Course Name – Pavement Construction Technology
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Institute Name – Indian Institute of Technology Guwahati
Week – 01
Lecture – 02

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, instructor for the NPTEL MOOC course on Pavement Construction and Technology funded by the Ministry of Education, Government of India. Today's lecture is the second lecture of Module One of this particular course, which will have a discussion on pavement types and their cross-sectional elements. So, in this particular lecture of today, we will be discussing some of the key features of pavements and their cross-sectional elements. At the very beginning, I would like to acknowledge the use of text, information, graphs, and images sourced from various textbooks, code standards, journal articles, reports, newsletters, and public domain searches. Pavement and its types; when it comes to pavement, one question that can suddenly come to mind is, why do we need pavement? We can, so the pavement has basically any surface that can give you a smooth and, nowadays, the important requirement is a safe ride.

So, if you are able to get a safe and smooth ride on any kind of surface, it is good enough for you. So, if the natural soil is there or the natural ground is there, if I am going to ply my vehicles over that particular area, we will be able to find situations of this kind. So, this particular one, when the traffic loads come up over the existing natural ground, will become excessively deformed, and under different climatic conditions, the situations may become worse. If it is rainy, then you might find a good amount of water getting accumulated.

This will further reduce the strength of the soil, and the traction forces will increase. So you cannot drive your vehicle on this kind of surface. So, what do you need? You need an engineered structure. So, that is why we call them pavements. A pavement is an engineered structure that provides smoothness and safety.

So, from the user's perspective, I will say I require two things. I required one surface to be smooth and the second surface to be safe. Now, safety is also becoming an important concern, not just smoothness. So, the user perspective says, "Give me an engineered structure," and because if I don't go for an engineered structure, then the situation, as I explained, is an unengineered structure where nothing good has been done. Only the natural ground has been made available for the movement of traffic.

Then, from the engineering aspect, one important factor is that it should have adequate stability. So, that says that the engineered structure should be stable enough for the movement of vehicles and pedestrians. Different kinds of vehicles should provide the desired performance under various climatic conditions; this is another important factor. So, that's why we call a pavement an engineered structure that provides a smooth, safe, and

stable platform for the movement of vehicles, including different types of vehicles: two-wheelers, four-wheelers, heavy vehicles, and pedestrians. As I mentioned, a pavement crust is needed since in most cases, if there is very low traffic and only some animal-drawn vehicles are present, then the existing natural ground soil can work in some cases with a small amount of stabilization.

So, it can serve the purpose; otherwise, in most cases, it is not able to because nowadays all areas have a good amount of vehicle movement. So, the existing soil layer is not capable of supporting the loads of commonly used vehicles. Now, if I don't go without this kind of structure, I will call it pavement crust because whatever is inside that pavement is my crust. So, if that pavement crust is not there, then the natural soil will deform excessively and hinder the movement of vehicular traffic. For a desired level of speed, this is also very important: if I am going from one place to another, I want to know how much time it will take.

So, that will depend on what speed I will be moving over that particular surface. So, speed is also a concern, and my journey should be safe enough. So, the engineered structures that are constructed for this particular purpose are three main structures. The most commonly used structure is the flexible pavement structure. Then we have a rigid pavement structure, and then a combination, which is sometimes used, though not very commonly, where some of the characteristics of flexible pavements and rigid pavements are utilized to meet specific requirements; composite pavements are constructed.

Otherwise, if you say what the two main broad categories are: flexible pavements and rigid pavements. Now let us go into more depth about what a flexible pavement is and what a rigid pavement is. I am trying to cover these things briefly because we need to discuss many more topics in the upcoming lectures of different modules. So I will try to give you a glimpse of the information from a construction perspective. Now, what you see on the left-hand side is a composition that is shown for a flexible pavement.

Here you can see I mentioned if there is an existing natural soil or ground layer. So, if it is a plain terrain, then the existing soil or ground layer is there; I will create a crust over it. Before that, I will make a subgrade, and this subgrade will be made of selected soil. And this selected soil may be the existing nearby soil or the soil that may be collected from some borrow area, or a soil that exists but has been stabilized through some method. So, that forms your subgrade.

This is your subgrade course. So, this is made of soil. Then comes your pavement crust. Your pavement crust is whatever you have above the subgrade. More features of subgrade will definitely be covered in upcoming lectures, where we will have a complete discussion on subgrade construction as well, so more features will be discussed.

Followed by what you have, two courses are shown here: the sub-base course and the base course. Now, these are granular courses and granular unbound courses with no binding material, most of the time used in these courses. This, what I am talking about, is a

conventional composition of a flexible pavement. We have different combinations; nowadays, we are depending on the climatic requirements and traffic loading requirements, and the different combinations are constructed. But the conventional one says you have a subgrade course, a natural soil subgrade course over which your pavement crust comes, which consists of a granular sub-base course.

Now here also, there is a further bifurcation in terms of a separation layer, a drainage layer; those aspects I will discuss in the upcoming one. Then you have a base course, which is also conventionally used as an unbound base course. So, these are granular courses without any binding material. Now, in flexible pavement, the binding material that is most popular or the most commonly used is bitumen. Bitumen is a hydrocarbon product that is most commonly produced from the distillation of crude oil.

Now you get different fractions; you might have read about them from the destructive distillation or fractional distillation, as there are different ways in which you can extract different products. So, from the distillation of crude oil, where we get diesel, petrol, and other products, the one residue that you get is your bitumen. Now, bitumen is used as a binding material in these courses; you have your binder course, and you have a wearing course. Because of this binding material, they have good strength compared to your unbound courses. Now, the other part is mentioned, so whenever a flexible pavement structure is mentioned, it is said that it is a type of pavement structure that primarily relies on flexibility, which means it is less rigid; the flexural strength is less compared to what is present in the others.

This is a comparative statement compared to what you have in rigid pavements. And since one layer is resting over the other, we very commonly say that the load transfer mechanism is through the grain-to-grain transfer. One layer is resting over the other layer. So, this is a typical composition and construction pattern of flexible pavements. This entire course is about pavement construction technology.

So, we will be discussing all these things. I just want to give a feel for how a pavement is and what a pavement is in this particular lecture; then, in upcoming lectures, further details will be discussed with you all. Now this flexible pavement is to be designed as per Indian Roads codal guidelines, which is IRC 37:2018. Now it helps you figure out what the crust should be and what the thickness of the individual layers should be in this particular one. We will have a brief comparison between these two most commonly used pavements: flexible and rigid pavements.

Flexible pavement is very popular. More than 90 percent of the roads not in India throughout the globe are flexible pavements. And this is what a cross section of a flexible pavement looks like, as shown here. Now, here you can see there is a natural soil subgrade layer; over this particular one, I will select a soil that can be an existing soil, but the characteristics must be controlled characteristics. So, I will select a soil with some desired characteristics, and I will construct this subgrade course.

Over this particular one, I have to construct a few layers, and that forms my pavement crust. The conventional flexible pavement consists of several granular courses and several bound courses. The granular courses are unbound courses; two normally used granular courses are your sub-base course and a base course. They serve different functions that we will discuss in the upcoming lectures. And so they do not have any binding material; when you go up the slope, you have your binder courses and your wearing course or surface course.

They are constructed using aggregates with some binding material, and in flexible pavements, the binding material is used as bitumen. It is also called asphalt or is a synonym for asphalt binder. These layers are quite flexible; they have less flexural strength compared to rigid pavements. So, it says it is a type of pavement structure that primarily relies on flexibility and grain-to-grain transfer; for these layers rest over each other, they do not have very high flexural strength; unbound materials are there. So, the load transfer mechanism is through grain-to-grain transfer, and they are resting on each other.

Now, for this particular one, the Indian Roads Congress has given guidelines IRC 37. IRC 37 helps you work out the crest composition of a flexible pavement and see whether this is good enough for a given design traffic or a sufficient amount for the existing traffic loading situations. Now, the other one that is common is your rigid pavements. Now, as the word itself says, this is a rigid structure. So, it has greater flexural strength or greater flexural rigidity compared to your flexible pavements.

Now, here you also see we have a natural soil subgrade. This is when we are constructing plain areas if you are constructing in some cut areas or where you need to raise the land because water logging may be a concern. So, you may need to raise the level of your road surface. So, you will also construct an embankment over the natural ground before you construct your subgrade course. Now, the subgrade is again a controlled one where you have control over the soil characteristics; your existing soil can be suitable enough to construct a subgrade, or you may have to select a borrow area, or you may have to stabilize the existing soil to construct your subgrade course.

What comes over this particular one? Either an unbound layer, which is again a granular course, followed by a base course, which is a bounded course, and then on top, we have a cement concrete slab. Now this cement concrete slab has a good strength. So, that is why this becomes a rigid pavement structure. Rigid pavement is a pavement structure that primarily uses cement concrete as a surface course. Flexural rigidity is quite high, and since its flexural rigidity is high, it distributes the load over a wider area compared to what is there because it makes a transfer through the aggregate contacts, or what we refer to as grain-to-grain transfer.

Now, a few more differences between this particular one, as I mentioned, are that it has a lower flexural strength. You can see this is again a composition that is shown here; you have the subgrade course constructed with a natural structure. With the selected soil, it can be natural, stabilized, or borrow area soil. And what you have over this particular one is your pavement crust. Now in this pavement crust, you have granular courses which consist of

more than 3 or 4, because you also have a granular sub-base course that is just above and followed by the base courses.

All information will be discussed further in upcoming lectures about this subgrade granular sub-base course. Followed by a granular base course, we then have a bituminous bound course, and on top, we have a wearing course. Now, since this is a bituminous bound material, you can see it is black in color. So, the color difference is there; you can see the aggregate pieces; this is a granular course. The granular course serves different purposes; the bound course serves different purposes.

And, they do not have these layers resting; they do not have high flexural strength; they rest over each other. So, if there is some major deformation happening in, say, your granular course, the upper layer resting over it will also get deformed, and in due course of time, the deformation can get reflected on the top of your pavement course. Thus, if the lower layer of the pavement or soil subgrade is undulated or excessively deformed, the flexible pavement surface will also become deformed in the near future. This is on the right-hand side of the slide; it shows rigid pavements, which pose high flexural strength or high rigidity in that case. Now, in this case, you can see again the IRC codal specifications which are used or referred to for this rigid pavement; it is IRC 58.

There are many more, but the one for the design of this particular one is IRC 58. There are some internal components for which you need to refer to some more IRC courses or BIS Bureau of Indian Standards codes. Now, it says you need to have a high-quality cement concrete mix as a surface course, or we can call it a wearing course, followed by the fact that in this particular case you need to have a good base, which is normally constructed with dry lean concrete, or as I am saying, cement-treated aggregates. At the bottom again, you can see this is a subgrade; again, this is a subgrade with selected soil. Now, there is always a requirement, regardless of the type of pavement structure, to provide a drainage layer.

So, the purpose of the drainage layer will be discussed again in upcoming layers; drainage is a very important aspect of any kind of pavement structure. So, this is a drainage system that is within the pavement structure. So, you need to have the drainage course; now here you can see that GSB one is a separation layer to separate the soil material from the granular material, and then there is a drainage course. So, these are two, followed by a stabilized or bounded course, which is in terms of dry lean concrete. Now, these two, because we know that cement concrete will expand at higher temperatures and contract during winters at lower temperatures.

So, this expansion and contraction should not be restricted. So, it says a debonding layer is to be provided. So, there is a debonding layer provided between this particular one. This debonding layer may be a polythene sheet, or in some cases, a bituminous layer is used as a debonding layer. When a bituminous layer is used as a debonding, one aspect to consider is that you have to whitewash this particular bituminous surface because bitumen is a black material and has a tendency to absorb heat.

So, since it will absorb heat, it will become hotter, and this will create a disadvantage to the concrete slab that is over it. So, this is a general bifurcation between the two. Now, let us see how a pavement structure looks from different aspects. One we discussed just now was in terms of the cross-section elements; here, those cross-section elements are shown subgrade. These figures are not drawn to scale, but just to give some idea of it.

So, you may not have all of these to the exact dimensions, but the main aim here is to give you an explanation of what these layers are, and I will also show some real pictures. So, as the subgrade course is there, you have a sub-base course, which may be a granular course; a base course may be there, and on the top, you have the bituminous courses. So, how does it look for you as a user? From the top, you have this black top surface for flexible pavements, which also has a slope. So, here you can say I mentioned that they have a slope here, and we call this cross slope or the slope the camber. Now and in some cases you might find there is a space between the two directions of traffic that is moving.

So, this particular space is known as the median. Now, where the actual traffic moves, that particular part is known as the carriageway. So, this is the carriageway, and then you have the medians. And if it is an urban section, you might have seen that kerb stones are also placed. These are small concrete structures to separate movement or to protect the edges.

So, these are kerb stones. Now, here and there you can see these are shoulders. Shoulders are again of different types. We will see in the upcoming slides what is there. So then comes the shoulder. So, the width that is your shoulder, which is your carriageway, including your median on both sides, becomes your roadway width.

Now, this width is there so you have shoulders; thereafter, there will be some side slopes, the water will come out, there will be openings in the kerb stones, it will come on the shoulders, and then, with these side slopes, it needs to get collected into your side drains. You need to have some spaces for utilities as well, utility corridors for various utilities that must be provided along the roadside, so you will have some utility. So, this shows you how much land you require for the particular road surface. So, if I know what my carriageway width is that I have to provide, median width, shoulder width, and the road margins I need, then this road margin plus roadway on both sides becomes your right of way, which is very commonly referred to as ROW. So, for different types of categories of roads, we have different requirements for ROW.

Whenever a new project starts and land acquisition begins, this term always comes into the picture. What is the row? What is the right of way required for constructing this particular road? In addition to this particular one, two terms have been mentioned here: building line and control line. Building lines are normally restricted, as there should be no construction within this particular range because this allows for future expansion; additionally, it often creates a safety hazard. So, we put that up to the building line; there should be no construction present there. And from the building line to the control line, there should be some particular structures that should only be allowed.

So, that gives you the control line. So, these are normally the terms that are used. So, the right of way is the area of land acquired for road purposes. Now, I will show some typical cross sections and how they look. Now, see, this is a typical cross section; I am trying to show the surface features, not the composition of it. So, here you can see that the first one is a typical cross-section of a two-lane highway.

This is again a description that has been recreated using the reference of IRC SP 73, 2018, which is a manual of specifications and standards for two-laning of highways with paved shoulders. Now, here you say this particular one is a two-lane highway; two-lane, conventionally one common terminology, is what is a lane width. For most cases, the lane width is taken as 3.5.

I will discuss this one also in a coming slide. where, but if one lane is equal to 3.5, two lanes will have a width of 7 meters. So, this is the middle of my lane of this carriageway; then one lane on this side, one lane on this side; this is a two-lane carriageway. So, many of you might have traveled on this kind of surface. Then you have a paved shoulder; here it is stated that the paved shoulder should be of a width of 2.5 on both sides, and then you have an earthen shoulder.

From the top, it appears to be the same surface. What the surface of your main carriageway is, is that there may be only a small difference in the composition, especially in the bounded layers. So, apart from the top, you will find that in most cases, the composition remains the same for the paved shoulder. So, from the top, I am trying to indicate the markings that are here. So, from the markings, you are able to work out that this is your paved shoulder, and there may also be earthen shoulders.

Then you can see again that the side slopes are there, you have the earthen drains, and you may require utility corridors for your electric lines and for other cables—all those things. So, ultimately, it says that this should be your right of way. So, this is now for me to know if I want to construct a two-lane highway as per IRC because everything has to be done according to some standard. So, as per IRC SP 73 guidelines, then what land should be available with me, this is important.

So, this is how it is. Now, see, this is for there are different types of highways; this is a four-lane divided highway without service roads. Now, this is another feature you might have encountered on various roads where there is one main carriageway; then there is something that separates the main carriageway, and you have some side roads, which are also known as service roads. Here you can see again that there is a part, there is an island, or there is a raised portion which we call the median; we will discuss this again. So, medians are there that separate the two directions of traffic; there was nothing about this raised portion. I just wanted to give information; there was nothing raised here actually, but here this is actually raised.

So, there is a raised area in between which we call the median, and this particular median width is already specified to be around 4 meters, and then it mentions there is kerb shyness.

Normally, I will explain in the upcoming slides when kerbs are present because the edges of these medians are imaginary lines created to prevent vehicles from hitting the median kerbs. So, that is why this is a kerb shyness, which is called that because it creates an imaginary half-meter distance near the medians in that case. So, if I have a 4-lane road, then there are 2 lanes in this way and 2 lanes on this side, a 5-meter median, paved shoulders of 2.5 meters, and earthen shoulders of 1.5 meters. So, if you see what is your roadway width in this particular way, the roadway width is 27 meters, and then what drains are there, and what utility spaces are there, this total makes your right of way. Now, in this particular case, there is no service road. Now, what is a service road? What does it look like? This figure shows how a service road looks like when there is a presence of it. So, the middle part is more or less the same.

You can see again that the 27 meters of roadway width is there. After the earthen shoulders, there is space for your drains. Then, followed by some earthen shoulders, you can see that a carriageway is there again. This carriageway is 7 meters wide. So, that it is a 2-lane road, normally service roads are constructed with 2 lanes. So, this is a conventional practice; there are always exceptional cases, and then there is an earthen shoulder on this particular site, and this is again the space for your utilities.

So, here is what is happening: if I want to separate out the local traffic from my main carriageway. So, to ensure that through traffic is not disturbed for my local traffic, I will prefer to give the service roads; this is what is here. So, again, this is given as per IRC 84, 2019. Now, as I said, you should be aware of how much right of way is required for you, because this is the beginning part and this land which you make available, since normally you design your structures for a life of, say, 20 years or 30 years. And in due course of time, there may be a requirement after certain years that you might feel the need to widen those particular existing roads.

There, then again, if the road development comes up, the land acquisition becomes very difficult; you want to have some more safety features, then in this particular case, it is very important to acquire the required amount of right of way and to control and make that available throughout the life of the road. So, a right of way that you acquired at the beginning should not be encroached upon, and later on, after a few years, when people encroached on it, your entire purpose is lost. A right of way is the land acquired for road construction purposes and the provision of utilities along its length. Because later on, if you find that there are more rains, the collection of the drainage system has to be good enough. So, all these utility corridors have to come up, and all these need to be done in the right of way only.

A minimum right of way must be applicable for the development of highways and expressways, while a desirable land width should be provided. It is desirable that we can definitely keep this much in that case to accommodate potential futures. Now, let us see what the road classification says about the different rights of way. It says if I construct 2-lane, 4-lane, 6-lane, and 8-lane highways, then what should be the minimum ROW, right of way? It says in case of 2 lanes, 30 meters, 4 lanes, 45 meters, 6 lanes, 60 meters, and 8 lanes,

120 meters. And when it comes to expressways, it says at least 90 to 120 meters of right of way should be there.

Again, for other categories, as we discussed in the previous lecture about the other classes of roads—major district roads, ODR, other district roads, and village district roads—there are also different terrains. For plain and rolling terrains, it is easier to acquire more land or to prepare more land for road construction purposes compared to what you have in mountainous and steep terrain. So, here you can see what the requirement is for a major district road; for a normal road, it says that you can go for 25, and the range should be 25 to 30. If this is for an open area, if there is some built-up area, it means there is some construction and habitation; then it can be slightly reduced.

So, these requirements are given under our IRC codal provisions. Now, we will discuss these key features in a bit more detail here. So, the carriageway was the one term which we discussed; the carriageway is the surface over which the vehicle moves. So, a carriageway denotes a stretch of road where vehicles can maneuver literally without encountering any physical barriers. So, this is here; in this case, you can see this width is available for the vehicles to move. They say there is a marking, so half of the width is available for this direction of vehicles, and half of the width is available for this direction of traffic.

Here you can see a term is used: dual carriageway. Dual carriageway means that the two directions of traffic are separated. So, how is it separated? It is separated by a median, which can be a raised median or a depressed median. When I discuss the median, I will discuss this aspect. So, here you can see this is another carriageway on this side; this is a carriageway on this particular side. So, the carriageway provides a dedicated space for motorized vehicles, separated from walking, cycling, and stationary activities, because it is for the maneuverability of the vehicles.

Typically, carriageways are located in the middle of the right of way of the road because the right of way is there; we acquire the land, and in the middle of that right of way, you have your main carriageways. The primary purpose of a carriageway is vehicle mobility because that surface is a different type of surface depending on different pavement structures, like the flexible pavements; you see, all these are flexible pavements. So, you have the black top surface appearing here. Now, the carriageway width, as I said, depends on whether we have a 2-lane highway or a 4-lane dual carriageway, like this 2-lane dual carriageway.

So, these are the terms we need to understand when we say what 2 lane means. So it states the recommended carriageway width for urban roads, which are specified as per IRC codal specification IRC 86. It indicates that a single lane without kerbs should have a width of 3.5 meters; if there are no kerbs on the side, only one lane is to be there. For two lanes with raised kerbs, the width is 7 meters. For a four-lane width, with or without kerbs, it is 14 meters. A six-lane width with raised kerbs is 21 meters, and an eight-lane width without kerbs is 28 meters. Now one important aspect that we normally see from the rural highways constructed, especially national highways, expressways, or state highways that follow the guidelines of IRC 73 is that if a single lane is to be constructed, the width per lane

should be 3.75 meters. And if multi-lane pavements are to be constructed under state highways and national highways, then if more than one lane is present, each lane should have a width of 3.5 meters. If multi-lane expressways are present, where the speeds are quite high, with design speeds of more than 100 to 120 kilometers per hour, they say that the lane width is 3.75 meters.

So, if I need to have two lanes, then it is 3.75 times 2. If I need to have three lanes in one direction, it will be 3.75 by 3. So, this is how for access roads to residential areas a lower lane width is applied; if there are certain limitations or restrictions for the urban section, then you can reduce this from 3.5 to 3 meters. The minimum width of an urban road without a kerb shall be, if I need to construct any urban road without any provision of kerbs, then I can go for at least a width of 5.5 meters. Now this is the second terminology, so with this particular one in this lecture discussion we will complete here, and in the next lecture we will again follow up with the key features of the pavement sections. Thank you.