Pavement Materials
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Lecture 06
Strength Properties of Soil (Part 1)

Hello friends, in the last class we have discussed about the Classification of Soil. And under the classification system, we discussed various types of classification system like textural classification, we discussed about the AASTO classification system, we discussed about the unified soil classification system and we also discussed about the Indian soil classification system which is very similar to the unified soil classification system with some minor addition of intermediate plasticity range within the plasticity chart.

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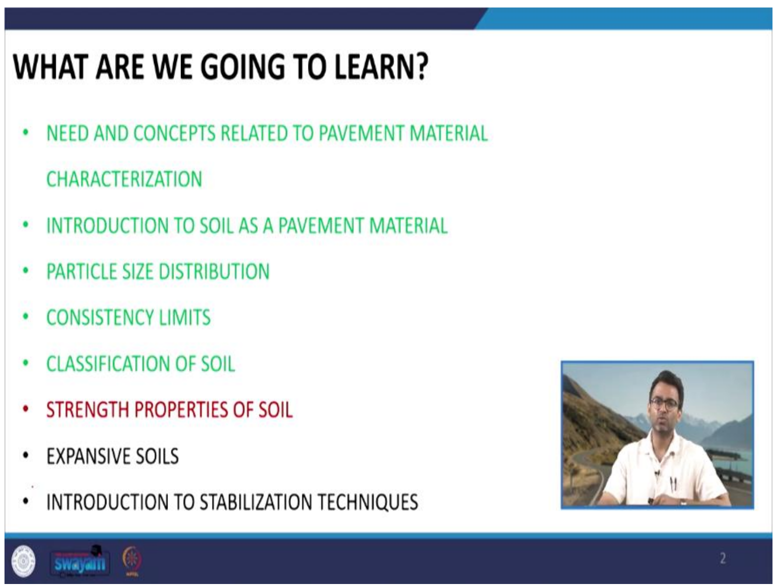

Today, we will start discussing about the strength properties of soil.

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Compaction

- Soil should have sufficient load bearing capacity/shear strength to take up load from super structure
- Mechanical Compaction of soils is one of the efficient ways to increase the bearing capacity of the soils
- This is true for cohesive as well as cohesionless soils: *the effect may however be of different scale*
- **Measure of compaction:** Dry unit weight of soil $\gamma_d = \frac{\gamma_t}{1+w}$

$$\gamma_d = \frac{W_s}{V_T}$$
$$w = \frac{W_w}{W_s} \times 100$$
$$\gamma_t = \frac{W_T}{V_T} = \frac{W_s + W_w}{V_T}$$
$$\gamma_t = \frac{W_s}{V_T} + \frac{w \cdot W_s}{V_T}$$
$$\gamma_t = \frac{W_s}{V_T}(1+w)$$
$$\gamma_t = \gamma_d (1+w)$$
$$\gamma_d = \frac{\gamma_t}{1+w}$$

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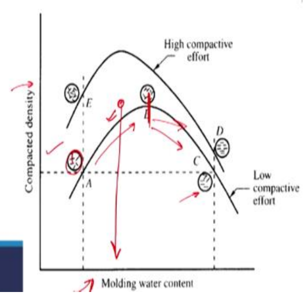
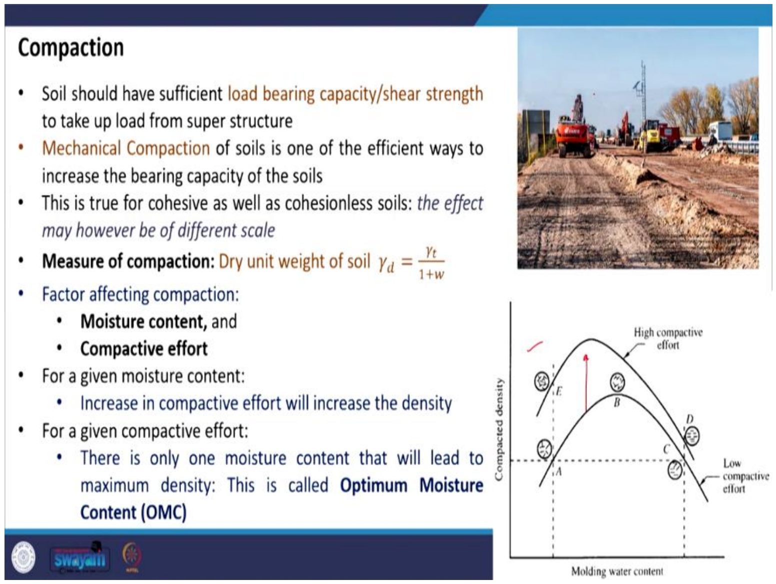
- **Measure of compaction:** Dry unit weight of soil $\gamma_d = \frac{\gamma_t}{1+w}$
- Factor affecting compaction:
  - **Moisture content,** and
  - **Compactive effort**





So, under the strength properties first we will talk about the compaction characteristics in soil, which is one of the very important characteristics especially when we talk about construction of pavements. So, ideally any soil over which a construction has to be done it can be any form of construction using like a building construction, like we are constructing a dam or if you are constructing a pavement that soil should have sufficient load bearing capacity.

In other words, it should have sufficient shear strength to take up the load from the superstructure. Now, there are various forms, there are various ways of improving the soil improving the load bearing capacity of the soil, among various techniques, mechanical compaction is one of the efficient and I would say one of the simple techniques to increase the bearing capacity of soils. So, this is true both for cohesive and cohesionless soil.

However, the effect of compaction on different types of soil can vary to different degrees. So, we will talk about these characteristics related to compaction for different soils today. Now, when I say that compaction is a method to improve the load bearing capacity of soil, when I say that compaction is an important parameter to be considered for construction, how do we measure this compaction degree or how do we quantify the compaction in a given soil.

So, the compaction can be quantified using the parameter dry unit weight of the soil. If you see the phase, various relationship looking at the phase of soil, there are various terms to be defined, which you might have learned when you took a class on soil mechanics or if you have not taken a class you will be learning about those terms once you take a class on soil mechanics.

However, you need not worry about those terms, because for us the terms that are important we will try to define it and we will try to understand the physical importance. So, the measure of compaction as I said is the dry unit weight of soil which is denoted as Υ_d,. So, Υ_d if you see the volumetric phase of soil is nothing but the weight of solids divided by the total volume of the soil material.

So, this is what you mean by the dry unit weight of soil and then it is related to gamma t which is the total unit weight of soil and W which is the moisture content in the soil. So, the definition of moisture content we have already discussed that moisture content is nothing but the $\frac{\text{weight of water}}{\text{weight of solids}} \times 100$. Similarly, Υ_t which is the bulk unit weight of soil or the total unit weight of soil is defined as $\frac{\text{total weight of soil}}{\text{total volume of soil}}$ divided by.

So, when I say that $\gamma_t = \frac{W_T}{V_T}$ and if you try to understand a soil mass it comprises of soil, it comprises of air void and it comprises of water. If all the voids are filled with water then we have only soil and water present in the volume. So, therefore, the total weight of any soil because air does not have any weight. So, the total weight of soil can be written as $\frac{\text{total weight of soil+weight of water}}{\text{total volume}}$.

Now, $\gamma_t$can therefore be written as $\gamma_t = \frac{W_T}{V_T}$. Now, moisture content as I said is equal to $w = \frac{W_w}{W_S} \times 100$. So, $\gamma_t = \frac{W_T}{V_T} = \frac{W_S+W_w}{V_T}$. So, $\gamma_t = \frac{W_S}{V_T} + \frac{w \times W_w}{V_T}$ is nothing but the dry unit rate of soil.

So, this is $\gamma_t = \gamma_d(1+w)$. Therefore, the dry unit weight of soil becomes equal to $\gamma_d = \frac{\gamma_t}{(1+w)}$ which is also a parameter to quantify the degree of compaction in the soil. So, higher the value of the dry unit weight more compacted the soil is, more dense the soil is, the soil will have higher strength.

Now, talking about the parameters that affect the compaction or in other words, the parameters that affect the value of γ_t are the moisture content and also the comp active effort. So, we will try to understand this figure first, this is the, let us see the dry unit weight in the y axis and in the x axis we have the water content.

So, when the soil is in dry state and slowly we start increasing the water content what happens that this water facilitates lubrication of the soil particles, the soil particles have now less friction between them to move about each other, so they can compact into a dense mass. So, as you start increasing the moisture content the density of the soil increases at a particular effort of compaction because as I said comp active effort will also affect the degree of compaction.

So, at a fixed comp active effort, this is what will happen. Now, a time will come when you will have enough water in the soil mass and now water will act as a film around the soil and when two soil particles and the film of water increases they will try to repel each other and they will try to separate the soil particles.

So, this water fill after a particular moisture content rather than facilitating compaction they will separate the soil particles and this is the point from where the density of the soil will start decreasing. So, this is what you see that it is an inverted U-shaped curve. So, with increasing moisture content first the density increases and after that density decreases. This type of curve is true mostly for cohesive soils.

We also have soil such as sand, we have sandy soils, the dry density versus moisture content graph of which is not very similar, because those type of soils are affected by different factors related to compaction, we will discuss about that. Talking about the structure of the soil, when the soil in a dry state or at a moisture content lower than the optimal moisture content that time the soil will have more of attractive forces between them and the structure will be more flocculated in nature.

So, you will see flocculated structure at this point. So, slowly as you go beyond the point B which means if you go further than the optimum moisture content, the repulsive forces start acting in the soil particles and they will try to form a dispersed structure which you see here. The structure will be more dispersed which means the soil particles will appear something like this.

And this is why again the strength of the soil in this state will be less because more are the flocculated structure, they are intermingled with each other which means they have higher strength. We will also discuss about another curve, which is the curve of shear strength versus moisture content. So, the shear strength versus moisture content curve will be similar to what we see for dry density versus moisture content.

But the optimum moisture content at which you achieve the highest shear strength is usually on the drier side of the typical density moisture content curve. Which means if the density is maximum here, probably for the same soil the shear strength will be maximum at a moisture content which is on the dry side of the optimum.

The reason being the same that on the dry side you have more flocculated structure more shear strength within the particles in comparison to the right side of the curve, where you see we have more dispersed structure which means, the shear strength of the soil will be less. This also tell us that in the field when we compact the soil and I am saying that shear strength is one of the important strength parameters, why not to compact the soil at a moisture content lower than the optimum or on the dry side of the optimum.

The reason being if you compact the soil on the dry side of the optimum, though you will have higher shear strength, but if the moisture content of the soil changes if more moisture comes in, then the soil loses its strength. So, that is why usually in the field the compaction is done corresponding to the dry density and not the sheer strength parameter.

Now, talking about the compactive effort, it is very simple to understand the more pressure the more energy you give to the soil, the soil will have higher tendency to densify and that is why in the same soil you get higher density corresponding to a particular moisture content by increasing the comp active effort.

The increasingly comp active effort also shifts the optimum moisture content to the left-hand side which means that a higher competitive effort, if you give higher competitive effort, the optimum moisture content at which you achieve highest density will be lower in comparison to the optimum moisture content for the soil which has been compacted at a lower competitive effort. So, for a given moisture content increase in comp active effort will increase the density which is very clear here.

And for any given comp active effort as we have discussed that there is one moisture content that will lead to maximum density in the soil structure and this moisture content is called as the optimum moisture content. And in the field finally, what we do, once we know this optimum moisture content from laboratory experiments, I know that this soil will be used in the field for the construction of embankment, for the construction of subgrade.

So, and it will happen that the soil present in the field will also have some natural moisture content. So, I can find out that moisture content, I know the optimum moisture content, I can add or I can subtract that moisture content depending on the natural moisture content to ensure that while I am compacting the soil, that soil is at the optimum moisture content in the field we have various machineries, that helps us to mix the soil with the required quantity of water, spread it to a uniform thickness and then further compacted.

So, for mixing the soil we can have blades we can have disc arrows, for spreading we have motor graders, and finally, for compaction we have different types of rollers. So, we will discuss about them as we proceed in this lecture. Now, let us discuss that using laboratory experimentation how do we evaluate the optimum moisture content for the soil and the corresponding dry density to be used in field construction.

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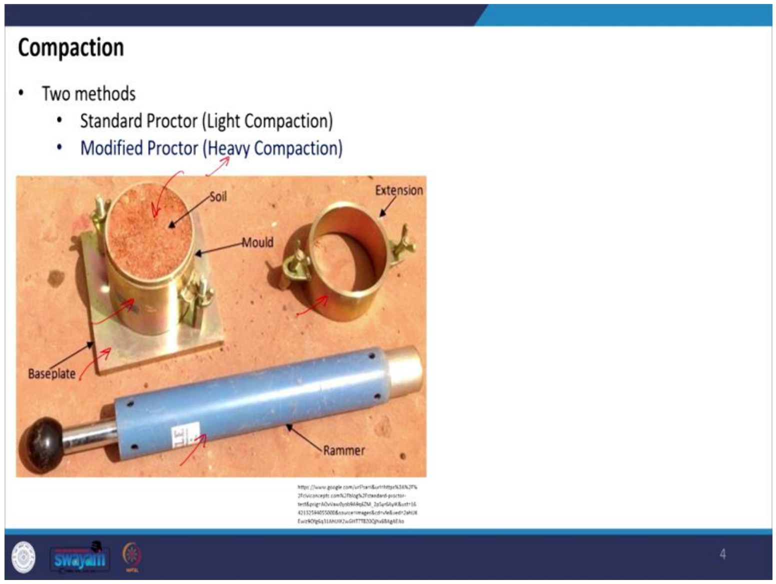

For the compaction of soil in the laboratory usually we have two standard methods one is the standard proctor which we also call as light compaction and then we have modified proctor which is also called as heavy compaction. For pavement engineering purpose most of the investigation which is done which means evaluation of the optimum moisture content and evaluation of the dry density of soil is done corresponding to heavy compaction.

So, these are some of the parts of the experimental setup which we have to use for doing the proctor density test. So, you see we have a base plate, we have a standard mold, we have a collar here and then we have the hammer here. And then finally we have to compact the soil through a particular process. So, before I begin discussing about the steps that are involved in evaluating the optimum moisture content, let me just show you the standard proctor mold.

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So, you can see in my hand I have the standard proctor model with the base plate and the cylindrical mode, which you see here. We have a collar which is put at the top, this is done to remove the excess amount of soil after we complete the compaction process.

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Then we have a hammer here, which is free to move in this way you can see, and this hammer has a specific weight, it has a specific height of fall while we are doing the compaction test.

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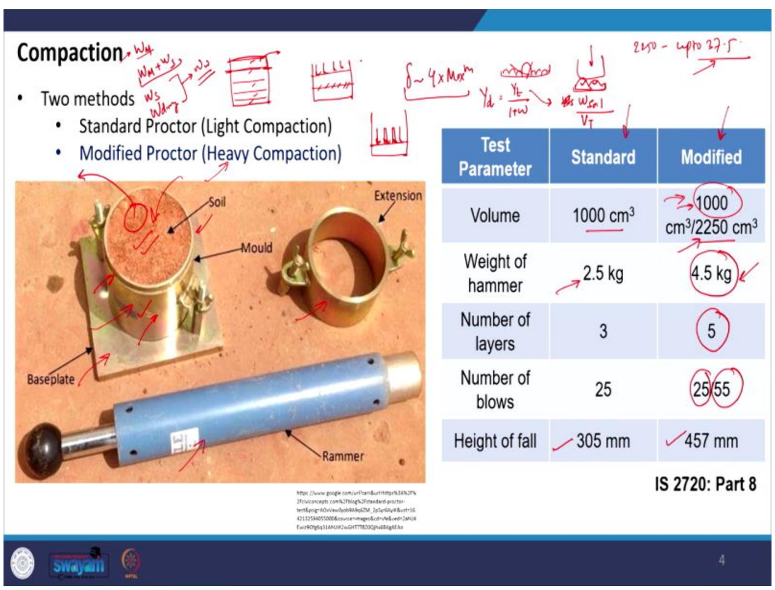
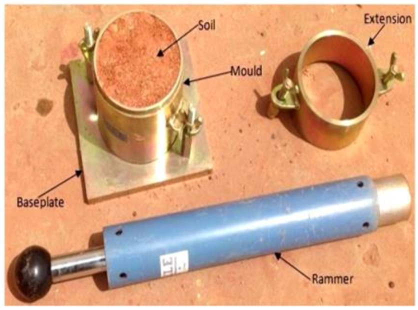


Compaction

- Two methods
  - Standard Proctor (Light Compaction)
  - Modified Proctor (Heavy Compaction)



Test Parameter	Standard	Modified
Volume	1000 cm^3	1000 cm^3/2250 cm^3
Weight of hammer	2.5 kg	4.5 kg
Number of layers	3	5
Number of blows	25	25/55
Height of fall	305 mm	457 mm

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Now, let us see that what are the steps involved and what is the difference between standard proctor and modified proctor and we will also talk about the steps that we use in the laboratory to do this experiment. So, this is in general a very simple experiment it requires some physical effort, but the procedure is simple. So, the standard proctor mold is 1000-centimetre cube in volume, the modified mold can be 1000-centimeter cube as well as we can have a 2250-centimetre cube.

So, the one with 2250-centimetre cube has a cylindrical dia of 150 mm while the 1000-centimetre cube cylinder has a dia of 100 mm. So, when to use 2250-centimetre cube in modified proctor, this is used when the maximum size of the aggregate in the soil structure you are trying to analyze is up to 37.5 mm. The reason being, let us say this is the small mold and in the aggregate structure which you are using you have some aggregates which are of very high size I mean very large size.

So, when you put this material in the mold, it may happen that those larger size particles is occupying the surface and when you therefore give the compaction this compaction is ideally given on these larger particles and there is an, the compaction is not uniform in nature or the transfer of energy is not uniform in the soil structure. So, in any of such experiments usually the dia of the cylinder is chosen such that it is more than 4 times the maximum size of the particle.

So, the dia should be about 4 times the maximum size of the particle in the structure and that is why a 1000-centimetre cube cylinder which is 100 mm dia cylinder is not suitable especially in cases when your aggregate structure has larger aggregate sizes. If it is not the case then we can use 1000-centimeter cube cylinder.

So, what do we do here, we take approximately 5 to 7 kgs of samples sometimes 15 kgs of sample depending on the type of soil and if you are taking a 2250-centimeter cube cylinder we have to take soil of almost 30 kgs in weight, so we take this material. If we are using 1000-centimeter cube we will take aggregates that are passing or soil that is passing 19 mm sieve size. In case of 2250, we will take materials that are passing 37.5 mm size.

We will mix it with preliminary water content, we will properly mix the soil and then we will fill it in the mold. So, when we are doing modified proctor, we fill it in 5 layers. So, you will fill one layer first, this layer you will compact using the standard hammer, so in the modified proctor we have the hammer of 4.5 kgs while in standard proctor we have the hammer of 2.5 kgs.

So, you take the 4.5 kg hammer compacted giving 25 blows, if it is 1000-centimeter cube cylinder or 55 number of blows if it is a 2250-centimeter cube cylinder. So, you will fill first layer give 25 blows randomly over this layer then what you will do, you will scratch the surface using a blade so that the next layer can have bonding with this particular layer which you have compacted.

Again, you will fill the second layer give 25 random blows and you will repeat this process. And you will fill the cylinder with the collar up to in 5 different layers. Then what you will do you will remove this collar, you will remove it. The excess material which you see at the top you will trim that soil you will make the surface plane as you are seeing in this picture and then you will do some measurement.

So, what are the measurements you do? You know the weight of the mold, so you remove this mold along with the soil and take the weight, so you know the weight of the mold, you take the weight of the mold plus weight of the soil. And then you again remove the soil from this mold and the soil which you have taken you add some more water which means you are changing the moisture content, remix it, recompact it.

So, we can take 4 to 5 different moisture content and do the same process again, I mean do the same process every time at each moisture content. So, once you complete a particular moisture content, you will take the weight of the mold is anyways fixed, weight of the mold plus weight of the soil and then you take some soil sample out from it, take the weight of the soil sample and then oven dry the soil sample then take the weight of the dry soil sample, so using the weight of the soil and weight of the dry sample you can get the moisture content in the soil.

You already know the volume of this particular mold, you can calculate the dry density using the formula gamma t by 1 plus W, where gamma t can be calculated as weight of the soil the whole soil divided by the total volume of soil which is nothing but equal to total volume of this mold which can be the 1000-

centimetre cube or 2250-centimetre cube as the case may be. The height of fall when you are doing the compaction in the modified proctor is 457 mm while in standard proctor it is 305 mm.

So, these are some of the test parameters we have already discussed the process of doing the test. So, finally, what we will have we will have a curve at different moisture content and different dry densities. So, you have some points here just join this point using a smooth curve and you see that at the maximum dry unit weight what is the moisture content and this moisture content is the optimum moisture content. So, I hope this process of doing the test is now clear to you.

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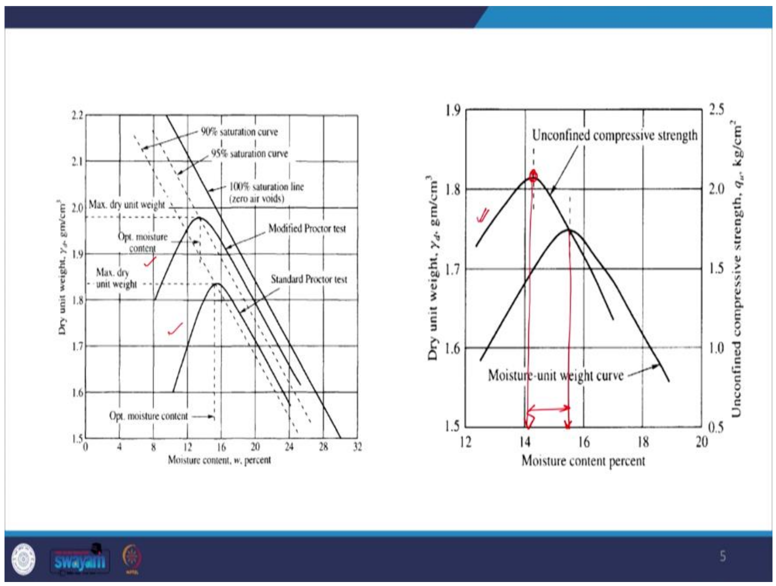

So, this is a typical curve which you will get after you perform the test as I was mentioning that if you are trying to find the shear strength of soil, you will have a similar curve, but the moisture content at which you get the highest shear strength will be lower than the moisture content at which you get the maximum density. But in the field as I mentioned we will take the curve corresponding to the maximum dry density. So, now let us see what happens if it is a sandy type of soil.

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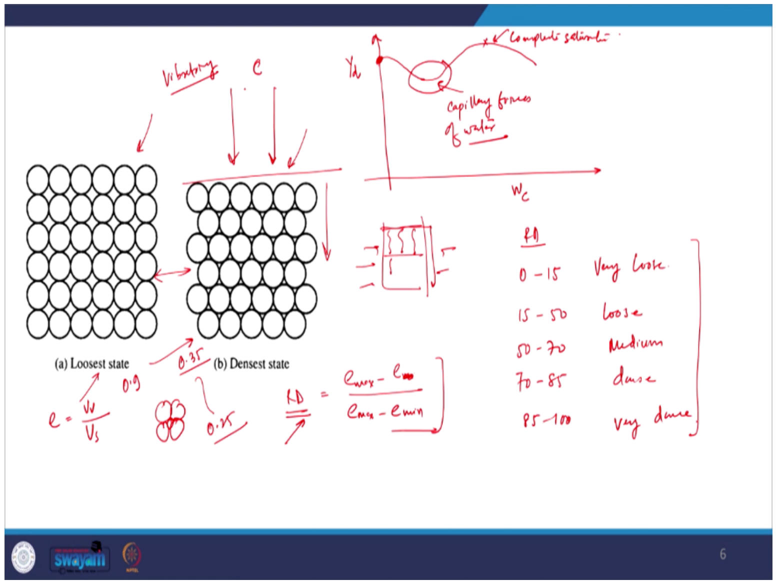

So, you see sandy type of soil has some typical characteristics, let us assume that we have purely spherical particles and they are placed in the loose state and I am assuming that these spherical particles are of same size. Then in the loose state, if you try to find the void ratio, now void ratio that is a new term maybe in our lecture, so, void ratio is the volume of voids divided by the volume of solids. So, the void ratio is typically very high about 0.9.

The same soil particles if we place in the dense state then the void ratio will be approximately around 0.35. Now, here we are assuming that these particles are of same size in the mass if we have larger and smaller particles, then the smaller particles will pack inside the voids created by larger particles. So, the void ratio in the denser state will further reduce and it can be as low as 0.25 let us say.

So, in sandy soils which do not have cohesion, in the losers state they have some packing characteristic in terms of void ratio, in the denser state also they have some backing characteristic. Now, these are both in dry state, both interested we have not added any moisture, still these two states can be achieved. So, the density of such type of soil in the field is rather quantified by comparing the actual density with these two-extreme states of densities. So, that is called as the relative density.

So, relative density for sandy soil is calculated as $R_D = \frac{e_{max}-e}{e_{max}}$. So, this is more often normalized form of denoting the density of the soil and if you see the variation of density of sandy soils with respect to moisture content if I am trying to see the dry density then when the moisture content is 0 and if we have compacted the soil then you will have some dense packing here with increase in moisture content initially the density will reduce and then after some time the density increases.

So, the question is why this reduction in density happens this reduction in density happens because of the capillary forces of water which resists the packing of the sand particles. And this is a point where you see complete saturation of the sandy soil. One more typical characteristic about sandy soil being cohesionless is that that applying only comp active effort to the soil will not lead to increase in density of soils.

So, this comp active effort which I am applying should be in addition to some vibratory loading. So, if you give a vibratory load to cohesionless soil, it will pack in more dense configuration in comparison to if you are giving only a static load to apply or to densify that particular soil mass. So, this you can also try to experiment very simply at your home, you take a glass a clear glass or a clear bowl, you just take some natural sand, which is in dry state and fill it in the cup and you just you will see that this the cup which you are seeing will have will occupy some space some volume.

So, if you packed with your palm on that particular cup on the sides of that particular cup, you will see that the sand particles will try to settle down it will pack into a dense configuration. So, this is a form of vibratory loading, which we are giving with our palms by just shaking the glass or just shaking the bowl and just by shaking it densifies. So, this also just indicates that vibratory loads are more appropriate for compacting the mass of cohesionless soil in comparison to the static load.

So, based on the value of relative density, we can categorize cohesionless soil into different categories. For example, if the relative density is somewhere between 0 to 15, then such type of soil are denoted as very loose, if it is somewhere between 15 to 50 it is in loose condition, if it is in between 50 to 70 then the condition is medium, if it is somewhere between 50, 70 to 85 it is in a dense state and if it is between 85 to 100 which means this is a very dense state.

So, this is an approximate way to quantify the compaction characteristic of cohesionless soils. So, let us know discuss that what we do actually in the field. So, in the field as I mentioned, we have different equipment’s for initiating the or completing the compaction process we have leads and we have disk arrows to pulverize the soil mix it with a given moisture content, we have motor graders to uniformly lay the soil in a particular to a particular depth and then we use rollers.

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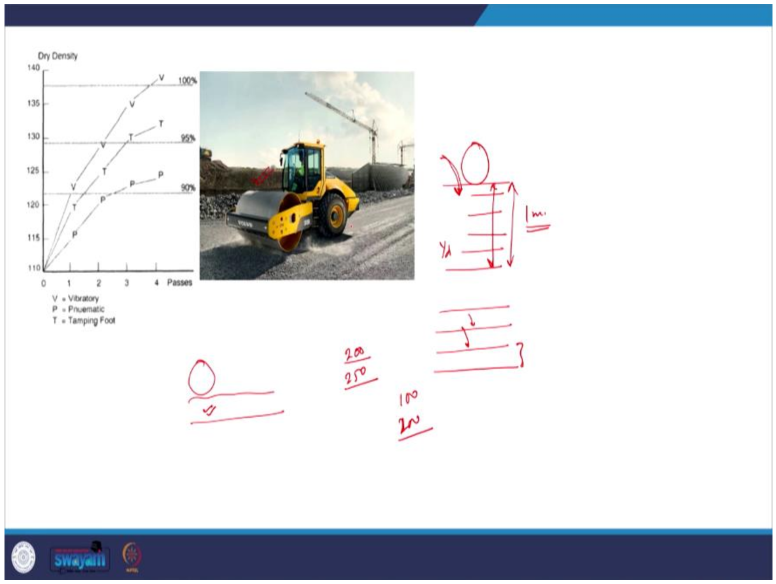

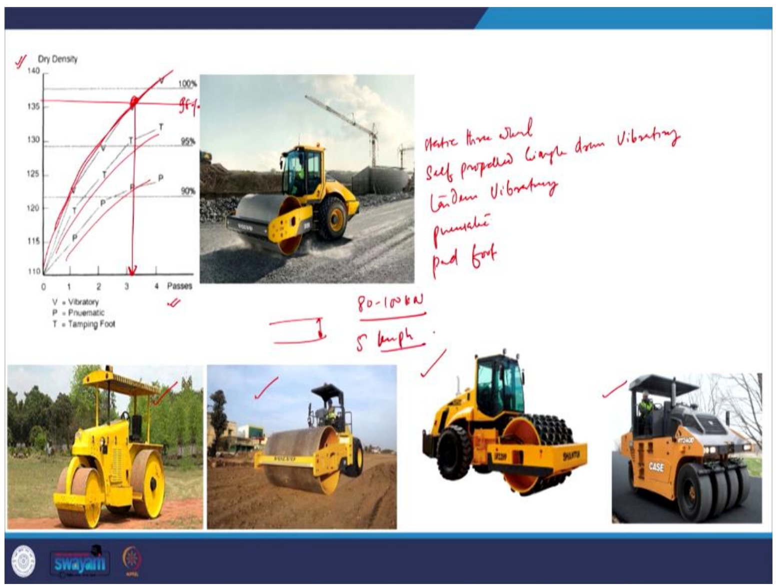

A typical ruler you are seeing on the screen here to compact the soil. So, usually let us say you are trying to construct a one-meter embankment. So, we do not put the entire volume to be put in this one-meter depth we do not put the entire soil at once and compact it because the machineries which we have the typical rollers we use, they will not be able to compact this entire soil to the required dry density because after compaction each layer each point should have that particular design dry density in the field.

So, usually the soil or any layer they are compacted in sub layers. And the depth of the sublayer in loose condition because we are putting soil in the loose condition will depend on the type of ruler will depend on the type of soil. So, for example, in embankment and in subgrade we use almost like at one go we can compact up to 200 mm or 250 mm in case of granular layers, we can compact in like 100 mm or 200 mm and so on depending on the type of roller we are using in the compaction process.

So, the question is that we have to compact the soil such that we are able to achieve a percentage or the or the dry density we observe in the laboratory. And we have rollers here, so one pass when you put the soil in loose condition and start rolling it. So, one pass of roller when it is completed, this will not compact the soil to the design dry density value. So, which means multiple passes of the rollers will be required such that we can achieve the design dry density.

And the design dry density is usually denoted as a minimum value of the percentage of the maximum dry density which we have evaluated using the modified proctor. For example, subgrade or granular layers typically, we have to compact it up to a minimum of let us say 95 percent of the maximum dry density or 98 percent of the maximum dry density we can go up to and that is a minimum value we can go up to 100 percent of the dry density more than 100 percent of the dry density because the more compaction we do the stronger is the soil at the site.

So, how do we assess how many passes of rollers will be required at the site. So, what we do typically we have to construct a test section in the test section we will use the same soil with the given moisture content and we will do some trial passes and we will draw the curve between number of passes and the dry density for different types of rollers depending on if you have already decided which roller have to be used, let us say you have decided that a vibratory roller will be used, so you will plot this graph or from the data you are getting from the tire stretch.

And this graph you will use for the construction purpose. So, from here you will see that what is my design specification, let us say the design specification is that minimum 98 percent of the dry density is required. So, you will see that what is that particular value, let us say this is the 98 percent of the dry density you have achieved in the modified proctor.

So, you will take this value and you do not add how many passes are required. So, you see for different types of load rollers the curve will be different because all the rollers give different magnitude of energy to the soil we are compacting. So, we have various type of rollers available for compaction we have static rollers that will just move and it will compact the soil, we have vibratory rollers which can be operated in different frequency. So, this will give vibratory load to the soil and we can compact it.

We can have shift foot rollers, these are mostly suitable when you are using cohesive soils. We have pneumatic trial rollers, which can apply different magnitude of pressure using the pneumatic tires. So, for example, if you talk about pavement construction, so, for the construction of subgrade and embankment, we have different options for rollers, for example, we can use a static three wheeled roller, we can use a self-propelled single drum vibratory roller, we can use a tandem vibratory roller, we can use a pneumatic tire roller, we can also use a pad foot roller.

So, the engineer has to decide which roller he or she needs to use. But ultimately, the purpose of the roller is to achieve the desired density value that is the design density corresponding to the value of density we have achieved in the modified proctored test in the laboratory. And typically, I will just give you an example that typically 80 to 100 kilo Newton rulers of different categories are used and the minimum thickness of compaction depends on the type of roller.

If it is a vibratory roller, you can go up to higher depths. If it is a static roller, you can come compact up to some limited depth depending on the capacity of the roller. And the roller are again moved at a very slow speed, for facilitating the compaction typically they are moved at 5 kilometers per hour at the site to complete the compaction process.

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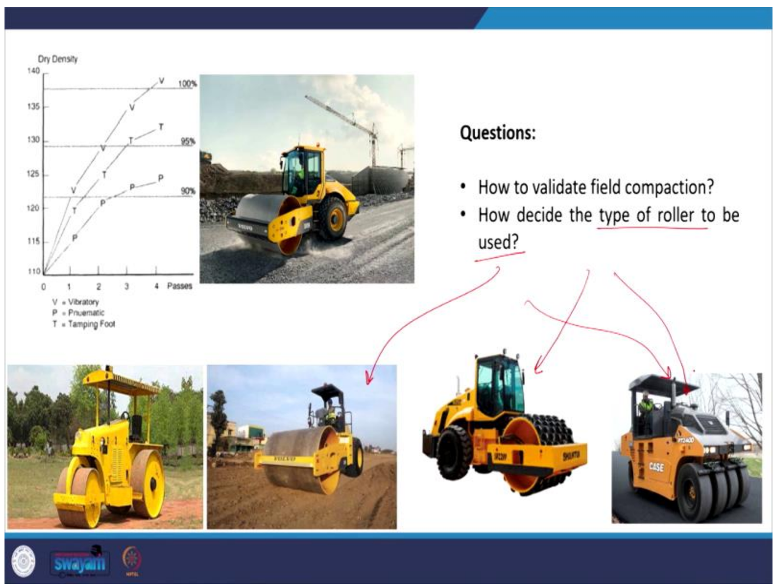

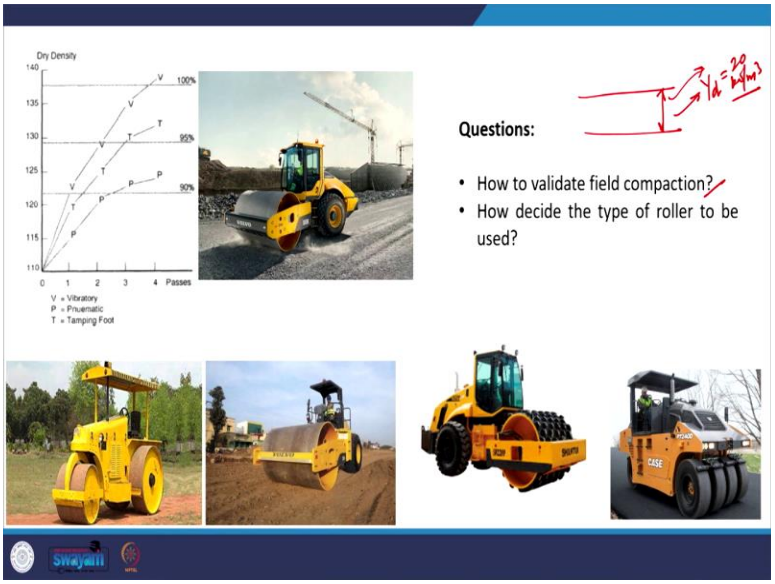

Two important questions which we also need to answer when we talk about compaction. So, the first question which we need to answer is that how to validate fill compaction, and the second question is how do we decide the type of rollers which we have to use. So, as I mentioned the type of roller to be used depends on the type of soil, for example, if it is a cohesionless soil, you can prefer to use vibratory rollers, you can prefer to use pneumatic tire rollers, if it is a cohesive soil, we can use pad foot rollers or shift foot rollers, we can use pneumatic tire rollers and so on.

Now, coming to the second question is how to validate the field compaction. So, what do you mean by validating field compaction? Let us say that we have a subgrade layer here and from laboratory modified proctor test we have evaluated that the dry density of the sample for design should be say 20 kilonewtons per meter cube.

So, here the question is that once the construction has been done and we go and visit the site, so, at the site what do we do to ensure that this layer which has been compacted has a dry density of 20 kilonewtons per meter cube. So, there are various methods that are available to validate the field compaction process. For example, we have a very popular method which is the sand replacement method.

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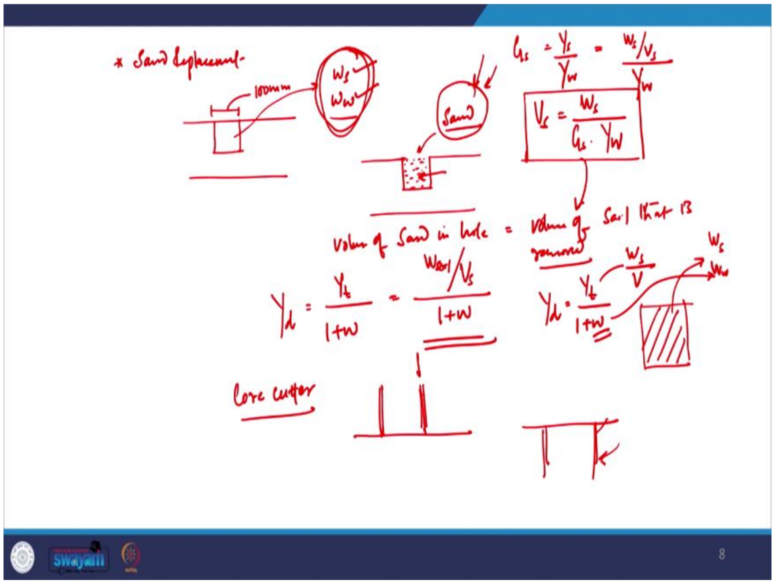

In this method what we do the subgrade soil which has been constructed we dig out some soil from this, this is typically kept as 100 mm. This soil is weighed, you take the weight of the soil and you also determine the moisture content in the soil. Now, this hole which has been made after removing the soil, what we can do we can fill it with a sand material. So, this is a standard sand material whose specific gravity we already know from laboratory experimentation.

So, this entire space which has been made will be filled by the sand material. So, the sand is basically a standard sand which we use to fill the hole and we can say that the volume of sand in the hole which we have put is equal to the volume of soil that has been removed. So, since this is a standard sand, we know the $G_S = \frac{\gamma_s}{\gamma_w}$.

So, from here I can calculate further that this is $G_S = \frac{\frac{W_S}{V_S}}{\gamma_w}$. I can calculate the volume of sand here

$V_S = \frac{W_s}{G_S \gamma_w}$. And this is nothing but the volume of the soil that has been removed. From the removed sample we also have the weight of the soil that was removed and the moisture content in that soil.

So, we can calculate the dry density as $\gamma_d = \frac{\gamma_t}{1+\mathrm{w}}$, where γ_t is the $\frac{W_S}{V_S}$ which is nothing but $\gamma_d = \frac{\frac{W_S}{V_S}}{1+\mathrm{w}}$. So, this is one way of validating the dry density of the soil of a constructed layer. Another popular method is a core cutter method which is again very simple in nature. We have a core cutter, so this core cutter is pressed inside the soil mass.

So, this is at the surface once it is pressed, you will see it like this. We know the volume of the cylinder we will remove this, so once we remove we will have the soil mass inside it, we can take the weight of the soil, we can know the moisture content of the soil and we can just use the direct formula of gamma t by 1 plus w, where gamma t is weight of soil divided by the volume of the standard mold and w is the moisture content in that soil. So, using the core cutter method also we can validate the field compaction.

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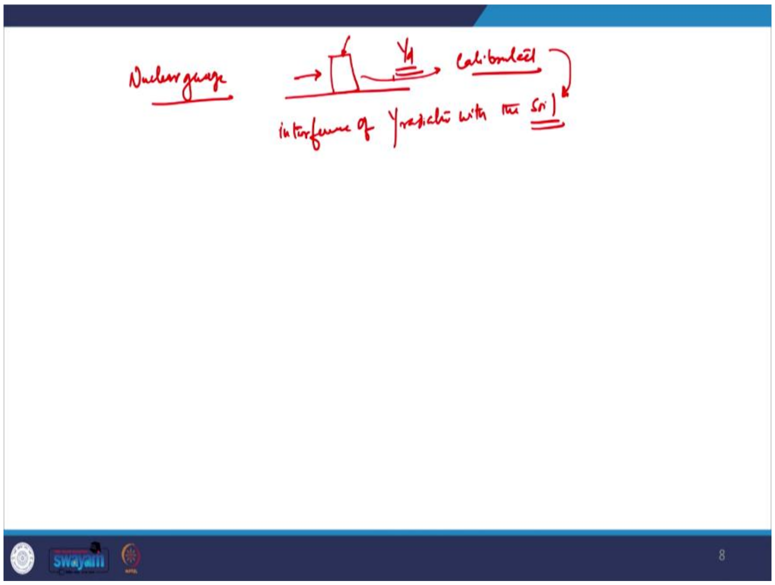

Another method to validate field compaction which is more commonly used these days is the use of a nuclear gauge. So, this nuclear gauge is nothing but an instrument which you can put on the surface of the layer. And once just by looking at the reading in this nuclear gauge, it will give you the dry density of soil.

This nuclear gauge basically works on the principle of interference of gamma radiation scattering and back scattering principle, interference of gamma radiation with the soil. But it is important that the density gauge or the nuclear gauge we are using to measure the field compaction should be calibrated properly so that the results which we get will be reliable. So, I hope that this is clear from our discussion up till here that how the field compaction can be validated after the construction has been done.

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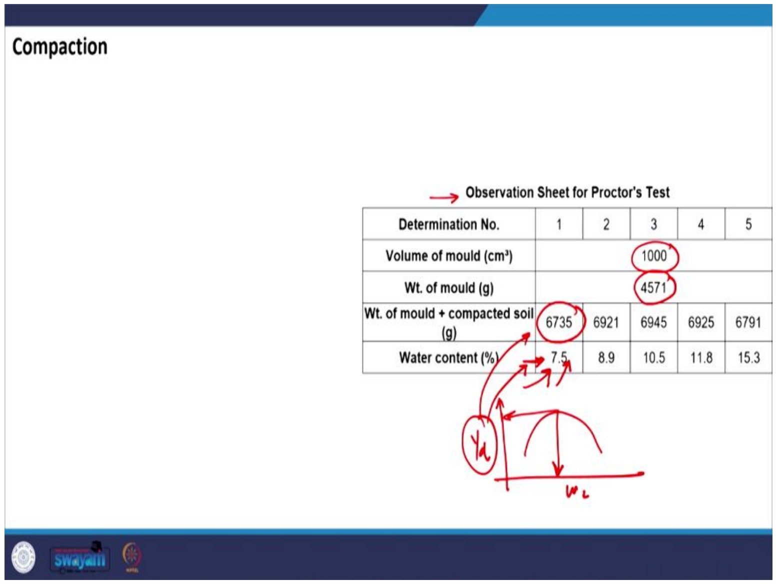

Well, this is just for practice, you can use this data and try to see if you can calculate the optimum moisture content and dry density. So, you see the volume of the mold this is a proctored test, volume of the mold has been given to you, the weight of the mold has been given, and the weight of the mold plus compacted soil has been given. This is the water content for each trial, corresponding to each trial.

One clarification we should have that this water content is not the water content at which we are molding the soil. When we mold the soil in the laboratory and during the molding process some moisture can be lost. So, you have to determine the moisture content using the weight of the soil and then oven drying it taking, the oven dried wet and doing the calculation to determine the actual moisture content.

And then you plot the moisture content versus dry density. And dry density can be calculated using this data, you already know the relationship between dry density and total unit weight and moisture content, use that relationship calculate γ_d and plot the curve, after plotting just calculate the maximum density and the corresponding moisture content. So, this is just for practice.

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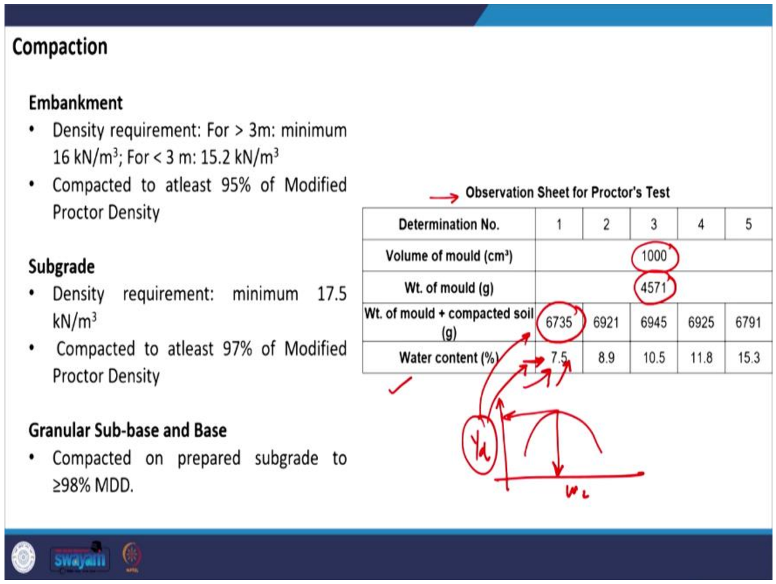

Now, coming to the specification. So, finally, we are learning about compaction for using it in pavement construction. So, when we are talking about pavement construction, we have to also see that what are the parallel specification corresponding to the requirement of dry density and corresponding to the requirement of the specification values.

So, if you talk about embankment construction, if the embankment is more than 3 meters in height then as per Ministry of Road Transport and Highways, the minimum density of the soil should be 16 kilonewtons per meter cube and if the embankment height is less than 3 meter, we can use the minimum dry density which is required is 15.2 kilonewtons per meter cube. And we do the modified proctor density in the lab and in the field, we have to ensure that the density is at least 95 percent of the modified proctor density.

Talking about subgrade the densities requirement is a little higher than in an embankment, the minimum density requirement is 17.5 kilonewtons per meter cube and the compaction should be carried out in the field such that we can achieve a density which is at least 97 percent of the modified proctor density. Talking about the requirements for granular sub bass and bass, they are compacted on the prepared subgrade to achieve a minimum density which should be at least 98 percent of the maximum dry density which we get from the modified proctor test.

With this we will stop here today. Today we have discussed about the compaction characteristics of the soil. We have tried to understand the importance of compaction in the construction process. We have tried to understand what are the factors that influence compaction in the soil, how the compaction characteristics of cohesive soils differ from cohesionless soil. We have talked about the steps involved for laboratory evaluation of optimum moisture content and maximum dry density.

We have discussed about the application of the laboratory results for construction in the field, how the number of passes of rollers are to be decided to achieve the desired density level. And we have also finally discussed about the available methods to validate the field compaction. In the next class, we will start talking about the shear strength of soil which falls under again the same topic that is strength properties of soil. Thank you.