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A very warm welcome to all of you. I am Rajan Chaudhary, a Professor in the Department of Civil Engineering at the Indian Institute of Technology, Guwahati, and the instructor for the NPTEL MOOC course on Pavement Construction and Technology, funded by the Ministry of Education, Government of India. Today's lecture will be lecture four under module two 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, we discussed the flexible pavement component; in the previous lectures, we discussed the subgrade course, its functions, and its characteristics. Now, the course that is followed conventionally in the construction of flexible pavement after subgrade construction is your unbound granular courses.

So, you can see this is a flexible pavement structure where at the bottom we have the compacted subgrade, and above that, we have these granular courses, which are granular base or granular sub-base courses; the one that comes immediately above the compacted subgrade is called the sub-base course. Now, we call them unbound courses because traditionally we do not use any binding material. We will also discuss certain courses that are used with some binding material. But the conventional practice says no binding material is used in the granular courses, and that is why the name is given as unbound courses.

So, the unbound courses are typically the sub-base course and the base course of a flexible pavement. So, the two courses that come over the subgrade, which is without any binding material, are the immediate one, your sub-base, followed by the one over it, your base course. And the mixes that are used for the courses that are used as unbound courses consist of the granular sub-base course, which is one course, water-bound macadam course, and cement-treated sub-base course. As I mentioned, we can use a material as a sub-base course that has a binding material; in this case, cement is the binding material. So, if fly ash or any pozzolanic material is used, then it becomes cement-treated sub-base courses.

Then, we have wet mix macadam. So, this is also an unbound course usually used as a base course. Then, in base courses, we can again have cement-treated base courses. So, this is again a cement-treated base course. So, these are four quite common, five quite common courses that are used under your sub-base courses and base courses in the construction of flexible pavements.

Coming first to the granular sub-base course, I will show you that this is a cross-section of a flexible pavement structure. Here you can see that this particular part is your compacted subgrade, or this particular one there is a course that is constructed; this is the course that is constructed. You can see this is the course that is there, and this is your granular sub-base course. Now, the granular sub-base course construction consists of laying and compacting well-graded material on a prepared subgrade. So, a well-prepared subgrade whenever this course has to come up has to be well compacted and ready for the construction of a granular course.

This granular course can be constructed in a single layer or in multiple layers depending on the requirements. The requirements are in terms of the load that is going to come, the design traffic that is going to come, or it may be in terms of the functional requirements. This granular course plays a very important role, especially in terms of the drainage of a flexible pavement structure. Whenever we talk about a flexible pavement structure, one parameter that is very, very important is your drainage. So this drainage is not only about what we are talking about; it also includes surface drainage.

When we say that the surface drainage on the top surface course or wearing course we construct should be dense enough so that any water that falls on it, with the help of the camber, goes to the side and, with the slope, gets collected in the side trenches we construct. So your surface should be dense enough. But there are chances that there may be some infiltration of water, which may take place because there may be some presence of cracks that can arise in the due course of the service life of the pavement, allowing the infiltration of water from the top surface or the earthen shoulders on the sides, so the water may percolate down. And that may allow the intrusion from the sides, and in the case of a high water table, the water may also make your subgrade saturated. So, different conditions can arise that can lead to the intrusion of water in your pavement structure as well.

Now, if there is some intrusion of water in the pavement structure, we should provide a dedicated path for the water to exit the pavement structure. If it has entered for one reason or another, then there should be a provision that allows that water to move out of the pavement structure. And that is what we are going to do with the use of these granular subbase courses. So the material to be laid is in one or more layers as a sub-base or lower layer, if I am doing the construction in terms of two layers. The lower layer will be called the lower sub-base, and the upper sub-base will be used as necessary, according to lines, grids, and cross sections, definitely whatever camber we are going to have.

So, we are going to start from the subgrade layers themselves, and as we go up, this camber or closed slope will be followed in the upper layers as well. So, the cross-section elements are to be followed from the subgrade itself, and they go up. If the thickness of the sub-base layer provided in the design permits, the sub-base layer shall have two layers: the drainage layer and the filter layer. Now, this is as per the requirements of IRC 37, which is for the design of flexible pavements. And the other, as I mentioned, the other important reference for all these construction-related works is our MoRTH specifications.

Now, what two important things are if I want a layer to serve the purpose of drainage. Any water that comes from any region from the top or any water that is coming from your subgrade. I want it to move out of my pavement structure, then I will provide a layer with high permeability or good drainage characteristics, and here you can see I have extended this particular one and provided this drain at the edges of my pavement structure, or it can be extended up to the edges so that water goes out of it and gets collected in your side drains. In both cases, we can see that this particular layer is spatially designed; spatially designed means the gradation, which is to be selected. The construction that is to be done should be such that it allows the water to move through it, and then it gets collected in the side drains, and you have these pipes that are going to take it to the nearby culverts or other water outlet facilities.

Now that this is to be there, it is to be an open gradation. Now the subgrade soil that is there can intrude into these granular courses. If it enters into granular courses, then it reduces the drainage capability or the permeability of these granular courses. So normally, whenever these granular courses are constructed, they are built in two layers. The bottom one is known as a filtration layer or a separating layer.

It separates your drainage layer from your subgrade material so that it does not allow any intrusion of fines into that granular material, thus preventing any reduction in its drainage capability. And then the upper one can serve as your drainage layer. So, I will always prefer to construct my granular sub-base courses in two layers. The bottom one will be considered a separation and filtration layer, and the upper one will be considered a drainage layer. Now, in certain cases, there may be some restrictions related to the crust thickness.

So there can be a possibility that only one layer of a granular sub-base course is to be constructed. Then, in that case, that layer has to serve both the purposes of your filtration or separation, along with your drainage purpose. So that along with that, we need to select a proper gradation so that it can act as a filtration layer. Otherwise, when we construct in two layers, the filtration layer or separation layer has low permeability and allows water to drain out to a lesser extent compared to the water that you provide through your drainage layers. The upper layer of the sub-base functions as a drainage layer to drain away any water that may enter through the surface cracks, not only from the surface cracks on your side shoulders; as we have seen, the formation width is present where you have your earthen shoulders as well.

So, it may enter from your earthen shoulders also if they are not constructed well enough, or there may be a high water table which may have occurred. Usually, we always say that the bottom of your subgrade should be at least 1.5 meters above your high flood level, but then also in certain cases, if there are some chances of water intrusion, then this sub base course should allow the water to move out of your pavement course. Otherwise, if water is present in your subgrade, subbase, or any other courses, it will lead to a reduction in the strength of that particular course. When there are bituminous bounded courses, we will later discuss the top bituminous bounded courses, and if water stays in these courses, it will result in the loss of strength because of the loss of bond between the aggregate and the binder.

And when it comes to the granular courses, they lose strength or the subgrade loses strength in the presence of water. If this happens, your subgrade will get highly stressed if the strength is lost, and there may be permanent residual deformation in your subgrade, leading to rutting or distortion that causes rutting failures in your flexible pavement structures. The lower layer of the subbase functions as a filter or separation layer, as I mentioned, to prevent the intrusion of subgrade soil into the pavement course, especially. The filter and drainage layers now have specific guidelines to look into how these layers are to be individually designed, like the filter and drainage layers designed as per SP 42 requirements guidelines for road drainage, SP 50, which is guidelines on urban drainage, and SP 20, which addresses the drainage aspects related to rural roads as well. For effective drainage, both the filter and drainage layers must be extended to the entire width of the embankment slope.

This is very important; if I do not have these drains at the edges, this entire area has to be extended to the edges. Otherwise, you can see at the top that the bounded courses are extended up to this one only, but when it comes to your granular courses specifically, they are extended to the pavement edges; this is your shoulder, and this, so they should be daylighted so that water moves through it, coming out on this side and this side, so this is an important aspect. The material to be used for the granular sub-base shall preferably be different material combinations, as it is a granular material. Natural sand can be used, crushed gravels can be used, crushed stone can be used, crushed slag can be used, or a combination can be used depending upon the gradation required. Because the amortization specification gives 6 gradations for a material to be used in sub-base courses.

I will show you on the upcoming slide. Use of materials like brick, metal, conker, and crushed concrete shall be permitted in the lower sub-base courses only, not in the upper sub-base course, because it has to serve the purpose of drainage as well. In addition to this one, where the situations are challenging and where you want better control nowadays, the use of synthetic geotextiles or geosynthetics is also becoming more and more popular. So, commercially available synthetic geocomposites, grid cell geolock with perforated vertical faces filled with aggregates meeting the requirements, and for this particular one, for the use of geosynthetics, we refer to SP 59 guidelines for the use of geosynthetics in road pavements and associated work. So, here you can see that these are geocells where you fill in the granular material.

So, they will serve two purposes for us. They will serve the purpose of a drainage layer. So, it serves because these are perforated ones. So, it allows water to move through it. Secondly, this will add to the strength of your pavement structure because it will serve the purpose of your reinforcement as well.

So geosynthetics serve the purpose of your drainage layer, your filter layer, and in addition to this particular one, it provides good reinforcement as well. So, here this, but specifically in this particular reference, we are mentioning it for the purpose of drainage. So, if you want to enhance the drainage of a particular course, you may make use of the combination of these geosynthetics along with your granular courses for the construction of a drainage layer. As I mentioned, MoRTH specifications give four different gradings: grading 1 to 6 and six different gradings. Now all these, depending upon their requirements, have where they need to be used; it has given six gradings, and different gradings can be used for different purposes and for different layer thicknesses.

Whenever a layer thickness is to be considered, we always say that the layer thickness should be 2.5 times its NMAS nominal maximum aggregate size. Now, this nominal maximum aggregate size is again a size where we say that the material should be whatever NMAS we recommend. It says that NMAS is if I do any aggregate gradation. I will come later on also if I do any aggregate gradation, say this is sieve 1, sieve 2, sieve 3, sieve 4, sieve 5.

If I do any gradation analysis and I work out the cumulative percentage passing. So, this is my cumulative percentage passing 1, cumulative percentage passing 2, and cumulative percentage passing 3. So, this is for 1, 2, and 3, and this is for 4. Now, here the size which will be on the top obviously will have 100 percent passing material, and there may be a sieve at the bottom where I may have very small material, say 0 to 3 percent cumulative percentage passing through it. So, this NMAS says it is the size at which at least 10 percent of the material is retained.

So, it is the, so in that, this is one sieve if I have any particular size S3 that can form. So, a sieve size which at least allows some material to pass over it. So, there are two definitions that are normally referred to for any mass. It is the first sieve size over which at least 10 percent of the material passes. So, if one size is where 10 percent of the material is passing, then the first sieve size is in the range where some 0 to 10 percent of the material is passing.

So, this is for NMAS; we will revisit this discussion of NMS in later slides for other mixes as well, where I will show you some gradations and some NMAS as well, just to give a reference about it. So, it says the grading to be adopted for a project has to be specified in the contract, which always indicates which grading is to be used in the lower sub-base and the upper sub-base courses we prefer to use for a drainage course. Normally, gradings like sixes are quite often used for making a drainage course in flexible pavements. Now, as I mentioned, the other aspect we need to check is that you can see this is the granular sub-base course, which is extended up to the daylighted edges. Whatever water comes through this particular upper course, through any cracks, should move through this because it has an easy path for removal, allowing it to be collected in the side drains.

So, there are a few definitions or requirements that are necessary if a single filter come drainage layer is to be constructed. It states that there are two requirements as per IRC 37: at least a drainage layer as well as a filter layer with a minimum thickness of 100 mm should be present. And if, as I said, in certain cases you do not have a good thickness of sub-base course available, you have to construct a separation, filter, and drainage layer in one course only. So, in that case, a minimum thickness of 150 mm is required. And MoRTH says whenever you construct, it is better to construct sub-base cores in two layers, with at least 150 mm in each layer.

So, it is advisable to construct the sub-base course in two layers, preferably 150 mm each, and as I said, at least 2.5 times the nominal maximum size of aggregates should be used as the layer thickness. So, if the NMAS of a particular gradation is, say, 19 mm, then it should be 19 times 2.5. So, I can say that the layer thickness should be 50 mm.

So, 50 mm should be the minimum depending upon, but this is not the NMAS of the gradations that are available; you have NMAS larger than this particular one. And, on the other hand, it says that the layer thickness should be at least 100 mm minimum, but if I am constructing in two layers, I would prefer to construct each layer of 150 mm. The total thickness of the granular sub-base course should be adequate to support the construction traffic. Now, another important aspect is that when you construct a granular sub-base course, the construction vehicle will come and compact the course. So, you need to ensure that the material which you are using in granular sub base cores should not get over compacted; otherwise, the drainage capability of that particular layer will get reduced, or the material should be good enough to bear the load that is going to come from the construction material.

Otherwise, its gradation changes, it breaks down gradation changes, and it does not serve. So, we need to ensure that the subgrade is strong enough to support this granular sub-base course material, and it should not become overstressed during the laying and compaction of the granular sub-base course. So, all these factors need to be taken care of while you are designing your sub-base courses. So that is why it says this thickness requirement may be worked out to satisfy the subgrade rutting limiting strain criteria, because when we discussed flexible pavement failure, we mentioned that two parameters we will consider: one is the strain at the top of your subgrade courses, and the second is the compressive strain at the top of your subgrade, which is the rutting criteria; the other important part is the tensile strain at the bottom of your bituminous courses. Now, as I mentioned, the typical types of courses used in sub-base or base construction are water-bound macadam and the granular sub-base course, where there are six gradations.

The second type, which is typically available in your IRC 19 and MoRTH specifications, is water bound macadam. Here the word says it is a macadam; it is a combination of aggregates that is bound by water. So, it consists of clean crushed coarse aggregates mechanically interlocked by rolling, with voids thereof filled. So, here we choose an aggregate gradation, and where coarser aggregate particles are taken, they are laid, compacted, and then we add some fines, which are known as screenings, to this particular layer, again compacted, and this gives you a good granular course for the upcoming courses of a flexible pavement. So, here it says that by rolling, the voids are filled with screening, and in some cases, we also put some binding material over the top of the screening with the assistance of water, and that is why we call it water-bound macadam.

This is IRC 19, which gives the standard specifications and code of practice for water-bound macadam. Nowadays, the wet mix mechanism is becoming more popular in the construction of flexible pavements instead of not being very popular, due to a few challenges specifically related to its performance, which we will discuss in the upcoming slides. The binding material to be used for WMM as a filler is usually the material that passes around 75 to 100 percent through a 75 micron sieve. So, that material is known as filler, where any material whose 75 to 100 percent passes through this 75 micron sieve during gradation is represented as filler. This is a conventional terminology we use for coarse aggregates, aggregates which are greater than sizes of 2.36 mm, and fine aggregates which are in the range of 2.36 mm to 75 microns. These are fine aggregates; anything that is below 75 microns is your fillers. So, it says what materials are to be used in the case of putting a binding material; it also states passing 100 percent through a 425-micron sieve and possessing a plasticity index value of 4 to 8 when the WMM is used as a surfacing course and less than 6 when it is adopted. Normally, in flexible pavement construction, only in some earlier days with the earthen surfaces or granular surfaces, when water-bound macadam used to form a surface course, we used to have the binding material that used to have some amount of plasticity. So, the plasticity index value was in the range of 4 to 8.

Whereas, if it is used as a granular sub-base course, the plasticity index should be restricted to less than 6; this is an important aspect. Otherwise, its water-holding capacity increases, and that may lead to the damage of your flexible pavement section. Now, the coarse aggregates, as I mentioned, are a coarse aggregate, then screenings, and then a requirement of binding material. So, two gradations are given for this coarse aggregate part: one you can see for a size ranging from 63 to 45 mm.

This is again the size ranging from 22.4 to 53 mm. This specifically mentions that two size ranges for coarse aggregates may be used as a sub-base and a base course or a surface course, not as a flexible pavement; it will not form a surface course. As I said, only a few earlier roads were surfaced by this water bound macadam. The coarse aggregate shall conform to one of the gradings given in Table 409 of MoRTH 2013. So this is the coarse aggregate gradation. And then, as I mentioned, once the coarse aggregate is compacted, you put the fines over it.

Again, two gradings are given for the fines, which are your screenings. So two gradations for screening materials are also given. So then this screening material is put over your rolled coarse aggregate and then again compacted with the use of water. So, screenings to fill in the coarse aggregate shall generally be of the same material as the coarse aggregate. However, economic considerations for non-plastic materials such as concrete, clay, or gravel, other than riverbed material, can also be used, but with due permission, and as I mentioned, the important aspect is that the plasticity index value should be less than 6.

Now, these are unbound courses, a water-bound course, and the granular sub-base course. If I use some binding material, which may be fly ash, cement, or any other pozzolanic material, lime can be used; then it normally comes under the category of cement-treated subbase courses. So, this is another part that states that the materials used for cementitious treated subbase shall consist of soil, river bed materials, natural gravel aggregates, reclaimed aggregates, crushed aggregates, or soil aggregate, modified with different cementitious materials such as cement, lime, fly ash, etc. So, if I am using any cementitious material along with these different kinds of aggregates, then it becomes my cement-treated sub-base courses. So, the one important requirement, if you are doing the cement-treated sub-base course construction, is that the minimum thickness should be at least 200 mm.

And it says that since it is a cement-treated one, there is a requirement in terms of strength; also, the strength should be at least 1.5 to 3 megapascals. This is another requirement: the unconfined compressive strength of the cement-treated subbase courses should be within this particular range. The gradation also includes the 6 gradations which were mentioned in the MORTH, out of which it states that for cement-treated sub-base courses, you use gradation 4 for the making of these cement-treated sub-base courses. Now, the other popular granular course used in flexible pavements is very popular: it is wet mix macadam, and it is used as a base course.

Now it is normal; either if you are using a wet mix, a water-bound macadam as a sub-base, then you need to follow up with your wet mix macadam as a base course. Even if you are using a granular sub-base course, it is also followed by wet mix macadam as a base course. We will also discuss these material requirements and characterization in upcoming modules. So, it says that clean, crushed, graded aggregates, granular material, coarse sand, etcetera are to be used and finally compacted to achieve a good result. So, at a proper water content and gradation, the WMM material has to be compacted to achieve the desired strength along with the requirement of your cross slopes.

And there is a requirement that the thickness should not be less than 75 mm because the gradation that is adopted can go up to a maximum of 250 mm. The gradation recommended by MORTH is shown here; we have at least 53 percent, so 100 percent of the material should pass it. As I mentioned, NMAS is the one size of the sieve size which has at least 10 percent of the material passing, or I can say it is the size where at least some material passes. So, for this particular case, I will say that the NMAS will be 45 mm, as this is the sieve size where at least 10 percent of the material will be retained, because here either 40 percent of the material will be retained or 20 percent of the material. Therefore, one sieve size over this particular one, where at least 10 percent of the material is retained, is your NMAS.

The other definition that is popular is the first sieve, where some material is retained. So, it makes 45 your NMAS. So, these are the gradations that are available; the IRC 109 specifies how the practice has to be done using the wet waste mechanism. And again, it is specified here that this material, which is finer than 425 microns in this particular gradation, shall not have a PI value less than 6. So, these are some of the general considerations for the materials to be used in your granular courses.

We will further discuss the functions of these granular courses in the next lecture. Thank you.