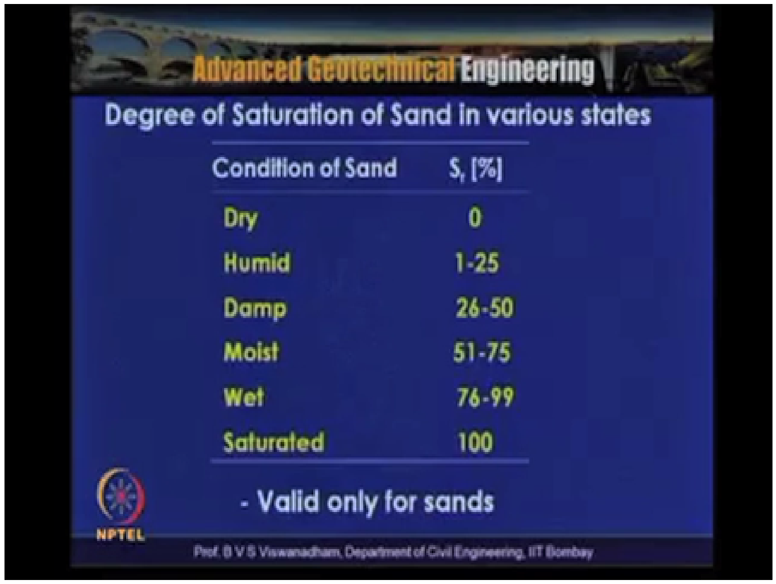

So if this particular slide shows a typical you know variation of degree of saturation for sands so this is strictly valid for sands based on the condition of sand if it is dry the degree of saturation is equal to zero humid one to 25 % and damp 26 to 50 %moist 51 to 75 % wet 76 to 99 saturated 100 that means that this is a degree of saturation if it is 100 then we can say that the zones of sand deposit is completely saturated so degree of saturation S R fine or silt sands are moist wet are hydrated clays are always completely.

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Or nearly saturated except .In the layer of soil subjected to seasonal variation of temperature and moisture fluctuations so what we discussed in the previous slide is that clays are always completely are nearly saturated except in layer of soil subjected to seasonal variation of temperature and moisture now we define one more parameter which is called a content air content is called a suffix is indicated by a suffix C.

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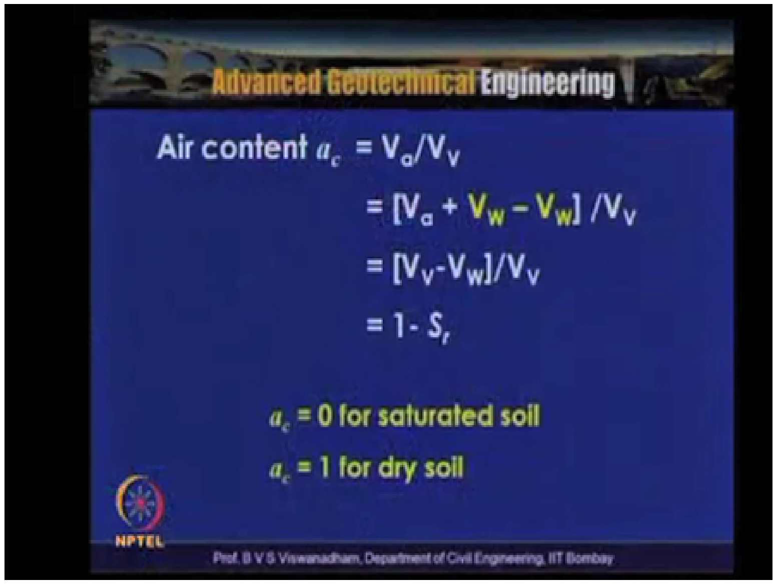

Which is nothing? But volume of air in volume of whites that means that which is ratio of volume of air to volume of whites degree of saturation we defined as volume of water to volume of whites so here the air content is nothing but volume of air in volume of whites so we can write here VA +V suffix W _V suffix W by V ,V so if you write VA+ V W as V ,V _ V W we can write this as V W by V is SR that is degree of saturation.

So we can write V ,V by V is equal to 1 so the air content is equal to AC = 1 - SR so if SR = 1 that means that for saturated soil air content AC is equal to 0 that means that for a saturated soil air content a suffix C is equal to0 for a dry soil air content is 1because all the voids are filled with our air within the whites.

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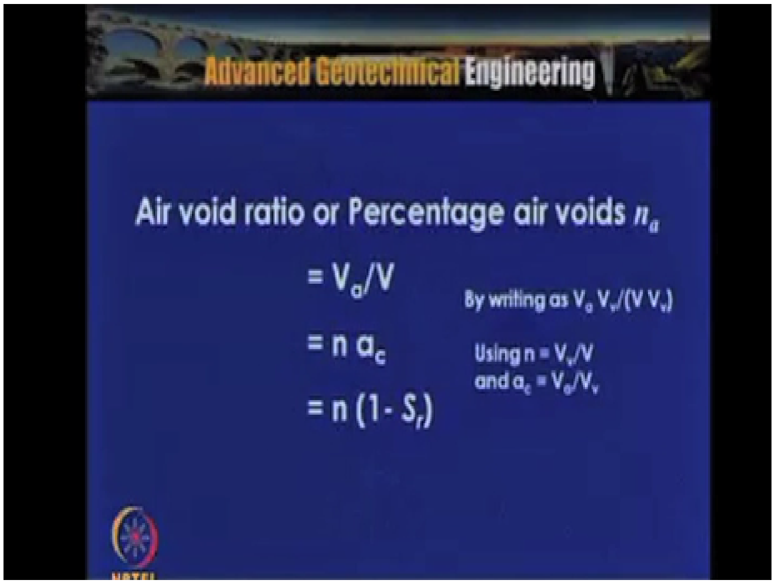

Then another parameter which is actually called as a void ratio or percentage water percentage air voids so another parameter which is actually called as air void ratio or percentage air voids n suffix a which is defined as volume of a to total volume so by writing V a into VV divided by V into V ,V and using n is equal to V ,V by V which is nothing but porosity we have defined earlier and a suffix C air content is equal to V a by V ,V.

We can write air void ratio or percentage air voids as n AC that means that if you substitute AC is equal to 1_ SR we can write percentage air voids na is equal to porosity into 1-SR so again if you see when SR = 1 percentage air voids na = 0 that means that air void ratio percentage air voids ma = n =1 – SR.

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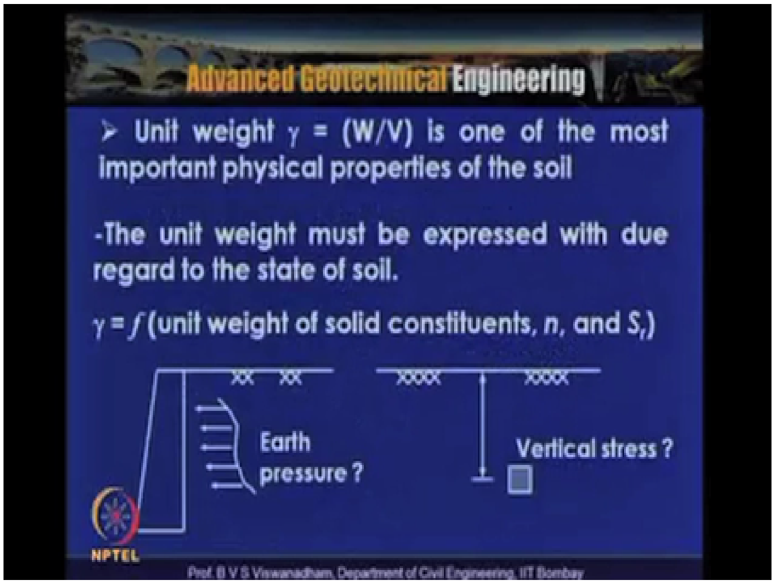

The another important parameter as far as soil engineering or geotechnical engineering is concerned is unit weight of the soil and this is actually has got number of terminologies depending upon the state of saturation or whether it is in the dry state whether it is in saturatedstate or whether it is in moist or partially saturated state so the unit weight general definition V is nothing but weight of the soil to the total volume weight of the soil mass.

To the total volume is one of the most important physical properties of the soil the unit weight must be expressed with due regard to the state of soil so as I said earlier the unit weight must be expressed with due regard to the status oil that means that whether it is a dry or moist or saturated so unit weight is a function of the unit weight of the solid consistent the type of the grains which are is composed of and porosity whether it is closely Platte Packer or lose repack and degree of saturation.

So the application of why do we want the unit weight of the soil suppose if you are what a retaining wall and the soil is you know placed behind the wall the soil exerts the pressure so if you wanted to calculate the lateral pressures you need to calculate what is the earth pressure so in this case in order to compute a pressure you need the unit weight of the soil for example if you wanted to determine a vertical stress or a total stress.

At a particular depth because of the certain depth of the soil or certain state of the soil then you need to know the unit weight of the different layers which are actually above that particular point of interest so if you wanted to determined you know the stresses in the soil or say earth pressures in behind the walls you need to know what is the unit weight of the particular material.

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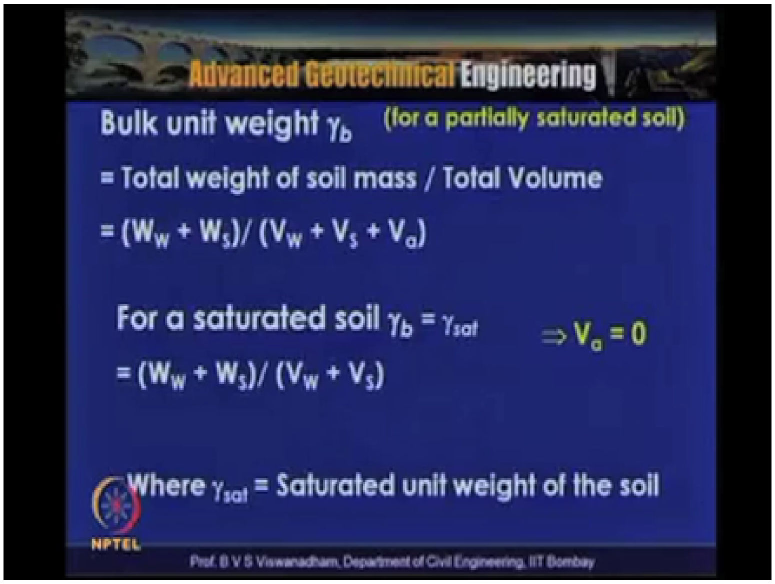

For a partially saturated soil bulk unit weight or γ bulk which is also it called as moist unit weight which is nothing but total weight of soil mass to the ratio of the total rate of soil mass to total volume so γ bulk is equal to we can write as weight of water plus weight of solids divided by volume of water+ volume of solids +volume of a weight of the air is equal to zero that means you are here having only weight of water + weight of solids divided by total volume for a saturated soil γ bulk is equal to γ saturated γ suffix b= γ saturated.

So because and volume of air is equal to zero in that situation for a γ sat it is defined as weight of water +weight of such weight of solids divided by volume of voids volume of water + volume of solids where γ sat is nothing but the saturated unit weight of this side for example this agitated unit weight of the soil can occur if the if you find a soil strata below the ground water table in another case for example dry unit weight.

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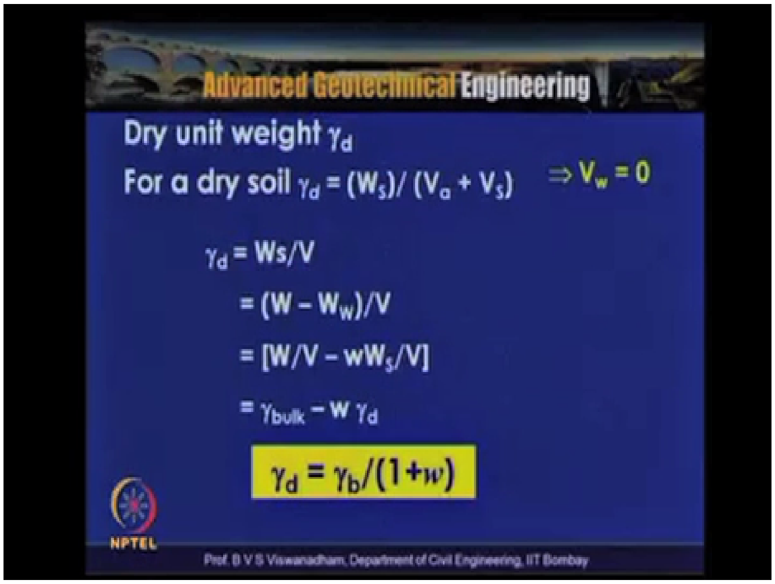

So dry unit weight which is indicated as γ suffix D for a dry soil γ D = WS divided by VA + V S here because the soil is in dry volume of water occupied in the whites is zero that means that volume of water is equal to zero in that situation it is written as for a dry soil WS divided by total volume which is nothing but volume of air +volume of solids so γ D is equal to WS by V we can write this as W -w w suffix W so W - w ,W by V we can write as W by V - W WS so if you write WS by V as γ D we can write γ D as γ bulk -water content into γ T.

So if you rearrange these terms we can write γ D is equal to γ bulk by1 + W so this particular you know relationship is used widely which is nothing but γ D is equal to γ bulk divided by 1 +water content so here the unit weights of γ D are in kilo Newton per meter cube γ bulk in kilo Newton per meter cube in water content expressed in percentage but here is indicated in this Mel form W in demote in terms of decimal form.

For example if the soil actually has got say 20 %water content here in this expression you need to use W is equal to0.2 so typical weights typical values of unit weight of weight for soils are given in this particular slide.

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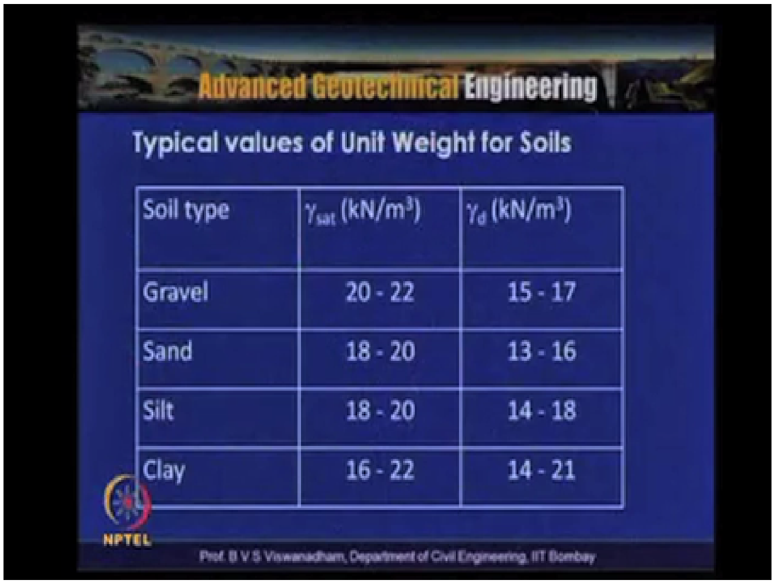

Soil type	γ_{sat} (kN/m^3)	γ_d (kN/m^3)
Gravel	20 - 22	15 - 17
Sand	18 - 20	13 - 16
Silt	18 - 20	14 - 18
Clay	16 - 22	14 - 21

So if you see here typical values of unit weight for soils is given for a soil type gravel the saturated unit weight can be20 to 22 the dry unit weight can be 15to 17 sand can be 18 to 20 and the dry unit weight can be the- 16 silt it can be 18 to 20 and 14 to18 in dry state for clay the saturated unit weight can be 16 to 22 and the dry unit weight can be 14 to 21 for some non soil like materials like say multiple solid waste they are even lighter than water someday the unit weight ranges from in the loose state for a freshman.

So solid waste it can be as low as 9kilo Newton per meter cube for industrial waste like coal ash the dry unit weight can be in the range of12 kilo Newton per meter cube that means that these light materials can be used in soil engineering or geotechnical hearing or some construction purposes if you wanted to do on construction on soft ground.

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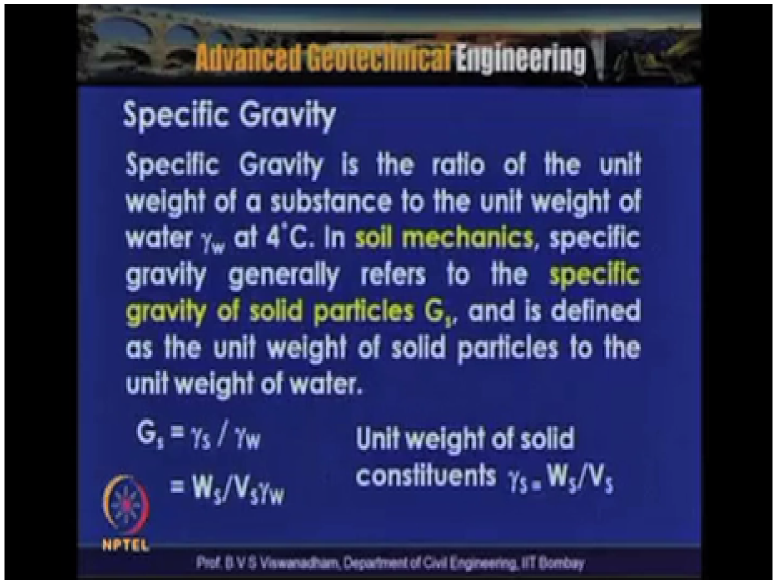

The another parameter which is called specific gravity the specific gravity is defined as the ratio of the unit weight of the substance to the unit weight of water γ W at 4 degree centigrade so in soil mechanics are Jordan engineering the specific gravity generally refers to the specific gravity of the solid particles so we use a specific gravity of the solid particles that is G suffix s and is defined as the unit weight of the solid particles to that of water that is GS is indicated.

As γ s by γ W which is nothing but γ s if you write it as W s divided by capital V s that is V s nothing but volume of the solids into gamma W so G s we can write it as WS by V s gamma W or weight of solids is equal to GS V s γ W that means that if you know the specific gravity of the solids in a given soil mass if you know the volume of solids and with the unit weight of water you can determine the weight of the solids.

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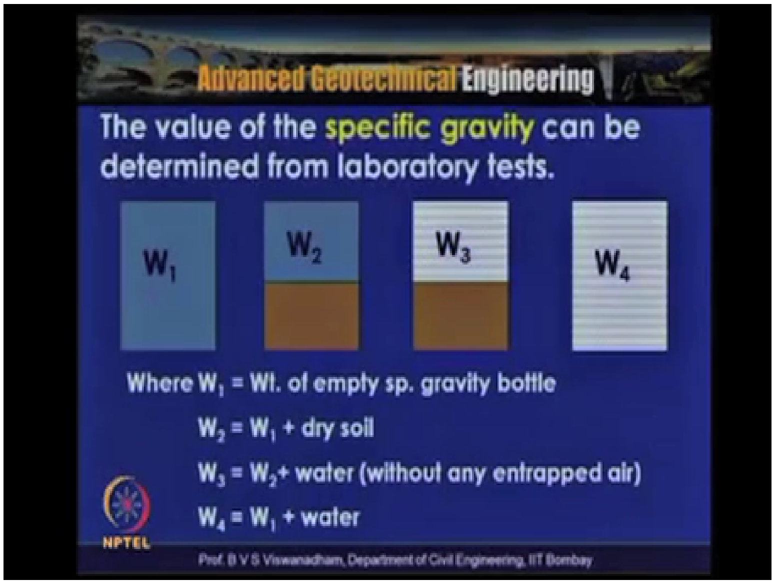

How to determine the specific gravity say in the laboratory if you see this simple illustration which is shown in this slide let us take you have got a particular material under consideration is filled in a specific gravity button and if you take weight of empty is the gravity bottle and if you indicate that weight as w1and if you take the desired soil in dry straight air-cooled and dry state and if you take that weight that is w2 is equal to w1 empty bottle + the dry soil and w3 what you do is that w2 +water without any entropy air.

So in order to do that you have to continuously shake and subjected to say some sort of boiling we're in the whites are entrapped air in the soil particles can be removed so if you determine that weight is indicated as w3 is w2+ water then once after doing that entire specific gravity a specific gravity bottle is filled with water and that way it is indicated as w-4 that isw1 +water .

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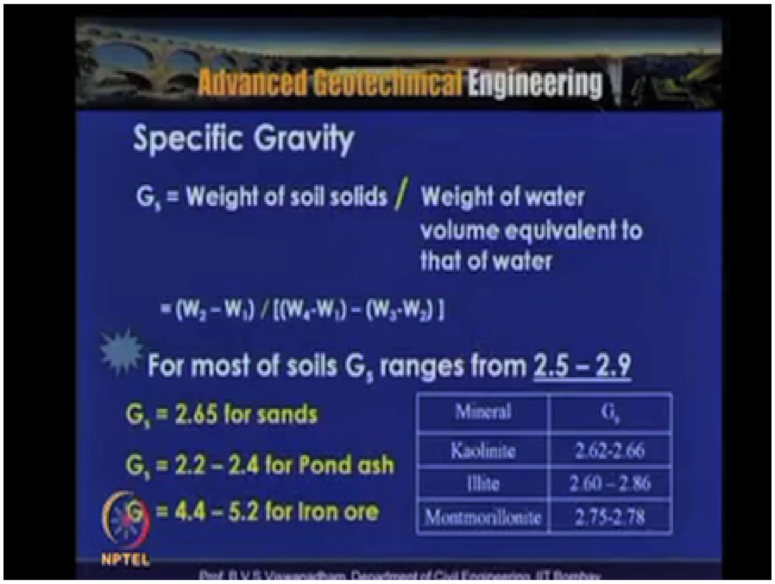

Now so we have got w1 w2w3 w-4Now we need to find out the specific gravity of the soil under consideration means so you need to take weight of the solids soil solids how do you get that is nothing but W 2 minus W1 W 2 e is the weight of the soil -W 1 is the empty weight of the bottom then weight of the water volume equivalent to that of water so what in order to get this what you need to do is that you need to subtract weight of water - weight of water occupied that is W 3 - W 2.

So what we are doing is that we are actually taking the water volume equivalent to that of soil solids so in order to get that what you need to do is that W 4 -W 1 -W 3 - W 2 you need to do if you do that so you will get the expression GS = W2 -W 1 within parenthesis divided by W 4 minus W 1 - W 3 - W 2 for most soils the specific graph to the solids ranges from2.5 to 2.9 here I have given for atypical minerals.

Which we are going to discuss in the next lecture KO light in light and multiple light these are the three predominant minerals in fine drawing fine-grained soils so if you see here for a kiln light base to the soil the specific gravity is around the range of two point six two point six for a light base in soil two point six two point eight six multiple right based soil the specific gravity can be in the range of two point seven five to two point seven eight so normally for sands.

The specific gravity of the solids GS will be equivalent to two point six five and for say non soil like materials say pond ash has specific gravity in the range of two point two to two point four in some cases for very light coal ash or a pond ash it can be as low as two and for air on more which is based on hammer tight type mineral where four point four to five point two it can have is a you know very high specific gravity.

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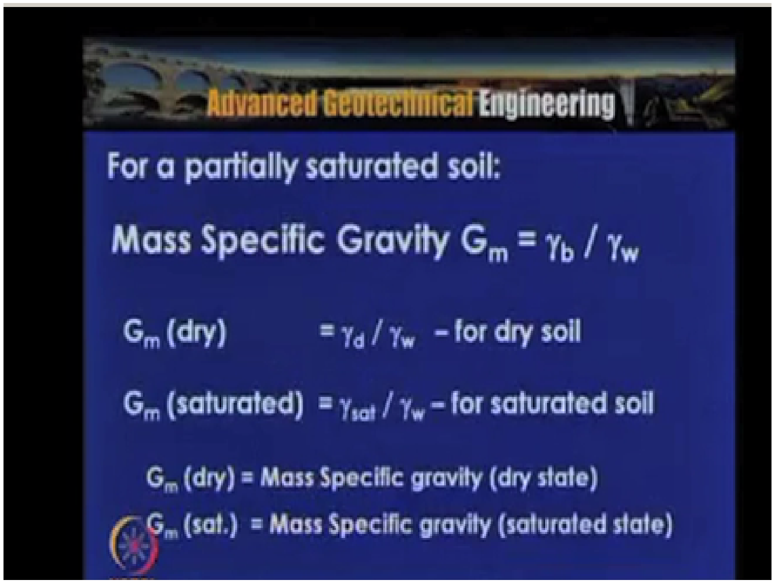

So for a partially saturated soil the we have discussed that which is γ bulk that is the γ bulk is nothing but the bulk unit weight are moist unit weight of the soil so for a partially saturated soil mass specific gravity is defined G suffix mm as γ B by γ W in case of say G M dry that is mass specific gravity in dry state which is nothing but a γ D by γ W for dry soil GM saturated which is nothing but a γ S at by γ W for saturated soil.

So GM dry is nothing but a mass specific gravity in dry straight which is nothing but a ratio of γ D by γ w GM sat which is nothing but a mass specific gravity in a saturated state.

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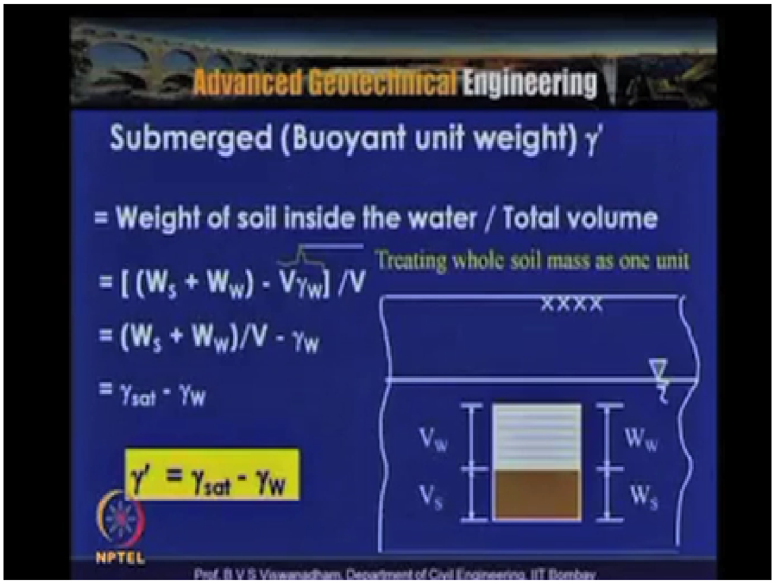

Then we knew that the soils when they are actually below the water table they are the Buoyant state so we define in order to calculate stresses at certain points below the water table and all you need to know the by on and unit weight or submerged unit weight of the soil so submerged unit weight or by another unit weight is indicated by γ sub or γ dash so γ dash is indicated nothing but submerged unit weight of the soil so how to you know get a relation between saturated unit weight of the soil and unit weight of water.

So further if you see the simple station here we have taken a ground surface this is the ground surface and this is the groundwater table and this is the soil mass which is completely saturated weight of water and weight of solids which is nothing but the weight of soil mass which is some much below the water table and volume of oil and volume of solids and volume of water on the left-hand side here so we can write the Y weight of soil inside the water divided by total volume so this can be written as very tough.

That is weight of solids + weight of water -V γ W so that much volume is displaced treating all soil mass as one unit we can write as WS plus w WS+ W -V γ W by V so this can be written as WS by W by W suffix W by V- γ W so which is nothing but V and we will get cancelled so W is + W by V is nothing but weight of saturated soil divided by volume which is nothing but a saturated unit weight of soil so we get relationship here γ submerged is equal to γ sat is equal γ sac –γ W.

So if you wanted to say compute the submerged unit weight of soil you need to take the unit weight of water subtract a unit of what from the saturated unit weight of the soil so γ dash is equal to γ sat -γ W.

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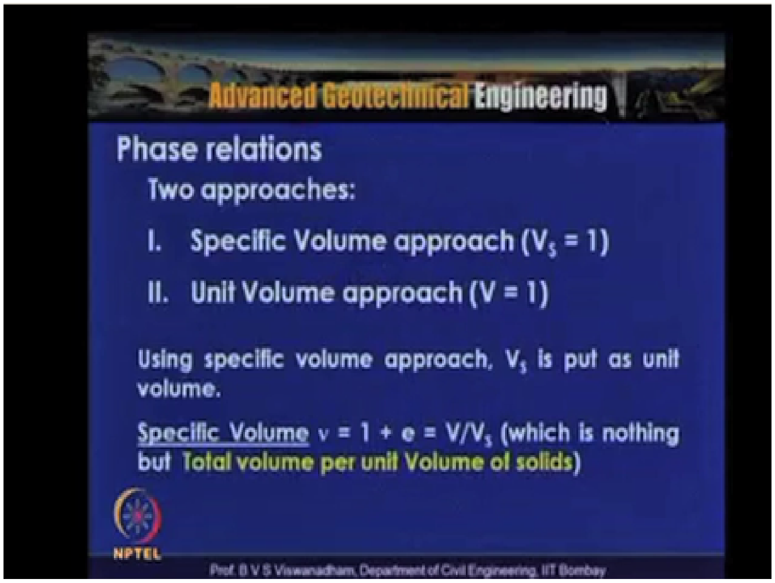

So now if you wanted to determine the phase relationship phase relationships you can actually use different approaches like you can assume volume which is nothing but volume of wall voids volume of solids and volume of water volume of solids volume of water and volume of a in case of partially saturated soil and weight of water weight of solids and weight of air which is equal to zero so there are two approaches which are there one is called specific volume approach.

In this the volume of the solids is set as one volume of solids is set as actually one unit volume approach which is sometimes is also very convenient is set a assumed as V =1 so this is assumed and these particular approaches are used if the volume is not known so using specific volume approach VS is put as equivalent to unit volume so in the specific volume so you know here this is another which is actually used in which is nothing but total volume per unit volume of solids so V = +E which is nothing but V ,V by V s that is nothing but V by V s so total volume per unit weight of unit volume of solids is nothing but V = V by s so here the specific volume is defined as 1+ e.

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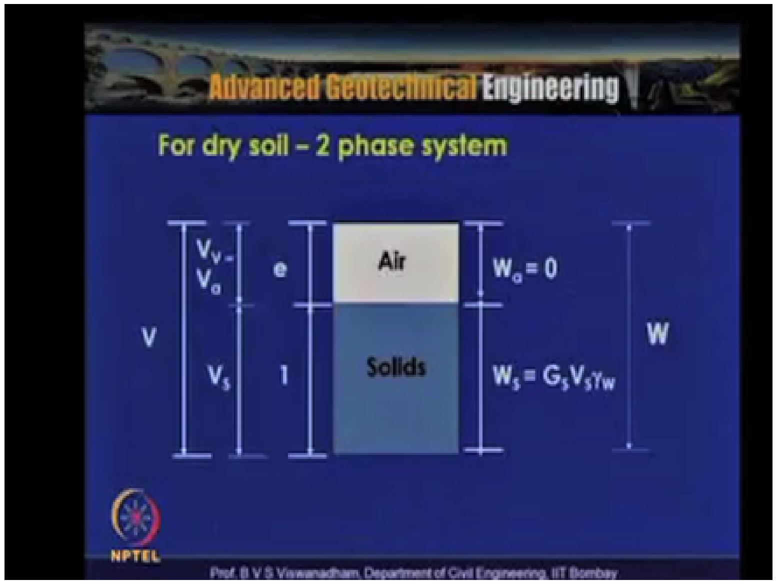

So for a dry soil in a two-phase system what you have here is weight of air is equal to zero so this is called two-phase system weight of solids is nothing but here we have set based on the unit volume approach here specific volume approach here V sis equal to one we have set here and volume of why—it is equal to volume of air because the soil is dry so WS is equal to GS v s γ W V as being one it is nothing but a GS γ W and W a is equal to 0.so this is taut weight of soil mass in case of a dry soil state two-phase system is nothing but W is equal to WS.

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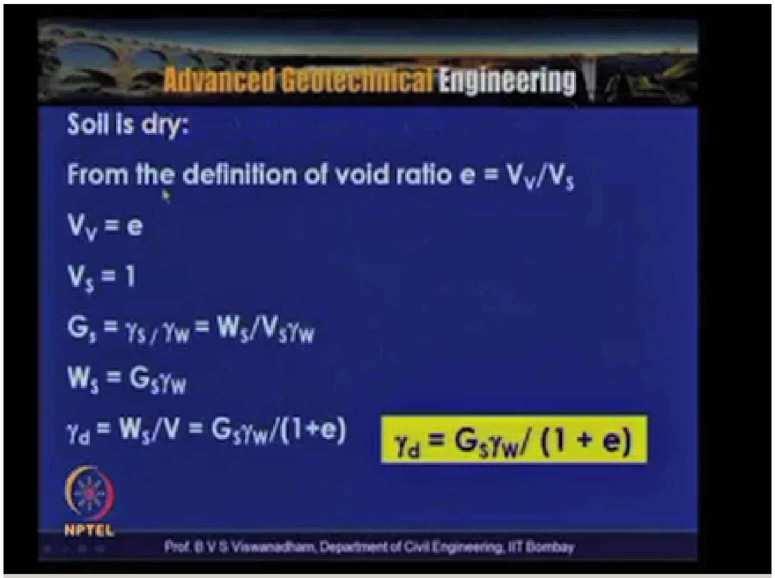

So for the soil is dry from the definition of void ratio we can write V ,V by V s so V, V is nothing but E V s is nothing but 1 so G s = γ s by γ W based on that WS by V s γ W so we can write WS = GS γ W and γ D are dry unit weight of the soil mass we can write as WS by V which is nothing but a G s γ W by 1 + K so here for a dry soil we can write a relation like γ D is equal to G s γ W by 1 + C so this is very useful if you wanted to if you know the dry unit weight of the soil and the specific gravity of soil.

What will be the void ratio of the soil mass that means that e is equal to G's γ W by γ D by _ 1 so if you rearrange the terms γ D = G's γ W divided by 1+ e we can use this relationship in case of basic relationship here for a saturated soil in this case weight of a is equal to nothing but e gamma W because weight of a weight of air is 0 here weight of air is 0 and weight of water is = e γ W and weight of solids is equal to GS γ W so total weight of the soil mass is equal to GS γ w + G γ W so from this if you look into the volume scale.

Total volume is nothing but 1 + e so the saturated unit weight of soil mass γ sand is nothing but W that is saturated unit weight of the entire soil mass divided by total volume so it is nothing but G is γ W + e γ W/1 +e so like this by using these phase diagrams one can deduce the interrelationship interrelation between the soil properties .

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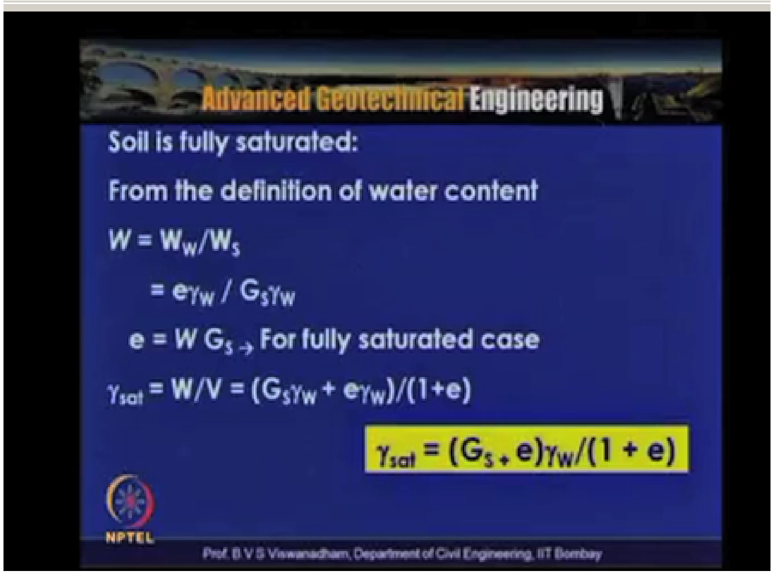

So for the soil is when the soil is fully saturated from the definition of water content we can write as W is equal to weight of water to weight of solids so weight of water in the previous slide we have seen as a γ W weight of solids is nothing but G's γ W because V s = 1 we have set so with that if you look into this the relationship is that E = WGS so E the void ratio is nothing but water content times the specific gravity of the soil solids for a fully saturated case.

So for a fully saturated case γ sat the saturated unit weight of the soil mass is nothing but W by V which is nothing but GS γ W + e γ W by 1 + e so the relationship with what we can write is that γ sat = GS + e into γ W divided by 1 +e.

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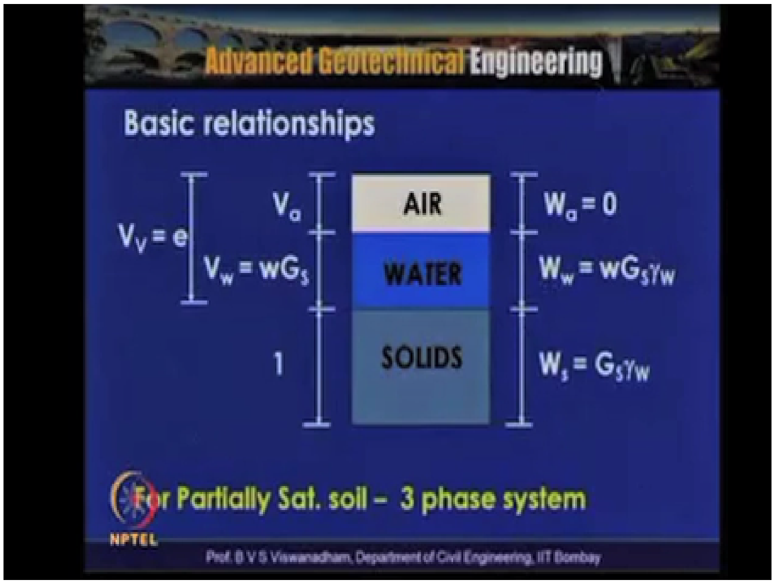

Similarly now we have seen the dry state of the soil and saturated state of the soil but if you have got a partially saturated or a V we define this as a 3-phase system so in this case you have weight of water weight of solids and weight of a that is nothing but 0 so but here as a volume we have got volume of solids which we have set as 1 because of the specific volume approach and volume of voids which is nothing. But e but which is the summation of volume of air + volume of water so from the definition.

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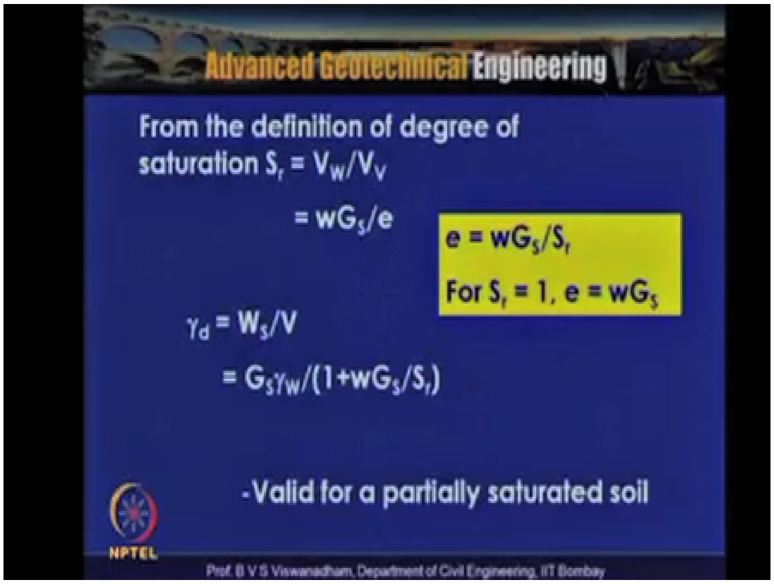

Of degree of saturation of soil we can write SR is = volume of water - volume of whites so volume of water which is nothing but here if you see weight of water is nothing but W GS by γW v WS is = GS γW from the water content definition we have written here weight of water is equal to WGS by γW so here by writing this what we get is that a relationship between for a partially saturated soil between void ratio water content specific gravity of the solids and degree of saturation.

Where E is equal to WGS by SR for s R = 1 = WGS that we have deduced it previously for a saturated soil so here γ D that is nothing ws that is a dry state that is GS γ w divided by V that is nothing but a volume which is nothing but 1 +e but E is nothing but w GS is R so for a partially saturated soil if you see the relationship is that γ D = GS γ w + 1 + WG s by s R so this invalid for a partially saturated side.

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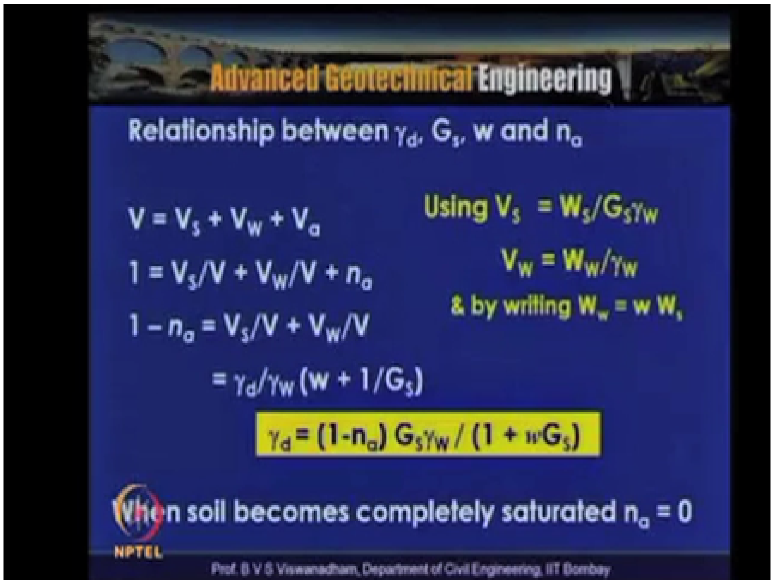

Now let us try to derive some interrelationship between D the dry unit weight of the soil specifically out of the solid GS water content and DNa so we knew that you know how to derive that let us say that we have total volume V is equal to V s + V W + V a okay so what we are doing is that by dividing both left-hand side and right-hand side by volume we can get 1 is equal to V s by V +V W by V + n suffix a which is nothing but V a by V we have written as na using V s is equal to WS by G's γ W and V W is equal to www suffix W by γ W and by writing W w is = W times W s we can get that na if you take it to the left hand side.

We get 1 -na V s by V + V W by capital v and if you substitute these expressions here and simplify you will get γ D by γ W into water content + 1 by G s so if you write this expression in terms of γ D we can write γ D = 1 -na G's γ W +1 w GS so for when the soil becomes completely saturated we knew that na = 0 so in this case what will happen is that γ D is = GS γ W by 1+ w GS this is actually the expression what we derived for a saturated side.

So this is for a partially saturated soil if you have the relationship between gum DGS wn na can be given by γ D into 1-na G's γ W 12 by 1+ w GS now having seen the specific volume approach let us see the unit volume approach also is sometimes very easy to deduce interrelationships or phase relationship phase relationships on the different phases of the soil for a partially saturated soil let us consider it and we have we say that it is a 3phase system and here.

What we did is that total volume is set as 1 so if you set the total volume as 1 then the portion which is the volume of voids is nothing but n because porosity is nothing but volume of voids divided by total volume so VV by 1 is equal to N nothing but this becomes small n that is porosity and this portion becomes this is this becomes 1 - n so the weight of the solids is given as GS into 1-CN into γ W GS into 1 -n into γ W based on.

The water content definition we can write W into GS 1- n γ W by taking γ W out we can write here the volume of water as w GS into 1 -n the rest is volume of the a and W a = 0 here so for a partially saturated soil and if you want say the total weight of the soil mass which is nothing but GS into 1- y n γ W + W GS into 1 - n γ W by total volume .

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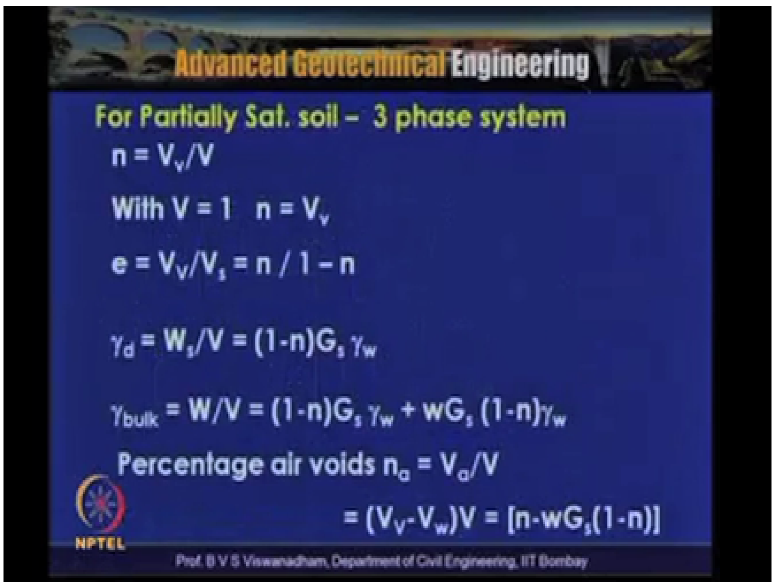

So for a partially saturated soil three phase system we have n = V V by V with v = 1 n is equal to volume of whites so we can write E is equal to V V by V s that is nothing but n by 1sm we have deduced earlier so we can write γ D = WS by V that is nothing but 1 - n into GS γ W that is we are expressing in terms of say porosity or that is 1 -n into GS γ w γ bulk from the previous slide we can say that W by V which is nothing but 1 - y n into G's γW+ W GS into 1 -n γ W.

Now percentage air voids NEA can be defined as VA by V so which is nothing but V V- VW by V which is which can be very simply it can be written as n - W GS into 1 -y n because total volume = 1 for a completely saturated soil similarly we can actually set and use this approach.

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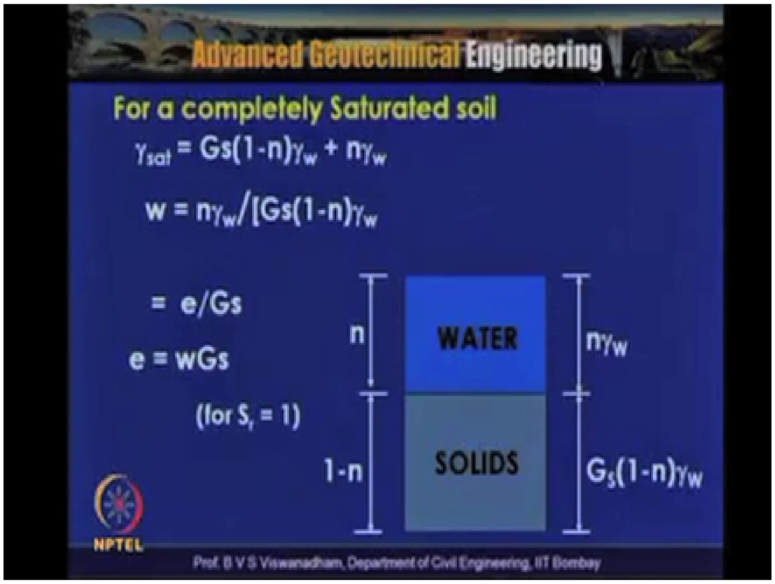

And we can write γ sat is equal to GS into 1 -n γ W + n γ W because for in case of completely n γ saturated soil you have got n γ W that is the weight of water and weight of solids is nothing but GS into what volume is nothing but 1 – n γ W so here the total volume set is equal to set as1 and Y n is the volume of water so water W is equal to we can write it as n γ W divided by GS into 1 - W which is nothing but e de by GS.So y equal to WGS is what actually we have got for a you know completely saturated soil.

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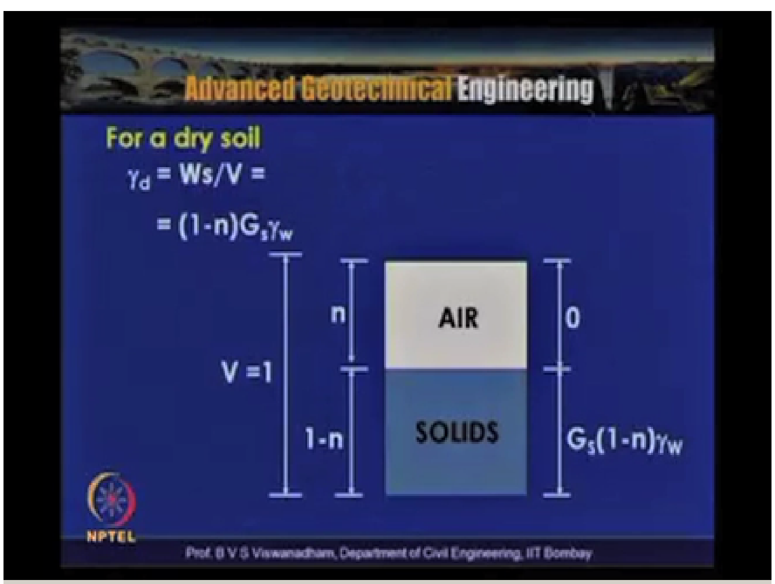

For a dry soil similarly so we have seen for partially saturated soil and the same for completely saturated soil and for a dry soil with the same approach we can write γD is equal to WS by V which is nothing but1 - n into G's γ W divided by total volume is equal to 1 because of this we can write this as 1 - n into GS γ W.

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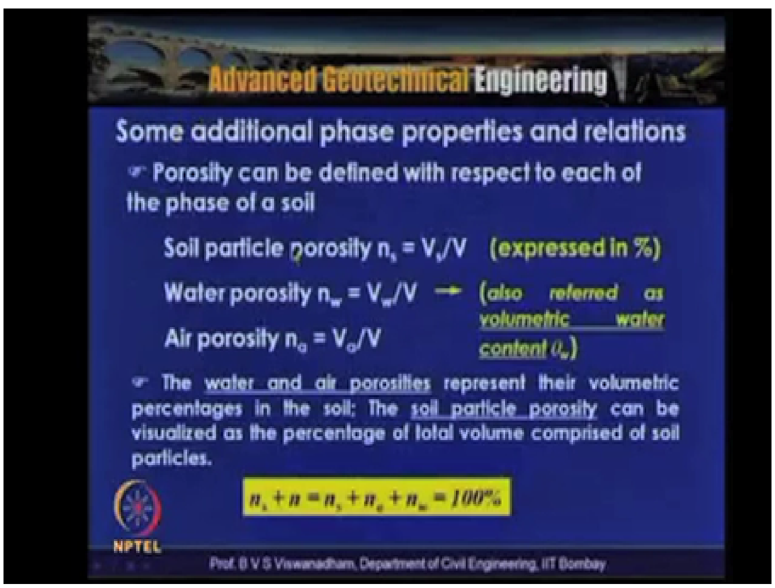

And let us also discuss some additional phase properties and relations particularly. Which are used in unsaturated soil mechanics and the porosity can be defined with respect to each of the phase of this side so we have defined normal the porosity as volume of voids in a total volume of soil but we have got different phases of soil particularly you have got a solid phase that is solids are there and water is there a or gas is there.

So soil particle porosity n suffix s is defined as volume of solids in total volume that is V s by V this is expressed in percentage and water porosity which is nothing but n suffix W which is volume of water in total volume so this is also referred as volumetric water content theta W so this is particularly used in soil science or in nowadays it is widely used in unsaturated soil mechanics air porosity and suffix K = VA by capital V so air porosity na = VA by capital v and water porosity n w = V W divided by V.

And this is defined this is also referred as volumetric water content theater W now the water and air porosity is represent their volumetric percentages in the soil so water and air porosity they represent their volumetric percentages in the soil that is volume of water in the total volume of a in total volume the soil particle velocity can be visualized as a percentage of the total volume compression of soil particles so the soil particle porosity is can be visualized as the percentage of total volume compression of soil particles.

So the soil particle porosity can be visualized as a percentage of total volume compression of soil particles but if you look into this n s is nothing but volume of soil solids - volume of total volume + n is nothing but volume of whites in a total volume so the summation of n S + n = n s + na + n W should be equal to 200percent that means that here in is water the air porosity NW that is nothing but water porosity ENS is nothing but a soil particle porosity the summation of n S +n = n s+ e na + n W has to be current to 100%some additional phase properties and relationships. If you derive volumetric water content or you know we have defined in the previous line as θ.

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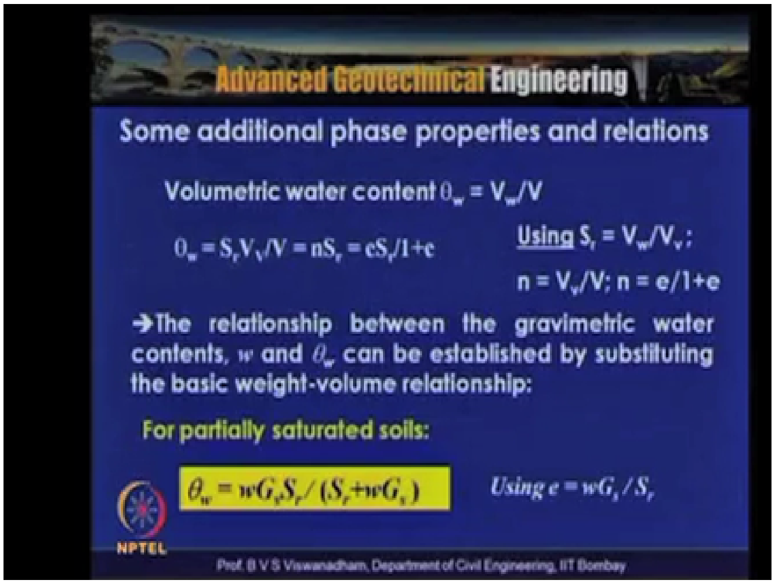

As volume of water - capital V so using degree of saturation as the V W by V, V and n = V, V by V we can write and using any is equal n = e by 1 +e if you substitute here for a degree of saturation we can write it in terms of theta W in terms of SR V V by V how we have written is nothing but V W = SR into V V we have written divided by capital V, V, V by V is nothing but porosity so we can write the volumetric water content is n times porosity times degree of saturation so here by using n is equal to e + 1 e.

We can write e sr divided by 1 + e so if you wanted to get say the relationship between the gravimetric water content which is what we have defined conventionally the water content and θ w the volumetric water content we can actually obtain for a partially saturated soil as by using E is equal to substituting G is equal to WGS by SR if you substitute here then what we get is that θ W is equal to WGS SR by SR + w GS.

So if you have this one you will get a relationship between volumetric water content θ W and the gravimetric water content W so θ W = WGS sr + / sr + w GS.

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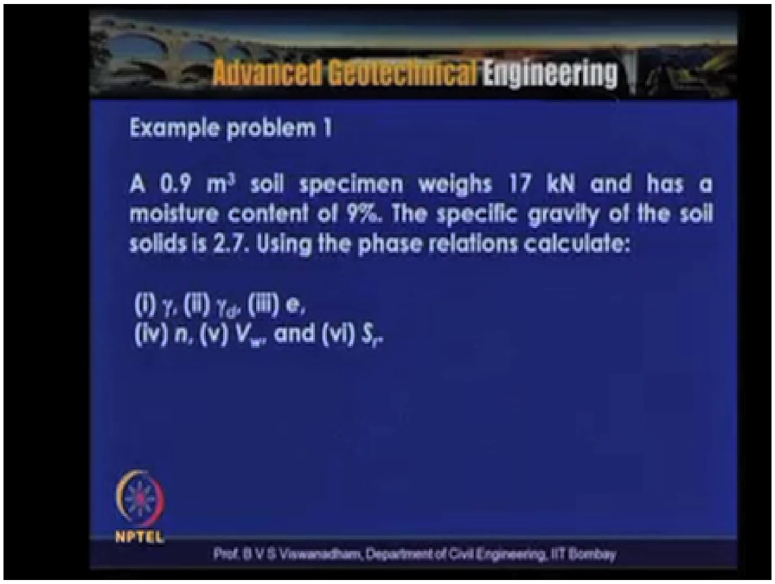

So having seen the phase relationships among the soil properties let us take some example problems and try to solve them so in this example problem in this slide it is given as a point eight meter cube soil specimen weighs 17 kilo Newton and has a moisture content of 9% the specificity of the soil solids is 2.7using the phase relationships so we need to calculate γ D e porosity volume of water and degree of saturation.

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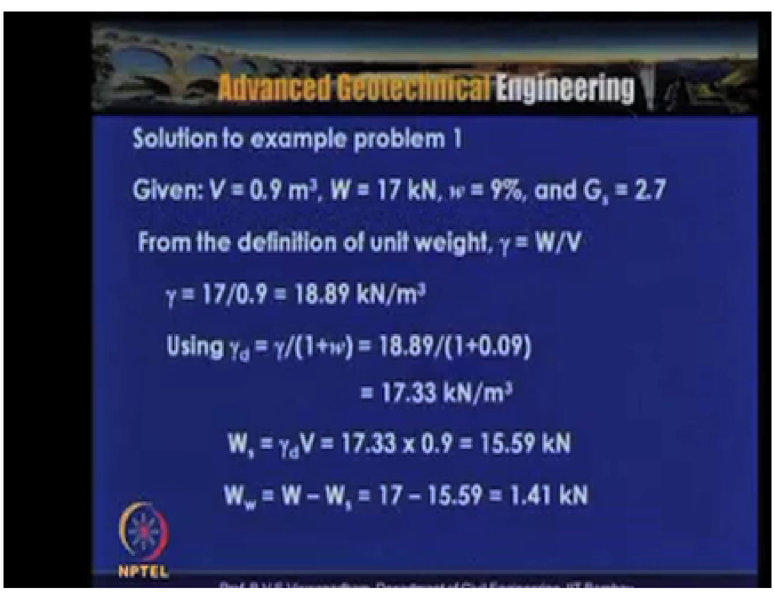

So the solution runs like this what is given is that volume is given point 9 U and weight is given as 17 kilo Newton and water content is given as 9percent and specific gravity of the solids is given as 2.7 so from the definition of unit weight we can write θ is equal to W by V so the θ the bulk weight it can be defined as a1770 divided by 0.9 we can write it as18 point 8 9 can provide Q using θ Dis equal to γ by 1 + W which is nothing but γ is nothing but γ bulk divided by 1 + W we can calculate what is the dry unit weight of the soil.

So from this if you look into this ws is equal to γ DV which is nothing but 17 point 3 3 into 0.9 which is nothing but 15 point 5 9 kilo Newton sand W ,W is nothing but W- WS nothing but weight of water in the soil mass is nothing but 1 point 4 1 kilo Newton's.

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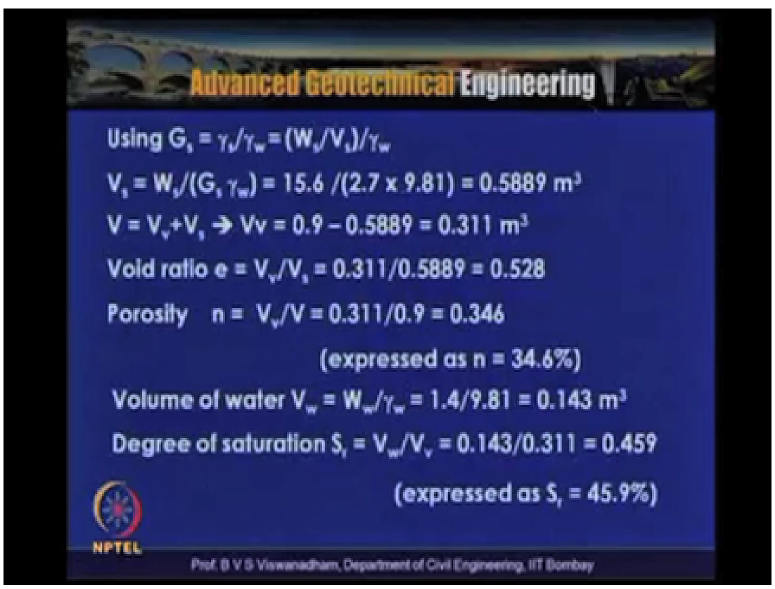

Then using specific gravity is equal to γ s by γW WS by V s γ W we can determine volume of solids as WS by G's γ W which is nothing but a point5 8 8 9 meter cube total volume is equal to V s+ V V and which is nothing but V V is obtained as point 3 1 1 meter cube so wide ratio is nothing but the volume of voids to volume of solids so in this case the soil mass has void ratio of 0.5 to 8 porosity is nothing but volume of voids are due to the total volume and total volume of the soil mass is given as point 9 so the porosity which is obtained as point 3 4 6it has 34.6%

and the volume of water is nothing but weight of water divided by γ W and γ W is equal to taken has taken as nine point eight one kilo n per meter cube.

So with that volume of water has 0.143 meter cube so the degree of saturation is given as volume of water to tell total volume of whites so based on this the problem for a given problem the degree of saturation is obtained as about forty five point nine percent and if you express.

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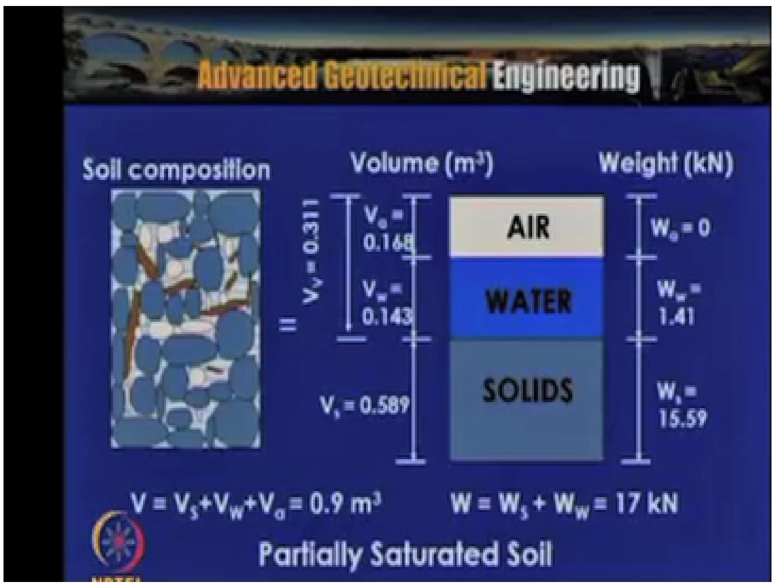

This in what we calculated in the soil composition for a partially saturated soil total volume is 0.9 if you are portion this volume of solids is 0.5 eight nine meter cube and the volume of water is 0.14three volume of air is 1 0.168 so total put two there you will get 0.9 meter cube volume of voids is nothing but volume of water plus volume of a which is nothing but point three one meter cube and weight of water.

Which is one point four one and weight of solids is fifteen point five nine total weight of soil mass is WS + W 17 kilo meter cube and V is equal to vs +BW v W + VA which is equal to 0.9 meter cube so by using these phase diagrams one can actually deduce the properties of soil and interrelationship between weight and volume ratios so in this lecture what we understood is that some phase relationships among soil properties and we have defined number of soil properties particularly like volumetric ratios and water content.

And we also discussed about the relationship between gravimetric water content and θ W the volumetric water content θ W so in the next lecture we are going to discuss about soil particle sizes and their arrangement and particularly soil particle sizes and arrangement their particle arrangement and then we will discuss about mineral gee claim ontology and then that leads to the discussion about the type of claim in terms present in the soil you.

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