Soil Mechanics
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Lecture - 11
Compaction of Soils - 1

Welcome to Compaction of Soils Part 1. Compaction is a process in which the soil solids are arranged into a dense state by applying a mechanical energy. As you all know the soil is widely used as a construction material. So this compaction is a phenomenon which is very much helpful in making the soil denser so that it is able to support the loads safely. In this lecture we will understand about the compaction characteristics of soils, factors affecting the compaction behavior of a soil and then we will try to look into the laboratory determination of compaction characteristics of soils. Then we will go into the field and try to understand the different methods available to access the field compaction characteristics of the soils.

So let us start with an understanding of what is compaction and where it is applied. In many situations soil itself is used as a construction material. As you all know many earth field structures are constructed with soil such as highway embankments, railway embankments, earth dams, highway and airfield pavements, backfilled trenches and in the environment applications such as landfills. So when the soil is used as a foundation material, it is desirable that in place of materials that possess certain properties so that it serves the purpose of the function. The purpose of compaction is to produce a soil having physical properties appropriate for a particular project.

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So let us try to look into the definition of compaction. Compaction is defined as the process of increasing the unit weight of soil by forcing the soil solids into a dense state and reducing the air voids. So compaction is basically a phenomenon in which the expulsion of air takes place. So compaction is defined as the process of increasing the unit weight of soil solids by forcing them into a dense state by applying a mechanical energy and reducing air voids. So this densification is achieved basically by applying static and dynamic loading to the soil depending upon the type of the soil. Compaction is measured in terms of the dry unit weight of the soil. So in this slide we have defined compaction which is the process of increasing the unit weight of soil mass by forcing the soil solids into a dense state and reducing the air voids.

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Compaction generally leads to the following desirable effects on soils which are summarized in this slide. The first and foremost one is increased shear strength that is the strength which is required to resist the stresses which are caused by the external loading or due to the sulphate of the soil. This means, the larger loads can be applied to compact soils since they are typically stronger. So increased shear strength means that larger loads can be applied to compacted soils since they are typically stronger. The more compacted soil mass, larger loads can be applied. Reduced compressibility, also means that larger loads can be applied to compacted soils since they will produce smaller settlements. So if it is un-compacted then one can think of inviting settlements.

Reduced permeability inhibits soil’s ability to absorb water and therefore reduces the tendency to expand, shrink and potentially liquefy and thus inhibits soils ability to absorb water. The reduced permeability or reduced compressibility and increased shear strength are the effects which are generally possible by compacting the soil. It means that the soil can be increased by shear strength when you compact the soil and it can have reduced compressibility and because of its compacted nature it can have a reduced permeability. The reduced permeability inhibits the soils ability to absorb water and therefore reduces the tendency to expand or shrink or potential liquefaction. Reducing the susceptibility of liquefaction can also be minimized. So the purpose of compaction is that it reduces compressibility, increases shear strength and reduces permeability and the purpose of compacting earth fields such as earth dams and embankments in highway airfield and canal is to produce a soil mass that satisfies two basic functions; one is the reduction in settlement and increasing the shear strength.

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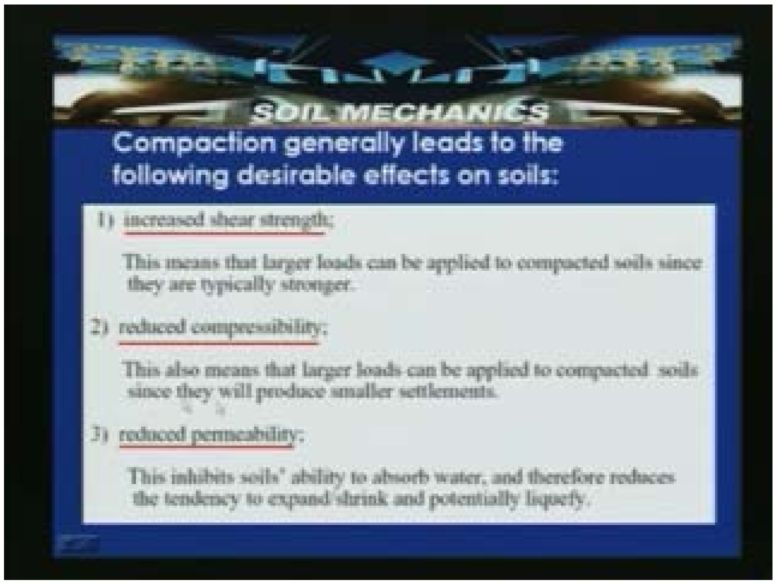

The basic purpose of compacting earth fields such as earth dams and embankments particularly highway embankments and railway embankments and canal is to produce a soil mass that will satisfy two basic criteria; one is the reduction in settlement and increase in shear strength.

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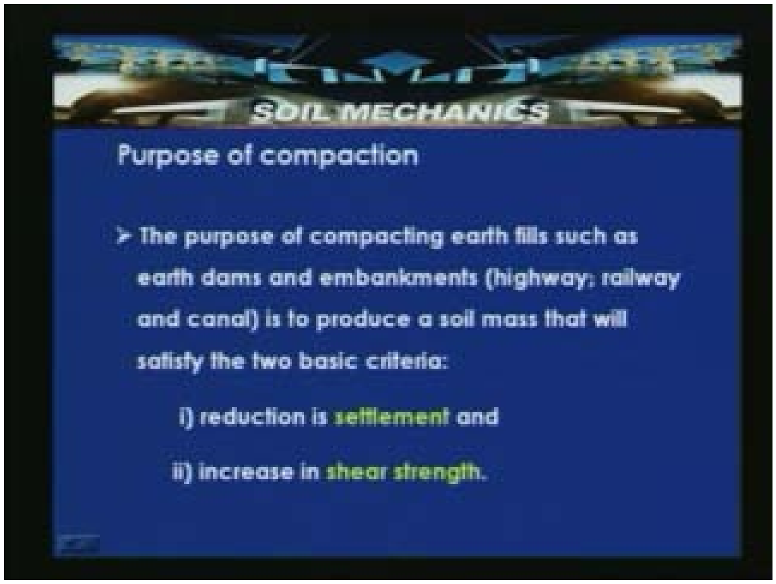

Let us look into the purpose of compaction: maximum shear strength occurs approximately at minimum void ratio that is with closer packing maximum shear strength can be achieved. Larger air voids may lead to compaction under working loads causing settlement of the structure during service. Suppose if you have a soil mass and embankment with larger air voids, once it is released for traffic loading it is susceptible for settlements and it can be out of the service very early. So larger air voids may lead to compaction under working loads causing settlement of the structure during service and large voids if left may get filled with water which reduces the shear strength. So these air voids subsequently when they come across water the increase of the water within the voids causes decrease in the shear strength so the stability of the structure will come into the picture.

Increase in water content is also accompanied by swelling and loss of shear strength in some clays. So increase in water content is also accompanied by swelling and depending upon the type of the mineral it executes swelling as we have discussed in the previous lectures and loss of shear strength in some clays. So we have summarized the purpose of the compaction here, like maximum shear strength occurs approximately at minimum void ratio and larger air voids may lead to compaction under working loads causing settlement of the structure during service and large voids if left may get filled with water which reduces the shear strength. And increase in water content is also accompanied by swelling and loss of shear strength in some clays.

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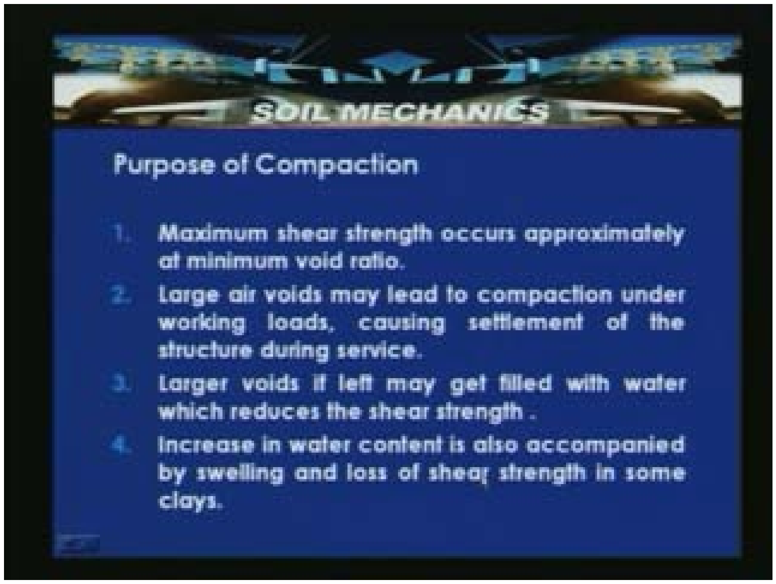

What are the advantages of compaction? So if you look into this, as we discussed settlements can be reduced or prevented. By compacting the soil the settlements can be reduced or prevented, soil strength increases because we are making the soil mass denser and denser and stability can be improved. So this is another advantage where the soil strength increases and stability can be improved and load carrying capacity of pavements of sub grades can also be improved because the more you compact the soil the load carrying capacity of the pavement sub grades can be improved. Undesirable volume changes like frost action or a swelling or shrinkage phenomena may be controlled. So the following are the advantages of compaction; one is that settlements can be reduced or prevented and soil strength increases and increases the stability of the structure and load carrying capacity of pavement grades; pavement sub grades can be improved and undesirable volume changes can be kept under control.

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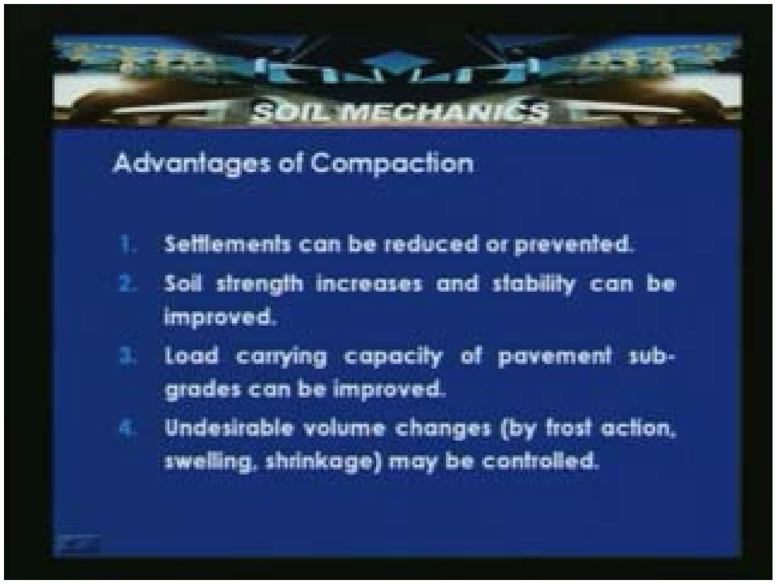

So in this slide the soil along with a three phase diagram is shown. This bucket consists of the moist soil where w_2 is the weight of the soil and v_t is the volume of the total soil. If you idealize this into three phase diagram then w_s is the weight of the solids and water in one part is shown here and then air which is above the water. So v_a is the volume of air voids, v_w is volume of water, vs is the volume of solids and w_w is the weight of water, w_x is the weight of solids. We have seen and understood this phase relationship in the previous lectures. Now we will be applying this with reference to compaction behavior of the soils.

Basically if you look into it, compaction is nothing but the expulsion of air; once we compact the soil what will happen is that the air which is present will be shunted out by applying a mechanical energy but all the air cannot be shunted out. To some extent there is certain relationship between this arrangement and optimum water content, we will be discussing this in the forthcoming sessions of this lecture. So here basically we said that compaction is nothing but a phenomenon which is expulsion of air and air which is present will be shunted out with a help of a mechanical energy or any suitable method like static loading or dynamic loading depending upon the type of the soil.

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So when loose soils are used for a construction site, compressive mechanical energy is applied to the soil using special equipment to densify the soil or to reduce the void ratio. Densification is nothing but the reduction in the volume of air voids. And this compaction phenomenon is almost an instantaneous phenomenon and soil is always partially saturated and 100% saturation cannot be achieved with the process of compaction.

Once the compaction is an instantaneous phenomena then soil will always remain partially saturated. That means, in compaction soil always remains like a three phase material and typically applies to soils that are applied or to be reapplied to a construction site. They are already applied, say you want to densify further then this particular concept will be applicable or you are constructing a new structure in which a new soil layer has to be compacted then again this particular technique will be helpful. So compaction phenomenon is an old technique and it has got roots in ancient China and India. It was reported that compaction was earlier used in the construction of Great Wall of China and in the foundation construction of the Taj Mahal in India.

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Before discussing the procedures for determining principles of compaction we need to know the two different types of soils; cohesion less soils or sandy type soils or gravely soils and clay soils or cohesive soils. So these two soils, exhibit a different soil structure. We all know this bulk particles exhibit single grain structure or to some extent a honeycombed structure. So when speaking about cohesion less soils, there are many possibilities of gravely soils. If you look into it, the particle can be angular, sub angular in nature; they can have a loose arrangement which means loose angular soil and dense angular soil. We can have dense angular soil with minimum number of minimum voids and loose angular soil exhibiting these white spots which are shown here in between, they are the large air voids.

In the other case a round uniform grain if you consider honeycombed soil in a very loose state exhibits the voids like this. The white spots in between these uniform grains idealize its spheres or the voids. And with loose arrangement here you will also see this type of arrangement such as a single grain structure where you will have large amount of voids. And the same situation in the dense arrangement you can spot less number of voids. So when speaking of cohesion less soil generally we have a got particle shape coming to picture where it can be loose angular, loose sub angular, dense angular, dense sub angular or it can have a mixture of particles or having uniform sized particles in a loose state or in a honeycombed state with honeycombed grain structure or in a grain structure with loose state and dense state.

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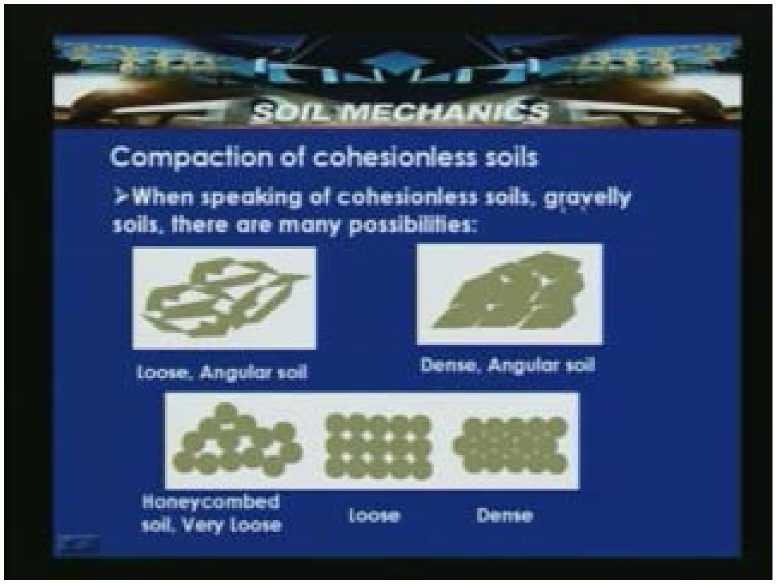

So soils in loose or honeycombed state are avoided or compacted, means that they are subjected to a process of densification before being built upon since they are prone to densification when subjected to vibratory or shock loading as from the earthquakes or vibrating machinery. So these loose deposits of soils are always problematic. Particularly sandy type of soils or fine sandy soils are saturated in a loose state, when they are subjected to a shaking either because of a blast loading or due to earthquake they will be subjected to a instantaneous densification in which they lose all the supporting strength and then the structures which are resting on the soil are susceptible to failure or large settlements. So in this slide on the left hand side you will see a soil mass with void ratio e_0 which is the maximum possible void ratio at lowest possible density and its initial height is h_0. This may be the layer thickness with h_0 with the void ratio e_{max}. So when after subjected to compaction e_f where $e_{minimum}$ is the minimum possible void ratio for the particular soil.

We knew that particularly coarse grained particles exhibit the void ratios like maximum void ratio and minimum void ratio. The maximum void ratio is the one at which the density is minimum and minimum void ratio is one at the density is maximum. So at this point the delta h is the compacted thickness so delta h by h_0 that is delta h is the change in thickness h_0 is the original thickness h_f is the final thickness here. So delta h by h_0 minus e_0 minus e_f, e_0 minus e_f is nothing but e_0 is e_{max} which is the initial void, e_f is the final void ratio, in this case it is $e_{minimum}$, so e_0 minus e_f is nothing but the delta e by 1 plus e_0. So sometimes if you know these void ratios you will be able to determine what is the compacted thickness. But here it shows that soils in looser honeycombed state are avoided or they are subjected to the process of compaction since they are prone to densification when subjected to vibratory or shock loading. So the relationship expressed here is delta h by h_0 is equal to e_0 minus e_f by 1 plus e_0.

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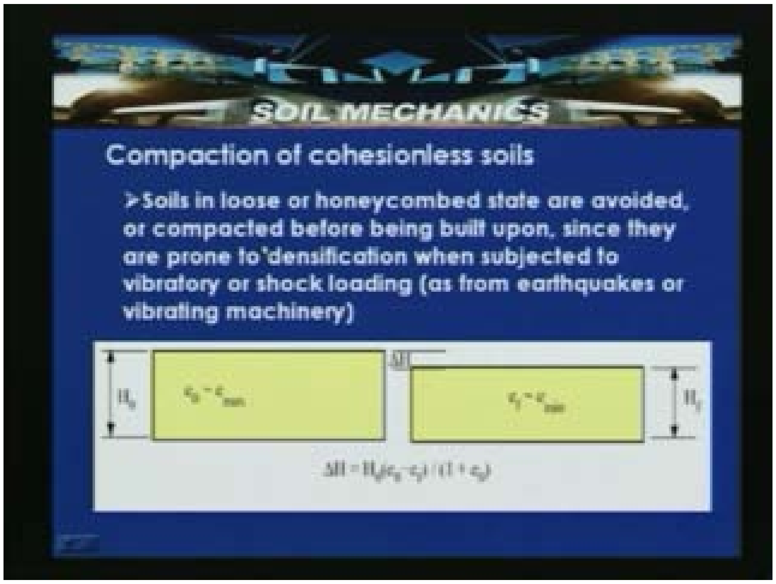

For looking into the compaction behavior of cohesion less soil let us look into some of these points. The relative looseness of a soil in its natural in situ state is determined by measuring, computing its relative density D_r this we have already studied in the previous lecture. The smaller the D_r for a given soil deposit, the more prone the soil deposit will be to densification and settlement. So the particles will be rearranged into dense state and then ultimately they will be subjected to settlements. For uniformly or poorly graded soil the spherical grain soils the theoretical range of void ratios is between 0.35 and 0.90.

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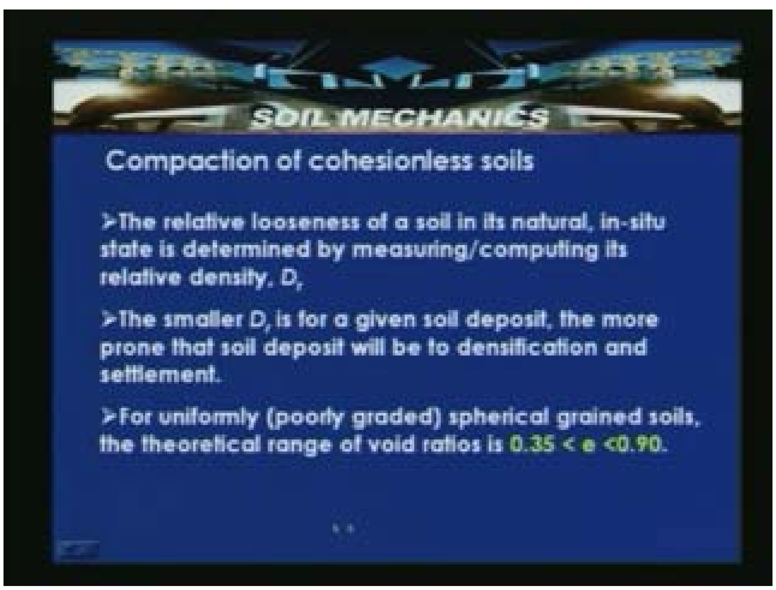

For non uniform well graded soils the possible range of void ratios is much smaller; well graded with sub angular sand void ratio is 0.35 to 0.75; well graded with silty sand 0.25 to 0.65. So if you look here the range of void ratios for well graded soils is less than that of uniformly graded soils. That is why it is generally preferred to use well graded soils in geotechnical applications as opposed to uniform soils. That is the reason why uniformly we use well graded soils for better construction and in order to carry the loads safely.

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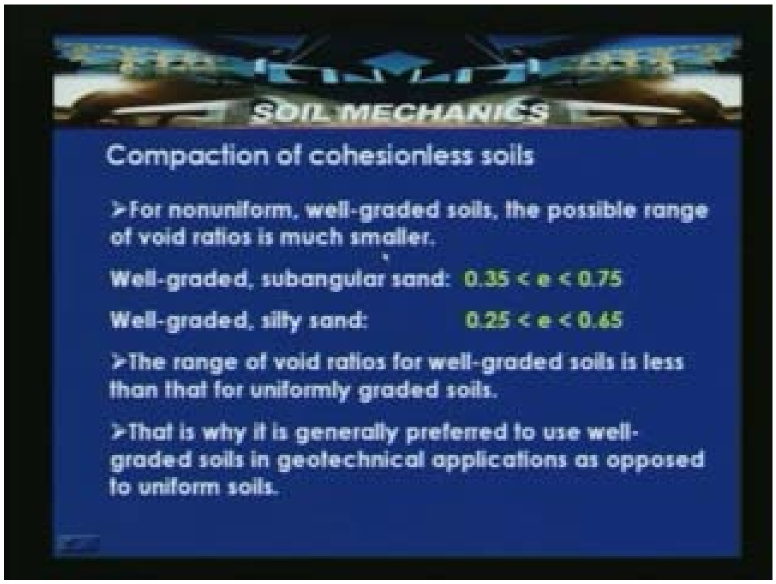

When you look further into the compaction soils, particularly sandy type of soils, can be compacted only by a vibration. Particularly cohesion less soils, sandy soils or a gravely soils can be compacted by subjecting them to special equipment with vibrations. Static load produces very little compaction into the loose sandy soils or gravely soils. Medium and fine sands do not get compacted easily in moist because of the shear strength developed by the capillary forces. , Dry or submerged sands can be compacted by vibration. Dry sand either the sand in dry state or in a submerged state can be compacted by subjecting them to vibration.

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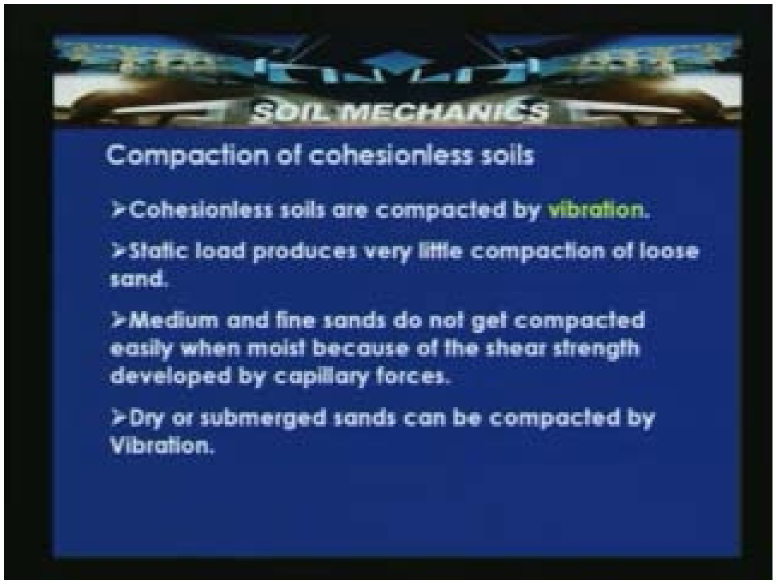

So what we learnt from this slide is that it is not possible to compact the gravely soils or sandy soils by applying static pressures because little compression is caused. But it can be possible by applying or subjecting to shaking or vibrations. We will be seeing this during the course of the lecture in the form of a small demonstration. Having discussed about the compaction of the cohesion less soils another distinctive type of the soil is the fine grain soil that is clay type of soils where the fine grain particles or platelet particles are predominant in the soil mass. So clays cannot be compacted by vibration.

Contrary to this cohesion less soils or sandy soils; Clays cannot be compacted by vibration; shaking or vibration does not produce any volume change; a very small amount of static pressure produces a large volume decrease of the platelet particles like mica flakes. So if you are able to apply a small amount of static pressure that produces lot of volume change than by applying a vibration to clay mass. So when compacting the clay the position of the particles must be changed by forcing the contact points along the adjacent surfaces to positions nearly more parallel with reduced voids. So we knew that these particles will attached like to face to edge orientation or edge to edge orientations. These platelet particles have to be rearranged by applying the pressure and to almost parallel positions so that maximum change in the volume of the voids occurs. In compacting the clay the position of the particles must be changed by forcing the contact points along the adjacent surfaces to positions nearly more parallel with reduced voids, that is what we are discussing.

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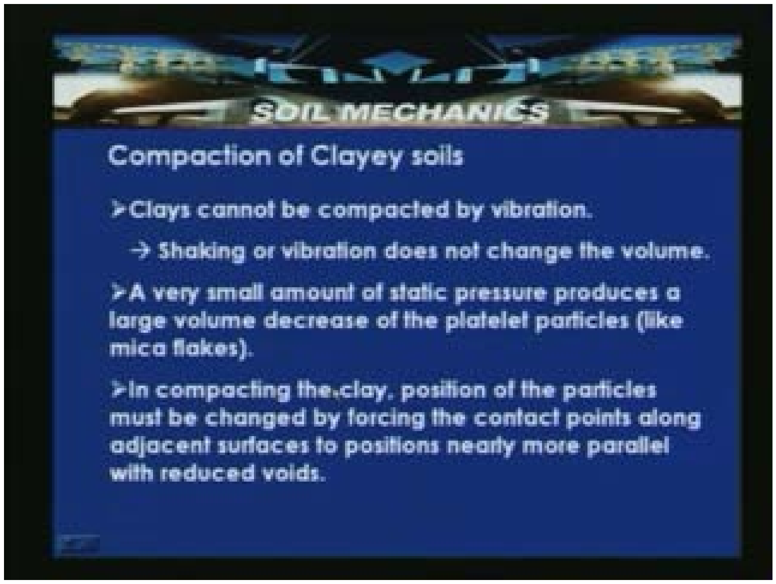

So, if you look particularly into the clay type of soil, the typical particle is of a platelet shape which has got adsorbed water with highly viscous liquid which is surrounding the clay particle and then is also surrounded by free water as shown here. The thickness of the adsorbed free water is depending upon the amount of the available water, this we have discussed in the particle forces lecture. So here in this case like a house of chords loose structure of clay before compaction is shown.

Therefore, you can see different clay particles attaching with edge to face or edge to edge orientations and these are the large voids in between these particles. So these particles can be rearranged by subjecting them to set of static pressure. Dense structure of the clay after compaction is shown here, it is almost like a parallel arrangement where from here to here the orientation of the particles has changed almost from 50 to 60 degrees. So we can see here these are the voids and these are the rearranged clay particles or platelets with the application of the static pressure with less number of voids in between these platelets.

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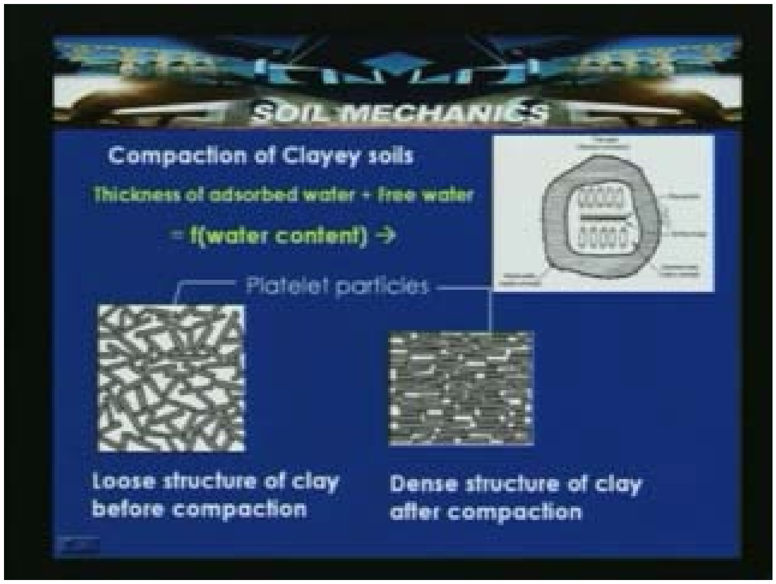

When the clay has higher water content less than saturation a thick layer of free water surrounds the particles or low viscosity. Under this condition only a small amount of pressure is required to force the particles to new positions. But a high degree of compaction cannot be produced with this high water content because the thick layer of free water prevents the particles from being forced close together. So when the clay has a high water content less than the saturation, a thick layer of free water surrounds the particles so that with low viscosity acts like a lubricating agent and under this condition only a small amount of pressure is applied and then the particles will be taken into new positions in the dense configuration. But you cannot think again that with higher amount of water content then again the water also inhibits the particles coming closer. Water and air tries to occupy the particles in between these and it inhibits the process of densification to some extent. But high degree of compaction cannot be produced with this high water content because the thick layer of free water prevents the particles from being forced close together. So having seen the typical compaction behavior of cohesion less soils and cohesive soils or clay soils let us look into a small demonstration.

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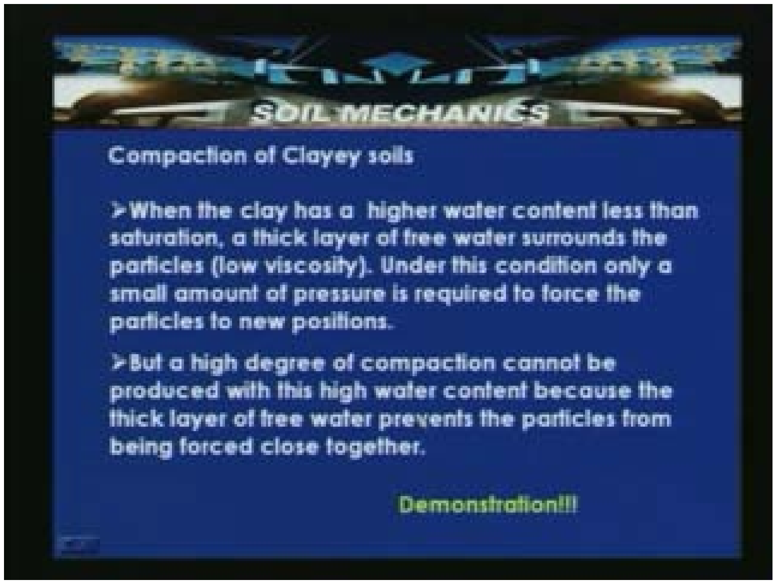

Here I am showing two different types of soils; one is coarse grain sand and the other one is very fine grained clay. This was earlier shown and this is red clay. Now as we discuss, if you apply a static pressure to a dry mass of the sand when little compression it can be achieved. But if you apply any set of vibration then itwill not be subjected to any change in the volume. So let us try to see by subjecting them to shaking. Here, this mark is the certain state of void ratio. So when this soil mass is subjected to shaking in this container for a certain period of time you can notice the particles are taking new positions and are arranging into slightly to some extent to denser configuration. So in this way the delta h whatever we are talking is occurring here. So in this process of shaking what we are doing is that to some extent we are expelling the air which is in between the voids of these particles. Now you can see this has come down so that is nothing but the delta h which has caused because of the rearrangement of these particles in a certain single grain state to a denser state than earlier. Now contrary to this material, let us look at a clayey type of soil with certain amount of saturation. You can see even when I subjected to shaking there is no volume change because this vibration or a shaking is not enough or not effective in compacting or in making the soil into denser configuration. Contrary to this shaking, these types of soils can be compacted easily by applying a static pressure so that the reduction in volume can be noticed. So this is a small demonstration which tells the two distinctive behaviors of cohesion less soils and cohesive soils.

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Now, having introduced the definition of compaction and then some different distinctive behavior of cohesion less soils and clayey soils let us try to understand about these principles of compaction. So the early theory was postulated by R.R Proctor in 1930. He postulated a theory for the compaction and with a laboratory test as well as some modified compaction test and finally the aim is to understand the compaction behavior of different types of soils and then carry this behavior into the field so that the soil which is collected from the particular site can be compacted to a denser state so that it can give a better performance with less settlements and more stability. So Proctor theory which is after R.R Proctor in 1930 showed that there exist a definite relationship between the soil moisture content and the degree of the dry density to which the soil may be compacted. So what Proctor postulated is that; a different relationship between the soil moisture content and the degree of the density to which the soil may be compacted. Then for a specific amount of compaction energy applied on the soil, single moisture content termed as optimum moisture content at which a particular soil attains maximum dry density. So particularly if it is clayey sand or sandy clay they will have a unique value depending upon the type of the gradation which is there in the soil. It will have a unique value of the maximum dry density or maximum dry unit weight and optimum moisture content. That is, the dry density corresponding to optimum moisture content is referred as maximum dry density. So these two things he has postulated; one is that he said there is a relationship between the soil moisture content and degree of dry density to which soil may be compacted and then he termed that there is optimum moisture content at which a particular soil attains maximum dry density.

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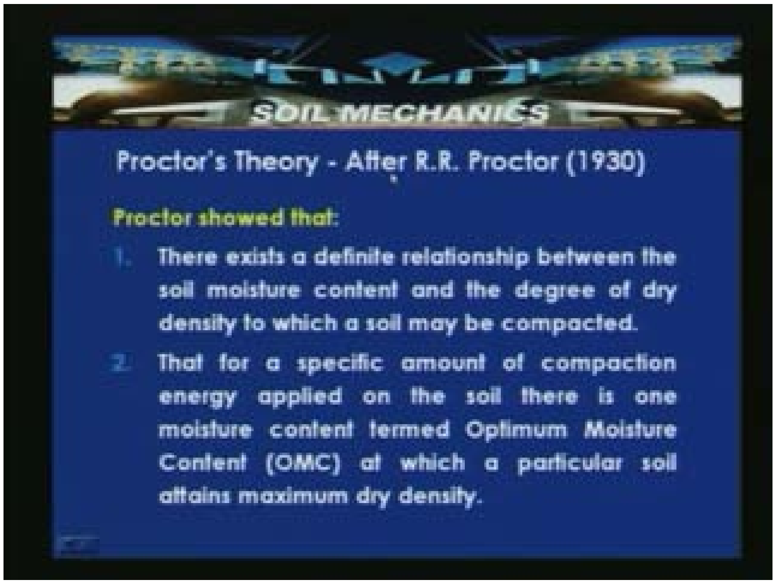

So Proctor's theory if you look in to it, proposes basically laboratory oriented tests to determine relationship between moisture content or water content, gamma d dry density. In most of the compaction terminology gamma d is referred as dry density, within principle it is dry unit weight or void ratio of a compacted soil in a standard manner and to determine OMC that is optimum moisture content for the soil. So if you look into it or if you list the factors which influence the compaction it is dry density or dry unit weight and compactive effort and the soil type gradation.

In the previous lecture we have discussed about the type of the gradation and presence of clay minerals. So soil type again comes with gradation, presence of clay particles and gamma d and compactive effort. So compactive effort is a measure of the mechanical energy applied to a soil mass. So compactive effort as given in one of these factors is actually nothing but a measure of the mechanical energy applied to a soil mass. Proctor proposed the tests to determine relationship between the water content, gamma d and void ratio with that actually it started and then finally unique values of dry density and optimum moisture content will be determined and then be used for assessing the field compaction characteristics.

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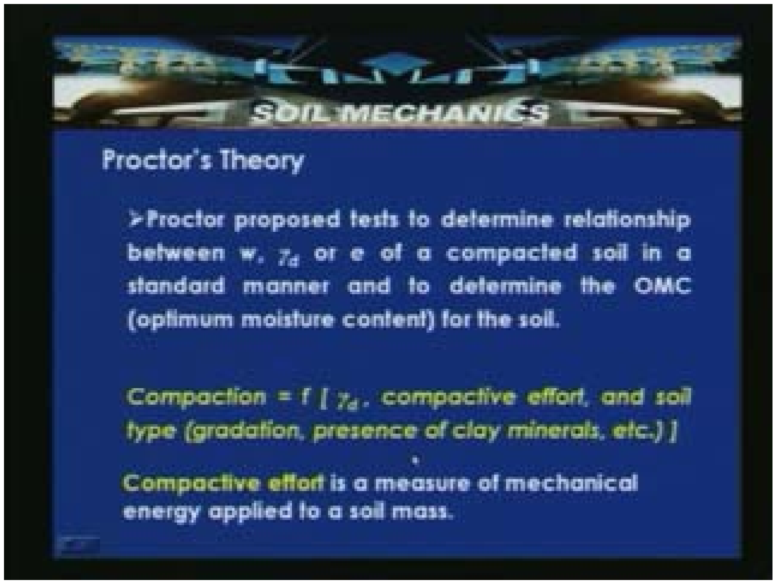

So for measuring the compaction of soils in the laboratory basically the two methods are involved; one is the standard Proctor test, it is named after Proctor 1930 and modified Proctor compaction test which we will be discussing in the next lecture.

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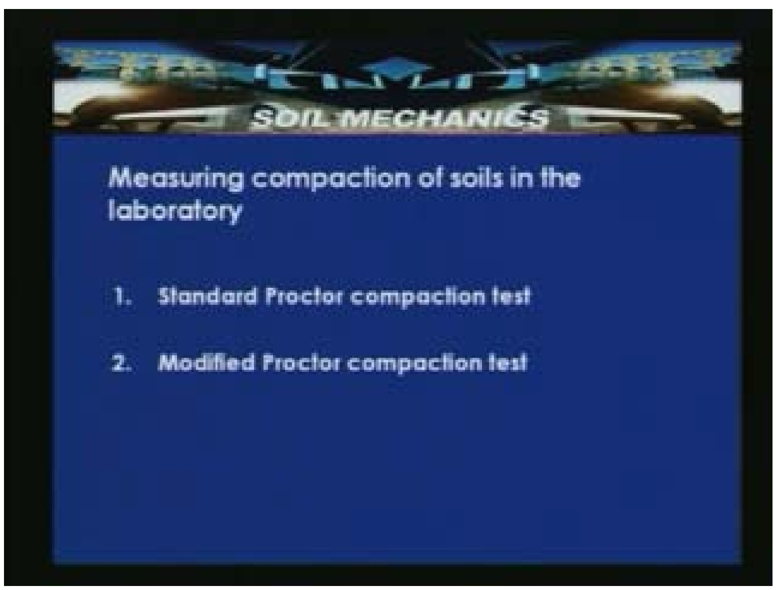

So standard Proctor test and modified Proctor test is also termed as AASHTO compaction test. So, let us look into in a standard Proctor test. Basically the scope of this method is to determine the relationship between the moisture content or water content and density of soils compacted in a mould of a given size, mould of a fixed volume and size with a 2.5 kg rammer dropped from a height of 305 mm. That means here in this figure this is the mould and this is the rammer which is dropping at a height h is equal to

305 mm. So this method covers the determination of relationship between the moisture content and density of the soil compacted in a mould of a given size mould of a given size with 2.5 kg rammer dropped from a height of 305mm. So what we are doing is, by dropping the rammer on to the soil mass we are applying a static mechanical energy onto the soil to rearrange the particle into the denser configuration or to expel the air in the voids. Shortly we will see how the presence of the water effectively plays a role in rearranging the particles.

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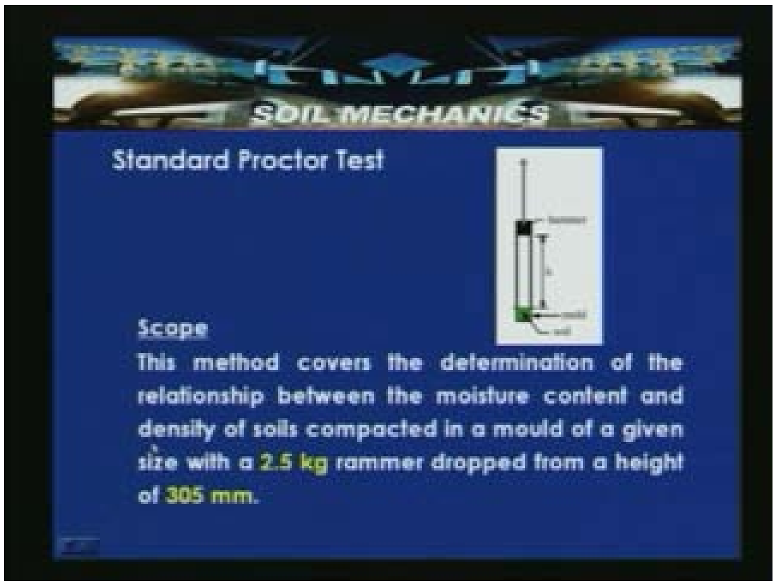

So standard Proctor mould and rammer specifications if you look into it internal diameter of the mould is 105 mm; height of the mould is 116 mm; mould has detachable collar and base plate. Basically the collar comes because the soil is compacted in three numbers of layers particularly for standard Proctor test in a loose fashion so initially to keep the soil within the volume a collar is placed. So mechanically operated rammer has a face diameter of 50.8 mm approximately about 5cm and a free falling weight of 2.5 kg. So these are standard and have been fixed 305 mm.

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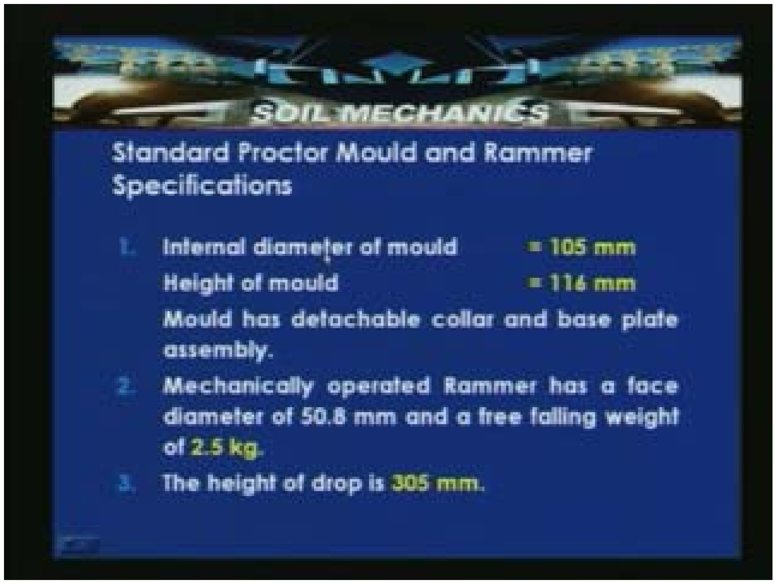

And the procedure is, approximately 5 kg of soil is thoroughly mixed with known water content. So initially we will not know that a particular soil can have a unique relationship between water content or moisture content and dry density. So, for that we have to assess that particular behavior so what we require to do in the laboratory is to take 5 kg of soil thoroughly mixed with known water content. So to start with, start with less water content; weigh the mould without base plate and collar and fix the collar and base plate. In the mould compact the weighed soil in three layers.

Basically in this standard Proctor test three layers are used giving 25 blows per layer. So in total we have given 75 blows but each layer is given 25 blows with the 2.5 kg rammer. Weigh only mould and soil after making soil flush with the mould edges and determine the weigh w. So by knowing the volume and by knowing the weight we will get the bulk unit weight of a soil mass for that water content. So this procedure has to be repeated by adding the next water content and then by repeating the same procedure we will have to determine the dry density for that water content under consideration.

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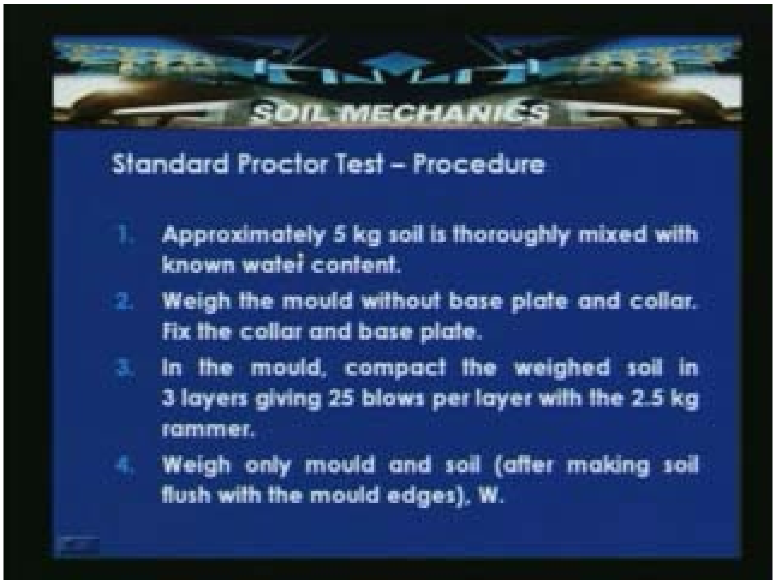

Therefore, by repeating like this, we will be able to establish a relationship between a given type of soil water content and dry density. So remove the sample from the mould and slice it vertically to obtain the small sample for water content determination, here we will take sample for water content determination. And thoroughly break the remainder of the material and increase the water content by one or two percentage points and repeat the above procedure for each increment. Continue this series of determination until there is a decrease in wet unit weight of the compacted soil mass. We will be discussing the reasons shortly as to why it decreases and initially why it increases. But this is the procedure to establish a relationship between the water content, dry density in a laboratory for a given soil.

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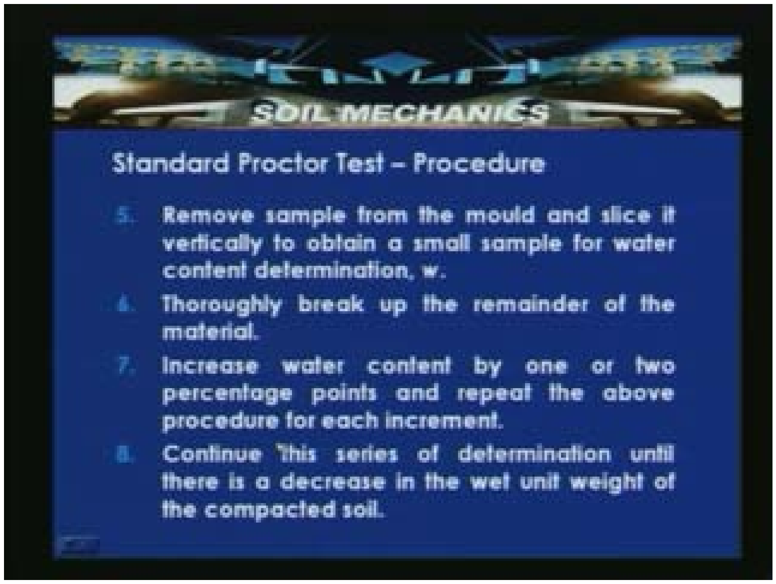

So compactive energy E applied to soil per unit volume is given as E is equal to NnWh by V dot dot E the energy which is applied is expressed here algebraically as NnWh by V dot N is number of the blows per layer, so in the standard Proctor test it is 25 blows per layer, n number of layers that is three in this standard Proctor test, W is the hammer weight so it is 2.5 kg and the height of the drop h is 305 mm and V is the volume of the mould. So compactive effort can be calculated by using NnWh by V; which is around 57187kgm by m cube or 594KJ m cube you will be able to determine the compactive effort. So the compactive effort which is given in the Proctor test is around 594KJ m cube.

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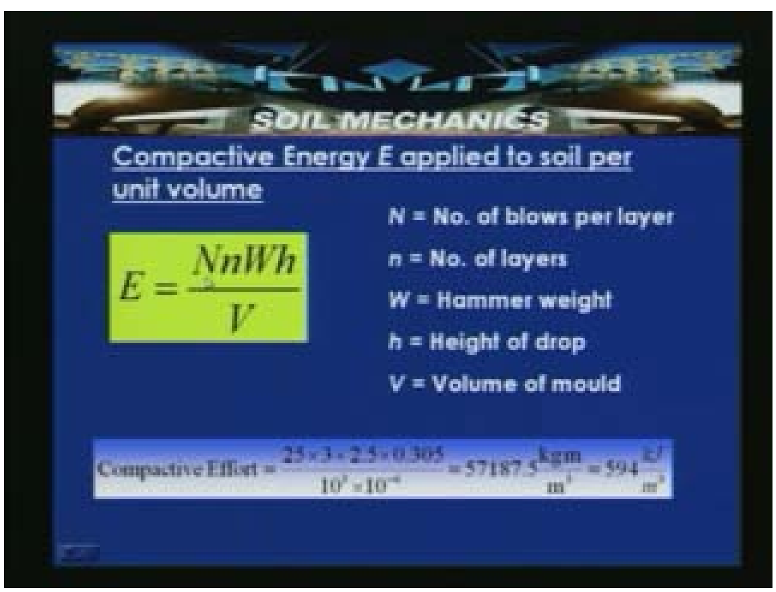

So the standard Proctor test procedure is a continuation if you look into it. The dry density calculations, we knew the volume of the mould and we knew the bulk density of the soil mass at a certain water content that is W by V. So dry density of the soil mass can be calculated by using gamma d is equal to gamma b by 1 plus W the water content.

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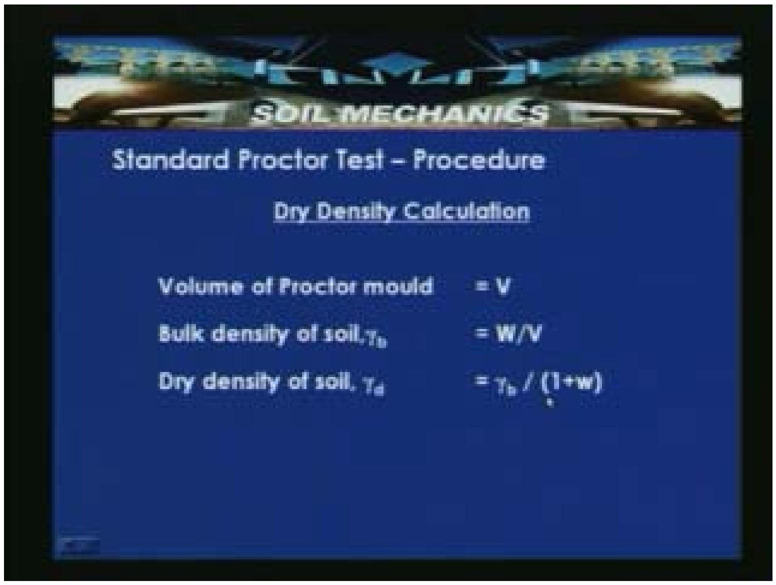

So with this we will be able to establish relationship between water content and dry unit weight or dry density. This particular slide shows a typical moisture content dry unit weight relationship. On the x axis moisture content or water content is plotted and on the y axis dry unit weight or dry density is plotted. So whatever gamma dry or gamma bulk is measured at each of the water content they are plotted here with the points. So by joining the points they form a typical bell shaped curve.

On the right hand side here you will see zero air voids line which will discuss later with 100 percent degree of saturation. And onto the right of this point is called the wet of the optimum and left side of this particular limb is called the dry of the optimum. So the water content corresponding to maximum dry density is referred as the optimum moisture content. This is the combination of water which is optimum here which is referred as OMC that is optimum moisture content. And the density corresponding to optimum moisture content is gamma d max that is maximum dry unit weight or maximum dry density.

Therefore here, in this slide which is on the right hand side different moulds are shown and we have tested different water contents. This is the procedure as to how energy is being applied to the soil mass, so the yellow color which is shown here is the face of the soil and this is the face of the hammer which is falling onto the soil. So as you can see here uniformly the blows have to be given so that uniformly energy is transferred to the entire soil. So care should be taken to follow this procedure and also to impart adequate number of blows with correct drop of the hammer. So by plotting like this we will be able to establish a relationship between the moisture content and dry unit weight of a soil mass. The reason is that, if you see here before the optimum moisture content the trend in the density is increasing with increasing water content. If further there is an increase in the water content you will see that there is decrease in the dry density and that is what one should observe. The other thing is that this line we called as zero air voids or 100% saturation line and this right side of the limb is always on the left side of the zero air voids line it never touches the zero air voids line, that is the particular characteristic of a compaction curve.

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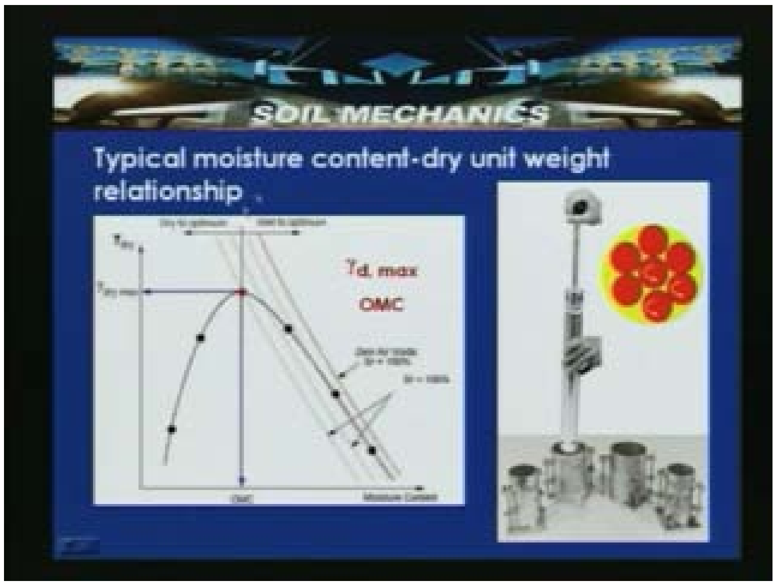

So if you look into the principles of compaction and moisture density relation we have to consider how this water which is being supplied to the soil grains is influencing in rearranging into the new positions. So compaction of soils is achieved by reducing the volume of voids, predominantly the volume of the air voids. It is assumed that the compaction process does not decrease the volume of solids or grains. The basic assumption is that compaction process does not decrease the volume of the solids or soil grains. Again the un-compacted angular soil grains are shown and here the compacted soil grains are shown, and un-compacted honeycombed uniform grains are shown and compacted uniform grains are shown. So compaction of soils is achieved by reducing the volume of voids. It is assumed that compaction process does not decrease the volume of the solids or soil grains.

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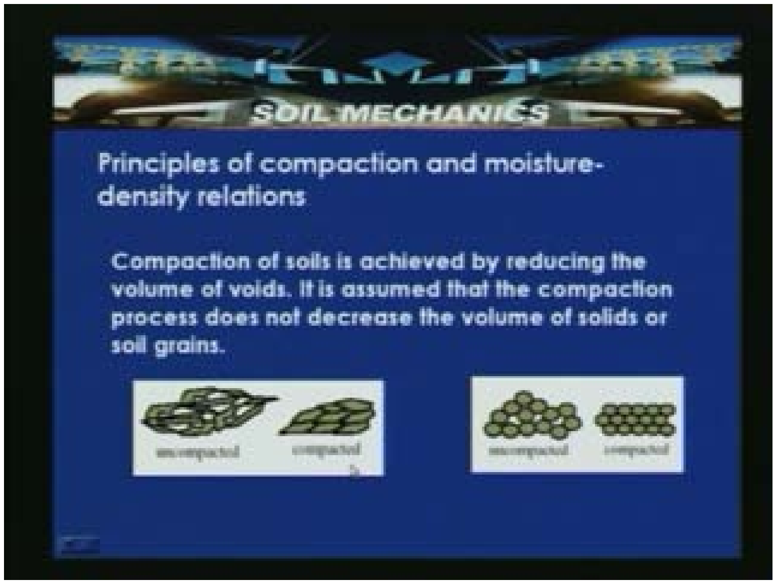

So, if you look into the principles of compaction and moisture content and relationship between dry density and void ratio, the degree of compaction of a soil is measured by the dry unit weight of the skeleton. The dry unit weight correlates with the degree of the packing of the soil grains. So recall that gamma d is equal to G_s $gamma_w$ by 1 plus e and that is what we have earlier derived while discussing about the face relationship. So if you want more compactness for the soil the less should be the void ratio, the less is the void ratio the more is the dry unit weight. So in this relation, if you look gamma d is equal to G_s $gamma_w$ by 1 plus e; G_s is the specific gravity of the soil solids that is constant, $gamma_w$ is the unit weight of water. So what exactly we have to look for is whether there is any change in the void ratio, the smaller the void ratio the higher the dry unit weight gamma d will be. So what we try to establish is that the relationship between water content or moisture content and dry density exhibits something like a bell shaped curve.

With increasing water content we see that there is an increase in density. But after attaining certain level of water content where the soil is exhibiting the maximum dry density then afterwards with a further increase in water content is observing a decrease in the dry density. So this is the typical characteristic of the compaction behavior of the soil where water plays a critical role in the soil compaction process.

Therefore, if you look into it to some extent the reason can be attributed like the water which is there lubricates the soil grains so that they slide more easily over each other and can thus achieve a more densely packed arrangement. So without water the lubrication will not occur, the soil remains in stiff position, there will be large amount of air voids, with large amount of air voids the soil exhibits less dry density with replacement of the air voids with water because we are supplying water by increasing the water content. This water also acts as a lubricating agent and softens the clay bonds and to some extent it helps to arrange the clay particles into the new and dense positions so that the maximum density of the soil can be achieved.

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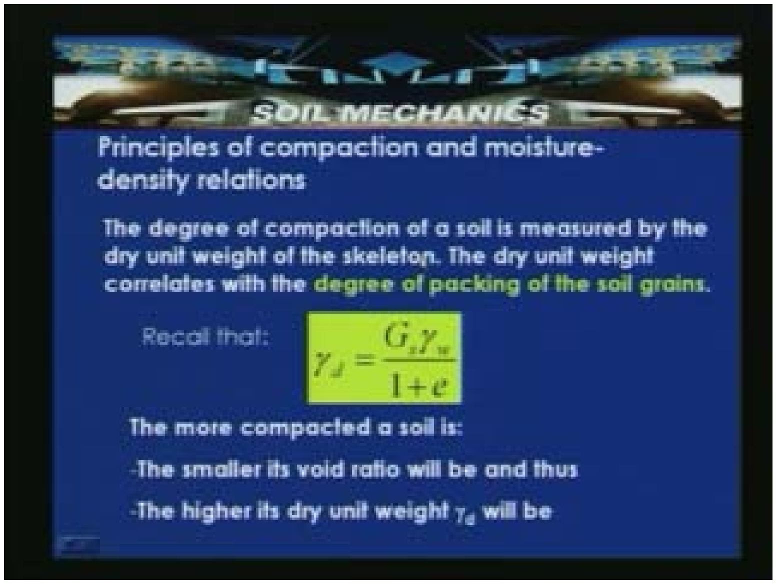

Therefore, little bit of water facilitates compaction and on the other hand, too much water inhibits compaction. That means, on the dry side of the optimum when you are having less amount of water it is helping you to compact the soil, when you are having more amount of water it inhibits the compaction. So, in this lecture what we try to understand is that we introduced the compaction behavior of the soil, particularly in part one lecture and we defined the compaction process and then we tried to understand about a standard Proctor test which is one of the laboratory test methods to determine relationship between water content and dry density of a given soil. In the next lecture we will continue with the role of water that plays a major part in the compaction behavior of the soils and we will try to discuss about other methods, modified Proctor test and factors influencing the compaction behavior of the soils and field compaction methods.

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