Soil Mechanics
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Lecture - 12

In the previous lecture, we have introduced about compaction and different methods for compacting soil. We also discussed a method of compaction in the laboratory called Standard Proctor test, after R.R. Proctor (1930). And we also discussed distinguished behaviour between compaction of soils for cohesion less soils and cohesive soils. In this lecture we will try to understand much about principles of compaction and the role of water played in the compaction process. We will also discuss the factors affecting the compaction characteristics of soils along with another modified Proctor Compaction test which has been developed for highway and sub grade works by AASHTO.

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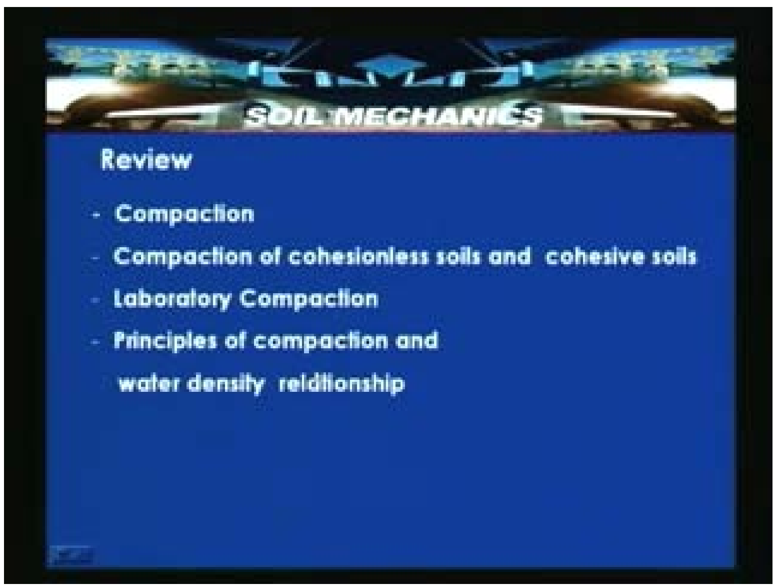

In the previous lecture, we have seen about a definition of compaction and compaction of cohesion less soils and cohesive soils. We have also seen a small demonstration how different cohesion less soils and cohesive soils are? Laboratory compaction method, we have seen a standard proctor compaction. In this lecture we will be discussing about modified proctor compaction test. Principles of compaction and water density relationship have been introduced to you. Here, we will be discussing about the role played by water in the entire compaction process along with the factors affecting the compaction. This lecture is compaction of soils part two.

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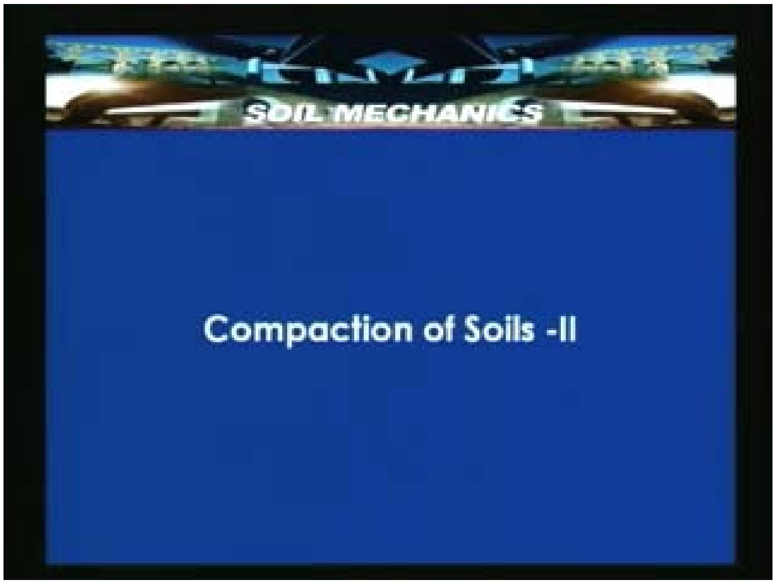

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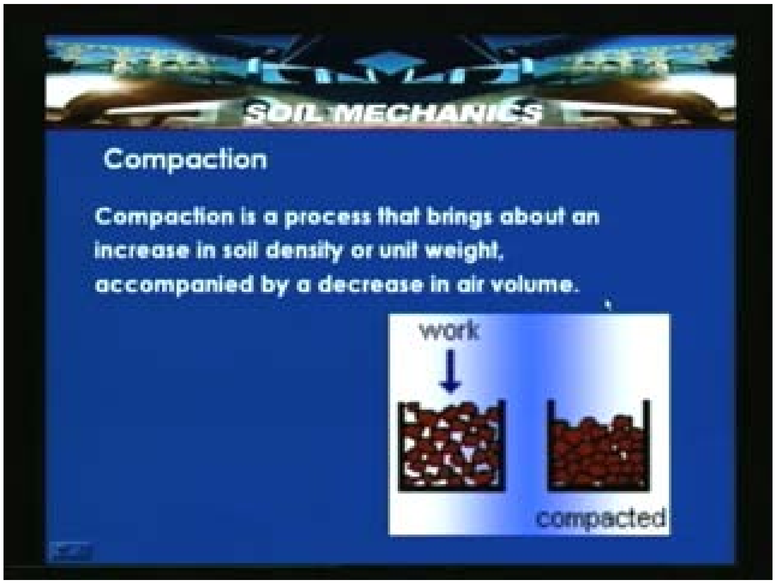

As we have defined, let us look once again that Compaction is a process that brings about an increase in soil density or unit weight. So here the degree of compaction is also measured as dry density or dry unit weight. Compaction is a process that brings about an increase in soil density or unit weight accompanied by decrease in air volume. For example, if you see here, if the work is applied for the loose aggregate then these aggregates are rearranged into the closer cohesions. In the process what we are doing is that we are shunting the air which is in between the void spaces between the solid grains. Here we say, the soil is said to be in a compacted state. So Compaction is a process that brings about an increase in soil density or unit weight accompanied by a decrease in volume. By removing the air, the aggregate particles will be tugged into the closer positions to increase the density of solid grains in a given volume. In the previous class we have discussed that the relationship between dry unit weight and water content can be obtained by standard proctor compaction. We said that it is of typical bell shaped nature curve.

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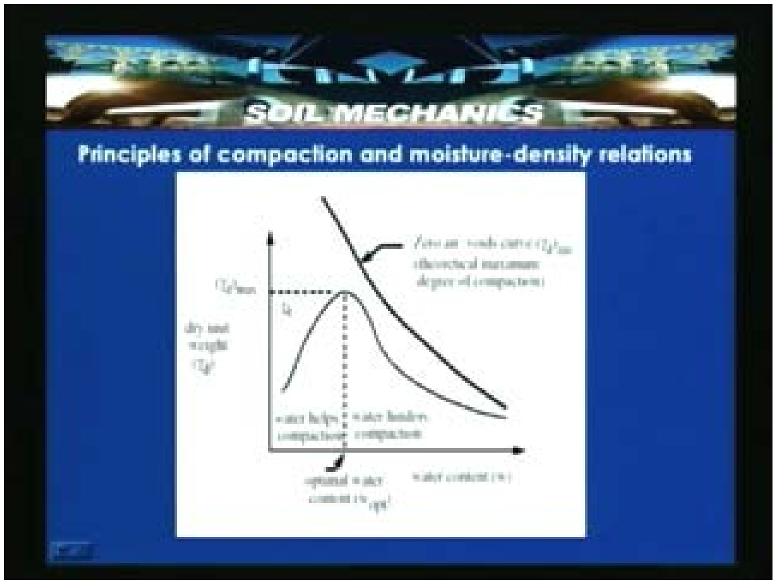

Here in this figure, once again the same curve is shown for you where water is helping the compaction up to this process. As you climb onto the hill here you will see that the dry density is increasing with an increase in water content. After reaching certain point you are absorbing that the dry density keeps falling with an increase in water content. This line we said that zero air voids line or 100 percent saturation line. We will be discussing more about this in this lecture. This point as at which maximum density exists is called the maximum dry density of a given soil and the corresponding water content is termed as the optimum water content or optimum moisture content. It is indicated as OMC (optimum moisture content) for a given soil. These values are unique for a given soil depending upon the soil type and it is a comparative effect of whatever you have given or gradation or combination of the different factors we will be able to influence these particular values gamma D_{max} that is maximum dry unit weight and optimum moisture content.

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Let us look into this mechanism once again. As we have seen, when the moisture content or the water content is less than optimum moisture content we will generally refer that as dry of optimum. If the moisture content is less than the optimum moisture content then we refer that as dry of optimum moisture content or dry of optimum which has got a practical relevance in compacting soils.

When moisture content is less than OMC, soil is stiff that is naturally the water is less so soil is stiff and difficult to compress because the friction between the grains is very high and it is very difficult to shunt more air from the soil mass. Hence low density and high air voids can be obtained. More air cannot be shunted out because the friction which is there between stiff particles will not allow us to shunt the air from the soil mass.

When the moisture content is less than OMC, soil is stiff and difficult to compress and because of that low density or dry unit weight prevails and high air voids can be obtained. Now, increase in moisture content lubricates. That means as you keep on increasing water content from say 5 percent, 6 percent, 7 percent like that, this addition of water to a given soil mass softens the soil. In the process it softens the clay bonds or bonds between the particles and reduces the surface tension forces because previously these forces are inhibiting the particles for coming close within the soil mass and makes it more workable. So in the process what will happen is that the particles will take a closest position as possible for a given soil so because of this, higher densities are achieved and low air voids can be obtained. It is not that 100 percent air voids will be removed but low air voids will be achieved. So, increase in moisture content lubricates and softens the soil.

Here we should appreciate the role played by the water in the soil compaction. Here, water plays as a lubricating agency and softens the clay bonds. So, in this process what will happen is that it reduces the surface tension forces within the soil and makes it more workable and higher densities and low air voids can be obtained. This is a very important concept we should remember about the principles of moisture density and compaction. Increase in moisture content lubricates and softens soil that is the process softening the clay bonds occurs, reduces the surface tension forces within the soil and makes it more workable because of this higher densities and low air voids obtained.

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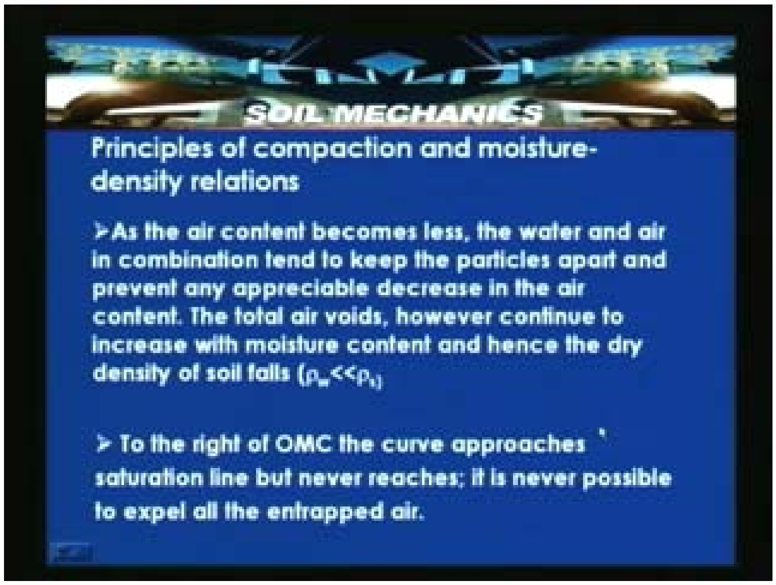

Now as the air content becomes less you see here in the slide it has been described here. The water and air in combination tend to keep the particles apart. So, once we crossed this optimum moisture content then air content starts becoming less. It is not that it is reducing to zero but air content becomes less. The water and the air combination tend to keep the particles apart and prevent any appreciable decrease in the air content. The appreciable decrease in the air content means it will never go into a completely saturated state but it will always remain in the partially saturated state. The total air voids, however continue to increase with moisture content hence the dry density of the soil falls. So, in the process what will happen is that, if you see, when water starts occupying the space between the grains air and water which is actually inhibiting the particles from coming close. The optimum moisture content is a threshold limit for that particular soil.

Once we cross that what will happen is that the particles will not be coming closer because of the presence of air and to some extent excess amount of water which actually inhibits the particles from coming close. Another thing is also that the unit weight of water or the density of water is much much less compared to density of the soil solids and because of that on the right hand side of the optimum moisture content with an increase in water content that the dry density falls.

On the left hand side of the optimum moisture content that is the dry of optimum, you will see with an increase in water content there is an increase in dry unit weight. But there is a peak at which the maximum dry density occurs at particular water content. That we referred as a maximum dry unit weight and optimum moisture content for a given soil.

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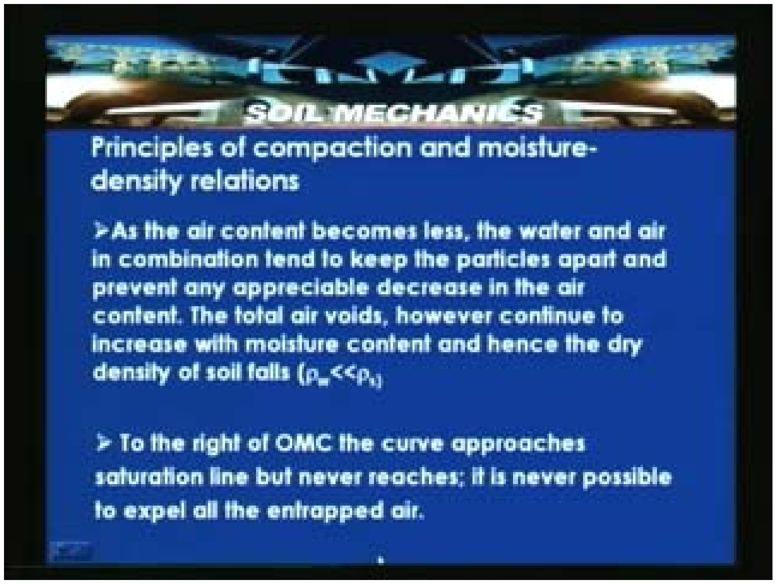

To the right of OMC the curve approaches saturation line but it is never possible to expel the entrapped air that is what actually has been discussed. So for compaction of soil whenever we draw zero air voids line the compaction curve is on the left hand side of the zero air voids line, it never crosses or it never touches that. If it touches it means that 100 percent saturation is achieved and that is conceptually wrong in the process of compaction. So, to the right of OMC the curve approaches saturation line but never reaches; it is never possible to expel all the entrapped air. This is also explained in the forthcoming slides.

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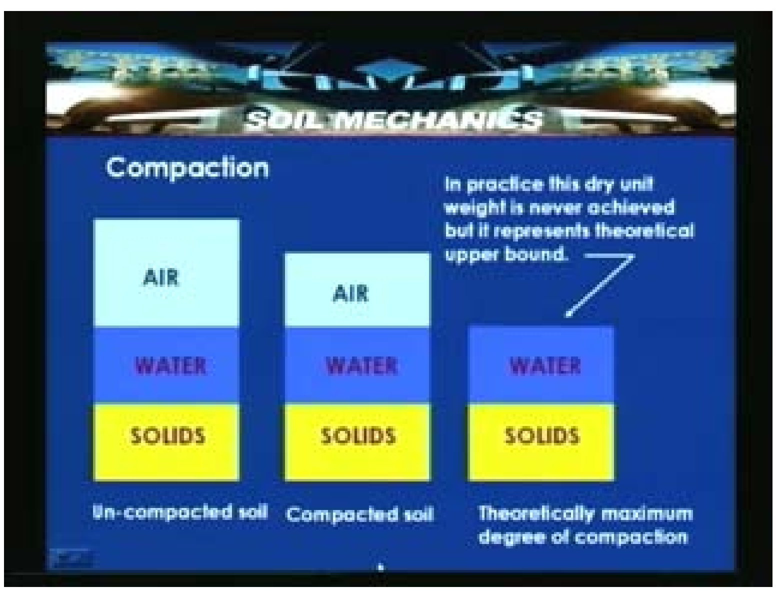

In this slide let us consider un-compacted soil and compacted soil. Here, a three phase diagram is again drawn with an un-compacted soil such as solids, water and air unit. So you will see more amount of air, water and solids. This may be from the borrow area which has come from certain area for compaction.

Let us assume that we applied a certain energy that is a compactive effort to compact the soil and we are able to successfully remove a certain amount of air. This is a modified three phase diagram for a compacted soil which is shown here consists of air, water and solids.

If you see further a theoretically maximum degree of compaction is this once you are able to shunt all the air out of the voids. In practice this dry unit weight is never achieved but it represents the theoretical upper bound for a theoretical maximum degree of compaction. So actually this is a case possible theoretically only. Theoretically we can say that, this is the maximum degree of compaction. But in practice this dry unit weight is never achieved but it represents theoretical upper bound. That means this air in the compacted soil cannot be shunted out whatever may be the energy which is applied to the soil. That is what actually this slide shows, an un-compacted soil with air, water and solids in 3 phase diagram and a compacted soil with a decrease in the air content and it shows that there is a compacted nature of soil exists.

This diagram shows a 2 phase diagram again with water and solids which is a theoretically possible degree of compaction. We also said that in practice this dry unit weight is never achieved but it represents the theoretical upper bound. To get a better understanding about compaction, again consider the 3 phase diagram for soil as shown below.

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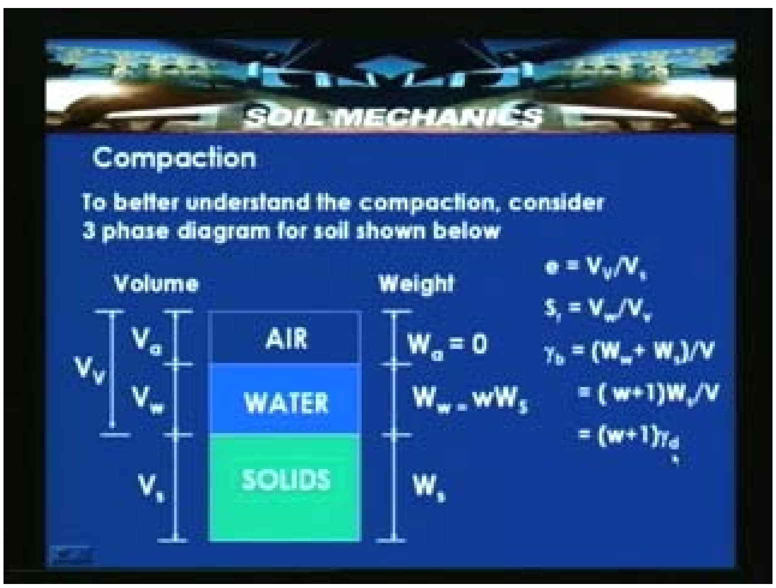

We have discussed these in the previous lectures that is air, water and solids. On the left hand side you will see volume, that is volume of air and volume of water which is in total put together is volume of voids and volume of solids. Here on the right hand side, weight of air is equal to 0, weight of water is equal to water content times weight of solids and W_s is the weight of solids. So, water content is the ratio of weight of water to weight of solids. The total weight of a soil mass here is W_w plus W_s and the total volume of the soil mass is V_a plus V_w plus V_s.

We knew that from the definition of void ratio; e is equal to ratio of volume of voids to volume of solids and degree of saturation is ratio of volume of water to volume of voids. These are the important things which we have to remember. We can deduce gamma_{bulk} or we can write gamma_{bulk} from the diagram as (W_w plus W_s) by total volume. By rearranging and writing for w is equal to W_w by W_s, then we can write gamma bulk as (w plus 1) into W_s by V. Here W_s by V is nothing but gamma_d that is the dry unit weight. So if we know the bulk unit weight of soil mass, we can calculate gamma d dry unit weight by this relation gamma_d is equal to gamma_{bulk} by (1 plus w).

In the compaction test when we add a known amount of water content to this what we get by weighing the mould is the bulk unit weight, that is weight of soil mass including solids and water which is divided by the total volume which includes volume of air, volume of solids and volume of water and with that we will be able to estimate the bulk unit weight. Bulk unit weight by (water content plus 1) will give us the dry unit weight. This is the next question which is widely used in the compaction of soils. We are just going into the analysis of this compaction curve.

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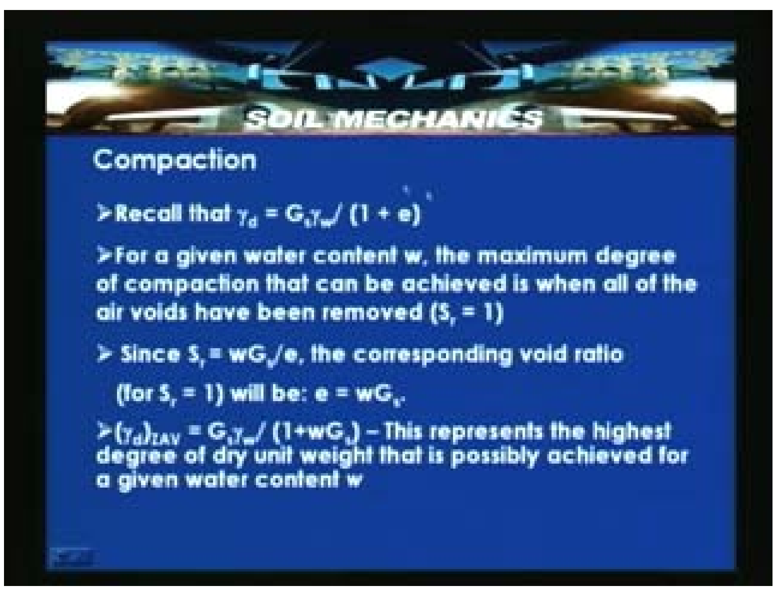

So recall that, we knew gamma_d is equal to G_s gamma_w by (1 plus e). We have derived for dry soil that is 2 phase soil gamma_d is equal to G_s gamma_w by (1 plus e). For given water content w the maximum degree of compaction that can be achieved is when all of the air voids have been removed, that is what we have said. That will be achieved once the degree of saturation S_r is equal to 1. Since S_r is equal to wG_s by e, we knew that e is equal to wG_s by S_r for a partially saturated soil then the corresponding void ratio for S_r is equal to 1 can be obtained as e is equal to wG_s.

For substituting e is equal to wG_s, we can obtain gamma$_d$ is equal to G_s gamma$_{w \text{ by}}$ 1 plus w G_s). So gamma$_d$ that is along the zero air voids line or 100 percent saturation line can be obtained by G_s gamma$_w$ by (1 plus wG_s).

By knowing specific gravity of the soil and by knowing the range of water contents for a given soil, we will be able to estimate the dry unit weight along the zero air voids line. Along this line, the degree of saturation is 1. The S_r is equal to 1 is valid for this expression. This represents the highest degree of dry unit weight that is possibly achieved for a given water content w. This particular dry unit weight gamma$_d$ at ZAV is possibly achieved for a given water content w. We have substituted for e is equal to wG_s by S_r, when S_r is equal to 1, we substituted e is equal to wG_s and we obtained this expression for (gamma$_d$) $_{ZAV}$ is equal to G_s gamma$_{w \text{ by}}$ 1 plus wG_s).

Now let us see whatever we have discussed in the form of a curve. On the left hand side here, the dry density in Mg by m cube or the dry unit weight in kN by m cube can be represented on the y-axis and water or moisture content is represented on the x-axis.

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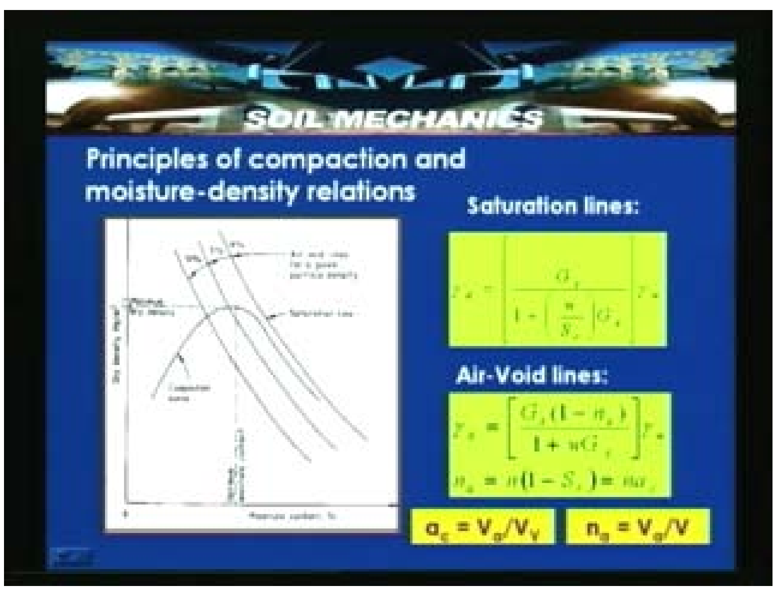

This is the bell shaped compaction curve which is shown here and this is a saturation line. This is what we are referring as 100 percent saturation line or zero air voids line. This particular line is also referred as zero air voids line or 100 percent saturation line. Air void lines for a given particle density can be obtained for 5 percent, 10 percent, that means these are all 5 percent air voids and these are all 10 percent air voids or 100 percent saturation line or 95 percent degree of saturation line or 90 percent saturation line and that is how these lines are plotted. In order to plot these things as we discussed in the previous slide we have to use this expression like gamma$_d$ is equal to (G_s by (1 plus (w by S_r) into G_s) into gamma$_w$. For S_r is equal to 1 that is 100 percent saturation line we will get this line. If for degree of saturation it is 0.95 then substituting this for the range of water content we will be able to find out this particular line.

In terms of air void lines these are particularly determined by using this expression. For example, gamma$_d$ is equal to (G_s (1 minus n_a) by 1 plus wG_s) into gamma$_{w.}$ By using this expression for a range of water contents we will be able to determine dry unit weight of a given soil mass. For example, n_a which is nothing but the volume of air in total volume of the soil mass that is percentage air voids which we have defined earlier. So by using that n_a is equal to V_a by V, we can determine this 5 percent air voids line or 10 percent air voids line or in terms of a degree of saturation line we can determine like 80 percent degree of saturation. For 80 percent degree of saturation S_r is equal to 0.8. For a range of water content we can even determine 80 percent saturation line.

Another thing which is required to be discussed here is as follows: We knew that percentage air voids is equal to n into (1 minus S_r). So percentage air voids is equal to porosity times (1 minus S_r) which is nothing but percentage air voids is equal to n times a_c, which is nothing but the air content. Air content is defined as volume of air in total volume of voids. So air content definition is different from the percentage air voids. With this definition a 20 percent air content line is not equivalent to 80 percent degree of saturation line. That difference is required to be noted. Many notations are there for plotting air content lines. This air voids lines can be plotted in terms of a degree of saturation lines or air voids lines or air content lines. One thing which is required to be noted is that 20 percent air content line is not equivalent to 80 percent of degree of saturation line. That is because of this particular definition which is lying between a_c is equal to volume of air to total volume of voids or n_a is equal to V_a by V.

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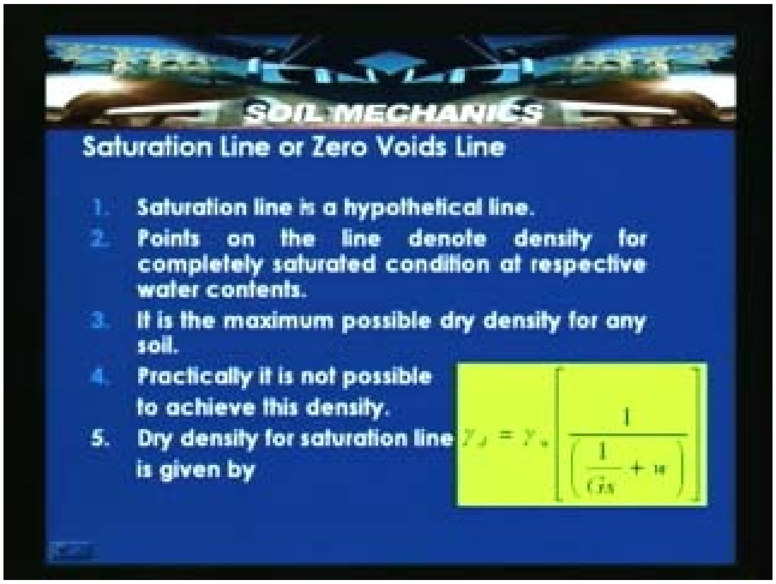

Now let us discuss about this particular 100 percent saturation line or zero air voids line. Saturation line is a hypothetical line. We said that in the field it is not possible to achieve this density but this is a hypothetical line which exists on the right hand side compaction curve.

Points on the line denote the density for completely saturated condition at respective water contents. So with this, it is not possible to achieve this particular density because the air cannot be shunted out of the voids. So points on the line denote the density for completely saturated condition with respect to water contents. It is the maximum possible dry density for any soil. Practically it is not possible to achieve this density that is what we have discussed earlier also.

Dry density for saturation line is given by this expression here gamma_d is equal to gamma_w (1 by (1 by G_s) plus w). This has been deduced earlier. So, for a range of water contents we will be able to determine the gamma_d or the dry unit weight or dry density. Saturation line is a hypothetical line. Points on the line denote the density for completely saturated condition and respect to water contents.

We have seen the principles of moisture content and principles of compaction. Now let us look into another method of determining compaction characteristics of a soil that is by using a method called modified compaction test or modified proctor compaction test or AASHTO compaction test. This is also called as it is written here AASHTO or modified proctor compaction test. The standard proctors test is not sufficient for airways and highways.

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Basically during the construction of airways and highways, it was felt that the compaction whatever being given in the form of a standard proctor compaction is not adequate for the soils. It should be possible to compact the soils by increasing the compactive effort. That was actually made possible by using this particular modified proctor compaction test method. This was adopted by US Army Corps of Engineers.

US Army Corps of Engineers developed this method of modified compactive test which used greater levels of compaction than whatever we are saying in the standard proctor compaction test and produced higher densities. By supplying higher densities to the soil means that in order to overcome this frictional forces which are in between solid grains you need applying certain amount of more energy and you will be able to push particles closer by shunting more air. With this process we will be able to achieve drier unit weight and it may be possible at less water contents. The optimum moisture content can be achieved because of this phenomenon.

Modified proctor test was later adopted by AASHTO and ASTM. AASHTO and ASTM even today adopts this modified compaction test basically used for compacting soil for highway sub-grades and basically to construct air strips on soils, there we require very solid sub-grades for resisting the impact of landing of the aircraft etc.. Particularly the modified compaction test is used to compact the sub-grade while preparing for this air strips. Let us look into the details about modified proctor compaction test.

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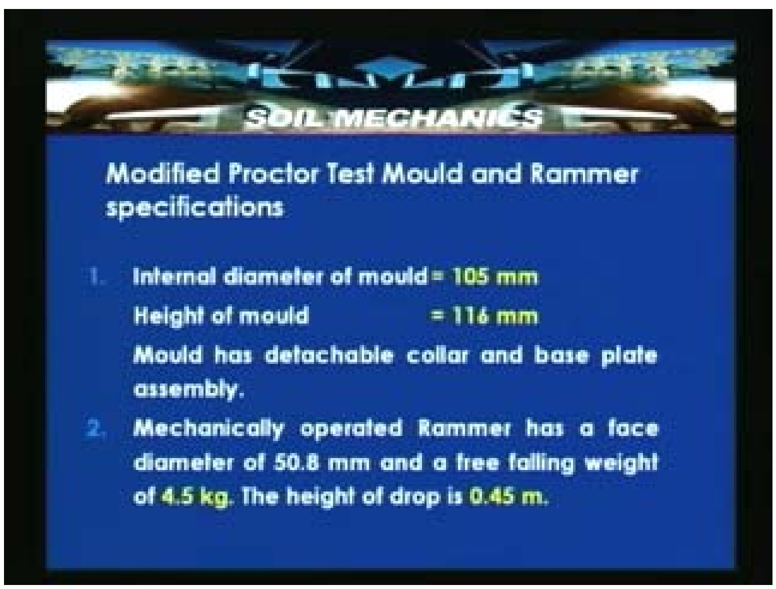

It is similar to proctor compaction test. It is done in the same mould but more energy is applied to the soil mass so that the air which is there in the voids can be shunted out to produce more dry density and at less water content. Internal diameter of the mould is 105mm the same mould which is used for standard proctor compaction test, height of the mould is 116mm. Mould has detachable collar and base plate assembly. Mechanically operated hammer has a face diameter of 50.8mm that is 5.08 cm and a free falling weight of 4.5 kg and the height of drop is 0.45m. In the case of standard proctor compaction test, we have used 2.5 kg rammer, falling at a height of 30 cm or 0.3m. In this modified proctor compaction test, we are using a standard a proctor rammer of face of diameter 50.8mm, with a rammer weight of 4.5 kg and a falling weight of 0.45m.

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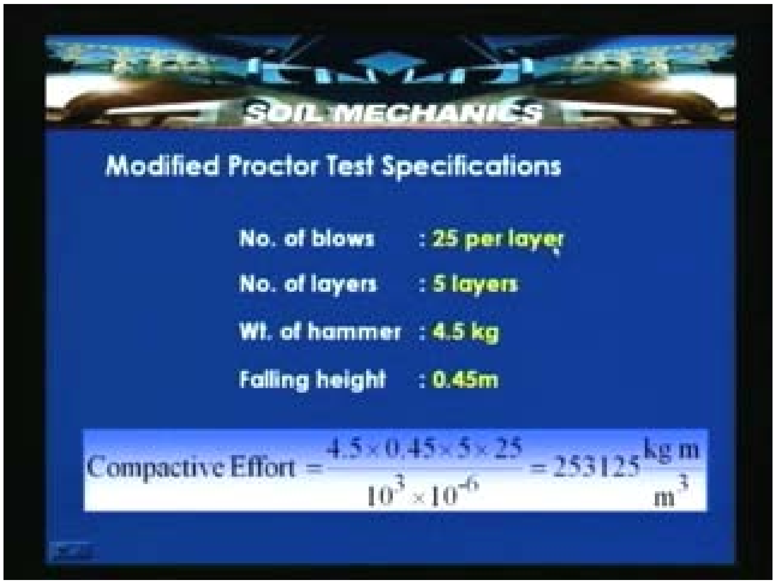

If you compare here, the number of blows are 25 per layer and in the case of standard proctor compaction test also we have used 25 blows per layer. The number of layers is 5 layers and in the standard proctor compaction test we have used 3 layers. So we can see the degree of compaction energy what we are applying. The weight of hammer is 4.5 kg in modified proctor compaction test. In case of standard proctor compaction test, it is around 2.5 kg. Falling height is 0.45 m in modified proctor compaction test and in case of standard proctor compaction test, it was 0.3 m. Similar to whatever we have done for standard proctor compaction test, if you compute the compactive effort.

The compactive effort is given by (4.5 into 0.45 into 5 into 25) by volume and normalization in units, where 5 is nothing but the number of layers and 25 is the blows per layer. We will get the energy equivalent to 253125 kg m by m cube. For any compactive effort this energy is 4.5 times the compactive effort in the standard compaction test. By giving this 4.5 times extra energy to this modified proctor compaction test, it is possible to compact the soils as close as possible to the maximum possible position. Expel the air quickly so that maximum dry density can be achieved at the possible low water contents.

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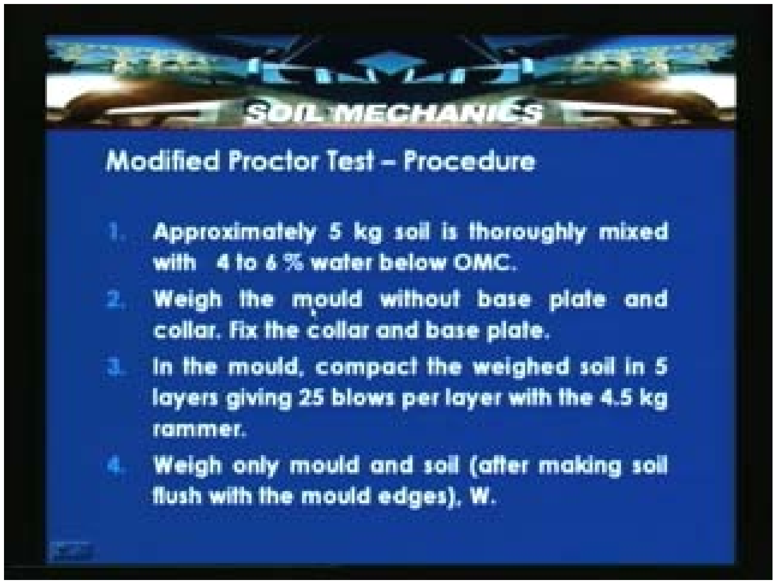

The procedure is similar to standard proctor compaction test. The differences have been discussed already. Approximately 5 kg of the soil is thoroughly mixed with 4 to 6 percent of water content. Depending upon the judgment this has to be decided. Weigh the mould without base plate and collar, fix the collar and base plate. In the mould, compact the weight soil in 5 layers giving 25 blows per layer with the 4.5 kg rammer. So the same principles whatever we have discussed for the standard proctor compaction test also holds good here.

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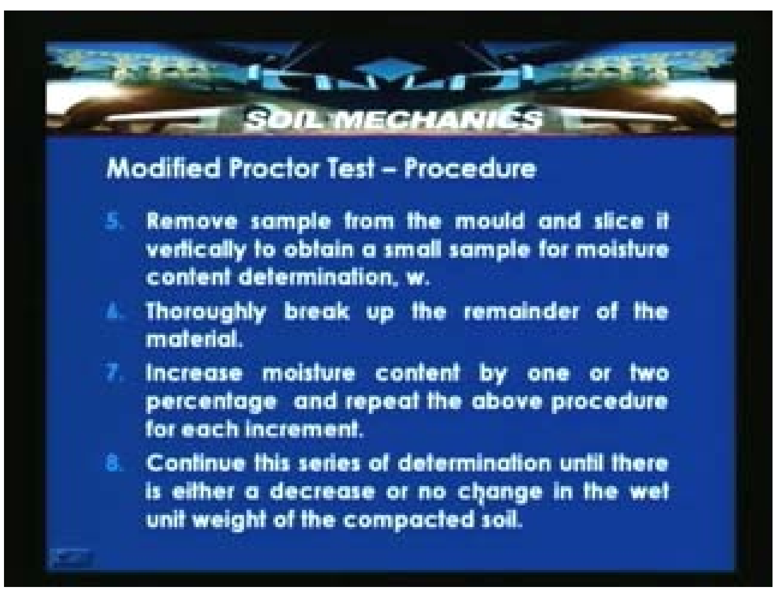

Weigh only mould and soil after making soil flesh with the mould edges so that weight has to be taken. Then remove the sample from the mould and slight it vertically to obtain a small sample of moisture content determination. Though we knew the amount of water we added, it is customary to determine the water content for each trail. Thoroughly break up the reminder of the material and increase the moisture content by one or two percentage and repeat the above procedure for each increment. Continue this series of determination until there is either decrease or no change in the wet unit weight of the compacted soil mass.

Generally there will be a decrease in the wet unit weight of soil mass because the process is that water starts entering in between the soil grains. The unit weight of the water is much much less compared to the unit weight of the solids because of that the dry density is falling on the right side of the optimum moisture content.

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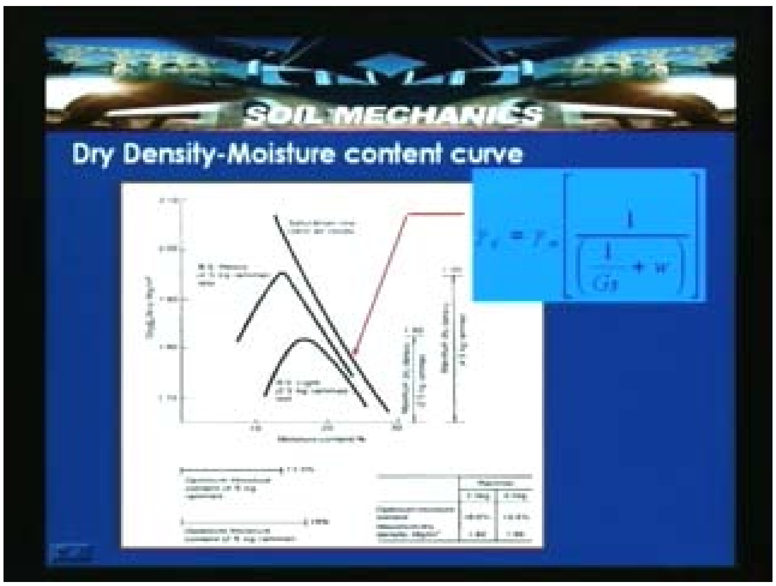

In this particular slide what we have shown is that dry density versus moisture content. We have compared AASHTO or modified proctor compaction test or standard proctor compaction test or light compaction test. In the case of Indian conditions it is also called IS Indian standard light compaction. For the British standard it is British standard Heavy Compaction test or British standard light compaction test.

Here this is a compaction curve obtained for IS light compaction where you can see a 2.5 kg hammer has been used with a fall of around 0.3 m. This particular curve is a compaction curve with maximum dry unit weight around 1.95 Mg by m cube or so and with a water content of around 15 percent that is optimum moisture content. This particular curve is around 19 percent or 18 percent optimum moisture content with 1.81, where you will see here that increase in dry density indicates that more amount of air could be expelled quickly so that the additional amount of dry density has come to this particular point. This is actually the effect of compaction energy on the soil which we will be discussing in detail in the forthcoming slides.

This line shows the saturation line which has been obtained from this particular expression $gamma_d$ is equal to $gamma_w$ (1 by (1 G_s) plus w) so the energy difference between these two is around 4.5 times. Here this curve is obtained by giving energy of 4.5 times the energy of this particular curve. For a modified proctor compaction test you will see that the curve shifts to the left hand side and shifts vertically upwards that indicates that the soil particles are coming closer by expelling the air quickly. So this additional energy is actually enabling the air to be expelled accurately from the soil solids and that actually makes this particular difference between these two.

Optimum moisture content what has been shown here is 13.5 percent and 18 percent. You can see the optimum moisture could be shifted by around 5.5 percent to the left hand side. The density here, previously it was around 1.82 but now it is 1.95. The increase in the density could attribute to this particular compaction energy which has been given.

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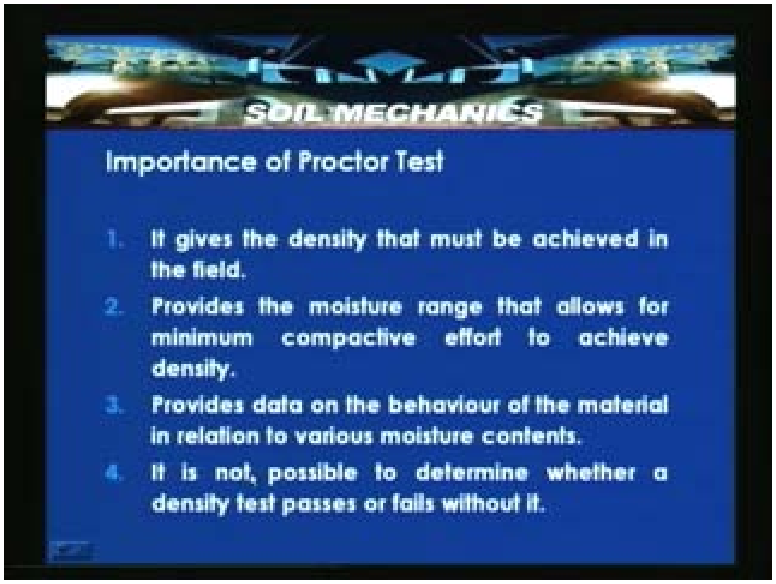

So if you look into the importance of the proctor test it gives the density that must be achieved in the field. Otherwise for a given soil before compacting in the soil we should know the compaction characteristics of the soil then we know that to what degree of compaction we can compact the soil so it gives the density that must be achieved in the field. That is actually possible depending upon the test either due to standard compaction or due to modified proctor compaction you can determine that density must be achieved in the field. It provides the moisture range that allows for minimum compactive effort to achieve the density. It also tells us that up to what range the soil should be maintained so that the maximum density can be achieved.

Otherwise for a given soil we will not be having this information then we will face difficulties in compacting the soil. It provides the moisture range that allows for the minimum compactive effort to achieve the density and provides data on the behavior of the material in relation to various moisture contents. It also tells us how the material behaves by varying the water contents. The behavior can be different for different soils so it provides a data on the behavior of the material in relation to various moisture contents. It is not possible to determine whether a density test passes or fails without it.

The proctor test has got a maximum relevance and is also is used widely even today in the construction of embankments, roadways and airways widely. The first job is to assess the compaction characteristics of soil in the laboratory depending upon the type of application either with the use of standard compaction test or modified compaction test and obtaining those properties for a given soil. Suppose if we have got 2 or 3 different borrow materials in a soil, all these borrow materials have to be ascertained to understand or to obtain $gamma_{dmax}$ and OMC that is maximum dry unit weight and OMC.

Each soil will have a unique variation because they entirely depend upon type of soil, gradation, the composition of the soil particles and mineral which is present in the soil. These entire things will add to the behavior of this particular compaction. So having seen the methods for determining compaction characteristics of soil elaborately very soon we will be discussing about the fill compaction methods and how we compare compaction. Basically we compare by using a term called relative compaction that we will be discussing later. This relative compaction or relative density is different for cohesion less soils and cohesive soils. So we will be discussing the field compaction methods separately for cohesion less soils and cohesive soils. Before that let us look different factors affecting compaction.

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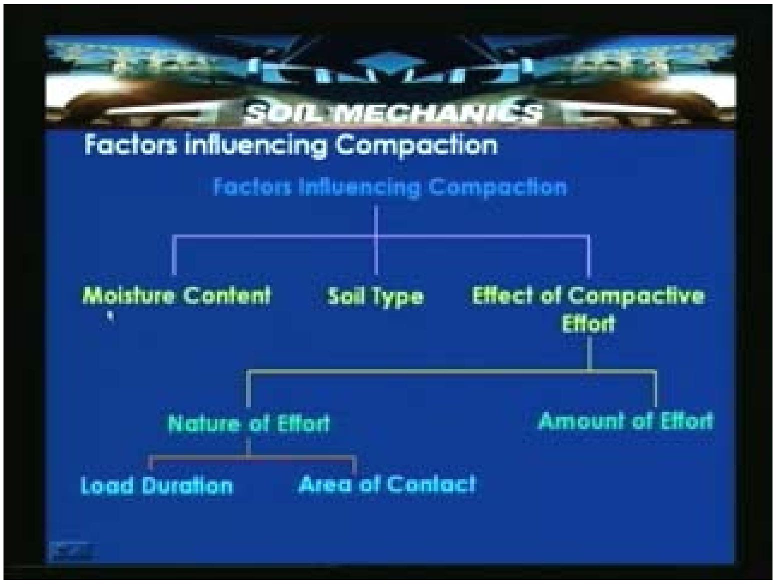

Factors influencing compaction are moisture content, soil type and effect of compactive effort. If you look into it the moisture content, soil type and effect of compactive effort are the major factors influence the compaction process. The effect of compactive effort includes the nature of the effort that is load duration and the area of contact. The area of the contact particularly for cohesive soils is very much important and the amount of effort which has been applied also comes into the picture. Let us list the factors influencing the compaction.

If you list, then moisture content comes in the first place, then the soil type and an effective compactive effort. Effective compactive effort is again subdivided into nature of the effort and amount of effort. Nature of effort is again subdivided into the duration of the load which is applied and area of the contact. Let us discuss each factor one by one. As you seen the moisture content, we also seen that the importance are the roll played with the water in the compaction. Let us look, how the soil behaves in the dry of optimum and wet of optimum in this section.

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It has been documented here, at low moisture contents the strength of the clay lumps and friction between granular particles is high, so given compactive effort will not be able to remove all air voids leaving the soil in an overall compressible state. So the soil is almost in a compressible state because the more grains are present more air voids are present.

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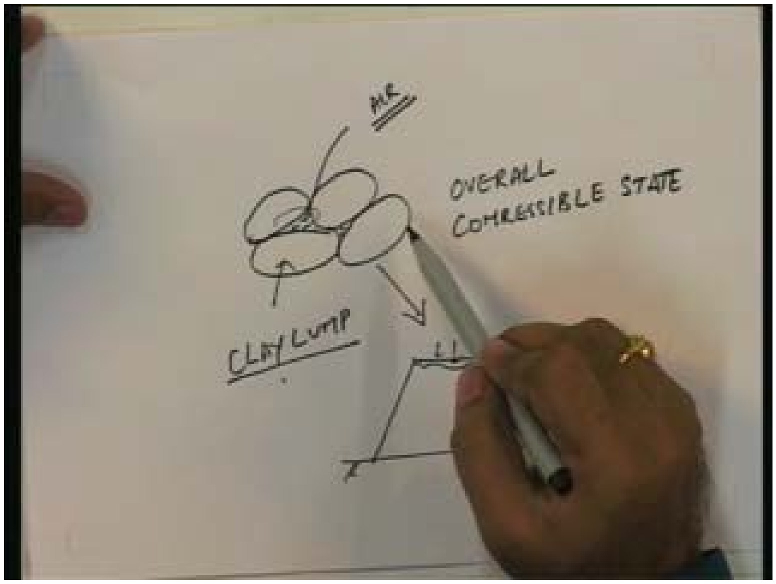

In the process what will happen is that, if you look into this case you will see that between the soil grains more amount of air is still present which could not removed because of the difference which is discussed here. This is the air which remains in the voids putting the soil in an overall compressible state. When it is subjected to stresses what will happen is that, further these layers of a fill or a structure will actually be in a potentially collapsible state because with the stresses these particles will try to come closer and in the process the entire structure for example, if this is an embankment of certain height because of these this particular alignment can be subjected to some settlements. With this process what will happen is that, it will lose the serviceability state. So this particular thing should be avoided.

Suppose, if this is taken as a clay lump and friction between the granular basically hinders to remove the air which is there in the void. Hence, entire soil mass remains in a collapsible state with the application of the stresses. This is actually which is required to be noted. At low moisture content the strength of the clay lumps and friction between the granular particles is high, so a given compactive effort will not be able to remove all air voids leaving the soil in an overall compressible state when it is subjected to stresses from further layers of fill or a structure, that is actually potentially in a collapsible state.

We have seen with low moisture content; now let us look what will happen at high moisture content. That is, at high moisture contents clay lumps become weaker because they try to become soft and in the process the bonds between the clay lumps try to weaken. In the process the friction between the granular particles will be reduced. In this process the air voids are more effectively removed so that the dense matrix can be achieved and more easily removed during compaction. The moisture content at which the maximum dry unit weight is attained is generally referred to as the optimum moisture content.

As we go on increasing the water content, a particular state will come at which this maximum dry unit weight is possible. That is we have termed as the maximum dry unit weight. So at high moisture content clay lumps become weaker and friction between granular particles reduces so the air voids are more easily removed during compaction. The moisture content at which the maximum dry unit weight is attained is generally referred to as the optimum moisture content. This we have defined earlier and we actually define once again with respect to a factor as moisture content. Now another thing is that, above the optimum moisture content that is we have reached up to optimum moisture content, now we go towards the right hand side of the optimum moisture content that is wet of optimum.

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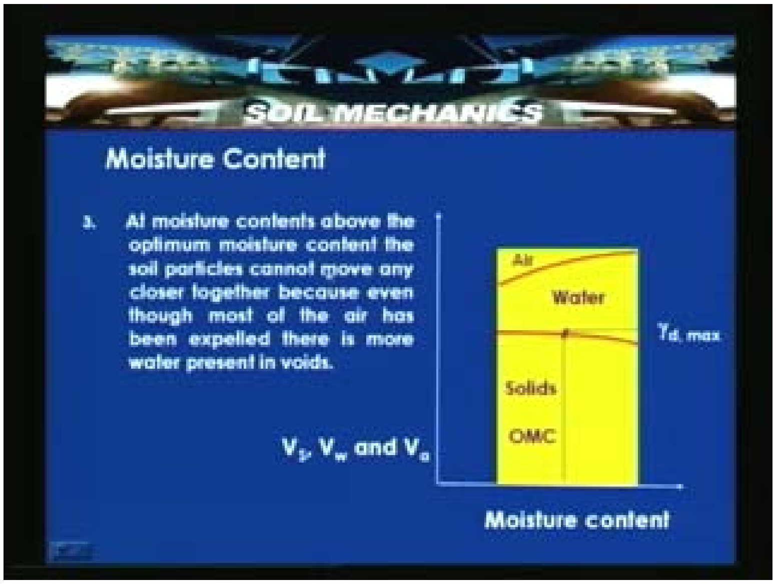

At moisture contents above the optimum moisture content the soil particles cannot move any closer together because even the most of the air has been expelled and there is more water present in the voids. In this diagram, particularly the volumes that are volume of solids, volume of water and volume of air is shown on the y axis and moisture content is shown on the x axis.

If you see here, this is a combination actually that has been achieved. There is a certain optimum water content at which the maximum dry unit weight is possible that is actually this one. So we can see that there is less amount of air than initially much dry side of the further of the optimum. You see that more amount of air is there but that we could over come by supplying more water to the grains then we could be able to shunt the air.

Gradually, you can see the depleting stage of the air but it never goes to zero here. This is the volume of the air portion and this is the volume of the water portion. Once we cross this particular optimum moisture content you see that the amount of water available between the voids is keeping on increasing. So in the process what will happen is that, as we have discussed that rho water is much much less than rho solids because of this process you see that again they also throw an explanation for why the dry density decreases with increasing moisture content on the wet side of optimum. So we have seen the moisture content, now let us look at another factor called soil type.

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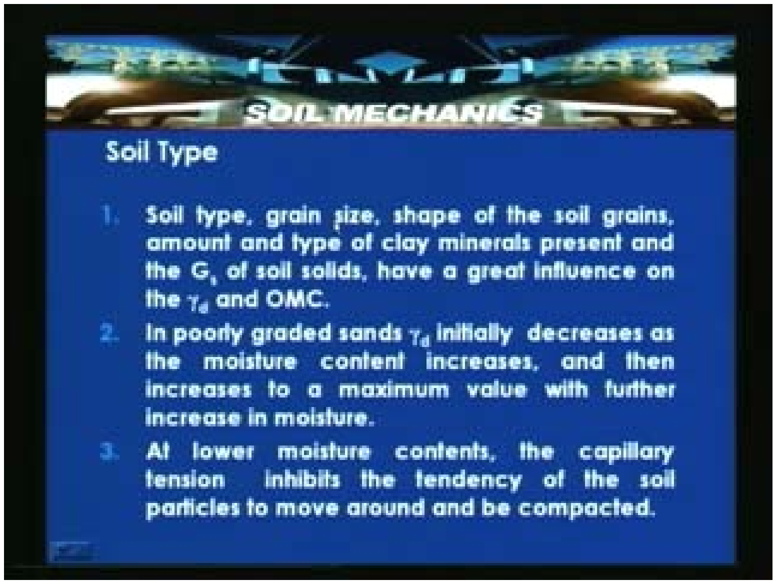

Soil type, basically grain size because particle size distribution which we have discussed earlier and how important it is and shape of the soil grains whether angular or round or sub-rounded aggregates or plate shaped particles. So the different particles can be there in a given soil mass. Amount and type of clay minerals, we also discuss the different type of clay minerals, for example Kaolinite, Illite and Montmorillonite.

Different characteristics of the minerals have been discussed. Specific gravity of the soil solids, for example if it is of iron origin, then the specific gravity of the soil solids may be very high. If it is of a fly ash it can have a low specific gravity. The specific gravity of the soil solids also influence the dry unit weight and have a great influence on the gamma_d that is the dry unit weight and optimum moisture content. In poorly graded sands the dry unit weight initially decreases as the moisture content increases and then increases to a maximum value with further increase in moisture content.

Particularly sands have got a different phenomena that is cohesive soils have got a different phenomena that is actually explained in the form of a bulking phenomena of soils which is possible. On moist conditions the volume appears to be very very high. Because of that what will happen is that, there will be some capillary forces between the grains and then these grains will induce some apparent cohesion between the particles and will hinder the particles from coming closer. In the process the density decreases. After adding certain amount of water, these films which are surrounded by the particles will get washed out and possible that particles will change to the closer positions.

In poorly graded sands that dry unit weight initially decreases as the moisture content increases and then increases to a maximum value with further increase in moisture content. At lower moisture content, the capillary tension inhibits the tendency of the soil particles to move around and be compacted.

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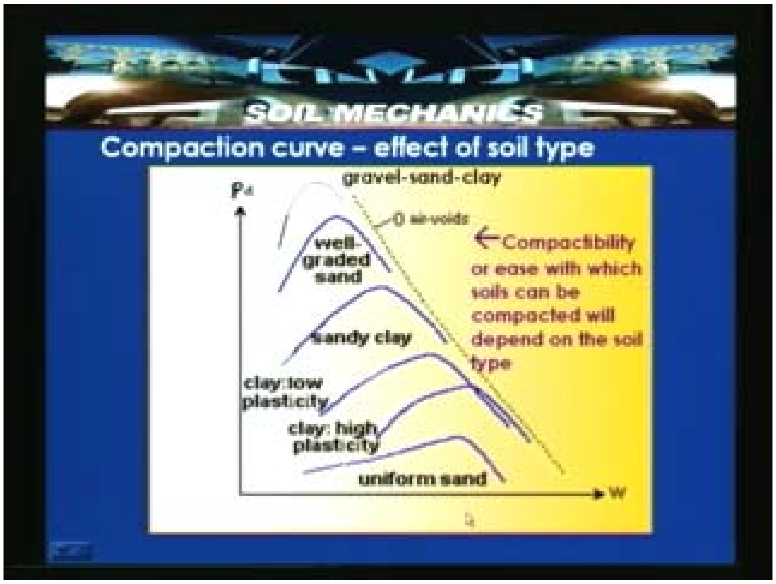

We have discussed about different factors affecting the soil and we also seen the different soils that are possible. In this particular slide, compaction curves for different soils are shown that is compaction curve effect of soil type. This is the zero air voids or 100 percent saturation line. This is for a uniformly graded sand that is the reason why when we are discussing about desert sands we said that, desert sands which are poorly graded in nature or uniformly graded in nature are difficult to compact them. So you can see difference between a uniformly graded sand and well graded sand. The well graded sand is the one which is ideal with something like a fuller characteristic curve. With that, we will be able to get the maximum dry unit weight and less close optimum moisture content.

Difference in behavior between a well-graded sand and uniformly graded sand can be seen. Then another difference which is required to be noted is clay of low plasticity that is lean clay and fat clay. Fat clay is the one which is more plastic in nature and lean clay is the one which is low plastic in nature. With that, a difference in behavior can be seen here. Sandy clay is supposed to have certain higher density compared to clay of low plasticity. This particular curve shows for gravel sand clay mixer. Gravel sand clay mixer is something like a combination where gravel particles are there and sand particles are there and then the clay particles also. Different types of particles are present in this.

In the process, we will be able get the maximum possible dry unit weight and at certain water content here. So compactibility or ease with which soils can be compacted will depend upon the soil type. You see that different soils have got different types of compaction curves. Uniform sand has got a different curve. There is a difference in silty clay, for example a lean clay or fat clay that is clay with high plasticity. There is certain difference which we will be discussing. A difference in distinguished behavior between well graded and uniform sand also can be seen. So compactibility or ease with which soils can be compacted will depend upon the soil type. This is an important thing which we should remember whenever we are dealing with compaction characteristics of soils.

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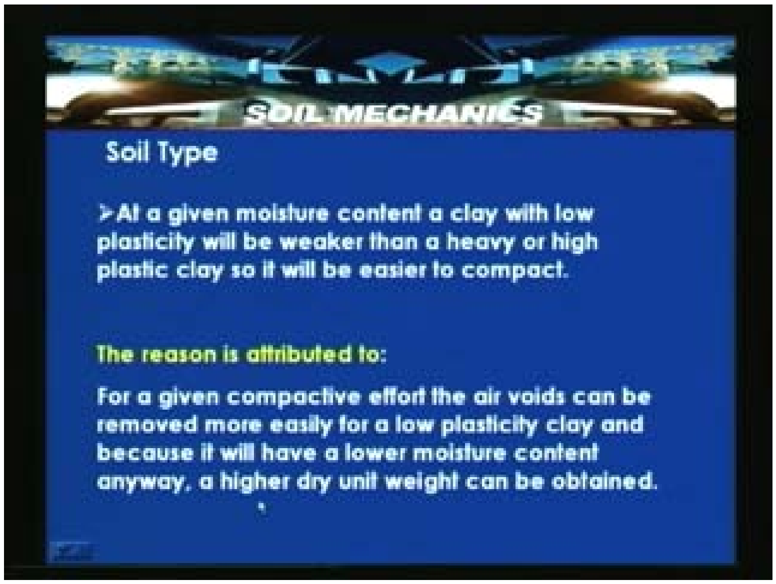

We have seen in the previous slide, at a given moisture content a clay with low plasticity will be weaker than a heavy or high plastic clay, so it will be easier to compact. The reason is attributed to: We have seen that two distinguished behavior for silty clay that is lean clay and fat clay. We knew that the liquid limit of fat clay will be higher than the liquid limit of lean clay.

For a given compactive effort the air voids can removed more easily for a low plasticity clay and because it will have a lower moisture content anyway, a higher dry unit weight can be obtained because the silty clay is weaker in strength and the clay lumps are soft in nature. In the process, with the given compactive effort we will be able shunt air more quickly and because of that the closer position is possible for the given matrix. With that, we are able to establish for a given compactive effort the air voids can be removed more easily for a low plasticity clay and because it will have a lower moisture content anyway, a higher dry unit weight can be obtained.

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Let us look into another factor which is called effect of compactive effort. This can also be discussed something like amount of compactive effort which is applied. It is not that, when you apply more and more blows to the soil, the soil particles will be able to compact to the maximum possible densities. There is also a certain optimum compactive energy required to be applied to the soils. By applying more there is no use, we will be creating instability in the soil matrix. Maximum dry unit weight increases with increase in compactive effort that is possible.

By increasing the compactive effort we will be able to see the maximum dry unit weight increase. Increase in compactive effort decreases the optimum moisture content to some extent. That is why we have seen, whenever we apply more energy in the case of modified proctor compaction test, we have seen that the curve is shifted to the left hand side and upwards compared to a standard proctor compaction test. So increase in compactive effort decreases optimum moisture content to some extent.

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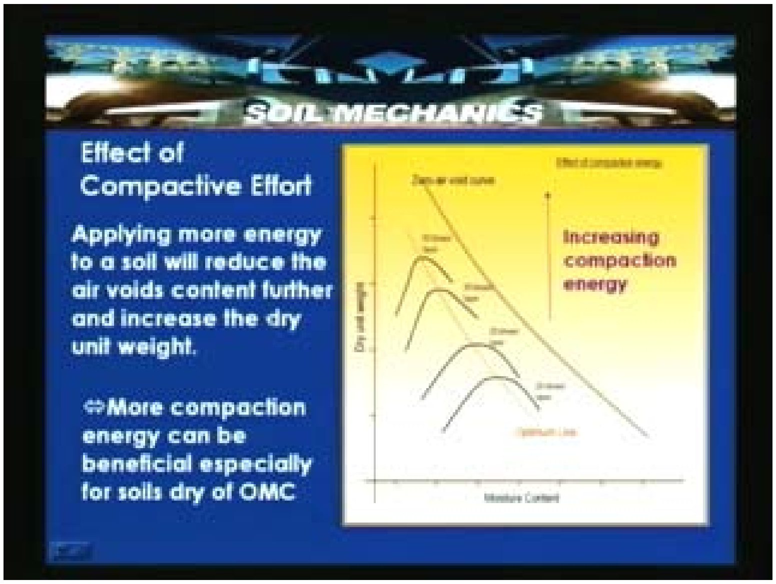

If you look to this effect of compactive effort, applying more energy to the soil will reduce the air voids content further and increase the dry unit weight. For example if you see, on the curve here a dry unit weight is shown and moisture content is shown on the x-axis.

We will see, this particular curve is obtained with 20 blows per layer, this for 25 blows per layer, this one is for 30 blows per layer and this one is for 50 blows per layer. As we increase the compaction energy in this direction you will see that there is increase in the dry unit weight and decrease in the optimum moisture content. The line joining this optimum moisture content is called line of optimums or optimum line. This line which is almost parallel to the zero air voids line is the optimum line which is nothing but this line joins the line of optimum moisture contents and maximum dry unit weight for a given compactive effort. By increasing compactive energy you will see that the curve is shifting towards the left hand side. More compaction energy can be beneficial especially for a soils dry of optimum.

You will see that more compaction energy can be beneficial especially for the soil of dry of the optimum. If you compact the soil on the wet of optimum, there is a possibility that the development of access pore water pressures can takes place. These pore water pressures are locked inside and create a case of some instability to the soil and result in failures of structures which are constructed with this process. So applying more compaction energy can be beneficial especially for soils dry of optimum. That is the reason that suppose in a particular compaction process if the soil is found to be wet in the side then it is advisable to allow for drying and so that the soil attains a particular state where it is possible for us to compaction.

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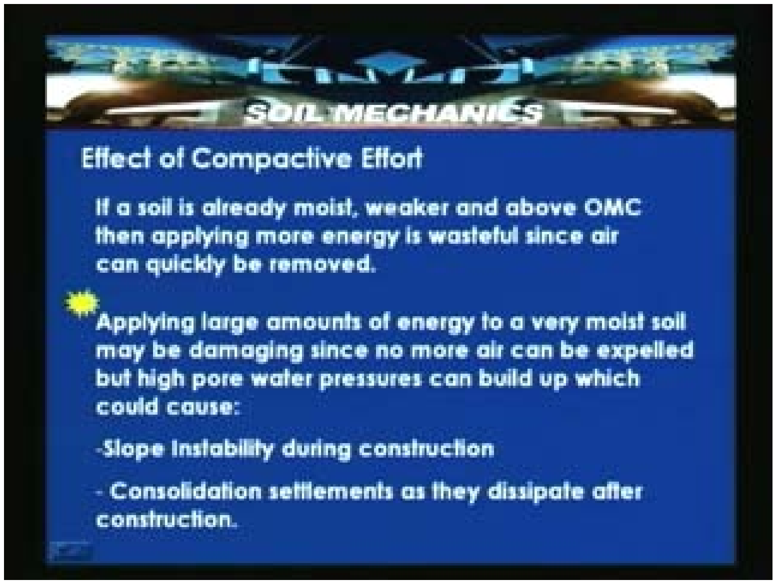

That is more compaction can be beneficial especially for a soils dry of OMC. If a soil is already moist, weaker and above OMC then applying more energy is wasteful since air can quickly be removed. Applying large amounts of energy to a very moist soil may be damaging since no more air can be expelled but high pore water pressures can be build up which could cause: Slope instability during construction that is what we have discussed or consolidation settlements as they dissipate after construction. These excess pore water pressures are pore water pressure developed by applying the energy to the wet soil already. These pore water pressures are locked in the soil which actually causes instability to the structure.

In this lecture, we have tried to understand about again role played for the water in the compaction process. The method of compaction by applying more energy is called modified proctor compaction. We tried to compare laboratory compaction, the standard compaction conditions and proctor compaction conditions. We have also discussed about factors affecting the compaction process mainly moisture content, soil type and compactive effort.