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A very warm welcome to all of you. I am Rajan Chaudhary, Professor in the Department of Civil Engineering, Indian Institute of Technology, Guwahati. Instructor for the NPTEL MOOC course, Payment Construction and Technology, funded by the Ministry of Education, Government of India. This lecture will be a part of Module 2 under Lecture 4 on Unbound Courses and Their Functions. 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. Now, under the unbound courses, especially covering the sub-base and the base courses, we also discussed the major courses in the previous lecture.

So, there are five different categories under which it can be grouped. So, the first one is that you have, immediately above the subgrade course, the granular sub-base course. The granular sub-base course, if it is unbound and contains no cementing material, is an unbound granular sub-base course. Water-bound macadam is also a kind of course that is used as a sub-base course or a base course.

Base course is the one that follows the sub-base course in the flexible pavement structure when we go from bottom to top. So, you have this subgrade here. Over the subgrade, you construct your sub-base courses, which may be bound courses or unbound courses, followed by base courses. Again, base courses can be bound courses or unbound courses, and then you have your binder courses or wearing courses, which are typically bituminous bound in the case of flexible pavements. Now, as I mentioned, the sub-base courses can be constructed using some cementitious material, which can be fly ash, cement, or any other pozzolanic material, or a combination of them; then it becomes cement-treated sub-base courses.

So, another common course that is used as a base course and is unbound in nature is our wet mix macadam course. So, it is the wet mix macadam base course, which is used; it is an unbound course that is used as a base course. Now, this unbound course, as we discussed in the previous discussion, includes these four courses. Now, if some cementitious agent is used within the base courses, then it will be a cement-treated base course. So, we will see some features of the cement-treated base course.

Now, in terms of material composition, it states that the MoRTH classification or IRC along with IRC 37-2018 states that cementitious base layers typically consist of aggregates and reclaimed asphalt material, which is older asphalt pavements. If they are scrapped out and that material is used again, we call it reclaimed asphalt pavement, or the abbreviation is RAP. You can use crushed slag nowadays; this is an industrial byproduct. Steel industries generate a lot of slag that

can be crushed and used in the construction of base courses. Crushed concrete aggregates are available if there is some building construction waste.

So, those aggregates can be crushed down and used in a cementitious material. Your cement-bounded base courses or soil aggregate mixture stabilized with chemical stabilizers. This is the important aspect we need to look at: what kind of stabilizing additives can be used. So, as I mentioned, any material that has some pozzolanic characteristics, such as cement, lime, fly ash, or a combination of these, or any other chemical additive that can bind these materials together, will be considered under the category of cement-treated base courses. This is what IRC 37-2018 states.

Now, the important aspects of these products should be that the material which is to be used as a base course should either be prepared by plant mixing. So, there should be a wet mix plant if I am using wet mix macadam, the unbound course wet mix macadam. So, it should be a plant produced or mechanized in an in-situ mixing process that should be the mechanized one. So, so as to achieve a controlled characteristics that is why mechanized one. And another requirement states that the minimum thickness of the layer in the case of cement-treated base courses should be at least 100 mm.

Now, this picture shows a cement-treated base course that has been constructed. Now, normally, these courses may develop some final cracks during the course of life. So, to prevent those cracks from moving to the top layer. The top layers over these base courses will normally have bituminous bound courses. So, to address these cracks at the level of the base courses, a crack relief layer is provided.

So, it says that in the case of pavements with a cement-treated base course, a crack relief layer is provided between the bituminous layer and the cementitious base, which delays the reflection of cracks from the cement-treated base layer to the bituminous layer. Now, what is this crack relief layer that is there? Normally, you can also go with an aggregate layer. A crack relief layer can be in the form of an aggregate layer, which may have a thickness of about 100 mm, and we can use the gradation that is even recommended for wet mix macadam. So, a 100 mm aggregate layer or other gradations specified by MoRTH can be used as a crack relief layer. In addition to this particular one, we also go for a stress-absorbing membrane interlayer.

We call it SAMI, stress-absorbing membrane interlayer. So, this is another one. What is this? It is an elastomeric modified bitumen that is normally sprayed on the surface at a rate of around 10 to 12 kg per square meter, and then aggregate chips are applied over it. When this stress-absorbing membrane interlayer is present, it is because a high content of elastomeric modified bitumen is applied. So, it arrests the cracks from moving to the upper layers, and a similar function is performed with the help of an aggregate crack relief layer.

So, these are the important considerations that need to be taken care of when you are utilizing a cement-treated base course in the construction of flexible pavements. Now, as per the gradation requirements, the CTB layer cement-rated base layer should have an aggregate gradation as per Table 404, which is recommended by more specifications, and here in the last lecture, as we discussed NMAS, any sieve size from which some material passes. So, here you see that 37.5 is

your nominal maximum aggregate size. Now, it says that the layer thickness should be at least 2.5 times your NMAAS. So, this will be less than 100 mm, and that is what is recommended if you go for a cement-treated base layer; it should have a thickness of at least 100 mm; that is why it can accommodate this kind of aggregate gradation. Now, in addition to the strength perspective, when we look for the characterization of materials, we also examine those characteristics again just for information, because, since it is a cement-stabilized course, it needs to meet some minimum requirements of unconfined compressive strength. And which states that the unconfined compressive strength, or UCS, when tested as per IRC 89, applies to soil and granular materials stabilized using cement, lime, and fly ash. This is the IRC codal specification 89, which says that the unconfined strength of cement-treated base core should be 4.5 to 7 megapascals for curing periods of 7 and 28 days, respectively, which was 1.5 to around 3 megapascals at 7 days of curing when it was for the cement-treated sub-base courses. So, there are specific requirements related to strength. So, it should have a gain in strength of around 4.5 at 7 days and 7 at 28 days. In addition to this particular one, since when we are designing these mixes at the laboratory scale, it is a controlled design.

So, we always put a restriction on it that the average laboratory strength values for cement-treated base coat should be at least 1.5 times the required minimum. So, at the laboratory when you are designing, you should get at least a value that is 1.5 times what you are looking for in the field's minimum values. So, this needs to be ensured again because that controlled environment definitely cannot be replicated in the field.

So, we want to have a factor of safety, which is why we want to have the laboratory strength at least 1.5 times what we have in the field. Now, there are advantages to using these cement-treated base courses because they are stronger layers, they are stiffer layers, and they allow the distribution of a load over a wider area. So, this is because the strength is greater; you can go with a smaller thickness of base courses compared to the thickness required when these are unbound courses. So, you require fewer materials, especially fewer aggregates, when you are constructing the cement-treated base courses.

But yes, the cost is added through the incorporation of any binding material, which includes your cement, lime, and fly ash, that adds to the cost. But the aggregate quantity that is required gets reduced. So, depending on the requirements and the site-specific or region-specific challenges. For the requirements of the projects in terms of the design traffic it is going to carry, we can select a solution to use a cement treated base course. So, as I mentioned, cement-treated base courses have a thickness typically lower than those needed for granular bases supporting similar traffic loads, as the load is spread over a larger surface area because of their higher stiffness and strength.

Now, coming to the general functions of unbound courses, the focus will mainly be on them because nowadays we frequently use bound courses in base courses, such as cement-treated base courses. So, the important unbound course in a flexible pavement structure is your sub base courses. Now, what helps in particular is that if I mention here my compacted subgrade followed by a subbase, which is most likely to be in an unbound state with a granular course, then you have a base course, and on top, you have a wearing or surface course. Now, this particular sub-base

course, you can see, is an open gradation; this particular subgrade is there. What it serves to do is protect, because the wheel load is going to come and get distributed over the subgrade.

So, it adds to the strength of your pavement's crust. So, it protects the subgrade from overstressing. Sub-base provides strong support, and now, as I mentioned, since you move in the base courses, you need to have mechanized construction. So, there may be pavers who come upon your sub-base courses to lay your base courses, which may be cement-treated or non-bound granular courses in terms of your wet mix macadam. So, it provides strong support for the construction and compaction of the base courses and the upper courses of the pavement structure.

The one major function served by this particular layer is the drainage of surface water. This is an important aspect of water, which we will discuss regarding the possibilities if it enters into the pavement structure; it has to be removed through the pavement structure, and that purpose is served through your unbound granular courses. So, this is one major importance. And so it serves as a drainage and a filter layer. We normally mention names such as drainage layer, filter layer, and separation layer.

So, the separation layer can be between a sub base and a subgrade. So that it separates through two materials. Defiance of your subgrade should not penetrate into the coarser aggregate structure of your sub-base course. So, that can be done using a separation layer. But I want the water to move from the subgrade; if there is any water in the subgrade that has entered for any reason, then it needs to move up through capillary rise.

So, I will require a material that allows the movement of water, but does not allow the movement of the fines. So, that kind of purpose can be served through a filtration layer that allows the movement of water. So, the water can move up to the upper granular layer which has a greater amount of voids and spaces for the movement of water. So, if any water that comes from your subgrade goes to this particular layer, it then comes out because it has an easy path to move out from the pavement structure. So, that particular layer that allows the movement of water will form your filtration layer.

This particular layer, which is specifically designed for drainage, forms your drainage layer because it has a high permeability. So, that forms your drainage layer. So, it conserves the multipurpose purpose as it serves the purpose of different types of gradations of granular course; that is why it is recommended. When we discussed it in the last lecture, we mentioned that MoRTH recommends 6 gradations for granular sub-base courses. The reason for these 6 gradations is that different gradations are used for different specific purposes.

So, this course also prevents the intrusion of soil grains from the subgrade into the base course layered above and counteracts frost sections. Because if the water does not go from the pavement structure, it moves through the capillary rise and capillary streams, goes to the base courses, and then when it rises, it freezes due to the lower temperatures on the pavement surface, which may lead to damages related to frost; freezing and thawing-related damages can occur because of this. Now, it is very important to understand the drainage of a pavement structure. One is the surface drainage, and the second is the subsurface drainage. Surface drainage is easy to understand in these terms because you can visualize it; you can see how it is happening.

So, any surface of pavement that the rainwater comes over should allow the water to move out quickly if the water drains quickly with the help of your camber or cross slope. Now, for this particular one, what do we do? First of all, we prepare surfaces that are dense and impermeable. So, whatever water falls does not remain. We provide a camber and a cross slope so that the water falls over them; with the help of the camber and cross slope, it goes to the side. So, these are measures, and then they need to be collected in some side drains and ultimately taken up to some exit facilities, which may be in terms of some culverts or any other measures for taking this longitudinal drain water away from the pavement structure.

So, this is what we see from the surface point of view: the surface drainage is there. So, water can infiltrate the pavement through surface cracks, but even in this particular case, there are chances that water may seep down. Now, this is a sealed surface, but there are chances that arise. In due course of time, during the life of the pavement, some cracks may appear on the pavement surface. In addition to this particular one, you may have these earthen shoulders that may not be properly constructed.

So, water may enter through these earthen shoulders, go down, and enter your pavement structure. Water, because of the high water table and high flood level, may reach your subgrade, causing it to rise to your pavement crust. So, this is another reason that can lead to your ingress of water. So, now my purpose is that whatever water is on the top should be moved out quickly, and whatever water enters my pavement structure by any means should also be taken or removed quickly from the surface. So, water can infiltrate the pavement through surface cracks, joints, and shoulders when the medians are constructed; when we widen the pavement, joints are constructed in that case.

Even with surface drainage measures and relatively watertight surfacing, water may penetrate through cracks and accumulate at the interface of the sub-base, base courses, and subgrade, where it can pool and stand in your granular courses or subgrade. This accumulation causes both structural damage and functional issues with these courses because, when it moves down, it carries the fines with it. So, again there are chances that the gradation changes when it moves down; it strips the binder from your bounded courses. So, it damages the structural integrity of your bound courses as well. Internal drainage of the pavement is primarily handled by the granular sub-base course or by providing some dedicated drainage layers.

We will see how that is done. Now, the main measures taken for providing surface and subsurface drainage are, as I said, for the structural integrity and functionality of this system, and my purpose is to prevent water from entering the subgrade or my granular courses during the service life. Now, for this one, the best measure for the surface is to provide a good camber and a cross slope, along with a dense and impermeable surface. So, you can see here a lot of rain is coming up; my surface is good enough. This is an exaggerated view; this slope is very high.

Normally, we go for a slope of 1.5 to 2 percent. So, it is an impermeable surface; water falls over it, camber is given, and it moves to the side. So, your surface is free; you can drive there are no chances of skidding, it does not damage your it quickly moves out of the surface. Now, again, what we do for the purpose of subsurface drainage is extend the granular surface course across

the full formation width. So, here you can see if this is a cross section, which is shown here. Now, this particular lower part, which I am showing with the vertical lines, is your embankment.

So, you have raised it to a height; this is what your subgrade is, compacted subgrade, which we normally consider with a thickness of 50 mm. On top of it, when we construct the granular sub-base courses, this is the granular sub-base course. This granular sub-base course, where the view is somewhat more challenging to explain. So, this sub-base course material has to be extended to the daylighted edges. Whatever sub-base coarse material is to be extended to the daylighted edges.

If I am giving a drainage layer, then this is the entire color that I am showing as a dark layer. So, if any water that comes from the top, from the bottom, or enters from the sides, when it goes to the drainage layer, because of the cross slope and the amount of air void connectivity, which has high permeability, it goes to this particular layer, and with the help of the camber, it comes out of your pavement structure, providing us with a dedicated surface layer, or I have extended the granular sub-base course, part of it, to the open edges of your crust. Ensuring the formation level is sufficiently elevated is one important aspect; whenever you construct these new structures, you must always ensure that you construct them well above the high flood level. This was already discussed in the earlier lectures. If this is not done, if adequate surface and subsurface drainage is not provided, then what happens? It damages your surface water, cracks your upper layers, and if this saturation is present, it strips the binding agent, especially bitumen, from your aggregates.

So, it says that water in the asphalt course can lead to moisture damage, modulus reduction, loss of tensile strength, and the dry modulus of the asphalt layer can be reduced by as much as 30 percent. That is why it is always said that bituminous pavements are susceptible to water, but they are especially susceptible when not done in the proper manner. If you provide a dense, impermeable surface with a good camber, there is no harm. It has served for years. It serves very conveniently with a good service life for the entire design life.

Modulus, and it even says modulus reductions of up to 30 percent can be expected for at least asphalt rated as a cement-rated base course. I can construct some courses using another binding agent instead of cement; it may be asphalt. So, there you can also get a reduction of 30 percent. Added moisture to unbound aggregate and base. So, when it goes to your lower layers, which are base courses and sub-base courses, a loss of stiffness of the order of 50 percent or more is expected.

When the water goes to these granular courses, they lose their strength and the loss of strength is up to 50 percent. So, see how challenging it is if you do not have a proper surface and subsurface drainage available to you. Saturated fine-grained roadbed soils could experience even a modulus of reduction. Similarly, it results in a significant reduction of 50 percent in your subgrade soils, also due to the intrusion of water. So, my purpose is to take care of the surface drainage; I need to take care of the subsurface drainage in a good manner.

One example I can give you now in a better manner is that this is your subgrade, and over the top, you construct this particular one as a layer, which is mentioned here as a filter layer. So, this separates your subgrade from your drainage layer, and on top of it, this is your drainage layer;

this vertical line is your drainage layer, and the bottommost is your subgrade. So, I am adding a filter layer here. This filter layer separates my drainage layer from the subgrade, does not allow any intrusion of fines from my subgrade to the drainage layer, but allows the flow of water. So, it has permeability, but it is low compared to your drainage layer.

So, this water from the subgrade will pass through; if any enters, it will go through capillary rise through this filter layer and will come up to this drainage layer, which is now exposed at the edges. Now, here you can see they are extended to the entire formation width; formation width includes your carriageway and the shoulders as well. So, even for the other shoulders, the granular courses are extended as well. At these edges, it is normally said that if they are kept as unbound materials, then there is a chance of failure.

So, that is why it says that 0.5 meters should be stabilized with some 2.5 percent emulsion or 2 percent cement. So, this small width needs to be stabilized so that the edges do not get disturbed. Otherwise, when they are open, they get disturbed because of the side slopes. Now, here again you can see this is what it mentions: that you have a shoulder, you have a shoulder; this is your sub-base course at the bottom of the shoulder.

Again, whatever material is there, this is your open-graded base course. So, you have this perforated item; I will show you in this particular example, in this particular figure. You can see if some slope is present, some side slopes are there, and one pavement is constructed on this particular edge. So, what I am doing here is that I have provided a side range; these are my longitudinal ranges that are provided.

Now, this is as it is, and this is a water table. My pavement crust should be high enough with respect to the water table. Then, what I am doing is extending my drainage layer here; this is the bottom layer, which is my filter. Now here in this longitudinal drain, I am putting up drainage material, which can be an aggregate with a particular gradation, and there may also be the use of some geosynthetic liner, which I will show you in the upcoming slides, and then there is a perforated pipe. So, whatever water comes from here goes into this aggregate and it flows through this particular perforated pipe, which will have a slope. So, it will go through perforated pipes and will be taken out of the pavement structure at some culverts or drainage outlet facilities that will be created.

So, this is one way to do it. The drainage layer is there. What is a drainage layer? It is a particular kind of aggregate gradation that we take, which makes that layer capable of draining water quickly out of it. So, MoRTH says that as well as IRC 37, grading sixth of our MoRTH table, which comes under the granular sieve base course, is good enough to drain the water out of it. They recommend that grading 5 and 6 be used for the sub-base cum drainage layer. The GSB gradations 1, 2, 5, and 6 are recommended for the filter cum separation layer. And in one important aspect, it says that normally when your pavement crust is not thick enough, or you do not have a high enough amount of design traffic, and your total sub-base course thickness comes out to be only 150 mm, then you cannot provide two layers, one acting as a filtration layer and the other acting as a drainage layer.

So, you have to come up with a single layer that serves both the purpose of a filter and a drainage layer. So, that is why it states that the minimum thickness of the single filter cum drainage layer should be 150 mm for the functional requirement. So, it says that for such cases, a single drainage cum filter layer with GSB gradations of 5 and 6 can be provided, and we have to consider the N_{MAS} of it for the appropriate gradation.

As I said, the layer thickness should be 2.5 times the N_{MAS} of it. So, you need to pick up the gradation fifth or sixth, if only a filter cum drainage layer has to be provided. And if a drainage layer can serve as both a filter layer and a drainage layer, normally consisting of two layers, then the bottom one is your filter layer, the upper one will be your drainage layer, and you can choose the sixth for use as a drainage layer. Now, some additional features that we make while providing these drainage systems include a longitudinal subsurface drain, which is a cross-section of a longitudinal subsurface drain. Here, you can see this particular one; there is a geosynthetic fabric that is overlapped at the top. Now, the purpose of it is that any fines should not get trapped in or reduced; if they go inside, it will reduce the drainage capability of your gradation, which is used here.

So, these are the graded crushed aggregates that are used here; they follow a specific gradation because they need to have high permeability, and then the water is collected into these perforated pipes. So, their designs are also given as per IRC guidelines, it says IRC SP 42 is to be followed for. So, here there can be a geosynthetic, a geofilter, or a synthetic geofilter that prevents any intrusion of fines into this aggregate gradation. And here outside, we can also put a coarse sand bed.

Now, this is on the top, and you have the compacted soil. Now, this will give whatever your drains are, and the subsurface drainage layer should be connected to this particular one. Anything which is coming to this particular one, this will serve your purpose throughout the service layer. So, the chances of getting clogged are very low. Now, here you can see another feature of this particular one; this is your drainage layer. Now, how this is constructed you can see this is the drainage layer where you can see it is again; this particular one is a synthetic geofilter layer, which you can put; this is the same gradation that you have for the drainage layer.

You have the perforated pipes; this is the crushed aggregate because the drainage layer uses the same material in this particular one, and this is the perforated pipes; the perforations are shown there. Now, it moves in longitudinal direction. So, at certain locations, you have to take out this water. So, again, unperforated pipes are there that are constructed to take out the water.

So, either you have cross-drainage structures. So, this longitudinal drain goes to some cross drainage structures, which can be culverts, where the water gets moved out of this particular one. Now, unfortunately, in some cases where the provisions of subsurface drainage are not taken care of, it becomes a big problem when water enters from the top cracks or sides and accumulates in these granular courses or the subgrade, significantly reducing your strength. So, it leads to the formation of ruts and the stripping. So, we need to, but it is already constructed.

So, some measures can also be taken in those cases to improve the subsurface drainage. One provision is shown here; if this is an already constructed structure, this is the direction. If this

vertical gradient is in this direction, I can provide a side aggregate drain; I will refer to it as an aggregate drain. So, I am providing aggregate drains here. So, I have to construct in my earthen shoulders; I have to construct these aggregate drains. So, whatever water is there, if it comes to these aggregate drains and moves out through these lateral drains in that case.

So, I am having the thickness of this particular one is normally 300 mm. So, these aggregate and we have the IRC SP 42 defined what type of gradations you can use. This is another one where only the cross drains in the shoulders are shown. These are aggregate drains. So, this goes in this particular manner. So, these are features that come into play once you have already constructed a pavement structure and the subsurface drainage is not good enough; then these provisions of aggregate drains, which have specific gradations, serve the purpose of providing good permeability.

Normally, a drainage layer is expected to have a permeability of around 300 meters per day. So, a good drainage capability is required; that is why this aggregate gradation is very important to follow in the field. Now, in addition to this particular one, sometimes nowadays, with more advancements, especially in geosynthetics, we make use of geosynthetics to achieve better drainage filtration as well as separation. An example of this can be seen in this manner. Here, in lieu of an aggregate drainage layer, the geosynthetic drainage composite serves as a filter layer; it allows water to move but does not allow the fines to pass through. We have a geosynthetic at the bottom as well, so geotextile at the bottom as well, geotextile. In the middle of it, we have a geonet. Geonet is a three-dimensional structure. This is an example of it.

It has very high drainage. So, the water does not allow any fines to get trapped inside it. Water will come into it, and through this geonet, it will come out of your pavement structure. So, now in addition to the drainage, it serves the purpose of filtration, separation, and it also adds to the reinforcement of your structure. So, this is another advantage. So, it says in lieu of an aggregate drainage layer, geosynthetic drainage composites, where a geonet between two geosynthetic layers can be provided, can be used. So, here you are in a very controlled environment because the gradation has to be continuously monitored; yes, it will definitely add to the cost, but the amount of improvement in the subsurface drainage obtained to secure the life and performance of the pavement is very good.

So, it serves the purpose of separator and filter and the IRCSP 42 states what how that is to be installed. So, nowadays, geosynthetics or the combination of geosynthetics to serve the purpose of filtration, drainage, and separation layers is also becoming popular. So, with this particular one, we complete this lecture. Thank you, all of you.