Course Name – Pavement Construction Technology
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A very warm welcome to all of you. I am Rajen Chaudhary, a Professor in the Department of Civil Engineering at the Indian Institute of Technology, Guwahati, and the instructor for the NPTEL MOOC course, Pavement Construction and Technology, funded by the Ministry of Education, Government of India. Today's lecture will be lecture 6 under module 3, which will have a discussion on the characterization of materials used in pavement subgrade construction. At the very beginning, I would like to acknowledge the use of text, information, graphs, and images sourced from various textbooks, codal standards, journal articles, reports, newsletters, and public domain searches. As per MoRTH 2013, the different materials that fall under the category for use in subgrade pavement construction are included. It states that the materials permitted for use in embankments are also normally used wherever any filling is required to raise the level of the ground.

Then, we proceed with the embankment construction, followed by the subgrade construction. So, in both cases, it mentions that the materials permitted for use in embankment subgrades, and when you are constructing the earthen shoulders, as well as your paved shoulders and miscellaneous backfill, especially when some retaining structures are constructed there, should also be considered for the backfill material. So, what type of materials does MoRTH recommend for use under these different categories, which are your embankment, subgrade, earthen shoulders, and miscellaneous backfill, includes soil, murram, gravel, and reclaimed pavement material, which is extracted from existing pavement material and can be derived from whatever you can mill it, get it from, or the scrap already existing from any pavement construction material. Fly ash, industrial waste, pond ash, and a combination of these can also be used.

A reclaimed material, when you are trying to reuse it, with some modification or a combination of fly ash, can be there along with your natural soil. So, these are the materials that are recommended for use, and finally, all these materials have to be used; this is very important. By default, they cannot be used; this combination or the selection of material has to be approved by the engineer in charge. Now, what soil stands for, and what the term encompasses, is a big term that includes different kinds of materials. Sediments are unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks.

Which may or may not contain organic material. So this is a big umbrella under which different kinds of materials will come into the picture. Soil is a general classification term that is used for materials used in subgrade or embankment construction. Another term that is quite popular when we say that it is clay soil. Now, again, a type of soil that falls under the category of clay soil.

What is that one? Clay soil and aggregates of microscopic and submicroscopic particles are very fine when the particles are even finer than 2 microns. So, then we so that comes out to be your say 0.002 mm. So, this is less than 2 microns. So, in this particular case, if the particles are even finer than this particular one, they normally fall under the category of clay; it is an aggregate of microscopic and submicroscopic particles derived from the chemical decomposition and disintegration of rock constituents.

These particles normally exhibit a plastic nature; we will discuss what a plastic nature is and how that particular one is determined. Now all these aspects will be related to pavement engineering, especially transportation engineering. Normally, the people working in soil engineering go into great depth regarding these soil characteristics, but here we will focus more on those that are quite relevant to our pavement construction or road construction aspects. So, they say that the clay size is normally one that is finer than 2 microns. The other category we normally refer to as silty soil.

This is another type of classification of soil: there are silty soils. These are fine-grained soils or the fine-grained portion of soil. Again, all these are under the bigger umbrella of the soil. So, it exhibits little or no plasticity and has no strength when air-dried. So, normally, clay soils have high plasticity, silty soils are normally non-plastic, and then you might have heard about sandy soils.

So, there are certain regions where sandy soils exist, and you might have heard the term black cotton soils. So, these are the different types of soil that can be classified through various means; those things we will discuss here. So, when it comes to the three most important aspects, one is the general soil classification and the common classification, which states that the soil may be clay in nature or it may be a silty soil. So when it comes to the sizes, it states that the portion of soil which is usually finer than 75 microns, or 0.075 mm, is less than this particular one and coarser than 0.002 mm, which is your 2 microns, because normally, the one below 2 microns falls under the category of clay soil. Now, what test do we normally do to understand the behavior of soil in order to judge the suitability of that material for road construction, especially because we require a bulk quantity of soil for embankment and subgrade construction, along with the construction of earthen shoulders or protection of edges and side slopes? The major quantity will be required for raising the level in terms of the embankment and the subgrade. If there are some major fields required because you are constructing roads in low-lying areas, then the quantity required may be very high. So there are some quite popular test procedures that are followed for characterizing or evaluating any soil for its use in road construction. Soil intended to be used in embankment and subgrade is primarily evaluated and characterized in the following way: one method is to determine the soil size distribution.

We just discussed that if the sizes are less than 2 microns, it may be clay soil; if the sizes are from 2 microns to 75 microns, it is silty soil. Based on grain size distribution, you can work out to a certain extent the nature of the soil. Then comes another important limit you might have read about in your other courses related to soil engineering: the liquid limit, the plastic limit, and the plasticity index. So these are three terms and the three characteristics that we normally determine for a soil to judge its suitability for use in subgrade and embankment construction. Another is your free-soil index.

Then we work out the characteristics in terms of their compaction density. So, two parameters are determined: the optimum moisture content, and when we work out the optimum moisture content, it corresponds to your maximum dry density. So, the optimum moisture content and maximum dry density are also worked out. Now, in addition to this, for strength purposes, we normally go for the California Bearing Ratio; we will discuss it, and normally, this test is done under soaked and unsoaked conditions, depending upon the conditions in the field under which the road will be constructed. Another parameter that is used is unconfined compressive strength or resilient modulus.

So these are some of the common evaluation practices that are used to judge the suitability of any soil for use in road construction. Now, as I mentioned, what is your gradation or soil size distribution? So I can pick up the sheaves that are expected to lie where the material is. So if a material has sizes ranging from 10 mm to 20 mm. Even more than that, 10 mm, I can say for 20 mm; if the sizes are from 20 mm and going below, say 1 micron, or even less than 1 micron, I will try to do sieve analysis accordingly, but for me, practically working with these sieves is possible; the gradation is possible up to certain sieve sizes only. Below those finer sieve sizes, it is not possible to do so using these different sieves.

So we will look into it. So the particle size distribution of soil quantitatively expresses the proportions of the mass of various-sized particles present in the soil. So I just want to see how much of the material is retained over 75 microns. So all this, which is getting retained over the above sieves, forms a part of the one that will be retained over 75 microns. So, I may be interested to know what percentage passes 75 microns, as that will tell me how much my soil is finer than 75 microns.

So, what is the chance that it is towards the silty nature, and then I may even look to know how many sizes are finer than 2 microns? Doing these gradations with sieves is usually possible for sizes above 50 microns. For sizes lower than 50 or 75 microns, we normally do not go with these individual sieve sizes. We have to go with either the pipette method or the hydrometer method. So, the grain size distribution and what I will show you in the next slide, what I get out of this gradation analysis, will provide the distribution curves. Through these distribution curves, I can get an idea of the nature of the material and determine where it can be suitable.

For coarser materials, I can even see whether those materials can be used as a drainage layer, filter layer, or separation layer. So all these characteristics can be based on my graduation, I can work it out. Two methods are given for finding the distribution of grain sizes larger than 75 microns because this is mainly what is possible conveniently with these different kinds of sieves. The first is wet sieving, which can be so, and the second is dry sieving. Now, when do we go for wet sieving and dry sieving? Normally, when the clay content is higher, the clay adheres to the larger particles.

So in that particular case, you will prefer that when clay content is higher, you will prefer wet sieving so that all the clay that is adhered to or attached to your bigger aggregate particles or bigger soil particles gets washed away, and you get a good determination of the sizes on different sieves. So then you will prefer to go with wet sieving, but it takes more time, and if there is a lesser quantity of clay, you can comfortably go with dry sieving as well. And as I mentioned, for sizes less than this particular one, you normally go with the pipette method or the hydrometer. Now we have many good pieces of equipment available, such as particle size analyzers, which can give you sizes ranging from nanometers to larger sizes. Now, I will just give you an example of what we do under this gradation analysis or sieve size distribution.

So, I am randomly picking. So, let's say I take these 4 sieves. So, there is one sieve that is 100 mm and another that is 75 mm. So, what I will do is take a standard material and put that standard material on the top sieve, and it will be shaken. Now you also have laboratory sieve shakers, and the sieve sizes are different; you can have 15-centimeter diameter sieves and 30-centimeter diameter sieves. All those different sizes of sieves are available depending on the range of particles present in your soil.

So if I do this with this particular method and find that there may be coarser particles, such as 70 mm or 75 mm particles, present in my soil, then I will prefer to keep these sieve sizes from 70 to 100 mm so that whatever is above 75 mm also gets filtered out. So I have taken a standard material, sieved it, and stacked it, keeping the coarser one on the top and the finer one at the bottom. So now, this particular one, I have sieved it and found that no material is retained on my top sieve. Now, there is an important consideration depending on the sieve size. There is a requirement for the maximum amount of material it can sieve.

So that is to be taken care of. So it states that the maximum weight of material retained on each side, where the completion of sieving should not exceed the prescribed value corresponding to the given sieve size. So this is an important point: if you take more than that material, the sieving will not be correct. So the appropriate amount of material that can be retained over a particular sieve is to be taken into consideration while you are doing this dry or wet sieving. Now, here I have seen no material retained over this particular sieve; on this sieve, 710 grams of material is retained, 1030 grams are retained, 2195 grams are retained, and below this particular one, I can go up to 75 microns. This is just an example; I will go up to those particular sizes, and at the bottom, I will put a pan.

So, below 75 microns, if I am going up to 75 microns or 50 microns, at the bottom of it, I will have my pan. So whatever passes through the 4.75 mm sieve is getting retained. So this is my total material that has been covered. Now the total weight of this material is 4195 grams, and initially, I may have taken, say, 4200 grams; then you may ask, where have these 5 grams gone? During this sieving, some fines may be lost; you will prefer to do a controlled sieving so that these fines are lost as little as possible.

So, there are still chances that some discrepancy will exist, especially in the total quantity of material you have taken, and finally what comes on the individual sieve size. So, for my consideration, I will take everything present on the different sieves. Now, with respect to this 4195, I can work out how much percentage of retention there is. So, 0 percent is 0 divided by the total material, which will be 0 percent. 710 divided by 4195 gives me 16.92 percent. So this gives me the percentage retained on these individual sieves. Now I want to know how much material will be retained over this 19 mm sieve. So I need to work out the cumulative percentage retained. So for this particular one, on the 100 mm, no sieve material is retained: 0 percent.

On this 75, 16.92. So, when it comes on the 19th, this will be 16.92 plus 24.55. So, that will be your 41.47; when it comes to 4.75, this 41.47 plus 52.32 will be the one. So, if I put all the material directly over 4.75, that means 93.79 percent will be retained, and the remaining will pass, and then definitely, it should be at the pen.

So, one is in terms of cumulative percentage retained; the second talks in terms of the cumulative percentage passing. So, 0 percent means that you have to subtract the cumulative percentage from 100. So, if 0 percent is retained cumulatively, that means all material passed, so 100 minus 0 is your cumulative 100 percent passing. When it is a 16.92 cumulative percentage retained, my cumulative percentage passing will be 100 minus 6.92, so that will be. So, if I put all the material, 83 percent of it passes through a 75 mm sieve or 58. So, this gives me an idea, then I would like to see, say, 75 microns. See how much material is passing; 80% of the material is passing. I can see that a very large share of the material is there, which may be in the portion of either silty soil or, if finer, in the lower sieves; it may be under clay in that case. Now, once I have this particular one, I can plot this gradation.

This cumulative percentage passing can usually be plotted on a semi-log curve, where the sieve sizes are plotted on a logarithmic scale and the normal arithmetic scale is used. Now, here you can see the percentage passing varies from 0 to 100 percent, and these are your sieve sizes. So, here you can see this is 1 micron, this is 10 microns, this is 0.1 mm, this is 1 mm, 10 mm, and 100 mm. Now, here is what important thing you can see when I plotted differently.

I did this gradation on different samples, maybe soil or others. This gradation has to be done for the sieve size distribution, whether it is soil or any granular material, in the same fashion; the only thing that will vary will be the sieve sizes that you will be using for granular materials and the ones that you are going to use when you are looking for soils because the particle sizes present will vary in different materials. Now you can obtain various information through these size distribution curves. Now, this is one size distribution curve you can see, so you can see there is a range of material present between these sieve sizes; there is also a range of material present between these sieve sizes.

So, I can see if this is 1 mm and that is 10 mm. So, what is there? This is 40, 40 percent, 1 mm, you can see this, 40 percent is passing for 1 mm. I can work out for this particular one, and how much for this is for 10 mm, and for 1 mm, I can see around 15 percent passing. So, between 1 and 10 mm, and from 15 to 40, around 25 percent of the material is present. From this, I can work out that I have materials in the range of around 25 percent. When I write on this particular one, it normally does not get good results.

So, 1 to 10 mm, 25 percent. So you will see different sieve sizes; you have a good amount of materials, and a good distribution is there. This good distribution means you have well-graded material where all sizes are present. So normally, this kind of distribution falls under a well-graded material. And depending on that, I can see how much material is finer in that case.

So, if I have a 75 micron one, I will see 0.075 maybe here. So in this case, I can see that 5% of the material is passing, and only 2.5% of the material is here. So I can also look into the fineness of the material. And now here you can see there is one gradation curve and another gradation curve, which is here. In this particular case, if I go for a wider one, this is the one I prefer.

So, this may be 0.1 or 0.2, or it may be around 0.15; 0.15 may be somewhere here. So, 150 of my cronies will be there, and this is, you will have to say, I can say, this is my 2 mm. So in this particular range, you have a very small percentage, even less than 5 percent, of material. So there is one particular size that is missing here. So this kind of curve shows that there is a gap where some particular sizes are missing.

Now the other one shows this kind of one where you can see all my percentages are within a very small range. So here it is, 100% passing, and here you can see for this particular curve that when it comes, it is 10% passing. So, within this narrow range of sieve, all my material is available. So this becomes uniformly graded soil. So, this is what you would call a uniform graded soil, and based on the sizes, I can say it is silty soil, sandy soil, or clay soil.

So these gradation curves give me an idea of whether it is well graded, uniformly graded, gap graded, or well graded. Now, the other important aspects come in terms of the Atterberg limits. Now, under these Atterberg limits, we want to determine especially the nature of the soil and how it behaves in the presence of water. So, the Atterberg in 1911 proposed a series of empirical tests to determine the consistency and plastic properties of especially fine soils. Now, three important things that we require, especially for determination for our purposes here, are: one, the liquid limit; two, the plastic limit; and on the basis of these two, we get the plasticity index.

These are three, and another, not the limit, that can be extracted from it is the shrinkage limit. Now, if I add, you can see if a soil sample is there with you; if you add water to it and keep on adding, there may be a certain consistency. Consistency means the amount of water at which the soil sample, along with water, may start flowing. If the water level is reduced, you might feel that when you are moving on the ground, if there is water present, then there is a chance it is slippery, and your leg might get stuck in the soil. So this is why, because the behavior of the soil changes with the presence of water or the amount of water that is present.

Now the term that is used is the liquid limit. It states that it is the water content expressed as a percentage of the weight of the oven-dry sample. At the boundary between liquid and plastic states, it says it is the water content at which the soil starts flowing. So, if this is my water content, this is my moisture content with respect to the dry weight of the soil. So, if I keep on adding after this particular one, the soil mass will start flowing with more water to be added. Now, there is another limit that is normally considered a plastic limit, and what it says is that the water content, expressed as a percentage of the weight of oven-dry soil, is at the boundary between the plastic and semi-solid states.

So, this is the consistency if I keep reducing it. Below this particular one, you will not be able to remove the soil sample, or it will crumble. So if I reduce the water content below this particular level, it normally comes into a semi-solid state. So, this becomes my way of determining; you will get a clearer picture if I further reduce the water content. So, here the maximum water content at the liquid limit occurs when it starts flowing; if I reduce it below this, it starts behaving as a semi-solid, and if I keep on reducing, the soil volume will not keep changing.

So this is the one that we call the shrinkage limit. It says it is the maximum water content expressed as a percentage at which any further reduction in water content will not cause any change in the volume of the solid mass. So there you can see how the behavior of the soil changes with the change in water content. Now, the first one, more things will be discussed here, especially in the determination part: how do I determine the liquid limit at the laboratory scale? There are various methods of doing this; the most common one is the mechanical method, which looks like this, and the other ones are the one-point method and the cone method. Now, here is what is done for any soil sample for which you want to determine the liquid limit: you take a standard mass of the soil, and this is all done as per IS 2720 Part 5, where the complete description of the determination of the liquid limit is given.

I will give you a brief idea. So we take a soil mass, add water to it, and fill this soil into this particular apparatus, specifically using sizes that are less than 425 microns, and a groove is cut here. Now, after that particular one, you are going to give these compaction levels to this particular one, and this is handled. You can see this particular one, so it will raise this cup and allow it to fall down. So every rotation will raise it and allow it to fall. Now, this particular one—so what are you going to do? You want to note down the water level at which these or the number of blows at which these two soil samples, after cutting these grooves, come closer.

So, if the number of blows, or I can say the drops of this particular cup, is noted down, I am trying to look for the water content where this particular soil mark gets closed after an application of around 25 blows. So this is one apparatus that is used for the determination of the liquid limit. So if I have more water content, then it will be, after say 10 blows, also able to get closed up. If it has a smaller amount of water, then you may be required to give 50 blows, and even then, it may not close down. Normally, I prefer to go when it closes down in the range of 15 to around 35 blows.

What can I do? I can initially add some water content, see if it closes down at 15 blows, and then I will add some more water. Then I will again see how many numbers I cut down this groove and again see for it. So this is how it is repeated, and finally, you normally look for the one where it gets closed down for around 25 blows. So this plot is drawn between these drops and your water content. On the other hand, when the plastic limit is determined, as I said, it is the water content.

If you reduce the water content below this particular level, the soil may start crumbling, or it may reach a semi-solid state. So I'll take a soil mass, add moisture content to it, and try to rub it down into a thread. And this thread should be typical of 3 mm in diameter. Now, if this is easily formed, then again, what I will do is some kneading, so in the end, I will start it again; this will reduce the water content. I will reduce it, and normally, when you roll this over the surface, you go for around 80 to 90 strokes in one minute.

One stroke goes forward and comes back. So I will keep giving this stroke, and I want to see the water content where this thread starts crumbling down. So that particular one is around a diameter of 3 mm. So that is the water content where it is now getting cracks and converting to a semi-solid state. So, I need to know these two limits: the liquid limit and the plastic limit.

These two limits give me an idea of how much the range is. One is where it acts as a fluid because it starts flowing, and the second is when it behaves as a semi-solid. So in that range, it is holding the water, so that gives me an estimate of that, and that is known as the plasticity index, which is my liquid limit minus plastic limit. So, this gives the plasticity index, which gives you an idea about the plastic nature of the soil, and if there is sandy soil, then definitely, when you look for it, you will not be able to form a thread from it. So if there is sandy soil, we will say that it is non-plastic because you are not able to find it, and there may be certain soils with very little difference between the liquid limit and plastic limit, or it can even be 0. So, the value can also be reported as 0 when the plastic limit is equal to your liquid limit.

So, the water-holding capacity can be estimated, or the plastic nature of the soil can be estimated through this plasticity index. Now, another important thing is the free swell index, which gives an idea of how much this soil can swell in the presence of water. So, for this, because this swelling will depend on different factors, it will depend on your gradation, and it will depend on the actual magnitude of swelling pressures developed. When there is swelling soil and you have put some layer over it, when water comes into contact with it, it swells.

Now it swells, pushing your pavement structure upward. So this is not good for your structural life or for the performance. You want to have soils that have low swelling potential. So I need to determine the swelling index, or I will call it the free swell index, of the soil. So, this free soil index is a measure of the increase in the volume of soil when it is submerged in water without any external constraints. I am not going to put any external constraints here in this case, and this gives an idea of how much it can damage, especially because of the swelling that can happen, particularly in expansive clays when finer clays are present or in clays that have a higher plasticity index, as they have a higher swelling potential.

So, this can be estimated through your free swell index; this will depend on other parameters, such as water content, surcharge loading, and several other environmental factors, but this is a simple test to get an idea of how much the swelling potential of a soil is. So, once I can do it, I can put my soil sample back again, the one that passes 425 microns. Then, I will put it in these graduated cylinders.

One will have kerosene in it. Why kerosene? Because it is a nonpolar one. There will be no expansion or swelling of soil. Second is the water. Second, I will put it in the water.

So, there, the swelling, free swelling of the soil will take place. Now there are two volumes.

I will leave it. This sample of the soil in these two cylinders, having been subjected to kerosene and water for a period of 24 hours with a standard weight of around 10 grams, is put as per the codal provisions requirement. Then I will see what the volumes Vd and Vk are. I will measure Vd, which is the volume of soil in the specimen, read from a graduated cylinder.

These are graduated cylinders; here, you can see the graduated marks on the cylinder. So, I will get the volume containing distilled water and kerosene. So, this is the volume of soil with distilled water; this is the volume in the case of kerosene. So, I am just going to see how much volume expansion has taken place. So, this gives me my free swelling index, and it says that expensive clay with a free swelling index higher than 15% should not be used as fill material. If you have to raise your road level, then it should not be used as fill material because of its high swelling potential.

Even certain soils may exist that have a swell index less than that one; it also states that they can be used as fill material. But you have to ensure that the subgrade and the top 50 centimeters of your embankment just below the subgrade are non-expensive in nature. You will always prefer to use a material that is inexpensive in nature when you are doing the subgrade construction, and you will try to keep it at least 50 centimeters below the subgrade, as well as the embankment part, with an inexpensive material. Now the MoRTH also recommends that if you are using any subgrade material, the liquid limit should preferably be less than 50% and the plastic limit should be less than 25%, because the reason that we will always prefer this is in terms of the plasticity index.

We will try to have soil with a lower plasticity index value. So this is how we indirectly try to restrict the use of soils having a higher plasticity index, and these are the requirements that we will discuss again when we come to the granular courses; these are the requirements for base courses and granular sub-base courses. Here, the requirement states that the liquid limit shall be less than 50% and the plastic limit should be less than 25%. So expensive clays exhibiting marked swell shrinkage properties when tested as per shall not be used; we already discussed that they should not be used if the free swell index is more than. So, these are some traditional methods, specifically in terms of the Atterberg limits and in terms of the gradation requirements. In the next lecture, we will discuss more about the optimum moisture content, maximum dry density, and California bearing ratio. Thank you.