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A warm welcome to all of you. I am Rajan Chaudhary, Professor in the Department of Civil Engineering, IIT Guwahati, and Course Instructor for the NPTEL MOOC course, Pavement Construction and Technology, funded by the Ministry of Education, Government of India. This lecture will be part of the third subgrade course and its functions under module two. At the very beginning, I would like to acknowledge the use of text, information, graphs and images sourced from various test books, codal standards, journal articles, reports, newsletters and public domain searches. Now, in this particular lecture, we will focus our discussion especially on the features of the subgrade of a flexible pavement. Now, this particular picture shows a section that has been cut to, and where the information is available, you can see the part where this particular person is standing; this is where a compacted subgrade is located.

So, there is a section that shows the granular layers; these are the two granular layers that are shown. So, at the bottom, you can see you have a compacted subgrade, then you have these granular materials: the first layer of granular materials, the second layer, and then your third layer of granular material. So these granular layers are constructed in multiple layers, and as we discussed in the previous lecture, these are sub-base courses and base courses; these are unbound courses, and there is no binding material in these particular courses. And then, on the top, you can see there are two layers, which are bituminous layers: the lower one is your binder course, and on the top one, you have the surface or the wearing course.

So, all these layers that we are able to see are resting on this particular prepared subgrade. Now, if you have a good crust, what is above your subgrade is your pavement crust. If you have a good crust that is constructed in a proper manner, then it will serve the purpose of giving a smooth and comfortable ride, and it will last, providing good performance for the design period. For our discussion on this particular subgrade aspect, different codal specifications and manuals will be referred to. Some of them are listed here on the right-hand side; one is this orange book, which is from the Ministry of Road Transport and Highways and is a specification for road and bridge works.

We call it the orange book, which is a very important book that refers to the various sections containing information related to the construction of roads and bridges. Then, this is the IRC 34, which contains recommendations for road construction in areas affected by waterlogging, flooding, and salt infestation. So, this is another code; then we have the IRC 37, which is the code that gives the guidelines for the design of flexible pavements. We have IRC 36 recommended practices for the construction of earth embankments and subgrades for road works. We have IRC SP 73; SP means Special Publication, a manual of specifications and standards for the lining of highways with paved shoulders.

We discussed yesterday what a paved shoulder is and what an earthen shoulder is. Then, the IRC 75, which is their guideline for the design of high-impact maps. So, many more will be referred to; these are a few examples that are shown here. We have good IRC codes and Ministry of Road Transport and Highways specifications and codes available to us on this particular aspect. Now, in our introductory lecture when we discussed the stages in which road development has happened, we also discussed some of the traditional methods of road construction.

And we discussed roads in the ancient period, even during the industrial era of the Mohenjo Daro civilization and the Roman periods. So, a quick revisit of the information we discussed in the case of Roman roads, where information is available, is that they used big stones at the bottom and some big stones on top, along with finer stones and the presence of lime mortar or concrete to construct them. Now, here they did not use to provide any slope in this particular case because the loads were not too heavy, but still, the construction was very heavy. Now, the Trezeguet method of road construction became popular in the 18th century, where the construction involved the excavation of the soil, followed by the laying of larger stones. You can see here that these bigger foundation stones are placed, but there is no slope provided in the larger stones; then, on top, the smaller stones are placed.

And finally, the top surface had a slope; this slope allowed the rainwater to drain from the surface, so this is a conventional representation of the Treseguet method of construction. Then, the Telford method of construction shows that even with the foundation stones, a slope was created. You can see on one side that the foundation stone height is 22 centimeters; on this side, it is 17 centimeters. So, with this particular one, the slope was introduced from the large foundation stones that were placed at the bottom, and then finer stones were placed over this particular one, and on the top, again this particular slope followed. So, this is how a good firm foundation was introduced or presented in the Telford method.

Now, when the Macadam method came to that particular point, whatever new construction was there was the one that was given more emphasis. But, when Macadam comparatively placed more emphasis, the emphasis was given on the ground where all these layers were going to be laid. So, the soil subgrade is the layer over which the upcoming layers of your pavement crust will come. So, it says that soil should have adequate density and be kept drained. So, the importance of subgrade was emphasized by the Macadam method, and therefore you can see that the slope was introduced from the subgrade itself.

So, the subgrade was reconstructed, and when it was reconstructed, it was constructed to a desired density and water content to achieve the required stability of the subgrade, and it was constructed with a slope considering the drainage requirements of this particular layer. So, now this is to just give an idea of how the importance of this upgrade came into the picture because finally all the layers that you are going to construct during a road construction, a flexible pavement construction, will be resting on some ground. So, that ground needs to be prepared. Now, if I have to construct a road, say this is my natural ground level, and because of any reasons, or if this is a low-lying area, a waterlogged area, I may have to create some final surface at this particular level. So, there may be a difference of, say, 5 meters. So, what should we do in this particular case? This is 5 meters because whatever your traffic requirement is, it may require you to have a crush of say 1.5 meters. And then, the ground that is to be prepared for these layers of your pavement crest may require 0.5 meters, half a meter of this. So, this makes you 2 meters.

Now, there are still 3 meters. So, when these levels are to be raised very high, this is done through the construction of embankments. So, the definition of what an embankment is states that it is a raised structure made up of soil, gravel, or lightweight material to prevent water overflow and support a road because now your subgrade has to come over it; the level has to be raised so that there is no overflow of water over the road surface; otherwise, the entire road gets submerged, and if the road gets submerged, your connectivity is broken, and it then becomes a challenge. So, you want your surface to be available for traffic under any situation. So, that is why you do not want it to get submerged underwater.

If it gets submerged underwater, traffic cannot move over it, and then the purpose is lost. So, that is why we always want to construct a road surface that is much higher than the water surface, water level, or high flood level in that case. So, for this particular case, when you need to raise these levels, which are very high, you need to construct some more layers, and these layers will come under your embankment construction. Now you say what is there so that the definition states it is built by placing and compacting layers or lifts of suitable materials placed on top of each other until it reaches the subgrade level. All these layers are to be constructed using a selected material in a selected thickness and properly compacted to achieve a desired density as well.

Desired density will control and give you the desired requirements of strength as well. An embankment is that portion of a roadway which has been built above the original natural ground, as I mentioned here; when we have this, this is your natural ground level, which you want to raise up to this particular level. So, it is the one that is constructed over the original natural ground by placing or depositing material obtained from cuts and borrow pits. Now, this much quantum of material, which is required when we go into the construction discussion of subgrades, will help us work out how much quantity of materials is also required. You can see this is the level that has to be raised; see how much the level has been raised here in this particular case.

So, a good amount of material will be required for this particular project, and mainly you will try to source some areas from nearby places because this huge quantity of material cannot be brought from faraway locations; otherwise, it will make your project very costly and not feasible as well. This particular construction of the embankment itself will become very costly. High embankments are raised structures of height. There is another definition given as per IRC 75, which states that high embankments are raised structures of a height of 6 meters and above built for the purpose of road transportation. So, this again gives some additional information.

So, for high embankments with a height of more than 6 meters, we have the Indian Roads Congress specifications IRC 75, which provide guidelines regarding the construction of high embankments. Now, certain common things need to be looked into whenever these embankments are constructed, because most of the time you have to raise the level to a significant height, and this cannot be done by subgrade construction itself. You need to go for embankment construction, and there can be different scenarios under which the embankment has to be constructed. So, one may be a routine case; what routine says is that when embankments are to be constructed over firm ground, especially reasonably favorable ground, using sand, and you have a good amount of sand, gravel, and other approved materials. Approved means these are the materials that are approved for use in embankment construction, which may be in terms of their gradation, strength, density, type of material, and plasticity index value.

So, any approved material, if there is firm ground, makes the construction quite comfortable or easy, especially for the embankment part. But there may be certain cases where a part of a section may have a short stretch of soft or loose soil, or there may be some areas that are waterlogged, which has created some marshy land that is shallow; however, this is only for a small stretch. So, in this particular case, either the embankment is made up of poor-quality materials, or you have a poor quality of material that is present for it. So, there in this case, you can see this is an excavation of what can be done with whatever soil layers are present; if it is there in a small stretch, it can be reduced, taken out, and then you can place any stabilized or other suitable materials that meet the embankment construction requirements. You can compact it, place that new material, compact it again, and make the embankment ready.

So, this kind of exercise can be done when it is a small stretch. There can be some exceptional cases where the entire stretch does not have good quality soil available and the embankment is very poor. You cannot directly say that this is the existing ground level even if I do not need to raise the level, but still, my embankment is very poor in strength. So, it then also becomes a challenge. So, it says that the exceptional cases in which embankments are built over soft or unstable ground, like marine clays, swamps, peats, creeks, or flood plains.

There is a high risk of instability and significant settlement after construction; soils may also swell or liquefy due to their loose nature, even at deeper depths. So, this has to be given due consideration even if you are doing embankment construction with selected materials, but also these embankments are to be of greater heights depending on what kind of land the embankment and the construction are coming up on; if it is very weak, that may also be a challenging situation. So, these factors need to be taken into account when you are making an embankment construction, and what you select for the use of embankment construction is another concern because it should be as per the requirements. Now, as I mentioned, it is a significantly important factor what foundation you provide for your subgrade to support and what foundation is available for the embankment for construction. So, the nature of the foundation material has a significant influence on the design of the embankment because if the embankment is poor, the existing natural soil is very poor.

Then, the embankment that has to be constructed, the type of material to be used, and the measures to be implemented are important. Another concern is that if you are considering what type of slopes to raise to great heights, what type of slopes should be provided, and if it is a waterlogged area, what type of measures related to the drainage aspect need to be taken care of. Say, for example, embankments resting on hard or favorable ground need to be analyzed, especially for slope failure. If the ground is good enough and firm enough, I will put up some layers of embankment over it; my major concern will be the slopes: what the best slopes are that I can provide, and the flatter the slope, the more stable your embankment construction will be. Normally, what is done is that you compact it in the complete layers, and then you create the slopes because otherwise it is very difficult.

So, for embankment construction, you can do the compaction across the entire width, and then you can remove this particular part. So, it gives you good slopes as well. So, this is one aspect when you do embankment construction over hard ground. On the other hand, when embankments resting on soft ground have to be analyzed not merely for slope stability but also for base stability and settlements. So, there again has to be a proper analysis done to determine whether the natural ground, over which the embankment is to be constructed, is good enough to bear the load of the embankment; only if the analysis allows it should you proceed with the construction of the high embankments.

While building embankments, one has to consider economic reasons; now the other concern is that if I say okay, the underlying natural ground is weak enough, I should go get some good material for embankment construction, but the quantity of material required is very high. So, it is not possible for me to give some borrow areas 50 kilometers away and 30 kilometers away to bring those good materials. And so certain regions may not have good soil. So, in that particular case, we have to go for some stabilization or other techniques in order to use geosynthetics. These kinds of applications have to be introduced so as to strengthen your embankment or to achieve the desired strength.

Several parameters and what several parameters are under this particular consideration will come into the picture; even when the seismic effect is there, it is a concern when you construct roads in hilly regions. The nature of loads, acceptable performance criteria, what the criteria are if it is a national highway, what the acceptance criteria will be, very high and stricter higher settlements, what type of settlements, bearing capacity, and the time available for many times when you do not get much because there are certain regions in India, especially where it rains for around 6 to 7 months. So, you have a very short period for your construction. So, all these things need to be taken care of regarding what type of material can be used. So, that is how the IRC 75 gives the information, especially for these specific challenges.

Now, as I mentioned, when you have firm ground, one major consideration is what type of side slopes you are going to provide. So, the formation is usually graded to a cross slope; you will give a cross slope whenever you are going to put these layers, whether you construct a subgrade or an embankment, to facilitate the drainage to the side of the pavement. This is the purpose of it. The embankment is to be built with side slopes ranging from one vertical in 1.5 horizontal to one vertical in two horizontal, which is the case under conditions that are unindented, meaning those that are not typically flooded.

That is, there, you can have a slope of one vertical and two horizontal, which means a 50 percent slope is there. So, this is one consideration, but where you have indented situations or where the embankment is likely to be submerged, you should preferably go for flatter slopes of up to one vertical in three horizontal, specifically because the reason arises in waterlogged areas where you have capillary rise and pore water pressure, which reduces your effective stress and consequently the shear strength of the soil. Now, because of this, the load-carrying capacity is going to reduce. So, there is a chance that your structure may fail because of this particular embankment. So, that is why it is always preferable to give a flatter slope when these waterlogged areas are present.

Now, we need to make things ready for the subgrade to come up over it. Because this is the case, we will consider the subgrade as the foundation of your pavement crust. However, as I mentioned, if the road level has to be raised, then you have to come up with the embankment construction, and the subgrade is to be constructed over existing natural soil. So, the existing natural soil can be an embankment, or if the level has to be raised, it can be the natural ground level. Now, what it says for subgrade is that it is the surface upon which the subbase, base, and pavement layers are placed.

So, what is your pavement crust? So, which consists of your sub-base courses, base courses, binder courses, and wearing or surface courses. So, all these layers are going to come over your subgrade and typically top 500 mm of the prepared foundation layer located at the bottom of your pavement crust. So, if you say on top, "this is my wearing course," I may have, "this is the thickness of my wearing course." I will say, "wearing course," then I will have a binder course, then I will have a granular base course, and then I will have a granular sub-base course. These are, so after this, I need to say it says around 0.5 meters of your subgrade. So, this and the granular subbase course here I am showing just as one layer; the thickness may be quite good enough, it may be say 40 centimeters. Here also, this may be again say 35 centimeters; your binder course may be say 150 or 100 mm, 10 centimeters. 10 centimeters may be your binder, this one, and then the wearing course may be say 5 centimeters. So, all of your layers up to this particular thickness have to rest over your subgrade.

So, this says the top 500 mm. So, the top 50 centimeters, half a meter, of the prepared foundation layer located at the bottom of the pavement structure is designated as subgrade. Now, this is a subgrade. The specific thing is there; it is a subgrade that is constructed with controlled parameters. Controlled parameters mean the soil characteristics are known to the density at which it is going to be compacted. This 500 mm thickness, the composition, and the construction information are there with us.

So, it is a reconstructed thickness; even if it is in a cut area, I have to go down and cut up to the subgrade bottom. If there is a level, say all; if there is a part, I will show you information in this particular manner. There may be certain portions. If I am constructing a road in this manner, there may be; this is how it looks.

So, this is in a cut portion. Now, when in a cut portion, this may be erased. Here you may have to do some, so this is what I have shown in a small, exaggerated view; you will not find this kind of vertical gradient here. So, my example is to show that if there is a certain portion where you need to cut the existing length, then you also have to go down to the subgrade bottom, remove the existing soil, and reconstruct that subgrade. It should not happen that you do so if there is an existing ground. So, if this is my existing ground, you should never put your pavement crust directly over it; just compact the top of it and call it subgrade.

No, that is not the way you do it for subgrade construction. You have to cut it down to a depth of at least 500 mm, remove it, and if this existing soil is approved, then you can use it; otherwise, you have to bring in borrow material or treat and stabilize it, and then you need to reconstruct it in different layers. It is not constructed because if you are going to compact it only on the top, it does not know what this soil has at a depth of 20 centimeters. So, this is one concern you should always address with the complete depth of your subgrade construction.

Subgrade may consist of the original materials, as I said. If this material is removed and you find that it is good enough, then you have to reconstruct it to achieve the desired density. The important thing is that when I recompact it, I will ensure the desired density and the desired slope, which is necessary for my pavement crust. So, it may consist of the original materials, as in cut sections or held-in materials; I may have to bring some from nearby areas, as in filled sections. This is one definition. On new roads, the main aim should be to construct the pavement as far above the water table as economically practicable because this is a natural phenomenon.

If you keep the level low enough, then definitely whenever it rains heavily, your sub grid gets flooded with water. If it gets flooded with water, it loses its shear strength, and then the entire structure rests on your subgrade. So, the entire structure fails. So, we always prefer to keep this particular one well above your water table. So, this is one important aspect that needs to be taken care of.

Now, what materials can I use? As I said, natural soil, existing soil you can use if it meets your requirements, meets your requirements in terms of strength and gradation. If it meets the requirements, you can use it. If it does not meet the requirement, you need to treat it, or you need to select some nearby areas from where you can get this particular material. So, the subgrade is primarily the bottommost layer, which is usually made up of in-situ material. I can use the in-situ material, select soil, some borrow area soil, or some stabilized soil.

Certain soils are mainly required for stabilization. If clay soil is there, I need to stabilize it. If we even have black cotton soils that need to be stabilized, and there are different methods you might have read about, you might be reading in other courses where soil stabilization is one part, and you do different kinds of stabilization techniques for trading. Some smaller aspects will also be discussed later. So, you may have to do some stabilization to improve the strength and characteristics of the soil. So, this is the requirement of IRC 37: the material used in the embankment, in the subgrade, or in the earthen shoulders.

As I mentioned, we have paved shoulders, which are more or less similar in composition to the main carriageway, and then there are earthen shoulders. So, in your earthen shoulders, in your embankment, or in your subgrade, the materials here are more or less quite similar, and the backfill materials are also used when some flyovers or other structures are constructed. What do we use there? We use soil; we use the mooram. Now, mooram is another term you might have heard; this reddish-brown colored soil is slightly more granular. Soil is a general term for inorganic and organic matter, air, and water that comes from the decomposition of rocks as well as from the decomposition of plants and animals.

So, the soil forms out of these many components, and a specific type of soil is murum, which especially comes from the weathering of rocks and is granular and especially reddish-brown in color. So, this is what a murram is used for. So, this is also quite frequently used wherever it is available. Or you can also use some industrial waste, including fly ash, that we look for. We have a pond ash, which is a combination of fly ash and bottom ash, that is also used, and as a mixture of these, they can be mixed together; even alone, fly ash may be difficult to construct with.

So, you may use a certain percentage of fly ash with the existing soil, and then you can use it. So a combination of these materials can be used. This has to be approved by the engineer in charge. So, this combination cannot be used directly without you obtaining prior permission from the engineer in charge of the project, and he will give the approval based on the specifications that are available. The material used in the subgrade shell satisfies the design strength criteria; one criterion is the strength, and many codal specifications specify the strength in terms of the California bearing ratio.

This we will discuss when we characterize or design; we will look into the design and characterization of subgrade soil. So, there is one strength parameter which is known as the California bearing ratio. So, strength can be measured in terms of the California bearing ratio, and if it meets that particular standard, say if I ensure that my California bearing ratio is at least 5 percent. So, whatever soil I use in subgrade should have a strength that is at least 5 percent CBR value; this California bearing ratio value should be at least 5 percent, then I can use it. So, depending upon what type of construction is there and what the guidelines say about it regarding the strength of those materials, you can use it once it has been approved by the engineer in charge, and he will use these causal specifications to determine whether this material is suitable or not suitable.

Now, as I said again, there is always a concern that this forms an important foundation for your pavement structure. So, you need to keep this one at the level of this one in a proper manner, so that it does not get submerged by water. So, it says that normally in plain areas, the road subgrade elevation in fill sections, especially when fill sections are present, shall be at least 0.5 meters above the original ground level in non-flood areas, as I mentioned that we normally construct at least. That is why we construct at least 50 centimeters of the subgrade, because it should be at least 50 centimeters above the natural ground level.

So, here you can see this is the natural ground level, and it says that your subgrade should be at least 50 centimeters above the top of the subgrade. So, this is the top of my subgrade. Now the other part says the road is passing through terrain in flooded areas. What happens if there are flooded areas? They say the bottom of the subgrade shall be at least 0.5 to 1 meters above the high flood level. So, even if the area gets flooded, my subgrade should not get affected. It says that the subgrade bottom should have a height of at least 0.5 to 1 meter above your high flood level. So that, because if any flooding is there, then also your subgrade does not get affected. If the subgrade does not get affected, it does not damage your pavement structure or reduce the stability of your pavement structure.

So, the level at which a subgrade is constructed is very, very important, and you need to ensure that the entire thickness of the subgrade is constructed with a controlled material to a controlled specification, which is in terms of density and strength. So, whenever a road is to be constructed, it is very important that you ensure that the thickness of the subgrade has been constructed with an approved material to meet a given density requirement. Unfortunately, many times this subgrade falls in waterlogged areas. If that falls, it raises a big concern. It is always mentioned that all caudal specifications are similar, because, as far as I know, as soon as water enters your subgrade, it loses its strength.

When it loses its strength, all layers that are resting and ultimately transferring your load to the subgrade will get distressed, and if they become distressed in flexible pavement, that distress or undulation will ultimately be reflected on the top. So, it is essential to keep the subgrade above the high water table to prevent damage to the pavement due to surface water and capillary water because there will be a capillary rise, and because of this, we need to have a capillary fringe up to a certain level. As the water rises, it creates pore water pressure, which leads to a reduction in the shear strength of the soil. So, that is why we always want to keep this water level well below at least 1 to 1.5 meters from your subgrade bottom. To maintain the design standards with respect to the vertical alignment, whenever you design any road section through a particular region, this information has to be properly collected so that the height of the subgrade is adequately considered during construction. In waterlogged areas, subgrade saturation from capillary rise, seepage, or pavement infiltration reduces its load-carrying capacity as pavement strength depends upon the subgrade support. This leads to weaker payment layers with constant traffic, reduces subgrade strength, and accelerates pavement deterioration. Even what happens if during subgrade construction, I have mentioned that I have selected good soil and good density parameters, but unfortunately, because of some challenges, if I am not using the soil that has been selected for it, I am using soil that has a strength lesser than what was considered during the design. Then the entire pavement structure will again fail because your pavement crust is designed considering the strength of your subgrade and the subgrade on which you rely, as you have reconstructed the subgrade with a selected material to a determined density.

But if that goes down, your entire pavement crust will not serve the purpose. So, even if you have constructed the above layers to the required standards, you will find that the entire pavement structure may fail in due course of time because there was a problem with the type of subgrade material you used. So, this is one important concern always when you begin construction: it is the subgrade from which you have to be very cautious for the pavement quality. Now, you can have different perspectives if there are certain areas where you find some challenges with respect to the high amount of water logging and standing water. Then, in that particular case, you can take some extra measures; also, some precautions can be taken. It is shown here that in the case of deep drains, you can use deep drains to lower the water table in the embankment.

Now, what is done here in this case is the construction of drainage channels that are 1.5 to 1.8 meters deep; this is one drainage channel that has been created, which is around 1.5 to 1.8 meters deep. And these are below the natural ground level. Now, this is as close to the road bank as provided for depressing the level of subsurface water, if any water is there, and weep hoses are provided. So, any water that is there will enter this particular one instead of entering your embankment and subgrade. So, instead of disturbing, I am providing this easy path for the collection and removal of what I will call subsoil water. So, this measure will be effective in keeping the bottom of the subgrade above the capillary fringe. So, this is one way I can do this that will help me, especially when there are waterlogged areas.

So, this is one way I can keep the water level below my subgrade. The other way is where this is now, but this is again a costly exercise; this is not a solution throughout the length if you have to do it. The other way around is what is to be done; if I cannot go for these, especially deep drainage channels, I have to raise the level. So, where it is too expensive or impractical to provide deep drainage channels throughout the length, it is recommended that an embankment of such height be provided. Then I will put up an embankment; I will raise the embankment in that case.

Embankment construction has to be done so that the bottom of the subgrade remains at least 1.5 meters. So, my concern will be that I will raise the level. So what is there that I will raise my bottom in such a manner, and I will construct it; these are my embankment layers. I am not given a uniform thickness; all layers will be constructed with a uniform thickness.

Take it in this manner that I showed this. So, uniform thickness has to be there. Now, I will put up the embankment construction so that finally, the subgrade bottom here is at least 1.5

meters from the high flood level. So if I am not able to go with these deep drainage channels, then I have to raise my level of the subgrade bottom through the embankment construction. So, this is another measure that is very important to consider so that you keep your subgrade well protected from the water.

So, it should be at least 1.5 meters above your high flood water level, and the thickness of your subgrade should be at least 50 centimeters. So, with this particular one, we have discussed some of the salient features of the subgrade soil, and we will discuss further aspects of it in the next lecture. Thank you.