Course Name – Pavement Construction Technology
Professor Name – Dr. Rajan Choudhary
Department Name – Civil Engineering
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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. The instructor for the NPTEL MOOC course, Pavement Construction and Technology, is funded by the Ministry of Education, Government of India. Today's lecture will discuss the different aspects related to the checks that are made to ensure the construction quality of bituminous bound courses under module 7. 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. As we all are aware, bituminous bound layers are highly important for a flexible pavement structure.

So, which are constructed as a bituminous bound base course, a bituminous bound binder course, or a bituminous bound wearing course? So, they form the backbone of your flexible pavement structure. So, it is very important to ensure that a good quality construction of these layers is done, so that we can ensure a long-lasting durable pavement. So, it says that bituminous bound layers constitute the primary structural component; these are the ones that add significantly to the structural strength of your flexible pavement, contributing significantly to its overall strength and performance. They play a major role; these are the top layers that are going to bear the maximum distresses due to traffic and changes in climatic conditions as well.

Ensuring quality during production and construction is essential, so it is very important to ensure that things go in the correct manner as per the required standards, because it is good to control; as we always say, precaution is better than cure. Similarly, here it is also very important to ensure the checks during production and construction itself, because thereafter rectifying those defects, especially in bituminous bound layers, becomes very challenging and is also a very costly affair. So, it is important that we do a good amount of checks in order to regularly monitor the quality of our bituminous mix production as well as its construction. Ensuring quality during their production and construction is essential to safeguard the structure's integrity and the long-term durability of the pavement. And in recent years, the need for stringent checks and quality control measures has increased substantially because we are experiencing a very high growth in traffic volume, and the requirements are also increasing in terms of wanting long-lasting payments, wanting payments that have low maintenance, and wanting a good smooth surface with lesser maintenance requirements.

In recent years, the need for stringent checks and quality control measures has increased substantially, driven by escalating traffic volumes and the growing demand for enhanced service life and durability of roads. So, we will be having a discussion of many codal provisions, including some that are listed here, which include the handbook of quality control for the construction of roads and runways. The manual for quality control in road and bridge works, guidelines IRC SP 11, has been merged with IRC SP 112. Then we have the guidelines on measuring road roughness

and norms, specifications for road and bridge works in our orange book, and specifications for dense graded bituminous mixes IRC 111. So, as we discussed in earlier courses, it is very important to understand the design, specifically the alignment of your road.

So, it is very essential for everyone to understand the drawings and the aspects shown in the drawings, such as the center line, the presence of curves, the width indicated, the ROW that has been acquired, and the radius of any curve depicted. And if some discrepancy is found, it can be pointed out, because all these designs are ensured at various levels; however, if a discrepancy is figured out, one can have a discussion with the designer to get those things incorporated, and there may be certain challenges that one may encounter during the course of construction. So, in that particular case, there may also be some requirements to be made in the design, specifically the alignment; if that is the case, then it needs to be discussed again, and prior permission has to be obtained. Now, as I mentioned, the drawings give good detail specifically at varying challenges with respect to the profile of your road, and they provide information about the cross section. Here, a typical cross section has been shown where there is a median of 1.5-meter width, then there is a carriageway of 7-meter width, followed by a paved shoulder and an earthen shoulder; it also shows the right of way and the proposed ROW. In addition to this particular one, it gives information about the layers, including the individual layers, such as the subgrade layer, and the granular sub-base course, which is constructed in one layer only. Then we have the wet mix macadam base course: layer 1, layer 2. So, a wet mix macadam total thickness of 250 mm has been constructed in two layers, followed by your bituminous base course, which is DBM of 60 mm thickness, followed by your wearing course of bituminous concrete of 40 mm. So, the center line is marked, taking care of the levers at the top of my carriageway in terms of the center line.

I can work out the levers; you can see the cross slope, which has been shown. It is on the carriageway; it is 2.5 percent. When it comes to the shoulders, it is 2.5 percent. There you are showing it is showing 3 percent; in addition to this particular one, you can see the side slope, which has been shown as one vertical to horizontal. Along with it, you can very well see that the material used in the granular sub base course will serve the purpose of both drainage and filter layer. So, it has been extended to the edges, and thereafter, on top of it, there is a selected earth fill; this is usually the subgrade soil, which is preferred to be used as selected material. On top of it, again, there is a compacted granular material, and then you have these WMM layers. So, it is very important to understand the drawings and the cross section; then only can you work it out.

So, if I have my horizontal alignment, I have the levels for my centerline at different changes; I will work out what the levels will be at the bottom of one particular layer and at the top of that particular layer, so that I can ensure the surface levels in the field. So, first I need to ensure specifically the levels in the field to get the correct horizontal alignment. So, the horizontal alignment is to be ensured with reference to the road centerline as indicated in the approved plans and drawings. So, it is important that whenever you refer to all drawings, they are approved drawings. There may be some preliminary drawings that are also available but may not be approved.

So, those drawings need to be vetted, and the one you are going to refer to is the approved one. So, this process involves verifying both roadway geometry and the edges of the various pavement

layers against the design center line in the case of horizontal alignment. So, I will work out the levels with the center line considering the width on each of the layers from the cross-section; I will work out the edges of each layer. So, this is very important and needs to be derived from your horizontal alignment. Adequate control of the horizontal alignment is possible, and for this particular process, you need to precisely mark your center line.

So, a good surveying team is required; you need to be acquainted with the use of a total station and a dumpy level to ensure the levels at different layers. You can see that these pegs are marked here; then a string may be there. So, these are normally used to check the surface levels. Now, this can be done so that adequate control of the horizontal alignment is possible if the center line is precisely marked. So, for that, you have the benchmarks; you have the temporary benchmarks in the field using reference fillers placed on both sides of the center line at regular intervals, and they should not get disturbed during the course of your construction.

To ensure adherence to the design, the edges of each pavement layer should be maintained. As I showed there, the edges of a granular sub-base course extend to your side slopes, whereas the edges of your base courses and the upper courses have a different extent. So, this needs to be verified from your cross-section and then needs to be checked with your surface levels at those layers. So, it says to ensure adherence to the design, the edges of each pavement layer shall be aligned in relation to the center line before construction, and for this particular one, you can put pegs, strings, or any other tools that can be used. And as per the MORTH requirement, it states that the edges of the carriageway, specifically the wearing course, the bituminous concrete course, or stone matrix asphalt or semi-dense bituminous concrete, which are preferably used as wearing courses or surface courses, shall be correct within the tolerance of plus or minus 10 mm.

So, this is what is very important when the top carriageway is considered. The corresponding tolerance, as we have seen, can only be achieved if we follow the tolerances from the bottom layers; otherwise, we may fall short on the width of our carriageway. So, we need to ensure it, and at every moment it should not be since you are given a tolerance of plus or minus; that does not mean at each layer you will go for a negative tolerance only. No, this is the range that does not mean you can use it; you have to use it judiciously, and this needs to be permitted by the engineer in charge of the project. So, that finally, when you are able to reach the top, it should fall within this particular range.

Now, the surface levels, as I mentioned during the course of construction itself, should always be ensured before and during the course of construction. So, this exercise goes simultaneously; you can see this is a surveyor, and they are also engineers, so any one of us can look into it and ask them to install the staff and your total station, and you would prefer to have a continuous check over it. As I mentioned in our previous lecture, for the compaction exercises, for the laying exercises, and for the number of passes, we need to have a trial stretch. Normally, a trial stretch of at least 100 square meters is preferred, so that you can get an idea about how the compactions are, in what manner the compaction process and laying process occur, and what the loose thickness should be when it comes out of the paver. So, you can also monitor whether the loose thickness is present.

Definitely, the pavers have sensors; they follow the levers that will be given through them using the pegs and the strings. So, these are all sensor pavers. So, with respect to that, they will construct your surface courses, but then also, because these are machines, we need to ensure whether they are working properly or not. So, the levels of the constructed bituminous bond core shall not vary from those calculated with reference to the longitudinal and cross profiles. As I mentioned, once you have the top surface levels for your central line, you can work out what should be there for any layer at any part of it at any width.

So, those calculated with reference to the longitudinal and cross profile of the road shown on the drawings as directed by the engineer should not be beyond the tolerances given by MORTH specifications. It says that when you are constructing the bituminous bound courses, the tolerances should be within plus or minus 6 mm. So, you can understand that here. So, these are very strict quality control checks specifically, which are required when you are looking into the bituminous bound courses. Now, in addition, there may be, as I mentioned, tolerances for AJS and also for surface levels; it should not happen that the tolerance is going in one direction, as that does not mean a tolerance; that means a fault is occurring. So, it says that the negative tolerance for wearing course shall not be permitted in conjunction with the positive tolerance for the base course.

So, I also mentioned in the previous lecture that if there are two layers, this is the usual thickness that is to be constructed. So, this is your base course, and on top of this, you have the bearing course. It should not happen that, on top of that, I am doing this in a particular manner; I have a positive tolerance for the base courses and a negative tolerance for the bearing course. So, overall, what is happening is that my wearing course thickness is getting significantly affected. So, this should not happen that I have to take care, and that is what is stated in the guidelines: the negative tolerance for wearing course shall not be permitted in conjunction with the positive tolerance for base courses.

And what it specifies is that the thickness of the former is important because if the thickness of the bituminous concrete is reduced by more than the following limits, it specifically states that it should not be less than 4 mm in any case when it is a bituminous wearing course of thickness greater than 40 mm. So, even for 40 mm, it can be 50 mm, 55 mm, or 60 mm. In those cases, when it is more than 40 mm, this overall thickness reduction because of the greater thickness of base courses and lesser thickness of the wearing course should not affect the thickness by more than 4 mm. And it says specifically that when this is for thicker ones, wear more than 40 mm; if it is less than 40 mm, it should not affect more than 3 mm. So, the tolerance given in the earlier slide I showed is plus or minus 6 mm, but that does not mean that in addition to this particular one, this check is there, because if you are doing it for base courses, positive tolerance is there and negative tolerance for wearing course; effectively, the thickness should not be reduced by 4 mm and 3 mm, respectively, for the different wearing course thicknesses.

And see, this is the paving operation that is going on, so once the paving operation is done, I will simultaneously make checks for the loose thickness as soon as the compaction goes on, and as soon as the section gets compacted, I can immediately proceed with my checks at some random places to ensure that if there is any fault, I will be able to figure it out and try to get it rectified before more length is constructed. So, to check compliance with the above requirement for bituminous wearing

courses, measurements of the surface level shall usually be taken at grid points, because we will form grid points to ensure that the entire section is captured in a good manner. On a grid, points are placed 6.25 meters along the length and 0.5 meters from the edges and at the center of your pavement.

Now in addition to the surface levels, we also look for the surface evenness, or we can call it the surface regularity. So, the measurement and checking of surface unevenness is mainly done by a 3-meter straight gauge, which we call a rolling straight gauge. And there is IRC 111, which dedicatedly deals with the dense bituminous course mixes, whereas MORTH gives an overall picture of all different types of mixes. So, IRC 111 states that the maximum permissible surface unevenness is 6 mm. Now, because two conventionally used hot mix asphalts as a wearing course are semi-dense bituminous concrete and bituminous concrete, stone matrix asphalt is also getting quite popular nowadays.

So, it has been stated that the permissible limit for surface unevenness is 6 mm for SDBC and 5 mm for BC in the longitudinal profile. So, when you are using in parallel to your centerline, this should not go beyond 6 mm for SDBC and 5 mm for BC, and in transverse, it says 4 mm for both in the transverse profile. Now, the maximum permissible frequency of surface unevenness in a 300-meter length is necessary because we will do multiple measurements. So, it says that if you measure 300 meters in length in the longitudinal profile, it should not go beyond these given limits. So, here you can see that for the bituminous concrete wearing course, for an unevenness in the range of 3 to 5 mm, it should not exceed 15 numbers.

So, along with that, a limiting value of 5 mm is given, but in addition to that, it states that you should not have more than a range of unevenness of 3 to 5 mm, with more than 15 in number for a 300-meter length. So, it further controls the surface evenness when the surface unevenness falls outside the tolerance. If it is going to say 20, and you are having 3 to 5, and because it is a bituminous concrete wearing course, in either case, the surface is low or high. So, the justification may be that you could say I am putting up more thickness. So, it can be accepted not only for whether it is low or high because it is related to surface unevenness or surface regularity.

So, it says that whether it is high or low, the full depth of the layer shall be removed and replaced with fresh material compacted to the same specifications. Now, this, as I mentioned, becomes very challenging. So, it is very important to ensure that it goes before the construction offered; we need to ensure what the levels of your base courses are. So, there we will see whether the base courses have positive tolerances; if so, we will warn them that the wearing course should not have negative tolerances, and in addition, we have to make this a continuous check for your surface evenness. Now, along with it, MRTH in a similar direction mentions that the maximum allowable difference between the road surface and the underside of a 3-meter straight gauge placed parallel to or at a right angle.

So, when we measure the longitudinal as well as the transverse profile, it indicates 3 mm for a bituminous pavement; this allowable difference can be a maximum of 3 mm for a bituminous surface or a bituminous wearing course and 6 mm for a bituminous base course. So, again, this is very close to what we have from IRC 111, and as per MRTS 2013, the longitudinal profile should be checked with a 3-meter straight edge or a moving straight edge along the middle of each traffic

lane. This is highly specific because now you have constructed the wearing course. So, we prefer that when it has to be checked along the center line of each lane, the middle of each traffic lane shall conform to the permissible surface irregularities. So, finally, when the surface is there, the wearing course or carriageway is there, it specifies the irregularity, and if a 4 mm irregularity is there for a length of 300, then it cannot be this particular surface of carriageways and paved shoulders.

So, it says that in 300 meters you cannot have a number of surface irregularities on national highways; it cannot be more than 15, and in the case of surface irregularities on roads of lower categories, it can be. So, there we can see that for a length of 300 meters, you cannot have more than 15 irregularities present there. So, this needs to be further ensured. So, this is how we check for surface unevenness and regularity as per the given standard specifications, and these include some bus lay-bys, truck lay-bys, and possibly some service areas or bituminous base courses. So, for bituminous base courses, you can see similarly in the case of 4 mm where it was for the wearing course, in a 300-meter length instead of 15; now it becomes that the allowable permitted number of surface unevenness can be 40 when you are counted in this particular one.

So, this needs to be further checked, and this is for 4 mm; what number of irregularities can be there? So, you have the quantum of the irregularity, the length in which it is to be ensured, and the number of these irregularities that can be permitted. Now, if there is some, as I mentioned, if certain irregularities occur, then the surface needs to be rectified. So what it says is that the current caudal specification for bituminous courses, other than wearing courses, specifically means that we can have a binder course or a bituminous bound course, such as a bituminous bound base course. Where the surface is low, the deficiency is usually corrected by applying a fresh material with a suitable tack coat, because the existing surface is bituminous and compacted as per specifications; this is quite a challenging task. But where the surface is high, specifically with base courses or binder courses, it is preferable to remove the extra thickness in the affected layer, which becomes challenging.

So, you need to have some milling machines with you to mill to the required thickness and replace them with fresh material, compacted to the required specifications, because if you don't, it may not be possible to reach the correct depth. So, it says if it is high, then it has to be removed first, and then you have to come up with your correct quantity of material. In most cases, the entire thickness may have to be removed because if you do not have a milling machine, it is very difficult to correct for a given depth. For wearing courses, now it applies to the wearing courses where the surface is high or low; the full depth of the layer shall be removed and replaced with fresh material. So, this becomes more challenging when you have these varying course mixes.

These are very costly mixes; the cost of materials is high, as are the costs of production and construction. So, if one needs to remove it, it can become very challenging. So, that is why it is always better to ensure these levels, specifically surface unevenness and the surface levels, well before and during the construction. In all cases where removal and replacement of a bituminous layer is involved, the area treated shall not be less than 5 meters in length and 3.5 meters in width, typically the width of a lane, so that the minimum area is also met.

So, you can see a treatment has been going on in a small area; this is a milling operation that has been done. Going on, this is a regular laying and compaction operation. In addition to this particular one, specifically in bituminous bond courses where the top course and wearing course are constructed, we need a smooth riding surface. To ensure riding quality, the surface should not be bumpy; there should not be waves that make your ride bumpy. So, for this particular case, specifically when it comes to the wearing courses, your bituminous concrete surface courses or any other surface course, we need to ensure the road roughness as well.

So, road roughness refers to the irregularities in the pavement surface that negatively impact vehicle ride quality and the user experience. You might have observed on some of the older roads that they give a bumpy ride; specifically, there is a wavy sort of structure there. So, when you drive at higher speeds, you experience bumps or the wavy structure more acutely than when you drive at a slower speed, especially if those bumps are closely spaced. So, it influences not only comfort but also vehicle delays because you cannot drive at the design speed; fuel consumption is high, and maintenance costs increase. So, it is always preferred that you get a good riding quality; from a user point of view, it is always important to have a good riding quality, a smooth surface, and a safe surface.

So, the term is smoothness; that is why there is another term, which is very frequently used along with roughness, that refers to the surface being as smooth as possible in that case. So, they can be used interchangeably with roughness, as both describe the same pavement characteristics we are trying to refer to. And why this usually can occur is that the road roughness may be good enough initially, just after the construction, but in due course of time, you might experience that the roughness or smoothness has reduced or that the roughness has increased, and the bumpy nature has increased because there may be some structural defects occurring. There may be some consolidation occurring, such as potholes and cracks, all of which make your ride rough in the coming years. So, this may show that road roughness is mainly a result of either the built-in irregularities.

So, there are already some built-in irregularities if you are ensuring that you are not able to ensure the levels properly; your surface regularity means you are not able to ensure the surface evenness. Then, that definitely gets reflected on the top, and you have a bumpy ride due to some construction defects or deficiencies. So, these are deficiencies that may also appear on the road surface due to consolidation if the loads are very high; some of the layers that are not properly compacted during construction may get compacted, while some may become over-compacted if the traffic is more than projected or if the axle loads are significantly higher than those considered in the design. So, in those cases, you may have this kind of bumpy ride. So, this is now to ensure that this particular one needs to have a smooth surface; we normally go for some measurements, and we call them roughness measurements.

So, one of the quite popular pieces of equipment that is used is a bump integrator. So, it measures the bumps in a given length with reference to a standard frame; it measures the vertical bumps when it travels on a road surface to get an idea about the road roughness, and this gives us a quantification of the road roughness in terms of the roughness index. So, where the project specifies these surface roughness requirements, there may be certain low categories of load where these

roughness requirements may not be specified, but otherwise, in most cases, they are specified for higher categories of roads and mainly specified currently in India, through IRC SP 16, which provides guidelines related to the road roughness that we get in terms of bump integrator value. So, the roughness index is measured, and it is mm per kilometer.

So, the roughness is measured by a calibrated bump integrator. This is typical; it is towed by a standard vehicle and runs at a standard speed in the center of your lane. Here, an important aspect is that you have to calibrate this equipment regularly. Nowadays, many other more precise equipment is available for measuring road roughness; portable equipment is also available for this purpose, but still, this is one of the most popular options. So, in all equipments it is important to ensure that they are well calibrated. So, we need to do the calibration with some high-precision equipment, specifically like a dipstick.

So, with those once these the bump integrator can be calibrated, so that we get the correct readings. The measurement shall be taken at the centre of each lane for a minimum completed length of 1 kilometer, because it has to be run at a certain speed of around 30 to 32 kilometers per hour. So, we need at least a stretch of 1 kilometer in length; once the laying is completed, we will go to this particular one. So, the typical measurement we can do at any period of time, as I mentioned, the roughness may be quite low; the surface may be smooth immediately after construction, but if some defects are left in the underlying layers, they soon get reflected in due course of time in the coming 1, 2, or 3 years. Many a time these defects are such that they get reflected during the course of construction itself.

So, if the roughness of the surface increases at any time during the service life of the pavement, we can measure this particular aspect and then we need to ensure whether this surface is good enough for users or if it needs some rectification. So, the typical maximum permissible values of surface roughness measured through a bump integrator for surfaces with dense graded bituminous mixes have certain limits specified as per IRC 111 2009, which states that if you have a varying course of BC, this is your surface roughness index, which is in terms of mm per kilometer. So, how much is it in 1 kilometer of length? It should be for a bituminous concrete bearing course for a good means; nearly this is possible when you have a newly constructed one, and in the initial years of service life, you always prefer to have a roughness less than 2000 mm per kilometer. And, as I mentioned in due course, if the roughness increases because of any structural defects, consolidation, cracks, or potholes, then if it falls in the range of 2000 to 3000, we can. So, a newly constructed one may have something around 800 to 1,200 mm per kilometer.

So, if this falls within the range of 2000 to 3000, we call that the surfaces having average roughness, and if it is more than 3000, it is a poor surface. So, that triggers at what moment we have to initiate with the any repair and maintenance for these surfaces. So, always we prefer for a newly constructed one definitely much lower to this 2000 value. Now, in addition to this particular one, there are a good number of requirements, as I mentioned during the course of production and construction. It is very important to control the qualities during that course of time.

So, what can be done is the different aspects that can be checked and shown during this period of time. MoRTH also specifies that the mix grading needs to be ensured. As I mentioned, there may be dust going out of the exhaust, so we need to ensure that we are not losing the fines beyond a prescribed limit, and we need to check what is coming from the cold bins in case of your drum mix plant. So, you can take out where it is going for storage silos, or at that moment in time, or before it enters the drum; you can pick up material from the cylinder conveyor for the entire width of your conveyor, and you can ensure whether the degradation is acceptable or not. Then, after the mix is produced, you can take it out; when you take it out, it has been coated with the binder.

So, you can extract the binder; you can also get the binder content. So, they specify how many times you need to ensure this particular one, like mix grading; this is an important part. For individual constituents, there may be certain changes that arise because the plant will be run for laying the bituminous base course, binder course, wearing course, and all may have different compositions. So, it says that once set for an individual constituent, if the geomix is not changing, even the stone queries you are using or from where you are getting the aggregates, the gradation may change in due course of time. So, you may have to change your job mix formula. So, you have to run your plant after a certain period of time with a different combination.

So, that is what it is important that one sets individual constituents for mixed grading and mixed aggregate from the dryer for each 400 tons of mix, subject to a minimum of 2 tests per day per plant. So, if you are having, say, one plant, it may not be sufficient enough for the ongoing project. So, if different plants are present, you may need this for one plant in that case. So, every day you have to monitor the mix grading, and at least for every 400 tons, you have to do at least 2 tests per day. Then, regarding the mixes, we can specifically have stability and void analysis of the mix, including the theoretical maximum specific gravity of the loose mix.

So, the simultaneously for this particular mix. You can ensure that the loose mix can be taken and that it is ensured for your specific theoretical maximum stress under gravity; it can be compacted in the laboratory again with the binder content and gradation that is available to see what stability we are getting, and this was discussed during the course of bituminous mix design. What is the strength it carries, what is the load it has, what is the flow value, how much density are we able to achieve from it, and what is the void content at the given number of compaction blows? So, we are trying to ensure whether that combination is now able to give you what you have designed, and simultaneously, you can have samples from your bituminous mat that had been constructed and compacted as well. So, from there, you can also have the compacted mix; you can core that particular mix, bring it to the lab, and ensure density, stability, and flow values. So, it says subject to a minimum of 2 tests per mix per day per plant. So, this is again about moisture susceptibility during the design phase; we have seen that for the mixes, what we ensure are the volumetric parameters, which are your voids in mineral aggregates and voids filled with bitumen.

Your air void content was there; those were the volumetric parameters, your density was there, and then the mechanical parameters were your stability and flow. In addition to that, we measured the resistance to moisture-induced damage in terms of moisture susceptibility. The tensile strength ratio was measured. So, we can see whether the produce mix is providing that much resistance to

moisture-induced damage for that particular one as well. It states one test for each mix type whenever there is a change in the quality or source of coarse or fine aggregates.

As I said, there may be one query that may be able to supply you with coarse aggregates for a particular period of time. It may stop, or there may be a shortage of aggregates, and another important aspect is if you are getting aggregates from two different queries. So, this also needs to be very well ensured at the plant level that the source being utilized for the job mixture has been derived from that particular source only. The density of the compacted layer, while construction is ongoing, requires one test per 700 square meters of area; you can also conduct tests at smaller intervals, but you still need to perform a minimum number of tests to ensure accuracy because slight variability will be present.

So, the acceptance criteria are there to ensure the density in the field. Binder content: again, we need to look at one set for each 400 tons of mix, which is the costliest component and needs to be ensured. It plays a major role in the performance of bituminous mixes, and it is a very costly component. So, we always need to take care that the right amount of binder content that we recommended in the geomix formula is getting incorporated into the actual mix. Now, similarly to how we did the density measurements for the other layers, we can do the density measurements for bituminous matter. So, we can use the nuclear density gauge or non-nuclear density gauge to measure the densities in the field.

So, this can help us to ensure that the compaction pattern which we are following is giving us the required density or not. This can be ensured at that particular moment in time. And as mentioned, the acceptance criteria for the test on density is that at least three minimum tests have to be conducted. Martial stability, if I am looking for samples, I will take at least 2 minimum samples, and then they will be subjected to the conditions that were present in other cases when we looked into the density check for subgrade courses and granular courses, such that the mean value of the number of samples for density is not less than the specified density plus 1.65 minus 1.65 times the square root of the number of samples times the standard deviation. So, this is the same as what we did in the case of other courses. Now, what I can do with nuclear density gauges is that I can cut down a core, and I can determine the density of these mixes in the laboratory. For different methods, we have water displacement methods, and there are some vacuum sealing methods that can give us the density of these. So, then I can ensure whether this density is meeting the requirement for the amount of compaction that is required.

So, in addition to this particular one, another important check is to ensure that whatever gradation we initially planned for the combined aggregates and binder is being ensured at the plant. So, a regular check has to be done for this particular item. And definitely in a laboratory, it is very controlled; at the plant, a small amount of variation will happen, but that should be within a permissible range. So, for different sieve sizes, different permissible ranges are given because they affect it in a different manner. You can see this is one which has been taken for dense graded mixes from IRC 111, which says that if a mix is to be used as a DBM and if the mix is related, it has particles of 19 mm or larger, 13.2 mm, or 9.5 mm, and 4.75 mm. So, whatever percentages we have arrived at during the geomix formula, the variation should not be more than this particular one. So, you can see very well for wearing coarse mixes of bituminous concrete and semi-dense bituminous

concrete. For each sieve, these are stricter compared to the one we have for DBM, which can be used as a base and binder course. As it goes down specifically for finer materials, the ranges become reduced; the lower values of the ranges are there. So, they play a more significant role, and if a small change is present, they affect the performance of your mixes.

So, here you can see this is only a very small, specifically the final fillers, where 75 microns are present, 0.075 mm, and only a variation of plus or minus 1.5 percent is allowed, and then the binder content is within a range of plus or minus 0.3 percent. Mixing temperatures again, it is mentioned that you can do this check at the plant; you can take out the loose mix specifically once it comes out from your pug mill or from a drum mixer in the case of a drum mix plant, and you can ensure these compositions are present.

In addition to this, other quality control checks will be there with respect to the aggregate requirements and binder requirements, which we will discuss further when we address the quality control and quality assurance part of bituminous bound courses. So, these are some of the important discussions that are required to ensure good quality construction of bituminous bound courses. Thank you so much.