

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 and the instructor for the NPTEL MOOC course, Payment Construction and Technology, funded by the Ministry of Education, Government of India. The lecture will be a part of module 5. It will discuss the equipment and the construction process of subgrade as well as embankment in the construction of road pavements. So, 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. When it comes to both embankment and soil, these are the layers that are usually constructed using the in-situ soil or soil from a nearby borrow area.

And if in certain cases the soil is quite unsuitable, some stabilization may be required for making use of it in subgrade and embankment construction; certain industrial waste, for example, fly ash, is also used specifically for the construction of embankments. Now, what does it say about the embankment? It is a raised structure of earth as per IRC 75, which is there for embankments having heights of more than 6 meters. So, an embankment is a raised structure made of earth or lightweight materials built above the natural ground to prevent water overflow and support a roadway, because we always want our road structure, the pavement crust, to be sufficiently high above the high-water level or the natural ground level. It is formed by using selected materials that can be obtained from cuts, borrow pits, or a combination of these materials.

Then, when it comes to subgrade, it is the top 500 mm of the foundation directly beneath the pavement crust. So, under your normally sub-base courses, what comes is your subgrade, and the top 500 portion of that particular layer beneath the pavement crust is known as your subgrade. It consists of either in-situ soil, selected soil from a bore area, or stabilized soil and serves as the pavement's foundation. It plays a very important role because you construct your pavement on the subgrade. So, it is the foundation of your road structure.

Well-compacted subgrades provide high strength and deformation resistance. We have also discussed earlier that they play a significant role. Their strength has a vital impact, especially on the performance of the pavement structure. And if you have a good subgrade or a subgrade with good strength, it helps you potentially reduce your pavement crust thickness. With a higher CBR value of soil, you can expect to have a lower pavement crust thickness.

The embankment, now that we are constructing this particular one, as I mentioned, we want to keep the subgrade well above the water table or the high flood level. So, one statement is that the embankment is constructed so that the bottom of the subgrade is typically 0.6 to 1 meter above the highest flood level or the natural ground level, whichever is higher. So, you will prefer to keep your subgrade well above the natural ground level or the high flood level in that case. And the various

codes that are referred to for the construction of subgrade and embankment, you have this specific manual on construction equipment for rural roads.

We have guidelines for the design of high embankments, IRC 75. We have recommended practices for the construction of earth embankments and subgrades for road works, specifically for subgrade and embankment construction. MoRTH specifications for road and bridge works are there. And then we have the pocketbook for road construction equipment, very useful for dealing with the different kinds of construction equipment. Now, let us see what the steps are that are involved when this construction of embankment or this upgrade takes place in the actual field.

So, the main steps that can be outlined under this particular process are first cleaning and grubbing. So, we clean the ground over which the road crust has to come up, or the road is to be constructed. We will discuss each of them in the upcoming slides to come up with the fixing of your central line and the cross sections; dewatering, if some water is present in that particular area, needs to be removed. Stripping whatever existing soil is there, we preferably try to remove a certain depth of it, and if it is good enough, we will keep it stored for later on to cover our side slopes, because it may be good for the growth of vegetation. Then comes compacting the ground, supporting that once before we start putting up the layers of embankment or subgrade, the existing ground also needs to be compacted and made ready to take the layers of embankment or subgrade.

Under that particular construction of the embankment, it will involve spreading materials in layers and bringing them to the appropriate moisture content. We discussed the determination of the moisture content and the relationship between the moisture content and density to work out the water content that can be achieved for a given compactive effort, the highest density, which is the maximum dry density, and corresponding it to the moisture content taken as the optimum moisture content. Then, once the material has been brought, which is spread in one layer, and when it is brought to the required moisture content, it needs to be compacted. The layer after compaction should ensure that there is no ponding of water because there may be a rainfall event in due course of time. And finally, some finishing activities have to be carried out; side slopes have to be covered up.

So, these are some of the main steps that are involved in the construction of your subgrade or embankment. Now, we will go through these steps one by one before cleaning and grubbing are done. There may be a requirement for some preliminary operations once you have acquired the land. What that includes is that prior to the commencement of earthwork, the site shall be cleared of any obstructions, and whatever right-of-way is available to us should be made available for the construction activities, including buildings. So, we may have to clear the existing obstructions, which may include some buildings.

So, land acquisition is there, fences have to be removed, utility lines, there may be some electric poles in the vicinity that need to be removed, abandoned drainage structures, old drainage structures may be there, and vegetation, trees, roots, undergrowth, grass, rubbish, etc., other materials are there to be removed within limits as per the requirements of the project. So, as per your design requirements or the designs given for that particular project, you have to acquire the land and clear it of all kinds of obstructions. When we are removing, specifically when we are removing trees and undergrowth adjacent to the earthwork, which raises concerns in different ways, it is often quite

important to remove these particular establishments or to remove the trees that are near your construction site within the construction area. For some of the following reasons, we need to have adequate sight distance.

If one is travelling on this particular road and there are some obstructing trees, one will not be able to see the person coming from the other direction. So, we need to make the line of sight clear, and an adequate line of sight should be made available. So, specifically at intersections, if I place some obstacles here. So, one coming from this particular side may not be able to see what is there from this particular side. So, you need to make the line of sight clear, and for this particular one, you may have to remove some of the adjacent structures, or you may have to remove some trees or other obstacle poles that are present there.

First is to provide adequate sight distance; second is that the landscape has to be improved. Once a new alignment is there, the landscape has to be improved. So that in the nearby vicinity, you are able to see what the existing features are. So, for the improvement of the landscape and to offer views of nearby scenic attractions, it may be required to remove. To remove dead or decaying trees because if there are old trees that are dead, there is a chance they may fall onto the road surface at a later stage, and any obstruction that hampers the drainage of the road surface needs to be removed.

Another part is to permit access because during construction, there will be a lot of movement of construction vehicles, and you have to collect materials; it may be the soil from nearby borrow pits. Then, you may also have to remove some of the existing trees or some of the permanent obstacles there. So, these are some primary requirements that are present. Now, once the site is made clear, the cleaning and grubbing need to start, and the removal and disposal of unsuitable materials specifically involve exactly where you are going to have your formation width or where the pavement crust is to be constructed. So, unsuitable materials may be in the form of trees, bushes, stems, roots, grass, weeds, and organic topsoil.

And specifically, this organic topsoil is typically removed to a depth of around 15 centimeters. And if it is found to be good enough, we will store it. We will store it, keep it nearby, and use it in later stages, specifically for covering the side slopes, because the growth of vegetation over the side slopes will be good enough to make them more stable. So, that is why if the topsoil is good, we will store it for later use to protect our slopes. So, we will remove this particular one from the areas designated for embankments and drains because we will have side drains.

So, specifically up to where the edges of your embankments will come, we will proceed with this particular cleaning and grubbing action. So, it involves the excavation and backfilling of pits with proper compaction. Now, this is again important because when these trees are uprooted, pits will be formed, and they need to be filled back and compacted. So, proper measures have to be in place because there may be large chunks of trees with a diameter of even 2 or 3 meters or more, and if they are removed, those pits that are formed need to be properly filled and compacted. They should not be loose; that particular portion should not be filled with loose soil and should not remain uncompacted.

Cleaning and grubbing must be performed in advance of your earthwork commencement because you need to make your site ready for the placement of your embankment or subgrade layers. Now,

it says that if the site has thick vegetation roots, we have a crawler or a pneumatic tire dozer. This is an example; this is how it is getting cleared. So, we can use, and we will discuss in the next part of this particular talk, where we will discuss the construction equipment. This is a dozer; it can be a crawler type or a pneumatic type depending on the site conditions and the soil conditions.

Often, adequate capacity can be used for cleaning purposes. See, this crawler is clearing the existing site; it is doing the cleaning and grabbing exercise. So, the dozer shell has ripper attachments for the removal of tree stems. You can see this is the ripper attachment, which can be there and which helps us to remove any amount of tree stems or any organic matter that is present. All tree stumps, etc., falling within the excavation and fill lines shall be cut to such a depth below ground level that in no case shall they fall within 50 centimeters of the bottom of your subgrade.

So, this needs to be ensured that at least the next 50 centimeters of the bottom of your subgrade should be made clear of all these kinds of conditions. Now, sufficient removal should be made to provide proper grades and connections with the new work, and many times, when we go for the widening parts, we go for the widening parts. So, there we are again because the construction work has to be taken up. So, we will do this particular exercise for a sufficient width to accommodate those works. The equipment used during cleaning, clearing, and grabbing operations includes a dozer, motor grader, hydraulic excavator, backhoe loader, ripper, and tipper truck.

We will discuss this particular one as mentioned in the second part of this video. A good detail regarding this construction equipment is available in the IRC pocket book for road construction. Now, once cleaning and grabbing are done, the important aspect that comes up is the fixing of lines and levels of the roads. This is important: after the site has been cleared, the lines and levels of the road, side slopes, drains, carriageway, and shoulders should be carefully marked and checked. So, this now comes to the exercise of the surveyor team.

They are going to put up these lines and levels with the help of the different kinds of pegs that we are going to place here in this particular one. And we need to ensure that the correct slopes and cross-sections are obtained everywhere. So, because there may be horizontal curves as well, there may be vertical curves as well. So, we need to ensure that the correct slope and cross sections are placed along the alignment of your road section. To facilitate the setting out of works, the centerline of the carriageway or highway must be accurately marked.

This is an important part. That this is the center line of the road. So, we need to accurately mark the center line, and this can be done with the help of these better pegs that are available. So, we can place those pegs here; it is also seen that with respect to the center line of it. We are at 20 to 25 meters; we can place reference pegs and angle iron in concrete. So, these better pegs can be placed at what distances? See if you are going for an embankment construction.

This is the height that is to be attained. Now, with respect to this, the slope that is to be maintained will allow for placing some better packs here while keeping a margin. So, these better packs will help us ensure that the land in which the construction is to be taken up and the alignment are properly maintained throughout the phase of construction. The limits of the embankment subgrade shall be marked by placing batter packs on both sides at regular intervals. The embankment subgrade shall be constructed wider than the design dimensions to allow for proper compaction, as

it is difficult to compact the edges, and the natural slopes that are formed may not have adequate density.

So, if I need to do this particular one, what I can do is construct it into a wider one, and then I can remove this particular one. So, I will have this one; I will have these slopes properly compacted. So, this is much advised. So, it is said that they shall be constructed wider than the design dimensions to allow for the trimming of excess material, which can be done at a later stage. Ensuring the finished section achieves the required density.

You should have the required density, especially at the edges, which are a challenging part, and it should not be less than what we have in the middle sections, to achieve the required density alignment and the specified side slopes. So, this is an important exercise in setting out your centerline and the margins for your construction activities. So, this involves the activity of the surveyor team in the construction process. Now, thereafter comes the dewatering exercise if there is some existing water, waterlogging, or standing water. So, if the foundation of the embankment is an area with stagnant water, it should preferably be removed; specifically, we can pump out the water in order to make that particular embankment foundation dry enough.

Now, during this particular one, we should take care that pumping out the water does not damage any nearby crops, any nearby works, or any property that is close to your construction activity. And for waterlogged areas, some measures are prominently suggested specifically by IRC 34-2011. It says that one way we can address this, especially in the case of waterlogged areas, is by depressing the level of subsoil water through some drainage measures; some deep drains can be provided. Second is by raising the embankment, and third is by capillary cutoff; these are given by IRC 34-2011.

I will discuss some of them here. So, one way to reduce the subsoil water level is by depressing it through drainage measures. Here you can see this by providing drainage channels; we have provided the drainage channels at the end, which are deep enough, specifically at a depth of 1.5 to 1.8 meters. So, these are highly deep drainage channels that have been provided on both sides below ground level near the road embankment.

Now, this will have to lower the water table and keep the subgrade above the capillary fringe. So, this is one way we have in this particular case: in these deep drains, we have weepholes that are to be kept at a distance of around 0.75 meters from the depth of these drainage channels. Here you can see the slope is one vertical to two horizontal, which is mentioned here. So, this is one way in which we can lower it down because the water will enter here and move out.

So, we are trying to lower the water that is present in the subsoil. Second, we can go for the raising of an embankment. So, the construction of this particular design of these deep drains may be quite an expensive exercise. So, the other way round may be that we can raise the embankment height, and we will raise the embankment height in such a manner that the bottom of the subgrade remains at least 1.5 meters above the highest water table or high flood water level.

So, this is again, if this is the high flood level, we will preferably try to raise the embankment in such a manner that the bottom of your subgrade is at least 1.5 meters above the subgrade bottom.

So, this is another exercise in which we can protect our embankment, or specifically the subgrade, from the high flood level because we know that if the subgrade becomes indented or submerged, then there will be a loss of strength, and this will lead to some failures in your pavement structure. Now, the other measure that is normally taken in certain circumstances is the capillary cut-off because whenever there is a high flood level, some water rises through the capillary fringes; with capillary action, it rises to a certain level, and this rise will be especially pronounced in the case of fine-grained soils.

So, we can give a capillary cut; this is an example. So, it states that where the water table is high and the soil permits rapid moisture migration by capillarity, there is a granular layer or a geocomposite. Now, here, a capillary cut-off can take the form of a granular layer. This granular layer is provided here; you can see that this granular layer is provided here. So, you have this high-water flood level, which is at least to a height of around 15 centimeters; we are going to provide this capillary cut-off, which is a granular layer. And this is your capillary cutoff, and now what we are doing with this, with respect to it, is that whatever water we are going to have from the capillary rise from this high flood level will be captured through this particular one and will be taken out.

So, we will not allow it to reach your subgrade level. So, it is mentioned that it should not be less than the height of this particular one between the bottom of the subgrade and the capillary cut-off; at least a distance of 0.6 meters should be there. So, in addition to this granular layer, we can go for a geocomposite one. A geocomposite can be a geomembrane on the underside because it allows water and a geotextile filter on the upper layer.

So, it will act as a filter as well as a separation layer. So, a geocomposite can also be done, but this one is preferably done when there is new construction, because laying a capillary cut-off is possible when you are doing it for new construction. The capillary cut-off shall extend across the full width of the embankment, and this is another important aspect; it should extend to the entire width, and it should have a proper slope as well. So, during the construction of the embankment, a proper slope should also be maintained because when you are going to put up the capillary cutoff layer, it is only with the help of the slope that the water will come out through this capillary cutoff layer. The surface on which the capillary cutoff is provided shall be maintained with a minimum cross-fall to ensure effective drainage. And what type of materials can be used, and what thicknesses have been recommended? This is again given as per IRC 36 2010, which states that if you have a subgrade of 0.6 to 1 meter above the high floor level with a plasticity index greater than 5, then if we are using... A fine sand with a capillary cutoff of 425 microns to 2 mm requires a thickness of 350 mm; coarse sand from 2 mm to 4.7 mm also requires this thickness. If we have a subgrade of 0.6 to 1 meter above the high flood level with a plasticity index of less than 5, specifically for sandy soils with sand content of not less than 50 percent, this thickness will be maintained. Different thicknesses have been recommended as per IRC 36 for the capillary cutoff layers. Now, once the dewatering action has been completed and before you start with the construction as mentioned, you will preferably store the topsoil from cutting areas and embankment foundations to be stripped to a specified depth, normally 15 centimeters, and stockpiled to a height not greater than 2 meters for later use, specifically if it is good enough for embankment slopes, cut slopes, and other disturbed areas, because re-vegetation is required to make your slopes stable. Many times, you may have to select some materials from the borrow areas because the existing soil may not be sufficient or may

not be good enough to meet all your requirements. In that case, since you may have to raise your level, the quantity required is more, which is good enough.

So, then you have to. You will try to select a nearby borrow area only, and while selecting this borrow area, certain precautions have to be taken. So, borrow areas are when earth is borrowed from land near the embankment. The following principles are generally followed for the location, depth, and drainage of borrow pits. Certain aspects need to be addressed if construction is to take place here, and I need to select a borrow area. So, you can see that a borrow pit needs to be selected, which states that the use of earth mainly available from road cuttings and excavations is recommended.

Whatever you are getting through the cuts in the cutting areas or through excavations, try to use that particular one first. If that is not found suitable or is insufficient, then we will go for borrow pits, preferably rectangular in shape, with one side parallel to the centerline. This is another side of it; if this is our center line, this will be parallel to the center line. No borrow pit should be dug within 5 meters of the toe of the final section of the road pavement. This is another important aspect that, within the toe of this particular one, should be at least 5 meters away from the toe of your embankment.

It should not be very close to your embankment's toe. The depth of the borrow pit should be regulated so that the borrow pits do not cut an imaginary line, and the other aspect is that the edges should be arranged in such a manner that if we draw an imaginary line with a slope of 1 to 4, it should not cut into the borrow area. So, this is an image of what I am doing; say, this is the widening part, which is to be attempted, and this is the width up to which it is attempted. Then, an imaginary line is drawn here with a slope of 1 to 4, and this should not cut the borrow area. So, this is again to make your structure stable enough. So, it says the depth of the borrow pit should be regulated so that borrow pits do not cut an imaginary line having a slope of 1 vertical to 4 horizontal, protected from the toe of final selection of the bank.

So, this is to be finally selected for this embankment bank, which is being created. Now, when we are going to place the layers, the existing line needs to be compacted. So, the first layer, whether it is the first layer of embankment or the first layer of your subgrade, the foundation over which it has to come up also needs to be compacted. So, what is compaction and why is it important? Compaction forms a very important activity in any of the road construction activities, whether it is the construction of the embankment, subgrade, granular courses, or bituminous-bound courses. So, compaction plays a very important role, and the primary purpose of soil compaction is to enhance engineering properties by increasing density.

When we do compaction, we increase the density, making it strong enough to resist deformation under applied loads. So, we are enhancing the density with the compaction given to the soil. Now, the prime principle properties affected by compaction, as stipulated in the IRC SP 97 2013 guidelines on compaction equipment for roadworks, are mentioned here. What we get out of the compaction or the enhancement, which is expected from the compaction, is an enhancement in the structural strength, an enhancement in the load-bearing capacity, and stability of the fills. When a lot of filling has to be done, the stability of the fills is present.

It makes it impermeable, so that the water does not enter your pavement structure easily. So, when you increase the density, impermeability increases. It does not allow water to easily enter your pavement structure, and the shear strength of the soil increases. Poor compaction will have more deformation under the wheel loads, while good compaction will have less deformation. Poor compaction will make your soil more susceptible to freezing actions and freeze-thaw actions compared to well-compacted soil.

Even poorly compacted soils will increase permeability and make your surface more permeable to water compared to a well-compacted soil layer. So, we will first prepare the foundation over whichever embankment or subgrade layers have to be laid. So, the original ground shall first be leveled to facilitate the placement of the first layer of the embankment.

So, we can scarify it. So, we can initially scarify the top layer. Mixed with water and then compacted by rolling to achieve the required density. If it is already an existing embankment, it needs to be recompact because that compaction might have been done a few days before. So, you may have to recompact that particular one, and when we recompact it, we actually try to get certain targeted densities. It says that when embankments are to be constructed, embankments up to 3 meters in height should not have a density of less than 1.52 grams per cc, or when embankments exceeding 3 meters in height are present, the density is not typically for fly ash; for fly ash, the requirements are different.

This is typically for when the embankments are constructed using soil. So, here when the height of the embankment is more than 3 meters, the density should be greater than 16 kilonewtons per cubic meter, and when it is to be used in subgrade, it has to have a density of more than 17.5 kilonewtons per cubic meter. So, this is the laboratory-determined density at a given optimum moisture content. Now, the density that is to be achieved will be a percentage of the maximum density that we obtain in the laboratory. So, if the difference between the subgrade level and the natural ground level, which is there, and the top of the subgrade is less than 0.5 meters, there may be another important aspect. If this difference is less than 0.5 meters, you need to cut it down. This is your top level and the existing ground level. So, here in this particular case, what will happen is that I will show you if this is my existing ground level, and after compaction, this upgraded top should be here. So, the existing ground level is then the difference between this particular one, if it is less than 0.5 meters. Then I have to cut it down; for this particular subgrade, I have to cut down the entire natural soil. It has to be broad, and then I will do the recompaction of this entire 0.5 meter. I will not leave this layer, which is within this 0.5-meter thickness, re-compacted, because I need to ensure the density and composition of this particular material in this 0.5 meter of thickness. So, it says that if the difference between the top of the subgrade level and the ground level is less than 0.5 meters. The ground does not achieve 95 percent of its relative density because, as I mentioned in the field, you have to achieve a percentage of your laboratory compacted density. So, for subgrades, it says it should not be less than 97 percent; for embankments, it says it should not be less than 95 percent. And then there are expensive clays in the subgrade, and 500 portions just below the subgrade; these are not allowed, but when it comes to the remaining portion of the embankment, it can be 90 to 95 percent.

So, anything just near or under the subgrade will be your embankment, and that should not have a density less than 95 percent of its maximum dry density. So, we need to ensure that it is not compacted; if it is subgrade and the natural ground level and the subgrade top have no difference, then I need to ensure that this entire amount is to be added to 97 percent of my elaborated maximum dry density. So, with respect, it shall be loosened up to 0.5 meters below the subgrade level and then watered; for re-compacting, I need to add the required amount of moisture to achieve the optimum moisture content, and then it shall be compacted in layers. So, there may be a case in which your subgrade top may be very close to the existing ground level.

So, in that case, you have to cut it down and bring it down to a depth of 0.5 meters; the entire soil has to be cut down, and then the construction has to be brought up from this particular thickness to your subgrade top. Here, when you are spreading the material, one important aspect is how you spread it and how you reach your optimum moisture content. So, embankment and subgrade material should be spread uniformly in layers, and a particular layer thickness should be followed, depending on your compaction equipment and how much they can compact in one go. So, uniformly spread in layers across the full width, preferably using a motor grader, this is again when we will discuss construction equipment; we will discuss this in detail.

This is a motor grader which has a blade, which has a movable blade. So, it can spread the soil, and it can help you maintain the grade as well as the cross slope. So, this helps us to uniformly spread your soil to the entire thickness and width and helps you to maintain the grade as well. The graded blade must have hydraulic controls because it can adjust the angle and initiate maintenance of the specified slope and grade, as we prefer to do it from the subgrade itself; otherwise, if a rainfall event occurs, waterlogging will happen. So, we will try to maintain our grades and cross slopes during the construction of the subgrade itself.

Each compacted layer shall be finished parallel to the embankment's final cross-section. So, when there is an embankment, we will do this final foundation construction at the required cross slopes. When using a vibratory roller, consider how much layer thickness you can put down in one go because it depends on the compaction equipment that is available. If we are using a vibratory soil compactor, we can go for a compaction thickness of around 250 mm. This is the compacted layer's thickness. The loose layer thickness will be a bit more than this, and this is how much the loose layer thickness will be to achieve the compacted thickness of 250 mm for trial stretches.

So, trial stretches of a particular length can be laid out in the field, watered, and then we look at how much compactive effort from different passes is required to reach this laying. The decision on the compaction is very important if it is done, or very useful if it is done with the help of the trial stretches. So, for different types of soils, we will go for trial stretches; we will put those soils in place, and we will decide how much compactive effort and how many passes of a particular type of roller are to be applied over the soil layer to achieve the desired compacted thickness. So, you will put down the loose layer, and it says that if you are using a vibratory soil compactor, it can be particularly good enough to compact to a thickness of 250 mm. If there is a static 80 to 100 kilo Newton roller, then you should preferably go for a compacted thickness of 20 centimeters (200 mm).

Now, for this particular one, once the loose soil is spread over the foundation or the bed that has been prepared for it. So, it is an embankment layer, or it is a subgrade level; once the foundation is prepared, the loose soil is put over it, spread with the help of a grader or dozer, and then the requirement comes to see what the current moisture content is in that particular soil. So, the moisture content of each layer has to be checked in accordance with IS 2720 Part 2 and shall be adjusted. Now, it needs to be adjusted to achieve a range that is 1 to 1 percent above and 2 percent below the optimum moisture content because there may be some loss of moisture due to evaporation. So, we will try to keep this particular one, which is at least plus 1 percent to minus 2 percent of your optimum moisture content, which was derived through IS 2720 Part A, which is for heavy compaction through the Proctor test.

So, if the optimum moisture content derived was 10 percent, we will try to go from 9 to, say, 12 percent in that case. We will ensure that if it is not there, and if we find that the water content is low, we will need to sprinkle water over it, which is done through a water tanker fitted with sprinklers. So, they have to have a uniform distribution of this particular item. Now to the entire bed, and then we can do some remixing of this water again, if required, with this particular water in the soil and thereafter. So, once this particular one is done, there may be certain cases where the soil may have a much higher moisture content than its optimum moisture content.

So, we have to leave it uncompacted; we have to aerate it for a given period of time so that the excess moisture content is lost through evaporation, and then the compaction process has to start. And we need to ensure that during this, a uniform sprinkling of water is happening; there should be no flooding, because if flooding occurs, then flooding may happen again if the proper camber is not present. In that particular case, we also need to ensure that if, at certain locations, some excess water has been applied, then that particular section or part of that stretch needs to be aerated to bring down the moisture content to the required level for your compaction. And as I mentioned, once this particular water has been added, we can mix it with the help of the graded blades, or it can be mixed with the help of disc harrows, which are quite often used specifically when you are mixing soil. So, this can be used once you have spread that particular water disc harrow, which can give a uniform mixing of it, and then you can use the graders again to put up the soil to the required cross slopes.

So, you can see these disc arrows are mixing the water with the soil, and then you can have these graders which can bring this soil with the required moisture content to the required grades at that particular level. So, after watering, the soil has to be processed using graders, harrows, rotary mixers, or other approved methods to ensure uniform wetting. Now that this exercise is completed, the compaction comes. So, this compaction can be done, as I said, with the vibratory rollers or with the static rollers, depending upon the compacted thickness. Vibratory rollers can give you a compacted thickness of 25 centimeters, and static rollers will give you a compacted thickness that is good enough for a compacted thickness of 20 centimeters.

So, the compaction is preferably done with the help of a self-propelled single drum; this is a vibratory roller or a pad foot vibratory roller having 80 to 100 kN static weight. We will discuss these different types of construction equipment, rollers, dozers, and the arrows in the latter part of this particular talk. So, here, just to give an example, now that the soil has been brought to the cross

slope with the required amount of water, compaction needs to be started. Each layer has to be thoroughly compacted.

So, this is important: if I need to construct a subgrade with a thickness of, say, 0.5 meters, that is 50 centimeters. Now, if I have vibratory rollers with them, I can do this particular one in two. So, one may be 25 centimeters, the other may be 25 centimeters. So, for subgrade construction, if I do not have these vibratory rollers and I am going with the static rollers, then I may have to compact the layer thicknesses of 20 centimeters, compacted 20 centimeters, and the top one will be your 10 centimeters.

So instead of doing in this particular manner, the other way around I can do it. I will go for the bottom one of 20, followed by the top 30. If I am going with the static rollers, I would prefer to have them 15 centimeters and 15 centimeters. So, the remaining needs to be ensured, and each layer thickness needs to be ensured. If the density measure indicates compaction, you can see that certain loose spots are present. So, the loose spots may be present because either the moisture content was quite high during compaction, or at certain locations, the compaction was not done properly.

So, you may have to add some water again and do some re-compaction. So, at many times, if you move over the layer of the soil, you can determine from your visual examination whether this particular portion is compacted well or not. And then we definitely need to do the laboratory measurements to ensure that the density is achieved, but during the compaction process itself, through your experience, you can get an idea of whether this particular part requires more compaction or not. Once the compaction part is also complete for one particular layer. It says that the drainage and finishing operations have to come up. So, the surface of the embankment or subgrade at all times during construction shall be maintained at such a cross slope that does not flatter than required for effective drainage, as we have mentioned, even if we are using the capillary cutoff layers in new construction.

We have to maintain them at such a cross slope that is not flatter than the required effective drainage of the earthen surface, because otherwise, if it does not have a cross slope and a rainfall event happens, then the entire layer will get saturated, and it will take many days to aerate it and make it ready for the next layer. So, it is always required that you construct your subgrade layers and embankments with the required cross force. Finishing operations, now that we have completed this particular one, the slopes of the subgrade and embankment have to be done. So, the finishing operations typically involve shaping and dressing the shoulders, earthen shoulders, verge, road bed, and the side slopes to conform to the alignments. As we have mentioned, we need to ensure the side slopes are at the required levels and are according to the cross sections.

So, they are shown on the drawings. Both the upper and lower ends of the side slopes, the upper end, and the lower end are to be rounded off. This is again important. They should not have sharp ends at the top as well as at the bottom to improve appearance and to merge with the embankment and the adjacent terrain.

So, this is important. This is also good for stability. And as we mentioned during cleaning and grubbing, the topsoil, which we have removed, if it is good for vegetation growth, will be placed over these side slopes, and this will help us facilitate the growth of the vegetation; typically, it is

laid in a thickness of around 75 to 150 mm. So, this is how the operations involved in the construction of a subgrade begin: we start with clearing the site, then we do the cleaning and grading, and we set the central line. Then, we are going to ensure the making of the foundation for putting up the layers of embankment subgrade, where individual layers of soil are to be layered; then, the soil has to be ensured for the required moisture content; thereafter, the compaction has to be done over it. So, these are some of the salient points that are involved in the construction of subgrade. Thank you.