Soil Mechanics
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Lecture - 2

In the previous lecture, we have seen the origin of soils and different types of soils based on their deposition like residual soils and transported soils.

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In this lecture we will be studying about soil aggregate basic relationships. Before looking into this soil aggregate basic relationships, let us look into different types of soils basically.

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If you see, this is a coarse-grained soil, coarse-grained sand with coarse particles having different shapes and sizes. So this particular type of soil is originated from the disintegration of parent rock.

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This is the similar type of sand which is originated from the fine weathering of the rock into forming something like fine particles. This is called some medium coarse to fine sand. So typically we have seen different types of coarse and fine sands.

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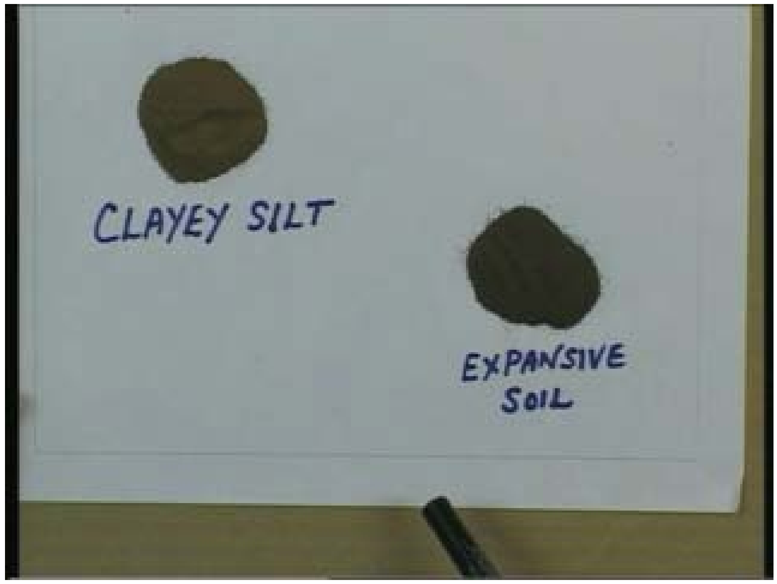

Let us look at another type of the soil which is basically silty in nature. The particles are very fine but not finer than clay particles. This particular type of soil has predominantly silt particles which are followed by clay particles, that is why this particular soil is called clayey silt. And this particular soil is also known as black cotton soil. This is basically an expansive soil which is prone for shrink swell characteristics. This is due to the prevalent mineral in the particular soil. The black color of the soil can be noted.

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This particular soil is known as red soil which is predominantly having silt particles as well as some fine clay particles and also coarse sand to fine sand particles. It is known as red soil because of the color. But it is generally collected from southern India in a place called Malaprabha in Karnataka. As we discussed, one of the examples of the transported soil is BENTONITE which is a fine grained volcanic ash. You can see the fine grained nature of this particular soil which has got very high shrink swell properties. This particular soil has also got varied applications in the soil mechanics particularly in borehole investigations, in barrier construction, etc. So having seen different types of soils, let us try to establish soil aggregate basic relationships.

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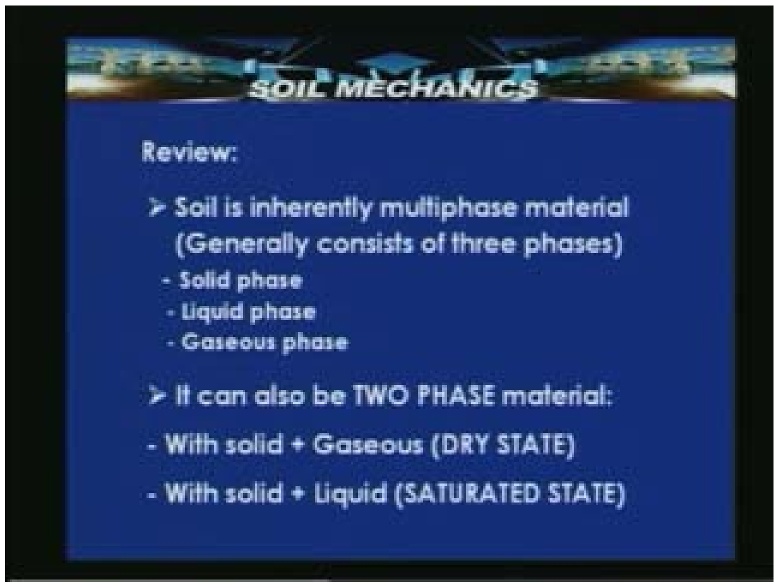

If you look into it, last time we have said that soil is basically a three phase material having a solid phase, liquid phase and gaseous phase and we call that state as a partially saturated soil. So soil is inherently a multiphase material. Soil can also be in two phase, if it is having only solids and air then it is called a dry state a two phase material and soil is also called as a saturated state if it has got solids and liquid in the form of water. Now with this background let us try to establish relationship and try to obtain different properties of soil mass.

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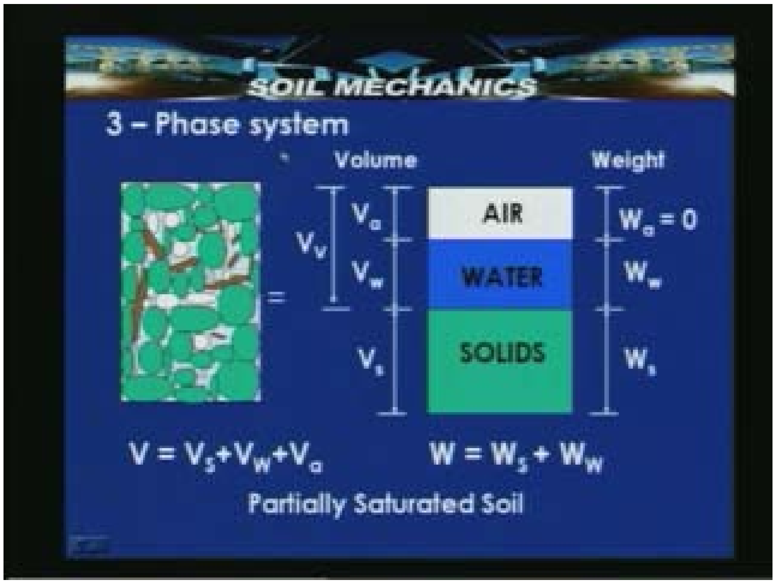

If you look into it, this particular diagram is an idealized 3-phase system for a partially saturated soil. What you see in this particular block diagram is the green particles which are soil solids, the brown ones are organic matter, other particles which are in white color are actually voids filled with air, the rest of the mass which is represented with broken line indicates the voids that is filled with water. This is a soil which has got solids, liquids and air in it. So this particular type of soil is called as a partially saturated soil.

Generally this can occur above the ground water table that is in the water zone. This particular soil can be idealized as follows: If you assume that if you are having a block of unit cross sectional area as you have seen here then the solids representing volume of solids which is nothing but the heights equivalent to the volumes because the area is having unit area, water representing volume of water which is nothing but height equivalent to volume of water and air representing volume of air.

On the left hand side you will see a gradation or a scaling with volume and on the right hand side you will see with weights. If you see on the right hand side here Ws is nothing but the weight of the solids, Ww is nothing but the weight of water and Wa is assumed to be 0 that is the weight of air is assumed to be 0. So, total volume of the soil mass is equal to volume of solids plus volume of water plus volume of air. If you see here volume of voids is a combination of volume of air plus volume of water. And weight of soil mass is weight of solids plus weight of water. So this is an idealized block for a partially saturated soil.

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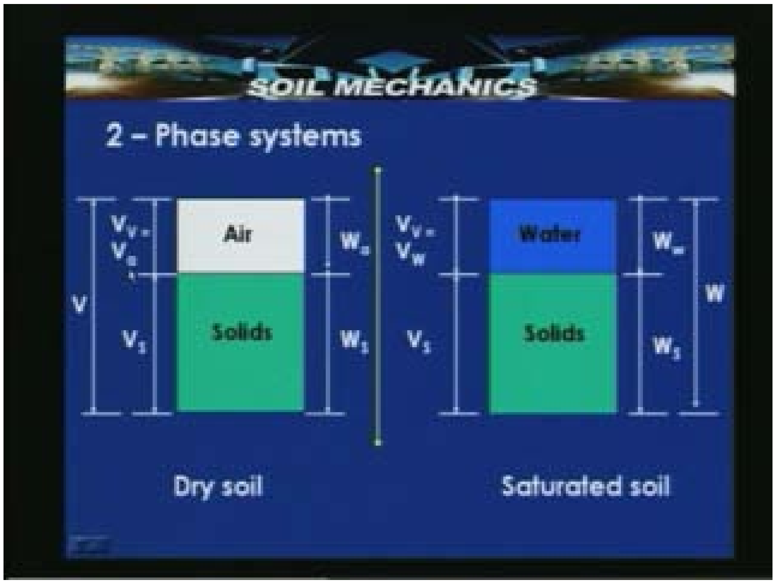

Now as we said the soil also can be a 2-phase material in dry state as well as in saturated state. If you see here, this is a dry state where solids and air are prevalent. Then what you see here volume of solids and volume of voids is nothing but equivalent to volume of air because all the voids are filled with air here so total volume here is nothing but volume of air plus volume of solids. And the weight of soil mass is nothing but weight of solids because the weight of air is assumed to be 0. In this case here if you see a saturated soil mass, the weight of solids and the weight of water forms the weight of soil mass where the volume of solids and the volume of water forms the total volume. We have seen this block, now let us try to establish relationships by using volumetric ratios or weight ratios and the combination of these two to obtain different parameters within the soil mass.

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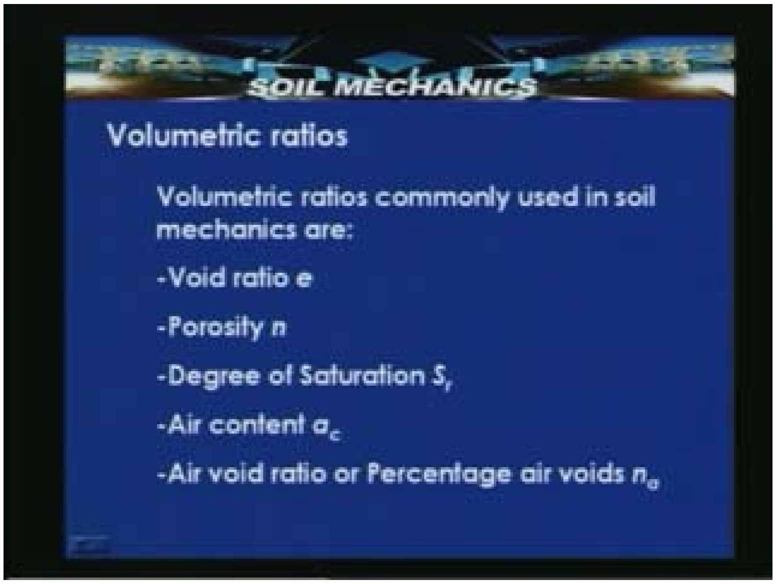

If you look into this, there are different types of volumetric ratios. The volumetric ratios commonly used in soil mechanics are Void ratio e, Porosity n, Degree of saturation S_r, Air content a_c and Air void ratio or Percentage air voids is n_a. These are the universal rotations which are used everywhere. So Void ratio is indicated with e, Porosity n, Degree of saturation S_r, Air content a_c and Air void ratio or Percentage air voids n_a. Now, let us try to define these parameters and try to establish relationship among them.

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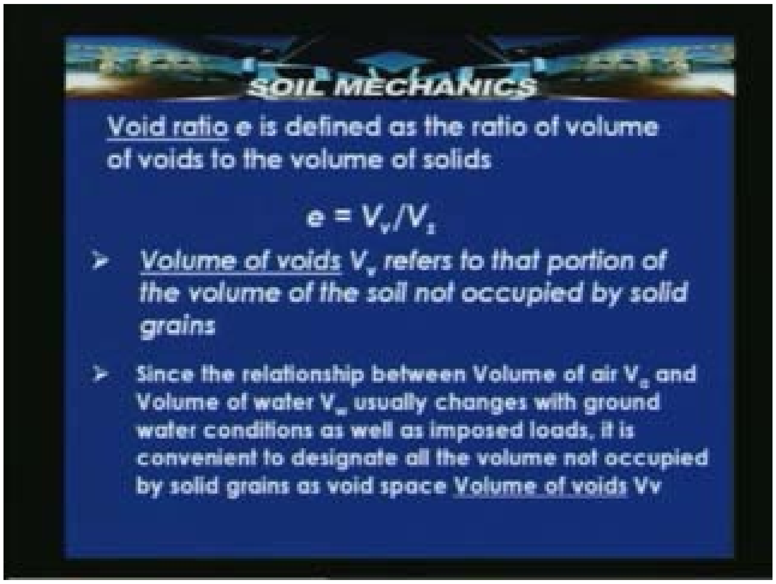

Now as we said the first volumetric ratio is void ratio e. Void ratio e is defined as the ratio of volume of voids to the volume of solids. That is volume of voids to the volume of the solid mass is nothing but a void ratio. Volume of voids refers to that portion of the volume of the soil not occupied by the solid grains. Since the relationship between the Volume of air and the Volume of water usually changes with ground water conditions as well as imposed loads it is convenient to designate all the volumes not occupied by solid grains as void space that is volume of voids V_v. In this slide we have tried to define the void ratio as ratio of volume of voids to volume of solids.

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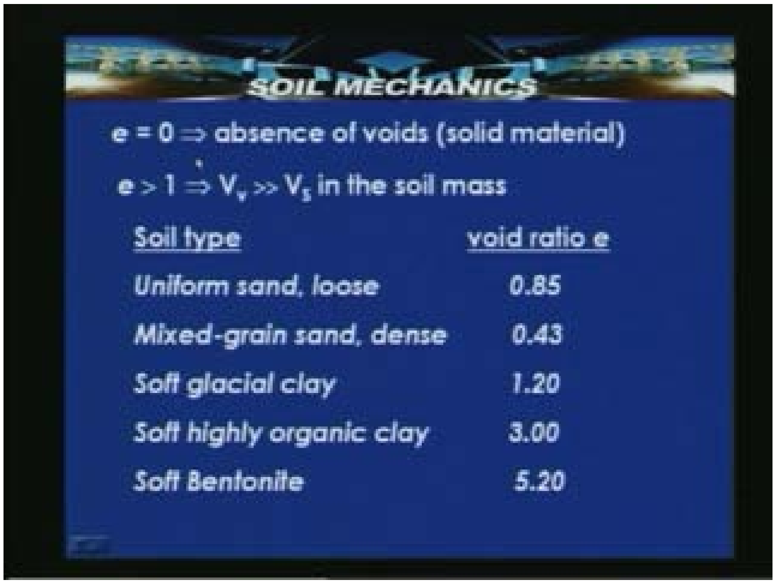

Now let us look into the different ranges of void ratios. If you see, e is equal to 0 indicates that the material is having no voids that is absence of voids means that the material is called a solid material. If the void ratio is greater than 1 which means that volume of voids are much greater than the volume of solids and that can be possible in the soil mass. If you take the different soil types and voids ratios e: For a Uniformly graded sand in a loose packing that is uniform sand in loose state, the void ratio can be 0.85.

A Mixed-grain sand in a dense packing state means that mixed grain in the sense the soil has got different ranges of particles and which are packed as close as possible that indicates the dense packing, in that case we can get a void ratio which is as low as 0.43. Soft glacial clay which is obtained through glaciation can have a void ratio of about 1.2. Soft highly organic clay can have a void ratio 3. The Soft BENTONITE that is from the volcanic ash which is very fine grained in nature can have a void ratio as high as 5.2. So we have seen different types of sands and clays and their typical range of void ratios. These are just to give us an idea about the ranges of void ratio. Void ratio is expressed generally as a fraction. If you look into it, if e is equal to 0 it is absence of voids that is solid material. If e can be greater than 1 that is volume of voids is greater than volume of solids that can be possible in a soil mass.

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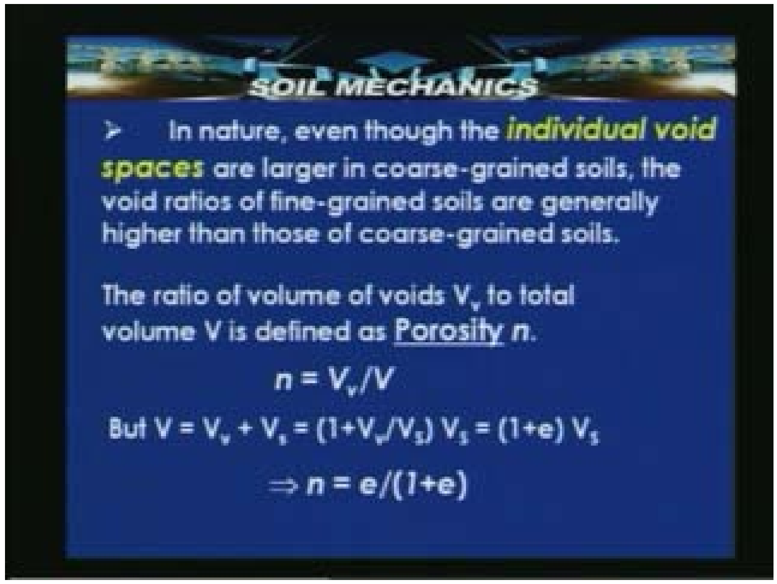

In nature, even though the individual void spaces are larger in coarse-grained soils, the void ratios of the fine-grained soils are generally higher than those of coarse-grained soils. The reason is that the fine-grained soil has got a very very finely divided particle which has got some chemical repulsions taking place. These chemical repulsions will not allow the particles to come closer that make the void ratio of the fine-grained soils to be on the higher side compared to coarse-grained soils. So the ratio of the volume of voids to the total volume is another ratio, which is called as Porosity n which is given as n is equal to volume of voids to total volume. That is here Porosity another volumetric ratio can be defined as n is equal to volume of voids to total volume V. But V is equal to V_v plus V_S that is volume of voids plus volume of solids. This can be rearranged as by taking the common V_S out we get (1 plus V_v by V_S) V_S that is (1 plus e) V_S. So if you see we have established a relationship between Porosity and Void ratio that is n is equal to e by (1 plus e). So if you know the Void ratio of a given soil mass you can calculate the Porosity of the soil mass and if you know the Porosity of the soil mass you can estimate the void ratio by using e is equal to n by (1 minus n). In this slide what we have seen is that, in nature the fine-grained soils are supposed to have a very high void ratio because of the high repulsions which are taking place between the particles than the coarse-grained soils and also we have defined the Porosity n is equal to volume of voids to total volume.

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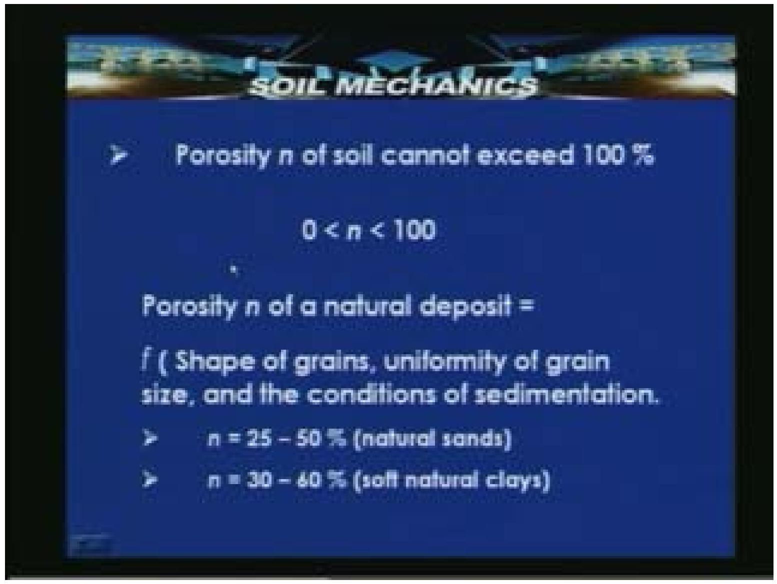

If you look into the range of the Porosity values of a soil, the Porosity n of soil cannot exceed 100 percent. That is it has got a value ranges from 0 to 100. So, Porosity n of a natural deposit is a function of shape of the grains, uniformity of grain size and the conditions of sedimentation, how it is being deposited and things like that. Generally Porosity is expressed as a percentage. For natural sands the porosity of a soil mass can range from 25 to 50 percent that is the porosity of a given soil mass can have a values ranging from 25 to 50 percent for natural sands. And n is equal to 30 to 60 percent can be there even for soft natural clays.

For some of the very soft clays we can have a value even as high as 90 percent. So the range of the upper limit of the porosity value can be 100 percent and the range is from 0 to 100. The Porosity n of a natural deposit is a function of the shape of the grain which means that the grain can be angular, sub-rounded or rounded in shape or uniformity of the grain size that means that whether it is uniformly graded that is all the particles are having same size or particles having different ranges. In that case there is a possibility of decrease in the Porosity and the conditions of sedimentation. This means that different types of sedimentation may be possible when the soil is getting sediment, it can have a loose packing as well as dense packing.

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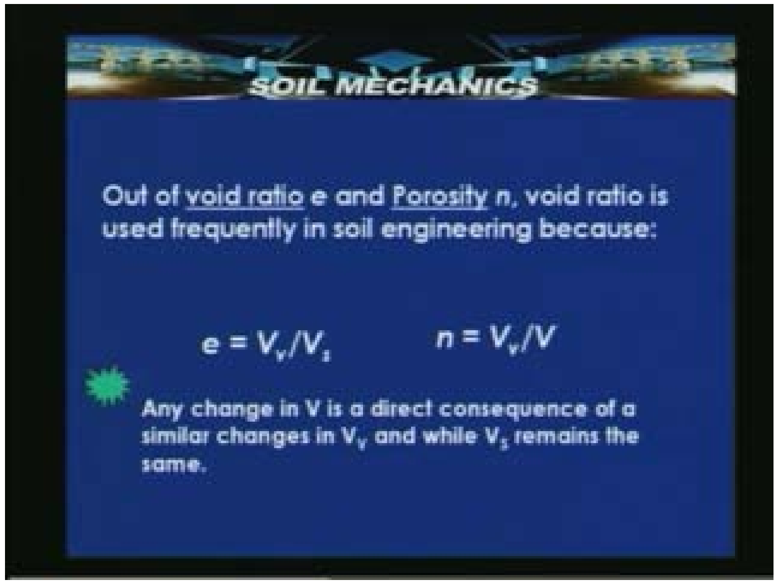

If you look into it, we have defined Void ratio and Porosity. Out of Void ratio and Porosity, the Void ratio is used frequently in soil engineering. The reason is basically if anybody has got the values for Void ratio and Porosity one prefers to use Void ratio because any change in the volume is a direct consequence of similar changes in volume of voids while volume of solids remains the same. For example, if you look at the definitions of Void ratio, Void ratio is equal to volume of voids to volume of solids and n is equal to volume of voids to total volume. So if any changes takes place in the Porosity both numerator and denominator changes because volume of voids is supposed to change and if there is a change then total volume also changes. The Porosity by definition has got both numerator and denominator and it experiences a change. Whereas in case of Void ratio only numerator part will change and the volume of solids remains same. So for the settlement calculations, for any other purposes we use Void ratio frequently. Before defining another volumetric ratio that is degree of saturation, we are going to see a very important parameter for a given soil mass that is water content and this is also called natural moisture content. Generally, based on the mineral it has, the soil also has some hygroscopic moisture content, that is the amount of water it can absorb from the atmosphere.

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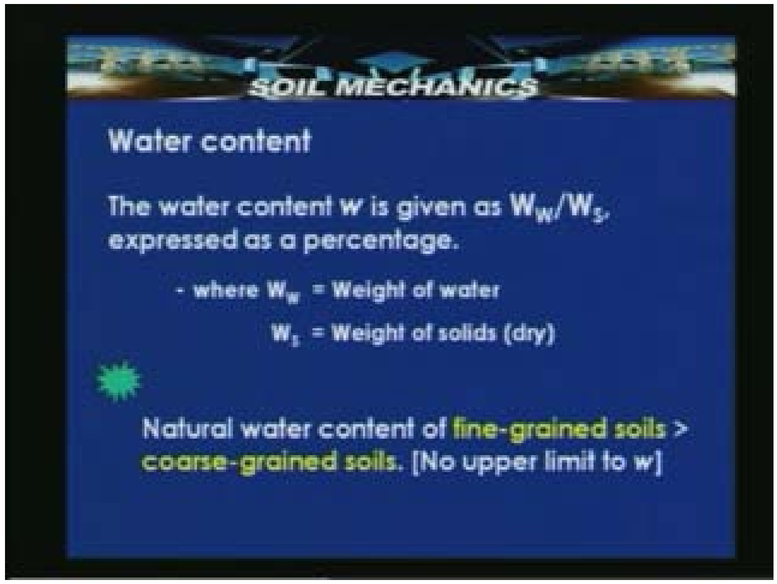

So, the water content W or a moisture content is given as weight of water to weight of solids. This is generally expressed as a percentage where weight of water is indicated as weight of W, weight of solids is equal to weight of solids in dry state is equal to W_s. The natural water content of fine-grained soils is generally greater than coarse-grained soils and this is generally expressed as a percentage and there is no upper limit for the water content. Fine-grained soils again based on the mineralogical composition it has, the fine-grained soils are supposed to keep higher moisture content than the coarse-grained soils. So the water content or moisture content is defined as weight of water to weight of solids in dry state. This particular ratio which is expressed as a percentage is called as water content. The natural water content of fine-grained soils is greater than coarse-grained soils; this is merely due to the mineral that the soil possesses.

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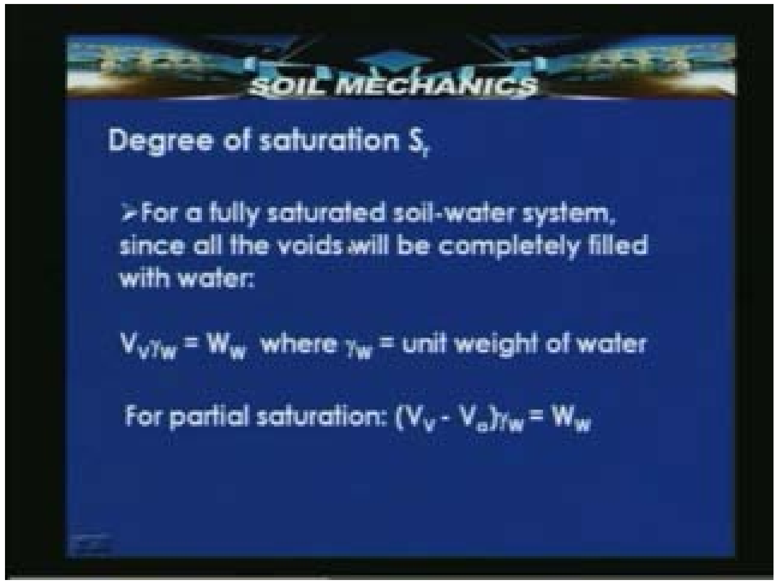

Now let us try to deduce the other volumetric ratio called degree of saturation. For a fully saturated soil water system since the voids will be completely filled with water because in saturated soil mass all the voids are completely filled with water. So we can write volume of voids into gamma w that is the unit weight of water is equal to weight of water. For a partially saturated soil that is for partial saturation V_v minus V_a is nothing but the volume of water into gamma w again it gives as weight of water. For completely saturated water V_v gamma w is equal to weight of water where gamma w is the unit weight of water. And for a partially saturated soil (V_v minus V_a) into gamma w is equal to weight of water.

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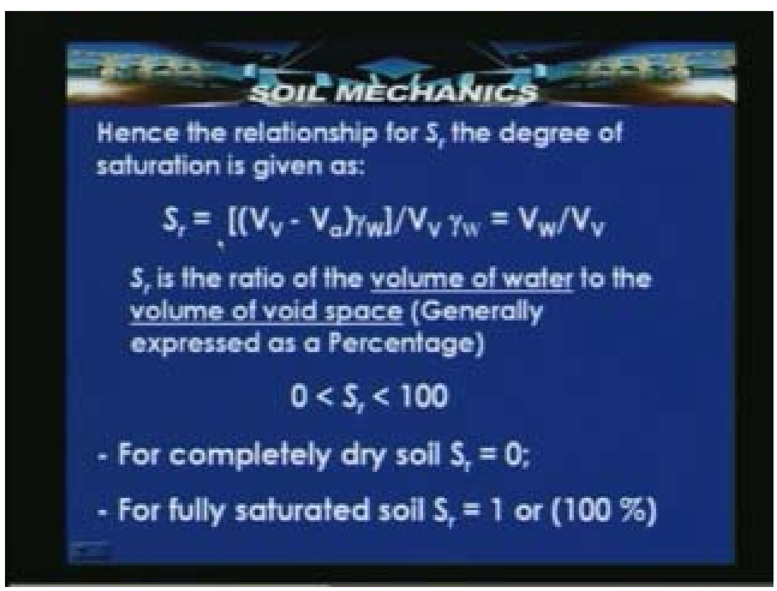

From this the relationship for the degree of saturation is expressed as S_r is equal to degree of saturation is equal to [(V_v minus V_a) gamma w] by V_v gamma w. (V_v minus V_a) gamma w is again nothing but weight of water and V_v gamma w is also nothing but weight of water. We are just expressing and rearranging the terms. So V_v minus V_a can be written as V_w and keeping V_v as V_v with that we can write S_r is equal to V_w by V_v, where V_w is the volume of water in the voids and V_v is the volume of voids. So S_r is the ratio of the volume of water to the volume of the void space. That is the amount of water in the voids of a soil mass is the degree of saturation. So S_r is the ratio of the volume of water to the volume of voids, generally this is expressed as a percentage and this has got a range from 0 to 100.

The upper limit of the degree of saturation of a given soil mass is 100 so if S_r is equal to 100 indicates that the soil is completely saturated. So for a completely dry soil S_r is equal to 0, for a completely saturated soil S_r is equal to 100 percent. In case of a partially saturated soil the degree of saturation varies from 0 to 100 percent. Hence the relationship for S_r we have expressed as S_r is equal to V_w by V_v, where volume of water to the volume of voids into 100 expressed as a percentage is the degree of saturation. We have said that for partially saturated soils the degree of saturation can range from 0 to 100.

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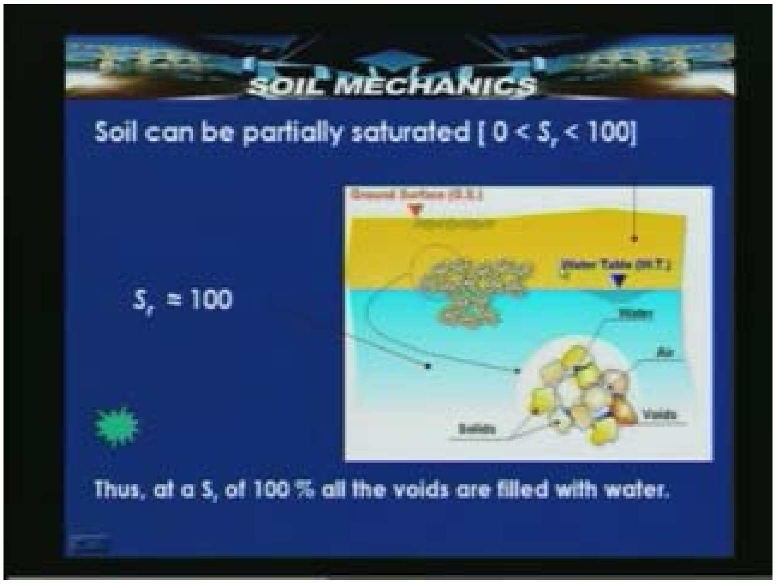

For example, if a soil mass is found like in the diagram here and the cross section of the profile of the soil is shown. Here you are seeing a water table, the soil above the water table is supposed to be in a partially saturated state which also depends upon the type of the soil and the soil below the ground water table is supposed to be completely saturated. All the voids in the soil are supposed to be filled with water and the degree of saturation is supposed to have 100 percent. If you look here the soil above the ground water table, if it is in the partially saturated state then it can have a degree of saturation value ranging from 0 to 100 percent. If in the dry state, if the soil is subjected to evaporation and other factors or if it is subjected to some seasonal precipitation then the degree of saturation can vary from 60 to 70 percent. This also depends upon the type of the soil that we will be discussing in the due course of our lectures. Thus at 100 percent degree of saturation all the voids are filled with water.

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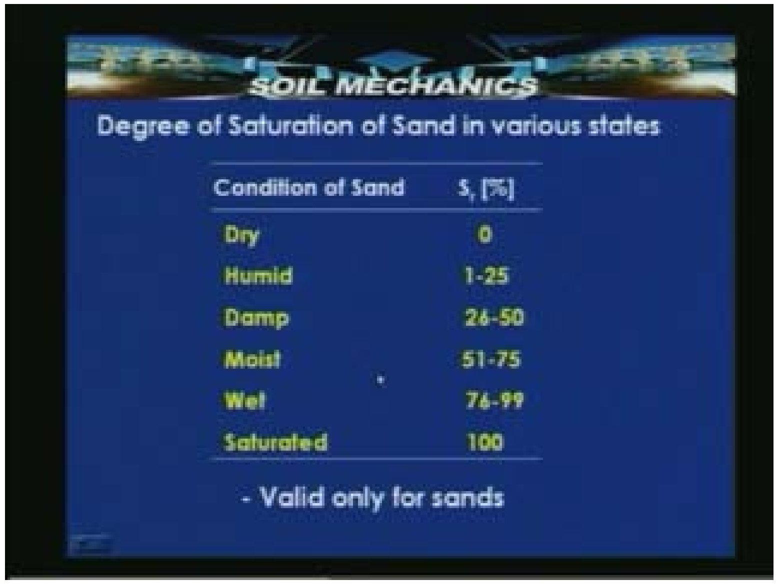

That is possible with this cross sectional diagram here below the water table where the soil is supposed to be at a completely saturated state. If you look into here, for a given type of sand we can rate the degree of saturation with certain numerical values. We can say that the sand is in Dry state if S_r is equal to 0, the sand is in Humid if the value is from 1 to 25, in a Damp state if the value is exceeding 25 but less than 50 that is 26 to 50 percent, the soil is said to be Moist if it is having a range from 51 to 75, Wet state 76 to 99 and Saturated is 100. This particular rating is valid only for sands where based on the condition of the sand we will say the soil is Dry, Humid, Damp, Moist, Wet and Saturated.

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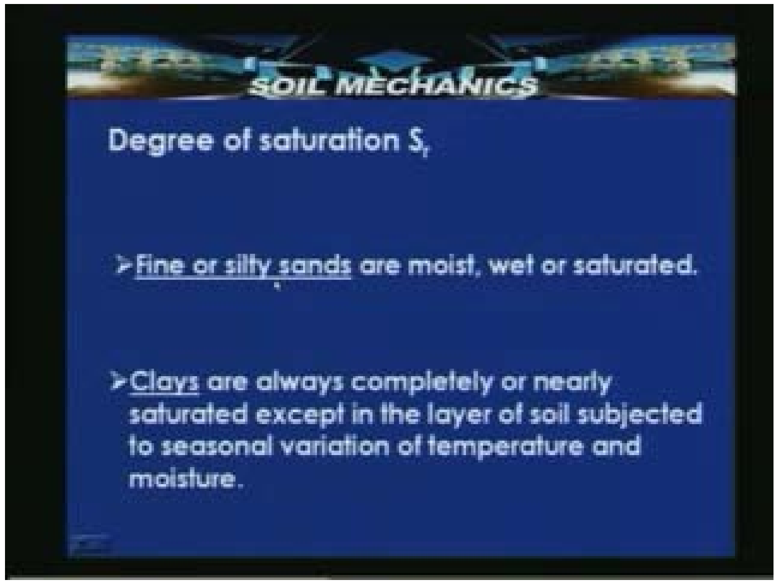

If you see here the degree of saturation for fine or silty sands are generally moist, wet or saturated because when you come to fine and silty sands, the particle size tends to be very very fine. Clays are always completely or nearly saturated except in the layer of soil subjected to seasonal variation of temperature and moisture. As shown before, if the soil has been subjected to some seasonal variation because of the temperature in arid climates particularly and seasonal variation of moisture, clays can be partially saturated.

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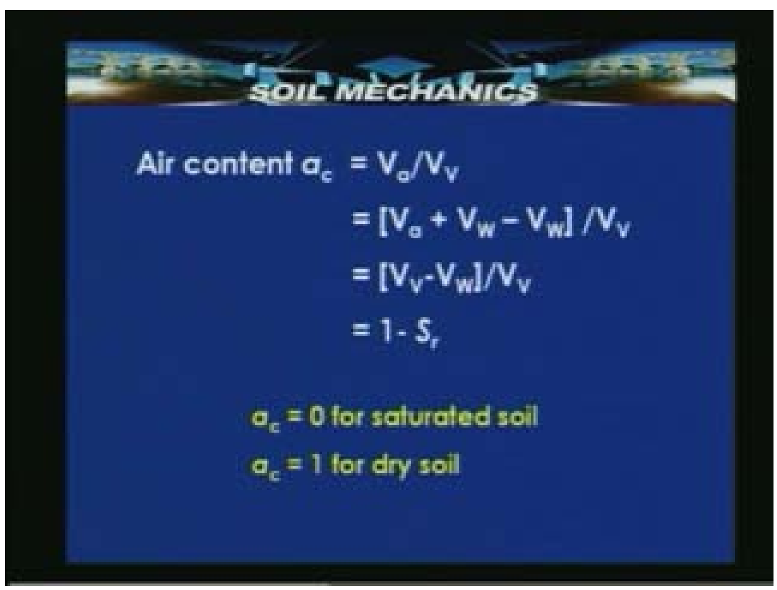

But generally clays are always completely or nearly saturated above the ground water table or except in the layer of soil subjected to the seasonal variation of temperature and moisture. Now let us try to define another parameter that is air content. Air content of a given soil mass basically comes into picture if once the soil is partially saturated. Air content a_c is equal to volume of air to the volume of voids which is expressed as a percentage. If you write volume of air plus volume of water minus volume of water, if you rearrange the terms you can write like V_a plus V_w as V_v. So (V_v minus V_w) by V_v can be written as 1 minus S_r. That is relationship between air content and degree of saturation is a_c is equal to1 minus S_r we have established here. So air content is defined as volume of air in the total volume of voids. If S_r is equal to 0 means that the air content is equal to 1, that is for a dry soil air content is equal to 1. If S_r is equal to 1 that is S_r is equal to 100 percent means that air content is equal to 0, all the voids are completely filled with water. If you see a_c is equal to 1 means that soil is in dry state and all the voids are completely filled with air.

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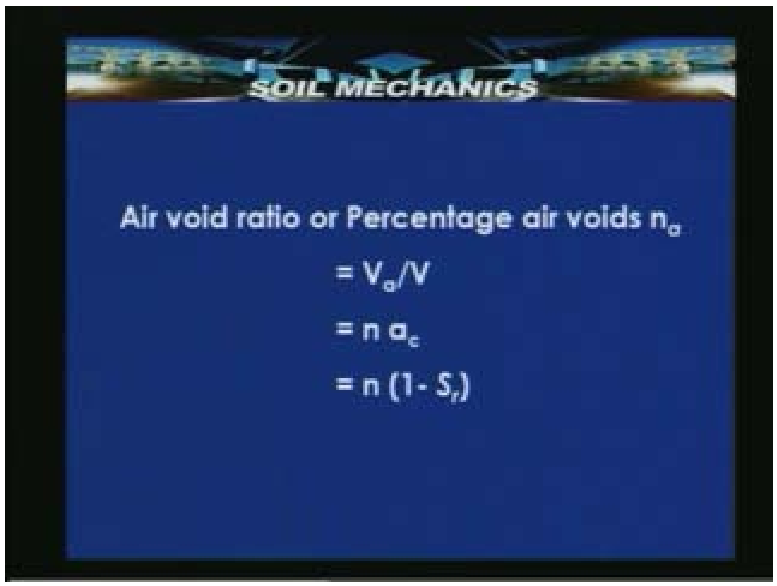

Another volumetric ratio is an Air void ratio or Percentage air void that is n_a which is defined as volume of air by total volume. This can be written as n_{ac} that is Porosity into Air content. This is expressed as n into (1 minus S_r) so Percentage air voids is n into (1 minus S_r). The relationship between Percentage air voids, Porosity and degree of saturation is n_a equal to n into (1 minus S_r). Having seen different volumetric ratios and defined water content.

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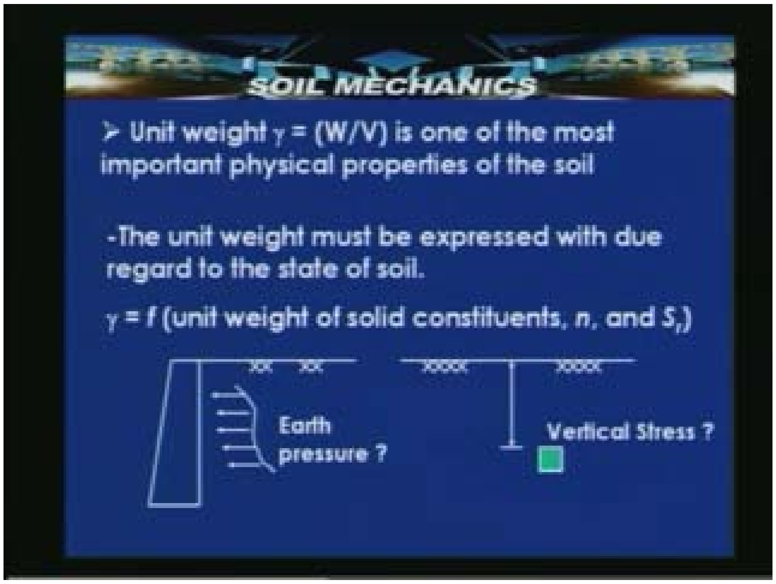

Now let us try to look into another important parameter in soil mechanics which is the unit weight of a soil mass. Unit weight is indicated by gamma is equal to weight by volume that is weight of a soil mass to the total volume of the soil mass. This is one of the most important physical properties of a soil. The unit weight must be expressed with due regard to the state of soil. Generally the unit weight of the soil mass is a function of the unit weight of the individual solid constituents. Suppose if the soil has got light weight particles the soil can be having a less unit weight. Or if the soil is having less Porosity or more Porosity it can effect the unit weight of the soil mass. If the soil has got degree of saturation that is S_r is equal to 0 or S_r is equal to 1 that means that if it varies from 0 to 100 percent, it can also influence the unit weight of soil mass. So we say that unit weight of a is a function of unit weight of the solid constituents (this is one of the phases of the soil phase) and n is the Porosity and degree of saturation.

If you know the unit weight of the soil mass, for example in this diagram one of the applications is shown here, a cross section of a retaining wall and a back fit. So it will be possible for you to estimate what is the amount of the earth pressure exacted by the soil on to the retaining wall? For that to estimate we require what is the unit weight of a soil mass?

For example, in this cross sectional diagram you are seeing a soil top ground surface and at a depth z below the ground level, if you wanted to establish what is the vertical stress at that particular point then you are required to determine the unit weight of a soil mass. The unit weight of a soil mass is liable for changing with the depth because of the increase in the water content there is an increase in the unit weight of the soil mass with depth. If the soil has got different status that is different type of soils, for example a silt layer, sand layer and clay layer, if you take the summation of individual unit weights of these layers you can take as gamma average. So, that if you take gamma average and at a particular depth you can calculate the vertical stress in that particular depth. So, the unit weight is an important property of a soil mass which is required from the application point of view to determine a lateral expression on a retaining wall or a vertical stress at a particular depth below the ground surface.

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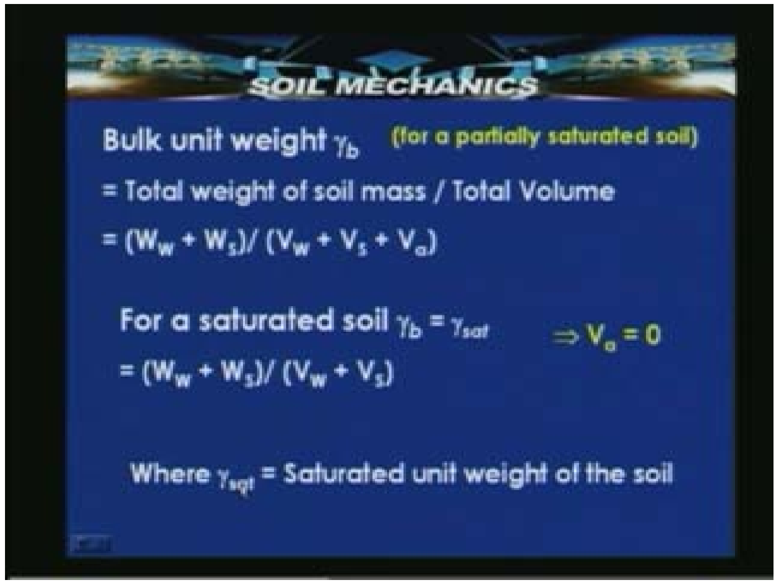

Now let us try to define different types of unit weights, that is one of the unit weights is bulk unit weight (gamma bulk). This is basically for a partially saturated soil where you have got solids, water and air in it. Air occupying the volume from the contribution of the weight, the weight of air voids is equal to 0. So bulk unit weight of a soil mass is defined as total weight of soil mass to the total volume. That is nothing but weight of water plus weight of solids plus weight of air is equal to 0. Then (weight of water plus weight of solids) by total volume which is nothing but volume of voids plus volume of solids that is nothing but volume of water plus volume of solids plus volume of air.

Therefore, for a saturated soil mass gamma bulk will become gamma sat if volume of air is equal to 0. That means (weight of water plus weight of solids) by (volume of water plus volume of solids). All the voids are filled with water so total volume is volume of voids plus volume of solids which is nothing but volume of water plus volume of solids. Here saturated unit weight of soil mass is indicated by gamma_{sat} which indicates the saturated unit weight of the soil mass. So here we have defined the bulk unit weight as the total weight of soil mass to the total volume which is nothing but (weight of water plus weight of solids) by total volume which is nothing but volume of water plus volume of solids plus volume of air.

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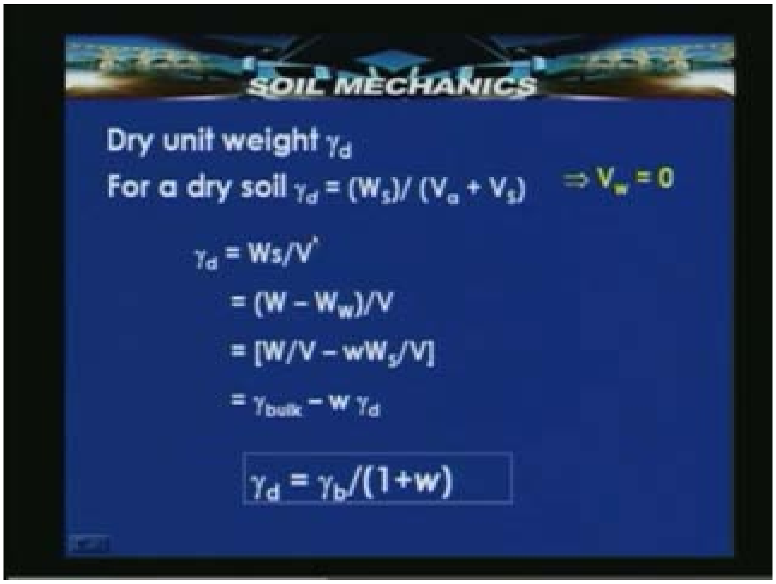

Dry unit weight (gamma d) that is for a dry soil gamma d is equal to W_s by total volume which is nothing but gamma d is equal to W_s by (V_a plus V_s). In this volume of water is equal to 0 because the soil is dry completely. So we say that gamma d is equal to W_s by V. We can see now gamma d is equal to we can write W_s as (total weight of soil mass minus weight of water) by V. If you rearrange the terms and simplify (W by V minus wW_s by V) this is nothing but water content is equal to weight of water by weight of solids. When we express weight of water is equal to wW_s, now we can write here wW_s by V where W_s by V is nothing but gamma d. Now, in this lecture we are trying to establish a relationship between dry unit weight of soil mass, bulk unit weight of soil mass and water content. That relation is now deduced as gamma d is equal to gamma bulk by (1plusW) where W is the water content or moisture content of a soil mass, gamma bulk is the bulk unit weight of soil mass and gamma d is the dry unit weight of a soil mass. This is generally required in an embankment construction or so. If you know the water content of a soil mass which has been compacted and also if you know the bulk unit weight of soil mass you will able to estimate the dry unit weight of a soil mass. There are many methods to determine this particular water content of a given soil mass.

Basically we determine water content in the laboratory by using oven drying method. In this oven drying method generally the soil mass of 50 to 100 grams is kept in the oven for about 24 to 48 hours at a temperature of around 105 to 110 degree Centigrade. Once you keep the soil mass in the oven what happens is that the water which is surrounding the soil particles evaporates and we will be able to determine the weight of the solid particles. If you determine the weight of soil mass before keeping minus the weight of solid particles will give the weight of water. The ratio of weight of water to weight of solid particles gives you water content.

For example, if the soil has got highly organic materials, in that case the soil mass is supposed to be subjected to temperature at 60 degree in order to prevent the burning of the organic matters. If you keep at higher temperatures other than 110 degree Centigrade for a normal soil mass there is a possibility that the entire structure of the soil can change. So this we will be learning later, but at this juncture the water content of a soil mass can be determined by using Oven drying method. There are many methods like rapid method and calcium carbonate method. In the field for example, you can use method of water content determination by lighting the soil by sprit. With this method we will be able to estimate the weight of the dry soil and weight of soil mass, with that we may be able to roughly estimate the water content. There are also modern methods like nuclear density gages etc.

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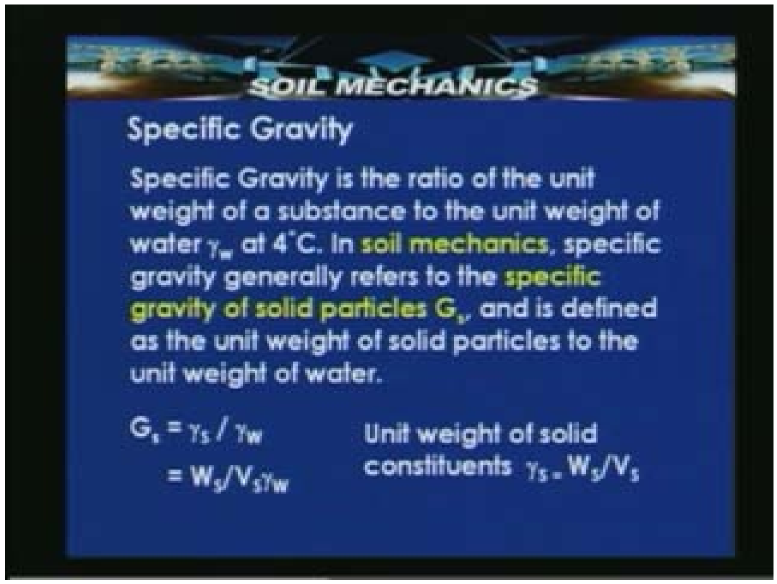

Now, let us try to define very important parameter in soil mechanics, the Specific gravity. The Specific gravity is the ratio of the unit weight of the substance to the unit weight of the water. So, unit weight of the substance and unit weight of the water at 4degree Centigrade is actually defined as Specific gravity.

In soil mechanics, Specific gravity generally refers to the specific gravity of the solid particles G_s, and is defined as the unit weight of the solid particles to the unit weight of water. We have not defined the unit weight of the solid particles earlier, we have only defined the dry unit weight of the solid particles that is gamma d is equal to W_s by total volume. The unit weight of the solid particles is defined here as the ratio of the weight of the solid particles to the volume of the solid particles. If you say gamma s is the unit weight of the solid particles which is nothing but W_s by V_s.

With the definition of specific gravity we can write now G_s is equal to (gamma s by gamma w), where the gamma s is unit weight of the solid particles and gamma w is unit weight of water. So if you express now gamma s is equal to W_s by V_s is equal to W_s by V_s gamma w. So if you know volume of solids and if you know the unit weight of water, generally unit weight of water (gamma w) is 9.81kilo by m cube or in the problems for using the computation we can use gamma w is equal to 10kilo by m cube. So by knowing G_s we will be able to determine W_s is equal to $G_sV_s$gamma w, the weight of the solids is equal to specific gravity of solid times of volume of the solids times of unit weight of water. How to determine the specific gravity of a given soil mass in the laboratory? There are many methods, but the volume of the specific gravity of a given soil mass can be determined in the laboratory by using a specific gravity bottle method.

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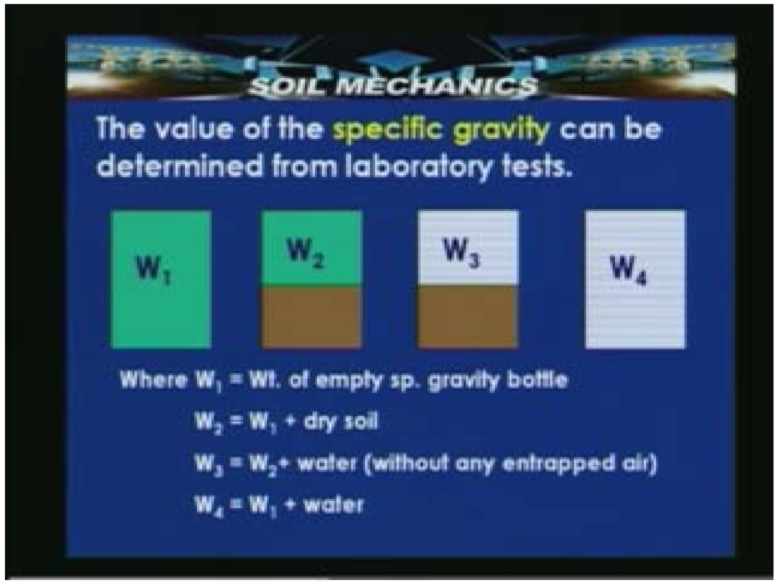

Thus, for this let us take a specific gravity bottle of known volume. Measure the weight of the empty specific gravity of bottle; let that weight be W_1. That is, here what you have seen W_1 is the weight of the empty specific gravity bottle. Now take known amount of weight of the dry solids where this brown portion is solids. Measure the weight of the solids with bottle that is W_2 is equal to W_1 plus dry soil. Now fill this bottle with water completely and see that entire entrapped air in the voids of the soil mass is driven out, that is possible by tamping the soil mass or by subjected to boiling. With that we will be able to drive out all the entrapped air within the soil mass otherwise you will be leading to the determination of a false specific gravity of the soil particles. Now to determine W_4 completely wash the contents which you have used for measuring W_3. Completely remove the soil mass and the water, clean it completely and determine the weight of water with the bottle that is W_4. W_1 plus water filled completely up to the brim of the bottle determines W_4.

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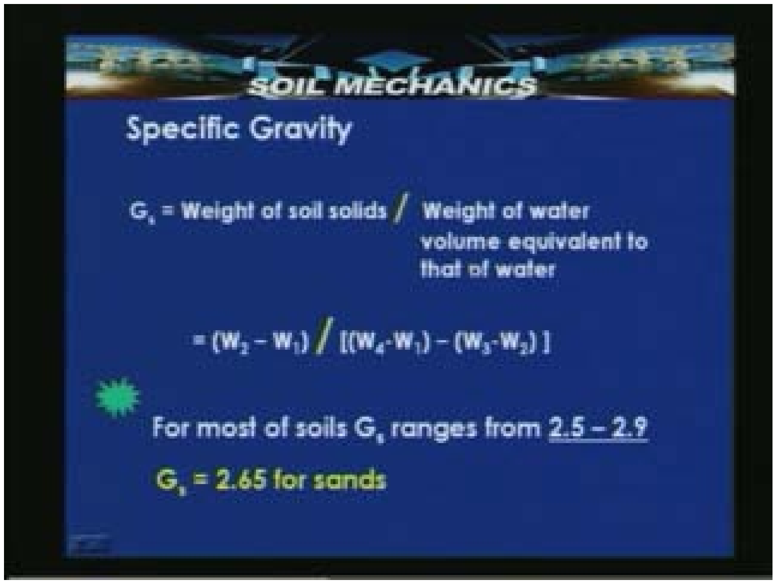

Now we are required to determine the specific gravity of the solids by establishing (gamma s by gamma w). So let us try to look into it, this can be possible by determining (weight of soil solids by weight of water volume equivalent to that of water). Here weight of soil solids is nothing but W_2 minus W_1 that is (weight of the dry soil minus weight of the bottle) will give me the weight of the soil solids. Weight of water volume equivalent to that of water is (W_4 minus W_1) minus (W_3 minus W_2). If you see, directly you are determining the weight of the volume of water in the volume of the solids equivalent to that of water.

If you see here with this expression you will be able to determine the specific gravity of the soil solids. For most soils G_s ranges from 2.5 to 2.9. For example, if the soil has got a hematite mineral it can have a specific gravity ratio more than 2.9. If the soil is originated from the coal ash it can have the value as low as 1.9. For example if the specific gravity of municipal solid waste can be much lower because of the organic matter. G_s is, for most of the sands it has got a range from 2.65.

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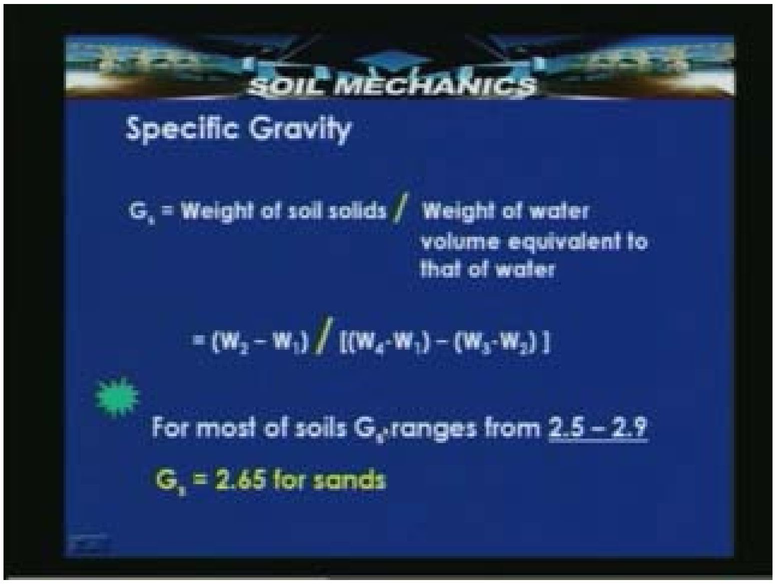

So G_s is equal to 2.65 for the most of the sands. General range of the specific gravity of the soil solids for a soil mass is from 2.5 to 2.9.

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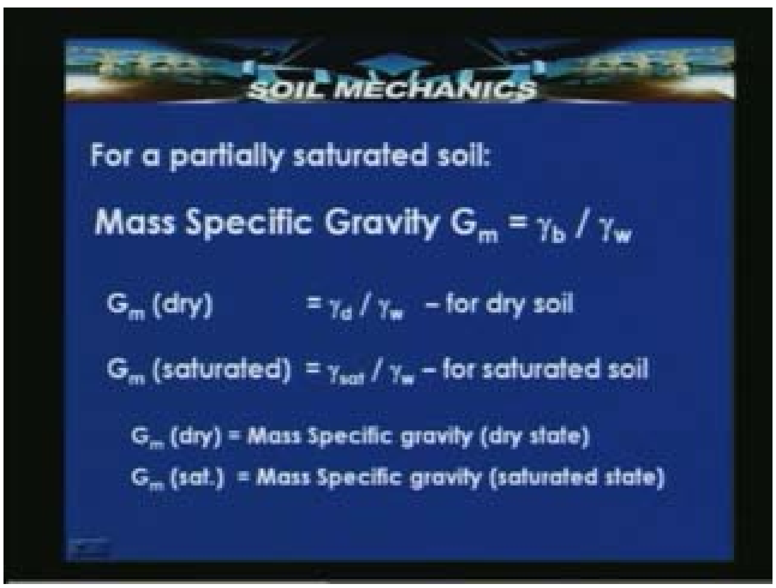

Let us define another parameter called Mass Specific Gravity. In case of a partially saturated soil that can be defined G_m as ratio of bulk unit weight of a soil mass to that of unit weight of water, that is G_m is equal to (gamma b by gamma w) which is defined as mass specific gravity of a soil mass. In dry state G_m (dry) is nothing but (gamma d by gamma w). In this case we use (gamma d by gamma w) for dry soil. In case of a saturated state G_m (saturated) we use (gamma sat by gamma w) where G_m (dry) is the mass specific gravity in dry state and G_m (sat) is mass specific gravity in saturated state. So G_m the mass specific gravity is (gamma bulk by gamma w).

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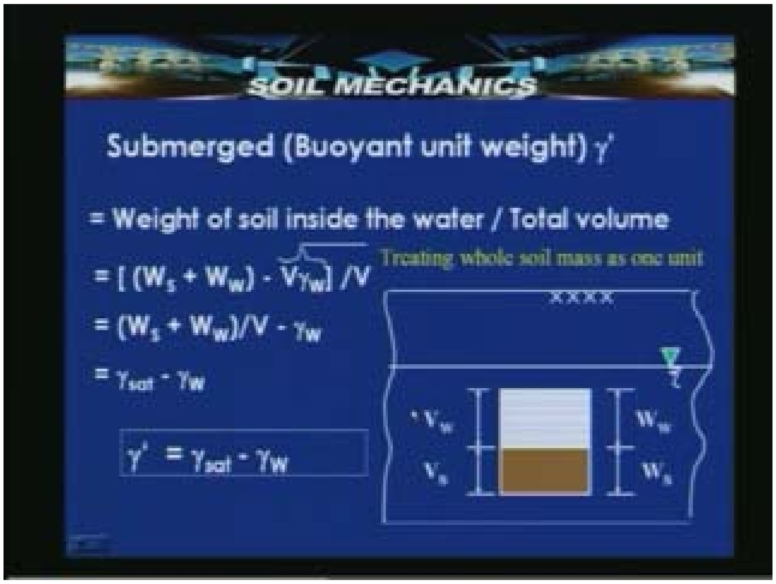

Now, let us define another unit weight. As we have said when soil mass is below the water table there is a chance that the soil can get submerged. In that case, in order to compute the vertical stresses we need to take a buoyance effect of the water into account. Submerged unit weight is equal to gamma dash or buoyant unit weight can be defined as weight of the soil inside the water to the total volume. Let us assume a element of the completely saturated soil mass having volume of solids and volume of water.

Now, all the voids are completely filled with water which has got weight of the water equal to the weight of the water which is present in the volume of voids and weight of solids is W_s. In this case if you are treating the whole soil mass as a unit, you can write weight of the soil mass inside the water is (W_s plus W_w) minus V gamma w, where V gamma w is the water which is replaced taking the buoyant effect into the consideration. If you are rearranging the terms we can write (W_s plus W_w) by V minus gamma w, this is nothing but (gamma sat minus gamma w).

Thus the submerged unit weight of a soil mass is defined as (gamma sat minus gamma w). So if you know the saturated unit weight of the soil mass we can determine the submerged unit weight by subtracting the unit weight of water. That is gamma dash is equal to (gamma sat minus gamma w) gives us the submerged unit weight of soil mass. Now, having defined about unit weights, water content and different volumetric ratios, let us try to establish the basic relationships using two approaches basically.

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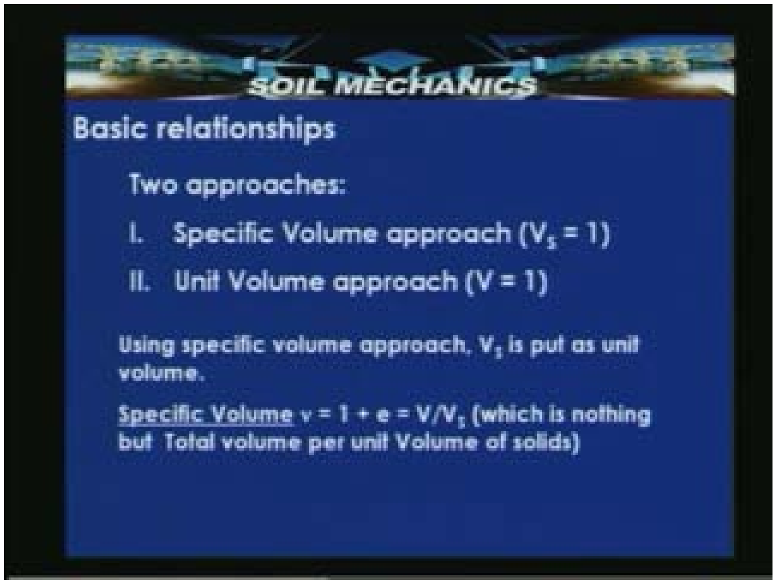

One is called specific volume approach and another one is called total volume or unit volume approach. In the phase block diagram method at least one of the parameters has to be given some value. So in the specific volume approach the volume of the solids is set as 1 and in the unit volume approach the total volume is set as 1. Let us first look into the specific volume approach or V_s is equal to 1 approach. Specific volume is defined as 1 plus e which is nothing but 1 plus void ratio which is equivalent to V by V_s which is nothing but total volume of soil per unit volume of solids. That is specific volume is equal to 1 plus e that is nothing but the total volume of the soil mass per unit volume of the solids.

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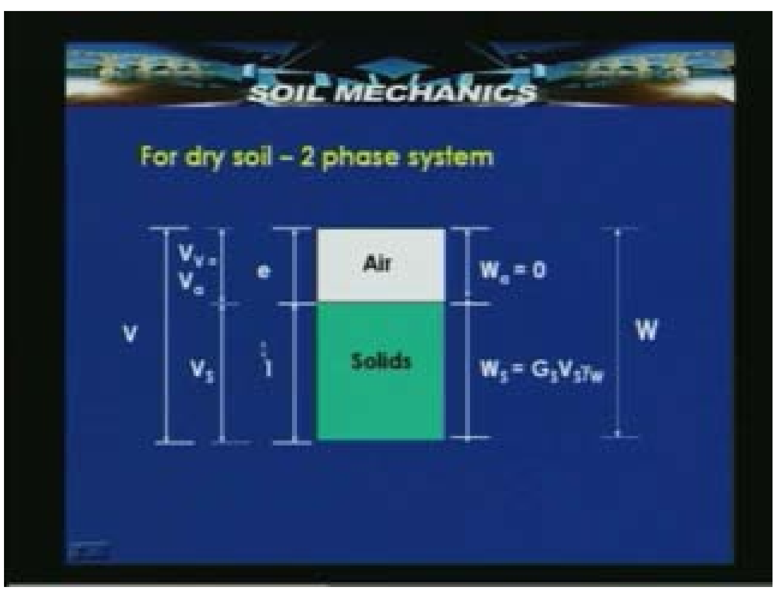

Let us try to look into this specific volume approach. Let us consider a dry soil in 2-phase system. On the left hand side we have got volume scale and right hand side we have got weight scale. If you see here, weight of the dry air is equal to 0 that is W_a is equal to 0 and weight of solids is equal to G_sV_s gamma w because if we set V_s is equal to 1 this is transferred to G_s gamma w and volume of voids is equal to volume of air. Now void ratio is nothing but volume of voids to volume of solids. This changes to be e is equal to V_v by V_s, when V_s is equal to 1 so volume of voids is equal to e. That is the reason why you are seeing e here. Now the total volume is nothing but 1 plus e. The summation of this, the total volume per unit weight of volumes into volume of solids is nothing but the specific volume is 1 plus e.

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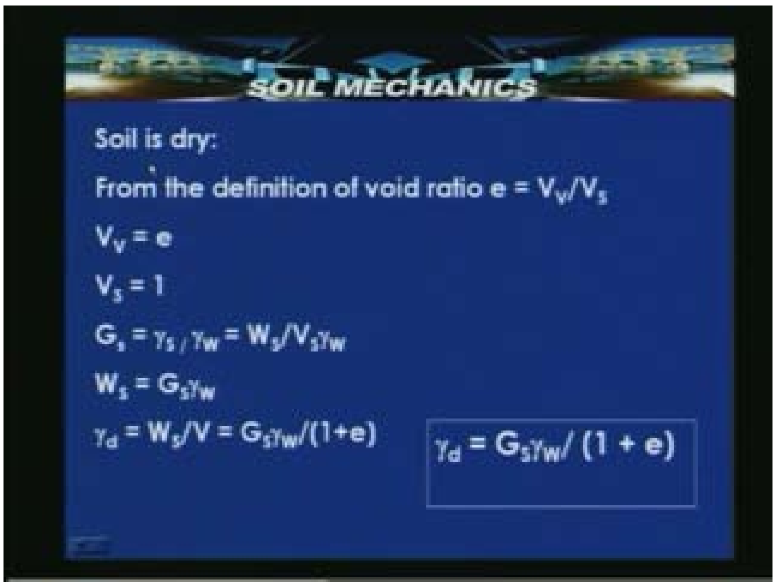

Let us assume that the soil is dry. So from the definition of void ratio e is equal to V_v by V_s, so we can set V_v is equal to e, V_s is equal to 1. Then G_s is equal to (gamma s by gamma w) with that we can write W_s by V_s gamma w. When V_s is equal to 1, W_s becomes G_s gamma w. Now, the dry unit weight of the soil mass is determined by (weight of the solid soils by total volume) where W_s is equal to G_s gamma w. We said that 1 plus e is the total volume from the phase block diagram. So the gamma d is equal to (G_s gamma w) by 1 plus e. This is the relationship between void ratio, specific gravity of the solid soils, unit weight of water and dry unit weight of a soil mass.

If you take a saturated soil mass, the basic relationship between these parameters can be established as weight of water is equal to e gamma w because all the voids are filled with water. Volume of water is equal to e, so e into gamma w is nothing but the weight of water is equal to e gamma w and weight of solids is equal to G_s gamma w. So the total weight of the soil mass is nothing but G_s gamma w plus e gamma w. Here total volume of soil again is nothing but 1 plus e. Now if you look into it from the definition of water content, we can say water content is equal to (weight of water by weight of solids) which is nothing but (e gamma w) by (G_s gamma w). For a fully saturated case, we have deduced the relationship between water content, specific gravity of solids and void ratio which is nothing but e is equal to WG_s. Then gamma sat is equal to W by V which is nothing but weight of the soil mass to the total volume, that is (G_s gamma w plus e gamma w) by (1 plus e).

We have established the relationship for a saturated soil mass and a dry soil mass by using the phase block diagrams. We also said that gamma d is equal to G_s gamma w by (1 plus e) for a dry soil mass and for the saturated unit weight of soil mass gamma sat is equal to (G_s plus e gamma w) by (1 plus e). Now, having seen soil in a dry state and saturated state, as you said that soil can generally exist in partially saturated state above the ground water table. In this case let us try to establish the relations where you have got three components air, water and solids. You see here, volume of water is equal to WG_s and the weight of water is equal to WG_s gamma w which implies W_s is equal to G_s gamma w.

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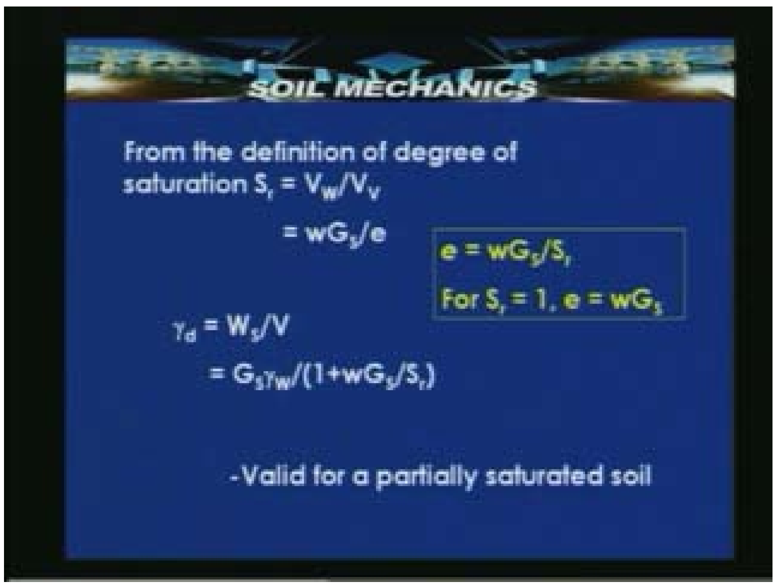

For a partially saturated soil if you look into it here we can establish relationship from the definition of the degree of saturation as S_r is equal to (volume of water by volume of voids) is equal to (wG_S by e). Then e is equal to (w G_S by S_r) that is for S_r is equal to 1, e is equal to wG_S. So gamma d is equal to W_s by V. For a partially saturated soil, we can write gamma d is equal to G_S gamma w by (1 plus wG_S by S_r). Here we have established from the definition of the degree of saturation that is S_r is equal to volume of water to total volume of voids as a relationship between void ratio, water content, specific gravity solids and degree of saturation is established as e is equal to wG_S by S_r. If you see here, for S_r is equal to 1 e is equal to wG_S which is valid for a partially saturated soil that is basically a soil with a 3-phase system.

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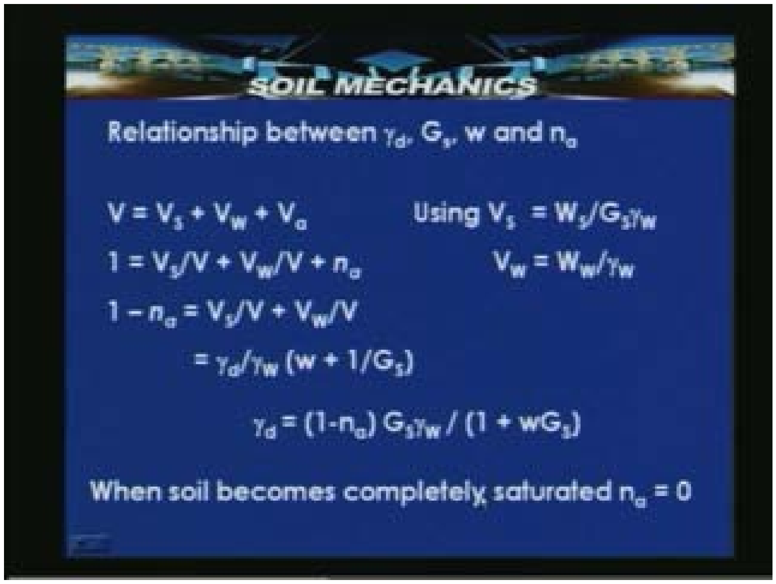

Now, let us try to derive a relationship between dry unit weight of a soil mass, specific gravity of a solids, water content and percentage air voids n_a. This we can deduce by using the definitions whatever we have learnt in this lecture. Volume of soil mass is equal to volume of solids plus volume of water plus volume of air. So using volume of solids is equal to W_s by G_s gamma w and volume of water is equal to (weight of water by gamma w). Now by rearranging the terms we can write 1 is equal to V_s by V plus V_w by V plus V_a by V where V_a by V is nothing but n_a that is the percentage as air voids. Now again rearranging the terms 1 minus n_a is equal to V_s by V plus V_w by V.

Now substituting for V_s is equal to W_s by G_s gamma w and V_w is equal to W_w by gamma w then by simplifying we get (gamma d by gamma w) into (w plus 1 by G_s). So gamma d is equal to (1 minus n_a) G_s gamma w by (1 plus w G_s) is the relationship between dry unit weight of soil mass, specific gravity of solids, water content and percentage air voids.

For example, in this expression if you put $n_a$is equal to 0, it is deduced to a completely saturated soil mass. That is dry unit weight of soil mass of the completely saturated soil can be given as gamma d is equal to G_s gamma w by (1 plus wG_s), this wG_s is nothing but void ratio of soil mass in a saturated state. In this lecture we have tried to determine soil aggregate relationships and we have tried to establish relationships using two approaches basically, specific volume approach and total volume approach.

So, in the next lecture we will try to look into the total volume approach and we will try to solve some typical problems to understand about the deductions whatever we have deduced in this class.