

Course Name – Pavement Construction Technology
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A very warm welcome to all of you. I am Rajan Choudhary, Professor in the Department of Civil Engineering, Indian Institute of Technology, Guwahati. Instructor for the NPTEL MOOC course, Pavement Construction and Technology, funded by the Ministry of Education, Government of India. Today's lecture will be a part of the lecture under module 10, where we will discuss the structural evaluation of flexible pavements through two techniques, specifically using the Benkelman beam and the other one by falling weight deflectometer. At the very beginning, I would like to acknowledge the use of text, information, graphs, and images sourced from various textbooks, quarterly standards, journal articles, reports, newsletters, and public domain searches. Now, for structural evaluation, we may need to evaluate any constructed flexible pavement structure to get an idea about its current structural strength, and this may be required to ensure the quality of construction, or it may often be required whenever we need some strengthening of the flexible pavements.

So, we want to determine the strength of the current structure and the required amount of overlay for this particular pavement structure to serve a specific amount of traffic in the coming years. So, the structure evaluation of pavements manual and what it normally consists of; here, under this particular evaluation, it involves applying a standard load to the pavement and measuring the response of the pavement in terms of stress, strain, or deflection. So, there are two codal provisions; specifically, one is IRC:81, which provides guidelines for strengthening flexible road pavements using the Benkelman beam deflection technique. Second is IRC:115, which is the guideline for structural evaluation and strengthening of flexible road pavements using the falling weight deflectometer technique.

So, here you can see that these are the two different techniques used for assessing the strength and working out the overlay for strengthening flexible pavements. So, the structural evaluation of flexible pavements is widely done using a Benkelman beam and a falling weight deflectometer. These are the two techniques or the set of equipment that are used for the structural evaluation of flexible pavements. Now, today in this particular lecture, we will discuss the Benkelman beam deflection techniques for the structural evaluation of flexible pavements. In 1953, Alvin C.

Benkelman developed the Benkelman beam. It is to measure pavement surface deflection specifically for the Western Association of State Highway Officials test road to obtain a design for flexible pavement overlay. Thereafter, continuous research has been done, and

a lot of exercises throughout the globe have been conducted on working out these Benkelman beam deflections to determine the overlay thickness for the strengthening of flexible pavements. So, the Benkelman beam is one of the earliest pieces of equipment used for measuring deflection and structural evaluation of pavements. In terms of the measured deflection, we can also compare the different flexible pavement sections, which are widely used across the world for evaluating the requirements for strengthening flexible pavements.

So, that is one of the prime purposes of it, where we need to work out what the requirements of our overlay for strengthening a given flexible pavement are. In this particular method of structural evaluation, a static load is applied to the pavement surface, and rebound deflections are measured at one or more locations with the help of a Benkelman beam. You can see that there is a vehicle with dual tires on one side; this is a beam whose probe is inserted between the dual tires, and then the deflection measurements are made. We will discuss them in detail. So, what is required in a Benkelman beam deflection study is, first of all, the Benkelman beam.

So, it evaluates flexible pavements based on the principle that their performance is closely related to the elastic deformation that can occur under wheel loads. So, here we will use static loads and look into the rebound deflections that take place. This elastic deflection or deformation depends on several factors. If you have a pavement composition, when a load is applied, some deflection will occur; deformation, or I should say, deformation, is present. So, this will depend upon several factors of the pavement; first of all, the type of subgrade soil, which is the subgrade over which the entire pavement crust is resting.

So, it will depend on the subgrade soil, its moisture content, the state of it, and compaction. How well it is compacted, then the other part is the thickness and quality of the pavement layers, which are different layers: your granular courses, sub-base courses, base courses, binder courses, and wearing courses, so their thickness and their strength. So, the thickness and quality of the individual pavement layers, the drainage conditions, how well the pavement is drained, and the pavement surface temperatures are important because specifically the binder stiffness changes with the change in temperature. So, if there is a good thickness of bituminous courses, then that definitely plays a role. So, this deflection under a load, which is used in this particular Benkelman beam deflection technique, will try to capture this information about the pavement structure as a whole.

So, the Benkelman beam consists of a cylindrical beam, a thin beam 3.66 meters long, pivoted at 2.44 meters from the tip. This is a side view you can see in this particular one; this is a beam that is 3.66 meters long from here to here.

This is the point where it is pivoted, so 2.44 on this side; this is not completely extended because of the limitation here on the slide. You can see here this is the one. So, it is pivoted

at this particular point, and then you can see there are two legs; these are the front legs, and then there is a rear leg. So, you can see this is a rear leg; these two are the front legs of this particular one.

So, here is the one where this particular one is pivoted. Now, when it is inserted, this is another one; when it is inserted between the dual wheels of a standard truck loading, this is a picture of the actual site. Now, what we do again is that you can see a closer look at where this probe of the Benkelman beam is inserted between a dual wheel, and then you are going to measure the deflections here. So, in this one, pavement deflection is measured using the Benkelman beam by positioning the beam probe between the dual wheels of a standard loaded truck; I will mention those particular details in the upcoming slides as well. Both rebound and residual deflections can be captured in this particular study, but what we require for this particular exercise, specifically the overlay thickness determination, is the rebound deflection, which is directly related to pavement performance and is a critical parameter used as per IRC 81 for the design of overlay thickness for flexible pavements.

The residual deflection can again result from the non-recoverable deformation of the pavement and also from the influence of the deflection bowels on the front legs of the beam. Because the deflection of the ball on the front legs of the beam can also lead to some amount of residual deflections, what we will require here for our overlay thickness design is the rebound deflection. Now, while conducting this particular exercise, the Benkelman deflection study will initially be divided into two main components: one is the condition survey, and the second is the actual deflection measurements. So this condition survey is to be done to collect some basic information about the road structure so that we can divide it into some homogeneous sections in that case. So, before measuring pavement surface deflections, this primary phase involves what is usually done: a visual inspection is done along with the measurement of rut depth, for which we can use a 3-meter straight gauge.

And then we will divide the sections into three major categories as per the IRC:81 requirements, and what it says is that a section can be called good if the rutting is less than 10 mm and there is no cracking in that particular section. Fair if the rutting is between 10 and 20 mm, with no cracking or cracking confined to a single crack in the wheel path. So, when this is there, that section can be called a fair. This is a classification as per IRC:81. Poor rutting greater than 20 mm, extensive cracking, and sections with cracking exceeding 20 percent shall be treated as failed sections in that case.

So, I can broadly keep those sections that need to be evaluated through the Benkelman beam into these three broader categories: good, fair, and poor. And because I will always prefer to work out the overlay thickness, I expect it is otherwise inconvenient if the overlay thickness is different in small sections of length. So, I will always prefer that the overlay thickness does not vary too often. So, each section is generally kept as a minimum of 1

kilometer of homogeneous section. So, at least you will have one uniform overlay thickness, because otherwise it becomes impractical.

However, in cases where some localized failures are present or where more detailed inspections are required, the cases may be different; otherwise, we will prefer to have at least a 1-kilometer section for one overlay thickness, which is worked out. Now, once this preliminary survey is done and the sections are divided into these three broad categories, the deflection measurement study begins. So, in each road section of uniform performance, there are at least ten evenly spaced. So, I can have one kilometer, and in at least ten measurements, these measurements should not exceed, and the distance between these measurements should not exceed 50 meters. This is another point: if there are multi-lane roads, the lanes may be distressed in different manners; for instance, the outer lane may be more distressed, while the inner lane may be less distressed.

So, there may be a requirement to conduct this study on all the lanes when we are doing it on the adjacent lanes as well. We will prefer doing it in a staggered manner. So, here you can see they are marking the points with chalk by a moving wheel, where we can mark the point along the pavement edge where these measurements are to be taken. Now, how far it should be from the pavement edge again is specified in IRC 81; it says that it can be 60 centimeters from the pavement edge if the lane width is less than 3.5 meters, and it can be around 90 centimeters from the pavement edge if it is more than 3.5 meters. So you can see the distance that is there from the pavement edge where these measurements are to be made. Now, for these measurements, a standard load has to be used. So, for this particular one, there should be a standard truck with a rear axle load of 8,170 kg. So this is an important requirement. The truck should be fitted with dual tires.

The tire pressures should be 5.6 kg per square centimeter. So, this needs to be ensured while conducting this particular. So, you need to have a truck that is loaded in such a manner that the rear axle weighs. So, those axle pads you require, or you can use at a weighing machine, or any weighing pads, you can ensure that the rear axle has a weight of 8170 kg, and the tires are inflated to a pressure of 5.60 kg per square centimeter. This is the requirement for the standard static load that is to be considered. Now, when these measurements are made, as previously mentioned, there may be corrections required for specifically two factors: one is temperature correction, and the second is seasonal correction. Now, why does temperature correction, as mentioned earlier, also affect the stiffness of the binder with the change in temperature? So, the pavement structure may be soft at higher temperatures and may be stiff at lower temperatures. So, it says the stiffness of bituminous layers varies with the temperature of the binder. Therefore, it is essential to correct all measured deflections to a standard reference temperature, and that temperature is normally taken as 35 degrees centigrade for the Bankelman beam deflection studies.

Second is the seasonal variation with the seasons, because if I take some measurements during the rainy season, then the pavement may be in a weaker condition. So, you may have a higher number of deflections that may be observed. So, one always prefers to take these deflection measurements when the pavement is in the weakest condition, and that particular one will again depend upon certain parameters. So, it is advisable to conduct deflection measurements during the period when the pavement is in its weakest condition; it typically occurs soon after the monsoon. Therefore, the deflection testing should preferably be carried out during this time to capture the most critical conditions.

However, it is not always possible to do the measurements at 35 degrees centigrade or to conduct measurements just after the monsoon is over. So, we need to apply the corrections considering the temperature and the variation in the season. So, as I mentioned, the standard temperature that is preferred for the Benkelman beam study in most tropical regions is 35 degrees Celsius for deflection measurements. In certain colder regions at higher altitudes above 1000 meters, where the average daytime temperature remains below 20 degrees for more than 4 months. In that particular case, it may be difficult to do this test at 35 degrees centigrade.

So, we prefer to go for 20 degrees centigrade. We normally take measurements when the temperature is more than 20 degrees centigrade, and then you do not need to make those temperature corrections either. So, these are for specific locations. Now, regarding how the temperature corrections are applied, it states that the deflection is expected to vary linearly with the change in temperature. So, the measured deflection is adjusted by plus or minus 0.01 mm per degree centigrade deviation from 37 degrees centigrade. So, if the temperatures are less than 35 degrees centigrade, then I need to add a value of 0.01 mm per degree centigrade; say, if the temperature is 32 degrees centigrade instead of 35 degrees. So, 3 degrees lower.

So the deflections will be less. Here I will multiply 3 by 0.01. So 0.03 has to be added to the deflection to get the corrected pavement deflections from the temperature point of view.

So, at 0.01 mm per degree centigrade, when the temperature is below 35 degrees centigrade, and if it is higher, say 2 degrees higher at 37 degrees centigrade, then I will deduct a value of 2 times 0.01 mm, that is 0.02 mm, from the measurements which are obtained at 37 degrees centigrade. So, temperature correction is necessary, and this correction is specifically mentioned because of the change in the binder stiffness. Now, there may be certain pavements that are very thin and do not have a good amount of bituminous layers; if thin surfacing is present, then you do not need to apply for these corrections specifically, such as premix carpet or surface dressing.

Or cases where these pavement structures are severely cracked; that is, another case where these surfaces are severely cracked, then also stripped bituminous layers are present. Then,

we do not need to apply these, and specifically, it is mentioned that correction is applicable only to pavements having bituminous layers of more than 40 mm in thickness. So, when the thickness of bituminous construction is more than 40 mm, we are going to consider the temperature corrections. Now, the second correction, which is the seasonal correction, has to be done. Now, what factors will this seasonal correction depend on? It will first depend on the subgrade soil because that is the most affected.

It is field moisture content, as I mentioned, because it is not always possible to conduct this particular exercise immediately after the monsoon is over. When the pavement is in the weakest condition, So, we need to work out what the soil composition is, what the subgrade soil type is, its moisture content, and what the average annual rainfall is in that particular area. So, these are the three parameters that are required, and for this one, for the seasonal correction, usually the soils are divided into three categories. The first is sandy and gravelly soil. Second is clay with a low plasticity index, which is a plasticity index of less than 15, and the third is clay with high plasticity, which is a plasticity index of more than 15.

So, we divide the subgrade soil in that particular section into these three broad categories, and then we look for the rainfall in that particular region. For rainfall, there are again two categories: one is when the annual rainfall is less than 1300 mm, and the second category is when the annual rainfall is more than 1300 mm. So, for these three combinations of soil and two combinations of annual rainfall, moisture correction or seasonal correction factors have been given by IRC:81. And now you can see to work this out because you need to have the soil sample to check what its characteristics are, whether it is sandy soil, gravelly soil, or clay soil, and what its plasticity index is.

So you need to obtain the soil sample. So, a test pick needs to be dug near the pavement edge. You can see this is a test pit, and then the soil has to be taken out from a depth of around 5 to 10 centimeters in the subgrade, and this normally depends on where we go for measurement. So, it is usually in the range of 60 to 150 centimeters. So, we scoop out the soil from this particular spot. So, the test pit is done, and then we try to scoop out the soil, and this is sealed.

Taken to the laboratory to do the gradation analysis and Atterberg limits measurements, and to get an idea about which of these three categories it falls under. And then, as I mentioned, IRC:81 has provided the moisture correction factors for this particular one. So, there are different plots; like the first one, I will just read out the moisture correction factor for sandy gravelly soil for low rainfall regions. So, for this particular one, if the moisture content is present for that particular soil, you will work it out, and then you will see what the moisture correction factor is. So, this is given for areas with low plasticity of less than 15 and for high rainfall regions.

This is how you work out the moisture correction factors for the soils that are scooped out, and usually, you will prefer to go for this one at least in 1 kilometer per test pit, and this frequency can be further increased depending on how much variation you are observing there. Now, once this part of the temperature is determined, you can measure the temperature hourly, and as I mentioned, for seasonal correction and subgrade moisture correction, you need to work out the test pits, preferably every 1 kilometer. Now, when the deflection measurements have to be started, as I mentioned, a standard truck has to be brought up with a rear axle weight of 8170 kg and dual tires, as I am related to this particular one. It is brought to that particular test location, as mentioned, which is at a prescribed distance from the pavement edge, and then the Benkelman beam probe is inserted between these dual wheels.

Thereafter, the first reading is noted down. Now, the first reading can be taken when you initially calibrate the Benkelman beam, and then the dial gauge can be set to 0 for the initial reading, or you can directly note the reading when no load is applied. When the load is applied, you note down the first initial reading. Now, this initial reading is to be noted down when using the dial gauge.

So, the deformation is less than 0.025 mm permanently. So that it gets stabilized, and then you note down the first reading. So, that is known as your initial reading. So, the dial gauge is what these people are recording the first reading of this particular one. Now, when the variation in deformation is less than 0.025 mm per minute, I recorded my first reading of the dial gauge.

Then the trucker asked to move ahead for a distance of 2.7 meters. So, thereafter, it is asked to move ahead 2.7 meters. So, all these points from the pavement edge and along the length of the carriageway will be marked in advance.

So that the truck will be directed to move to the next point. There again, I will record the reading when this particular measurement is less than 0.0 and the deflection is less than 0.025 mm per minute. I will record my second reading, which is known as my intermediate reading. Thereafter, it is further asked to move ahead a distance of 9 meters, and then the final reading is recorded again when the recovery is less than 0.025 mm per minute. So, what I recorded in this particular instance was the first reading where the probe was inserted; that was my initial reading. Second, when it was moved ahead by a distance of 2.7 meters, that was the second reading. Then, for the third reading, when it moved ahead for 9 meters, I got my third reading, which is my final reading. Now, here in this particular case, because the beam is designed in such a manner, we need to work out the actual deflection that is present.

So, for this particular one, what is done is, first of all, we will measure the difference between the final and the initial readings. So, the reading has moved to 9 for the 9-meter

measurement, which is 11.7 meters; that is the final reading. So, the difference between the final and initial we call the final differential reading. Another one is that we are going to work out the difference between the intermediate and initial, so that it can be counted as the intermediate differential reading as well.

And we are going to see how much difference there is between these two. If the difference is within this particular range, then the actual pavement deflection is considered to be twice the final differential reading because what it records is half of the deflection that we are getting on the dial gauge; it is half of the deflection. So, we are going to do this because this is how the Benkelman beam is calibrated; by using some blocks of standard thickness, we can calibrate it. So, whatever we have, if the difference between the final differential and the intermediate differential is less than 0.025, then in that particular case, the final differential reading will be called your actual deflection.

So, if this difference is more than that, then we have an apparent pavement deflection, which is again twice your final differential reading, but you also need to get the true deflection. In the first case, when the deflection difference was less than this one, the final differential reading, twice of it, became your true deflection, or I can say the actual pavement deflection. But in the second case, when this may be more than that, then this final differential reading will become yours; instead of actual, it will become your apparent deflection reading. And to get the true deflection or the actual deflection, you have to add to this apparent deflection a value that is 2.91 times the difference between the final and twice the difference between the final and the intermediate readings

So, in that case, true deflection readings have to be worked out. So, one is this is your final differential minus intermediate diffraction; if this is less than 0.025, then twice your final differential reading will be your actual deflection. If this is not there, then what is this twice your final differential reading? It is your apparent deflection to that particular one you need to have to work out; this is 2.91 times twice your final minus intermediate readings.

So this and that give you the true deflection. So from this particular one, what you get is your actual pavement deflections. This is the exercise that is there. Now, once you get these actual deflections, first, you will apply the temperature corrections to them. So, regardless of the temperature at which you conducted this particular study, you will apply the temperature accordingly. And how can I measure the temperature of a pavement surface? Normally, I dig a hole in this particular one to a depth of around 40 to 45 mm, and the diameter of the hole may be around 1 centimeter.

I will pour in glycerol and insert a thermometer. I will wait for about 5 minutes. I will get the reading. So, I will get my pavement's temperature. So, this is how I can work out that the pavement temperature was this. So, this true deflection is the actual deflection; you will

apply the pavement correction, and then on this temperature-corrected reading, we will apply the moisture correction factor.

So, we will multiply those temperature-corrected readings by the moisture correction factors, and that gives you the final corrected reading. So, there are two steps: first, temperature corrections are applied, and second, moisture corrections are required. So you get a corrected reading. Now, here in this particular case, we do not determine the overlay thickness based solely on one measurement; I mentioned that at least 10 measurements have to be taken in one section, and the distance should not be more than 50 meters. So, on the basis of those numbers of measurements, we will work out the mean and the standard deviation.

So, here you can see that on the basis of those two corrected deflections, we will work out the mean and the standard deviation. And it is suggested that from this, you get the characteristic deflection which is used to determine the overlay thickness, and that characteristic, what is that characteristic deflection, is your mean plus twice your standard deviation if you are looking for higher categories of roads, such as national highways and state highways, and this characteristic deflection is the mean plus the standard deviation for other categories, such as rural roads or major district roads in that case. Now, once you have this characteristic deflection, you can see this is the plot that shows the relationship between the characteristic deflection and the overlay thickness corresponding to different design traffic. Now, design traffic normally; whatever overlay you will be requiring for it, you will target it for a period of at least 5 to 10 years. So you need to work out the design traffic that is going to come in those 5 to 10 years.

Specifically, it is usually designed for a period of 10 years. So the design traffic for this particular one, already stated in IRC:37, explains how you work out the design traffic. This is the N_s , which is the design traffic in terms of standard axles that will be encountered. Here you can see it is $365 \times A \times (1 + r)^x - 1$, divided by r , into F . Where you have the lane distribution, it says the r is your annual growth rate of commercial vehicles' design life, and you have, along with this, a lane distribution factor also, which is to be there.

D is the lane distribution factor. So, a cumulative standard axle is to be catered to in the design, with initial traffic in the year of completion of construction, in terms of the number of commercial vehicles per day, duly assigned to account. Now, in this particular case, it has already taken care of the lane distribution. So, you do not have to apply for the lane distribution factor separately. And then the design life, as I mentioned, is as per IRC:37; you need to work out the design traffic. Once you have the design traffic, say it may be that the design traffic for the coming 10 years is 100 msa.

So, you have the design traffic, which is 100 MSA here, and you have, for example, a characteristic deflection obtained from your previous mean and standard deviation of 4. So, then you will see and work out how much oldie thickness you get. So, I will see from here. Possibly, this particular one may be around 295.

So, 295 mm of overlay thickness is required for this pavement structure. Now, this 295, which is given for this particular example by IRC:81, is in terms of bituminous macadam only. So, you will not go for a wearing course in terms of bituminous macadam; you will prefer to go either for some binder layer or a wearing course layer. So, it may be in terms of DBM or BC. So, this thickness, in case you are providing it in terms of DBM and BC, will become 0.7 times what 295 is. And if this is more than enough, you need to provide some; the structure is weak enough that you may require putting up some granular layers. The thickness of the granular layer will be 1.5 mm of this overlay thickness in terms of the bituminous mechanism. So, this is how this Benkelman beam deflection study is done, and the measurements help you to work out the overlay thickness by this simple technique. So, this is one way of doing the structural evaluation and working out the overlay thickness for flexible pavements through the Benkelman beam study. Thank you.