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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. Instructor for the NPTEL MOOC course "Payment Construction and Technology," funded by the Ministry of Education, Government of India. Today's talk will be a continuation of our previous discussion, which was on the Mixed Design of Bituminous Bound Courses under module 4 of this particular course. In 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. In the last lecture, we discussed the different phases of a bituminous mix when it is compacted using aggregates and binder.

Now, we discussed the different volumetric parameters; here you can see the volumetric parameters. This is a three-phase diagram: this is your air, this is the binder that is free, and this is the small amount of binder that can be absorbed by your aggregates, and then the remaining is the aggregate volume. So, this is shown in this particular manner: this volume of the aggregate is the bulk volume of the aggregate, so it can be mentioned as  $V_{sb}$  or  $V_s$  in whichever manner. And then this is the volume of bitumen that you have as free bitumen; this is the volume of air that we have.

The volume of free bitumen plus the volume of air is your voids in mineral aggregates. We discussed this particular one yesterday, and this forms your  $V_v$ . So, this forms the total volume of your mix, and if we talk in terms of weight, then the volume corresponding to this  $V_{sb}$  will be the weight of the aggregates for this entire free as well as the absorbed bitumen. We have to work out the weight, and that will be  $W_b$  of the bitumen. So,  $W_s$  plus  $W_b$  will be your total weight of the mix, where you do not include the weight of the air, considering it as negligible.

Now let us consider an example to see how the shears can be used. So, for example, the total volume is just an example to explain things in a simpler manner; it is not meant to suggest that the determinations or the figures shown here are a realistic picture, but rather to make things easily understood. So, if the total volume of a compacted specimen is 100 cc, this has been made as 100 cc so that we can make the other computations simple. The volume of air, if one can figure it out, is the total volume of this particular specimen, which we determined through the water displacement method that we discussed in the previous lecture. So that the  $G_{mb}$ , when we measured the  $G_{mb}$ , where the weight of the mix is present and the bulk volume of the mix is there.

So, this is the specific gravity corresponding to this particular one; since the weight is known to us, the bulk density will be determined through this water displacement method, and I can get the volume of the specimen. So, here I have taken an arbitrary number. So, that lets the volume of the specimen be 100 cc, out of which the volume of the air is 5 cc. To explain what VMA means, what VFB means, what air void contents mean, what percentage of binder absorbed means, and what

effective binder content means, I am trying to explain all this through this simple example. So, if the volume of the air present in this 100 cc of a compacted specimen is 5 cc.

Now, the volume of effective free bitumen, if the freed bitumen is, say, 10 cc in this particular case. So, this VFB or Vbf or Vbe, which is your 10 CC in this particular example. The volume of mineral aggregates corresponds to its effective specific gravity. So, we discussed in the previous lecture that if there is a void, there is an aggregate, and there may be some surface voids. So, part of it may be filled with your binder that gets absorbed on the surface.

So, the remaining voids, which are these, plus this volume, will be your effective volume. So, it does not include the words that get filled with water. So, that is what your Gse is, effective specific gravity, and if you recall, yesterday we discussed an expression where it is the percentage of mix minus the percentage of bitumen and the percentage of mix divided by your maximum specific gravity, which we worked out, and this is the percentage of binder by weight of mix; the percentage of binder by weight of mix is the specific gravity of bitumen. And this is the maximum specific gravity that we determined through your rise specific gravity meter or through the vacuum sealing method. So, if that is known, then we get this value of Gse.

So, as the weight of aggregates is known, you can work out the volume correspondingly. So, this is the specific volume that is shown here; it is the one that includes the solid part plus the volume of the solid part plus the volume of voids that are not filled with bitumen. So, this is mentioned here as 84 cc. Binder absorbed in the aggregates is 1 cc. So, this much binder absorption is present; 1 cc gets absorbed.

So, if this 1 cc is this volume, then 1 cc plus what you have here is 84 cc. This is 84 cc. So, this 1 cc is the volume of bitumen being absorbed, and 84 cc is the remaining volume of your aggregates. So, this 84 plus 1 is 85, which is your bulk volume of the aggregates. Assuming the specific gravity of the binder as 1, it is mentioned that the specific gravity of the binder is 1, and the bulk specific gravity of the aggregate blend is 2.5. Now, with this particular one, we will try to attempt this exercise. Now, first of all, we are trying to look for the voids in mineral aggregates. Now, if you recall, the voids in mineral aggregates that we mentioned yesterday were the volume of bitumen that is free or the volume of bitumen that is effective, plus the volume of air, divided by the volume of the mix. Now, in order to express it as a percentage, what is the volume of free bitumen? Here, the effective binder is 10, and the volume of air is 5 cc; the total volume is 100. So, this will give you 15 percent of your VMA.

Now, the voids in mineral aggregates in a compacted specimen are 15 percent. What is the air void content? Air void content is the volume of air divided by the total volume of the specimen. So, it is 5 percent. So, this is how we got air void content:  $G_{mm} - G_{mb}$ , upon  $G_{mm}$  multiplied by 100. I am just trying to explain what it means.

Now, in addition to this one, the other part was how many voids get filled with the bitumen. So, we had the binder that is free. Here we will consider only the binder that is free, which is either Vbe or Vbf in whichever manner you mention. This is the volume of bitumen that is effective for coating, or the volume of bitumen that is free for coating. So, that was 10, and VMA was your 15.

So, into 100, this comes out to be 66.6 percent. So, this is what you have for your VFB. Now, here it comes: bitumen content by weight of the total mix. Now I have to figure it out.

So, for that particular one, how much is the total binder? 1 gram, 1 cc is absorbed in the aggregate; 10 is free. So, the total volume is 11 cc, and considering a specific gravity of 1, I am taking the weight of the binder as 11. So, this particular one, my total weight will be 10 plus 1, which will be my total weight of the binder, considering a specific gravity of 1. Now, the weight of the aggregate in the specimen, the specific gravity, and the bulk specific gravity were given as 2.5. And what was the bulk volume of the aggregates? It was the effective volume plus 1 cc that was absorbed by the bitumen. So, in the previous slide, we mentioned that  $V_{sb}$  is your 85 cc. So, considering this 85 cc and this bulk specific gravity, this will be the weight of your aggregate. Now, 212, so what will the percentage of bitumen be?  $P_b$  will be the weight of the bitumen, the weight of the bitumen divided by the weight of the aggregate, plus the weight of the bitumen, multiplied by 100. Because here we have to consider the weight of the mix.

So, for that particular one, the weight of the aggregates is 212.5, and the weight of the binder from here is 11 grams. So, the total is 223.5 grams. So, this percentage of binder will be 11 divided by 223.5. So, it is 11 divided by 223.5, which gives us 4.92 percent by weight of binder we have in this specimen. Now, if one asks what the binder is with respect to, or the binder that is being absorbed in the aggregates. So, that is  $P_{ba}$  because it is with respect to the weight of the binder that is absorbed upon the weight of the aggregates, as this percentage is with respect to the aggregates.

So, the binder absorbed is 1, and the weight of the aggregates is 1212. So, this comes out to be that the binder, which is getting absorbed in aggregates, is 0.47 percent. So, this gives an idea of what we are doing there, and then there was another term,  $P_{be}$ , which refers to how much of the effective binder is available, and this is with respect to the mix. So here this should be the weight of the binder, which is free upon the weight of the mix multiplied by 100.

So, that particular one, considering the 10 grams, was free. So, the specific gravity is 1. So, 10 cc was free, specific gravity 1, 10 grams is the free binder, and this is the total weight of the mix: 223.5. So, the binder that is effective is 4.47. So, this is  $P_{be}$ . Now, because of the absorption of the binder, the initial binder content, which was 4.92, is effectively 4.47 only because a part of it is being absorbed into the aggregates. So, this explains the volumetric computations that are to be done during this bituminous mix design or understood to be understood during the volumetric mix design. Now, once the volumetric parameters are determined, such as your maximum specific gravity, bulk density, the specific gravity of the aggregates, and the compacted specimen density.

The other parameter that is to be determined is the stability of that particular mix, especially because the method we use for the design of bituminous mixes is known as the Marshall method of mix design. This method was first developed in 1939 by Bruce Marshall of the Mississippi Highway Department. And this gets further refined or modified, especially during the Second World War. The US Army Corps of Engineers modified the equipment and procedures specifically for use during World War II to design airfield pavements. And then, in due course of time, continuous extensive laboratory and field studies have been done, and this method has been modified, and presently, widespread acceptance of this particular one is there for the design of bituminous mixes for use in flexible pavement construction.

The two important key steps involved in this Marshall method of mix design are the evaluation of paving bitumen, the binder that is to be used, and the evaluation of aggregates to be used, which we discussed in our previous lectures about how the different binders are to be evaluated, how aggregates need to be evaluated for use in a particular bituminous bound course, and then the second one is the fabrication and evaluation of Marshall mix specimens for determining optimum binder content. Now, here it says that once you fabricate this compacted specimen, your exercise should focus on determining the optimum binder content, which is the best one. They should not be too high; they should not be too low. As I said, being too low may also be a concern, and with being too high, one common concern is that the cost will increase. So, other concerns may be regarding the performance, so you need to work out the one that gives you the optimum performance.

Now, for this particular exercise, the cylindrical specimens that are to be prepared. The most commonly used are 4-inch specimens with a diameter of 101.6. This is specifically for aggregates with NMA up to 1 inch. And for NMA greater than this particular one, normally for NMA up to 37.5 mm, which is one and a half inches, we can normally go for specimens prepared with a diameter of around 6 inches. And that particular method, when this design is mixed, is known as the modified Marshall method of mix design, especially when modified for 6-inch specimens, while the one practiced with 4-inch specimens is the standard Marshall method of mix design. There are certain differences, such as the hammer weight, the mold sizes, and the requirements based on the parameters obtained from it. So, now during the fabrication, one important aspect is the selection of the binder and aggregates, followed by fabrication and the determination of the optimum binder content. Now, during the fabrication, certain things are to be taken care of; one important parameter is at what temperatures the aggregate and binder are going to be blended.

Now, because we need to heat the aggregates, we need to heat the binder, but at what temperatures does it need to be heated so that we can get a good coating over it? So, we need to determine the mixing and compaction temperatures. In many cases, the agency which provides the binders, specifically the modified binders, on the basis of their experience during the development of their binders, recommends that for these binders, it is preferable to use these mixing and compaction temperatures. For most of the paving grade binders, extensive research has been done, and for paving binders, it is suggested that if you are using a paving grade binder to produce bituminous mixes, then the two viscosities recommended for mixing and compaction temperatures are such that the mixing temperature should be the one which gives a viscosity in the range of 170 plus or minus 20 centistokes. So, the compaction temperature should be the one that has a binder viscosity in the range of 280 plus or minus 30 centistokes. So, for this one, we now need to have information available on the variation in the viscosity of a paving grade binder with temperature.

So, here you can see this is a plot where the temperatures are shown; this is a log-log plot that shows there is a temperature and there is a viscosity. So, we need to plot the relationship between the viscosity and the temperature, and from that relationship, we need to work out the temperatures where the binder has a viscosity in this particular range. So, here you can see this is the range, this is the range of temperature where your mixing viscosities are met, and this is the range of the temperature where your compaction viscosities are met. So, as there is a range of viscosity, you will have a range of temperatures. So, in that range of temperature, you will heat your binders up,

and aggregates are usually heated to 10 to 15 degrees centigrade higher than your binder because the binder is more susceptible and gets highly oxidized when subjected to higher temperatures.

So, aggregates are kept at a slightly higher temperature. So, we mix them at mixing temperatures, and then finally they are compacted at the temperatures which correspond to this viscosity of 280 plus or minus centistokes. Once the mix is prepared at this particular temperature, corresponding to this one, the mix is stored in the oven for a period of two hours. This is for conditioning, and that is done at the compaction temperatures. So, the compaction temperature we are going to use to produce those cylindrical specimens will condition those specimens at those temperatures for two hours.

This helps us simulate the short-term aging that can happen with this mix when it is produced at a hot mix plant. Because it will be produced there, it may be stored for a period of time, then transferred to the field, and finally layered and compacted. So, it remains at that higher temperature for a long period of time. So, to simulate how much aging occurs and how much binder absorption happens into the aggregates, this conditioning is done. And thereafter we compact these by pouring the loose mixes into cylindrical moulds and giving the standard blows as specified by the Asphalt Institute Manual Series; IRC 111 also provides the method for working it out.

ASTM guidelines are available, and IS guidelines are also available to conduct the Marshall method of mix design. So, the blows are applied, and this compactive effort is applied as we pour the loose mix into the cylindrical molds and compact it by giving blows on both sides. Now, this compactive effort has to be good enough to produce the density that will be there in the mix after 2 to 3 years of service life. So, this is an important aspect that the compactive effort needs to be selected at the laboratory scale as per the Martini method of mix design, which recommends 75 blows on both faces of the specimen. So, one phase is given, and when the NMA is higher, we go for 6 inches of specimens; it states that for 6-inch diameter specimens, we go for 112 blows on both phases.

And once this compaction is done, we go for the density void analysis, and the second is the Marshall stability and flow determination to work out the optimum binder content. So, these are all the pics shown in a systematic manner. You have your binder, fine filler, fine aggregates, and coarse aggregates. The batching is to be done.

You need to combine all those aggregates. Aggregates are heated to the mixing temperature, then poured into the mixing bowl. The binder that has been brought to the mixing temperature is added. And whatever trial binder content you may start with, depending on the mix you are targeting, the initial trial binder content may be, say, one binder content of 5 percent, and you may have to do various trials; we normally go with an increment of around 0.5 percent. So, I may go up to 7.5 percent. So, I may do these at 5, 5.5, 6, 6.5, and 7 or 7.5 percent. So, normally, we go for at least four to five trial binder contents to obtain the optimum binder content.

So, I will first pour the binder corresponding to one trial binder content, then it will be mixed, then we will condition it in the oven, bring it to the compaction temperatures, and then compact it, and here you get your specimens. Now, all these specimens are compacted specimens, and I have shown here how the nomenclature can be given, say for 4.5; for each binder content, I will at least prepare 3 replicates.

So, here you can see for 4.5, 3 replicates, 5, 5.5, 6, 6.5; here are 5 different binder content trials. In addition to this particular one, you have to prepare a loose mix for the determination of your maximum specific gravity. So, if a mix design is to be attempted where three or four different aggregate stockpiles are present, and you normally work out four to five trial binder contents, with at least three specimens at each binder content, then three to four specimens may be required for your loose mix, especially for the maximum specific gravity determination. It can be done with all binder contents as well, or it can be done with a binder content that is closer to your optimum binder content.

So, then 3 to 4 specimens may be required there. So, in total, you may need to prepare around 18 to 20 specimen batches, loose mix batches, out of which around 15 to 16 will be compacted and the remaining will be in loose mix for the determination of your maximum specific gravity. So, for this particular one, you usually may require one mix design of around 25 kg of aggregates and 4 liters of binder. Now, once the specimens are compacted and volumetric parameters are determined, we work out the determination of Marshall stability. This was discussed in one of our previous lectures as well, when the characterization of bituminous mixes was addressed. So, this is tested to determine the Marshall stability and flow; this gives us a measurement of the strength of the mix, especially resistance to plastic flow of compacted specimens.

They are to be first brought to the test temperature, which is 60 degrees; for that, they are kept in a water bath for 30 minutes. Then they are transferred to this Marshall stability mold, where the load is applied at a rate of 2 inches per minute. And simultaneously, the deformation is measured, and the flow is measured. So, you have the load measurement setup, and you have the displacement; the deformation measurement setup is there, and maximum load is reached, and then the load starts decreasing. So, we are going to note down the maximum load taken by the specimen and the corresponding flow or deformation that has taken place in the specimen.

So, the stability is the maximum load, and the corresponding amount of deformation is the flow. These two are to be recorded from this specific test. Once this is done, the volumetric parameters are determined, stability and flow are determined, and we plot these properties with respect to the binder content. So, what will we plot? We will plot the specific gravity or bulk density, which is also referred to as unit weight, of the compacted specimens with respect to the bitumen content.

The second one is bitumen content versus Marshall stability. Thirdly, because we have chosen, say, 4 to 5 trial binder contents: bitumen content versus flow, bitumen content versus air voids, bitumen content versus VMA voids in mineral aggregates, and bitumen content versus voids filled with bitumen. So, these four parameters we got from the volumetric measurements, along with this fifth parameter, which is the density measurement. The four parameters we got are one, two, three, and four from the volumetric measurements, and this one we got from the stability and flow measurement. So, these stability and flow are also to be plotted with bitumen content, and the other four volumetric parameters are to be plotted to see the trend of how these parameters vary with the change in bitumen content. And finally, we need to target what the air voids should be, what the VMA should be, and what the VFB flow should be because of all requirements.

Now, this is a table as per IRC 111-2009, which states that if a viscosity grade binder is used, then, as per the Marshall method, 75 blows are given. The stability should be at least 9 kilonewtons at a temperature of 60 degrees Celsius. It says that the flow in mm should be in the range of 2 to 4. So, I need binder content that should meet these requirements. There is another parameter, the Marshall quotient, which is the ratio of your Marshall stability to flow, which states it should be in the range of 2 to 5, and the percentage error should be in the range of 3 to 5 percent.

It says that the voids filled with bitumen should be in the range of 65 to 75 percent, and thereafter, for voids filled in mineral aggregates, it also says that it depends on the NMAS of that particular mix and the air void content target. Since the air void here is 3 to 4, or 3 to 5, if my target is 4 percent. So, I will look for this 4 percent, and my mix may have to be for an NMAS of 13.2. So, in that case, my minimum VMA requirement will be 14. So, I will do this design considering that I have already identified what the requirements are for flow; according to this table for a viscosity grade binder, it should be in the range of 2 to 4. Air voids should be in the range of 3 to 5; the bitumen content versus VMA should be more than 14 percent, VFB should be in the range of 65 to 75 percent, and there is no specific requirement for bulk density; it is just to observe the trend of how density varies with the bitumen content, and Marshall stability should be greater than 9 kilonewtons. So, I need to pick up binder content that meets all these requirements stated for a particular mix. Now, there are certain requirements for modified bitumen that are slightly different from what we have for viscosity grade binder. Now, this is when the standard Marshall method of mix design is used; when we are using a modified Marshall method of mix design, the stability requirements and flow requirements are to be multiplied by 2.25 and 1.5. So, whatever stability 9 kilonewtons will be raised to a figure of 9.9 kilonewtons into 2.25, and what is the flow from 2 to 4 will then become here 3 to 6 because it is to be multiplied by 1.5.

So, this is because you are making specimens that are 6 inches. Now, in most cases, we prefer IRC 111, which also says that air void content is a very important factor in controlling the performance of bituminous mixes. So, always aim to achieve 4 percent air void content and then check at that trial binder content whether you are able to achieve the remaining parameters. If you are able to achieve a binder content that gives 4 percent air voids along with the other parameters, then that can be taken as your optimum binder content. Now, what we get out of it is that we need to balance out, specifically, that all parameters are met regarding our binder content. And it may happen that, for the trial binder content which is for four target four percent air void content, some of the parameters may not be able to be met.

In that case, you have to make some changes, especially since the changes are made with respect to the change in the aggregate blend. Mainly, we focus on the aggregate blend. So, here I have this VMA because the VMA states that we should have a VMA that is greater than that particular figure. So, any VMA, I will see this shaded part where I need to have the binders that meet the requirement. So, there in this particular range, my VMA is meeting a requirement of VFA 65 to 75 percent.

I am plotting my asphalt content. And, I just want to see where my requirements are not met. So, VMA here says that the voids filled with the vitamin air void and stability are too high. So, in that case, what may happen finally is that you may have a small range of binder content in which all criteria are passing. Within this particular one, there was always a preference to have a lower binder

content because, if a range of binder content is available, you could say this may be from 5.2 to 5.5. Now, one may prefer to go for the lowest option. In addition to this particular one, the current guidelines and recommendations state to go for a binder content that gives you 4 percent. So, whatever binder content gives you 4 percent of your air void content, see whether it meets the other requirements; if it meets the other requirements, that can be considered your optimum binder content.

So, this slide shows the six different plots that are drawn between the bitumen content: the first one is unit weight, the second is bulk density, the third is air void content, the fourth is Marshall stability, the fifth is voids filled with asphalt or bitumen, and the sixth is voids in the mineral aggregates. And for different mixes, we will have different requirements in terms of the voids in mineral aggregates; for example, here we can see that the requirement for voids filled with bitumen is that the air void requirement is 3 to 5 percent, the Marshall stability requirement is a minimum of 9 kN, the Marshall flow requirement is from 2 to 4, and a ratio of Marshall stability and flow is also given as a Marshall quotient, which is mentioned here. Now for the VMA, depending on the NMS of the aggregates in that particular gradation and the air void content we are targeting.

So, as mentioned previously many times, we target a design air void content of 4 percent. So, if I look for an NMA of 13.2 for 4 percent air void content, I will require a minimum of 14 VMA percentage. So, one way I can approach this particular one is by trying to find where I achieve a target air void content of 4 percent. So, from my plots, I will see this particular one, and then I will look into it; it may be somewhere around, say, 6.75 or 6.7. Now, for that 6.7 percent of my binder content, which corresponds to 4 percent of air void content, I look for the other parameters; I will see what the Marshall stability is. Specifically, the Marshall stability in this case may be a value around 25-27. In that particular case, I will check for the flow to see what the range of flow is given here. And I will see what the VMA requirement is; I will see what the VFA requirement is. If it meets my requirements, I can accept this particular binder content, and I can consider it my optimum binder content.

If it does not work out, then I will have to make some changes in my aggregate gradation. So, an example has been created here, where this is a bituminous mix design; Marshall specimens are prepared at 5 different binder contents using a paving grade VG 30 binder. And the bulk specific gravity information given is that the bulk specific gravity of the combined aggregate blend was determined to be 2.674; the specific gravity of the binder is 1.03, then, as I mentioned, we can determine the maximum specific gravity at a particular binder content, which may be quite close to your optimum binder content. Because this comes with the experience of the different kinds of mixes, 5 percent was selected, and the Gmm was determined at a laboratory scale.

Once that Gmm was determined, Gse was obtained using this Gmm, and then this Gse was kept constant, considering that there will be no appreciable or significant change with this aggregate's specific property. So, not much change is expected. So, Gse, which is derived from 5 percent binder content having this Gmm value, was then considered for the other binder contents as well, and using this Gse, all these Gmm values were determined. Simultaneously, the other parameters, VA, VMA, VFB, Marshall stability, flow, and quotient, were determined. So, here it is mentioned that

Gmm was measured in the laboratory at 5 percent, and then the Gse was computed, and from there all other Gmm values were derived using this Gse.

So, a plot is drawn using those values; some of the plots are shown here. This is the plot of the air void content, Marshall stability, VFB, and the Marshall flow; the VMA plot is there. So, in addition to this, you will also have the density plot because you need to know what density will be achieved at optimum binder content. So, if I am targeting 4 percent air void content, I will look for this particular one, and there may be a binder content that has a value somewhere around 4.66. Now, if my target for air void content is 4 percent, I have this binder content, and I will now need to check whether all other requirements are being met or not.

So, this is my Marshall flow value that I got; this is my Marshall stability corresponding to this particular one; this is my voids filled with the bitumen; this is my VMA. I ensured it with my requirements here; for this particular one, my air void content is 4 percent, the range required was 3 to 5. When I checked for the Marshall stability, it is 10.34, higher than the requirement of 9 kilonewtons. For Marshall flow, it is 3.16, while the requirement is 2 to 4 mm. For voids filled with bitumen, it came out to be around 71 percent, while the requirement is 65. When it comes to VMA, it came out to be 13.83, and the requirement is 13 percent. So, I can consider this 4.66 as my optimum binder content, and I need to get from the plot between the density and the binder content the density of the mix to which it is to be compacted in the field. So, this now becomes my optimum binder content. This is a conventional method of mix design that is used for bituminous mixes, and as I mentioned earlier, bituminous-bound mixes are of different types. We have the ones that are used for wearing courses, which we can use for binder courses and base courses. And for wearing courses, we also have different kinds of mixes: we have bituminous concrete mix and stone matrix asphalt.

This is one kind of mix that we discussed earlier. This is a gap-graded mix. A particular size is being reduced to increase contact between the coarser aggregate particles. And SMA is a mix; stone matrix asphalt is a mix that is becoming quite popular, specifically because of its high rut resistance, aging resistance, and high durability. So, especially nowadays, for flexible pavements designed for traffic of more than 50 msa, it is always recommended to use SMA as a wearing course. And while compacting this particular one, the guidelines that are to be followed are IRC SP 79-2023, and there are certain considerations because now, here you will have a slightly lesser proportion of fine aggregate.

Filler is quite high, and then the coarse aggregate skeleton is there. So, a stone matrix skeleton looks like this compared to what we have in the conventional dense-graded bituminous concrete mixes. So, here you can see the proportion of larger aggregate particles; coarser particles are more likely to bring more contacts between larger aggregate particles for better load dispersion and greater strength. And since the voids are going to be filled up with the mastic, which is your fines, fines are normally 8 to 12 percent of the filler used in this case. And the binder, which is also required, is a bit higher for the stone matrix asphalt because a high amount of filler is present.

So, it fills the interstices, and this forms a matrix that is strong enough to take the traffic loads. Since there is a good amount of fines and a slightly higher binder content, there is a chance that when these mixes are produced at high temperatures, especially when mixed, produced, and compacted, this binder may move down in your loose mix due to gravity. So, this phenomenon is normally known as drain-down, where the binder moves within the mix under gravity. So, there will be a variation in the amount of binder content; the top of the mix may have a lower amount, and there may be excessive binder content in the bottom part. So, this variation is not good for performance, and it needs to be controlled for that particular purpose.

Fibers are very commonly used to stabilize it in order to control this draindown feature. And if you see the requirements, the requirements here are also very similar. It directly says to go for a 4% air void content for the determination of your optimum binder content.

And it says the minimum starts at 5.8%. Then cellulose fibers are one type of fiber for stabilizing additives. Voids in mineral aggregates are to be quite high enough so that it states 17 as a minimum value, allowing you to accommodate a larger amount of your binder in this particular case. So, there are voids in the coarse aggregate, which causes asphalt binder draindown. As I mentioned, this draindown is pressed to ensure that the movement of binder under gravity is within a limited value only.

So, that is 0.3 percent. I will just show you in the next slide this tensile strength ratio, which will determine the indirect tensile strength of conditioned and unconditioned samples. Conditioned was subjected to freezing and thawing, while unconditioned was not, and both samples were then brought to a temperature of 25 degrees centigrade. This we discussed in one of our previous talks, and there it states that this ratio should have at least a minimum value of 85; the preferred one is 90 percent, and the same TSR strength ratio in the case of bituminous concrete or other dense graded mixes is 80 percent. So, here you want to be more durable; the requirement is higher. This is how a skeleton looks, and there is one test that is usually done to ensure that good contact points exist between your coarse aggregate particles, which we refer to in terms of stone-to-stone contact.

So, in stone matrix asphalt, it is important to ensure that there is good contact between the coarse aggregate particles, and for this, a test is done where first only the coarse aggregates are dry compacted. The voids in those dry compacted aggregates are checked in coarse aggregates, and we call that particular one voids in coarse aggregate under dry rodent conditions. It is filled in layers by tamping, and the volume of the cylindrical measure is known; the weight of the aggregate is known, and the specific gravity is known. So, I can work out the volume that will be in these compacted aggregates in this particular cylindrical mode. So, this gives me my VCAdrc, which is voids in coarse aggregates in a dry rodded condition because there is no binder; only aggregates are present.

So, this is for the course. Now, I will add the binder to it, and I will prepare a mix. So, when I prepare a mix, I can work out what the percentage of fine is, what the percentage of asphalt is, and what the percentage of air is. If this percentage is less than the voids in dry rodent condition, then I can expect a good amount of stone-to-stone contact, and this is what is ensured in this particular specimen. It says that the voids in the coarse aggregate of your mix should be the voids less than in your dry rod condition. So, this helps us ensure good stone-to-stone contact in SMA mixes, and

this is a simple representation of the binder drain-down test, where you prepare a mix, subject it to this wire mesh basket, and keep it in an oven. So, the prepared mix, whatever binder is lost through this particular sieve, is collected down, and we see that this should not be more than 0.3 percent. So, the binder drain down is restricted, and this is the IS 18104. So, this is to ensure that there is no loss of binder during production and construction, especially. So, this binder drain-down test is done. Similarly, another popular mix is OGFC, which is favored in many countries specifically because of its abilities related to quick drainage, high skid resistance, and low tire-pavement interaction noise. These mixes are designed with a higher air void content than what we considered for SMA and the bituminous concrete and other dense gradient mixes, targeting 4 percent air void content.

Here, we are targeting an air void content of 18 to 25 percent. So, this is important. Now, the compaction process is different. There, usually in SMA, we give the Marshall compaction through the Marshall hammer of around 50 blows on both phases. So, the compactive effort needs to be changed when you work out with different mixes. So, when these mixes are designed with higher air void content specifically to allow water to flow within them, they are, in most cases, not considered structural layers.

They are considered a drainage layer of thickness 1 to 2 inches, and the water flows within them. They are constructed over an existing dense graded surface. So that water does not enter the layers below, it travels within that layer and moves out from the edges. So, here again, the requirements are in terms of cellulose fiber, the binder content, and the air void content in the range as per IS 129, which is 18 to 20 percent, and 18 to 22 VMA. This is again the voids in coarse aggregate in the mix that have to be less than so as to ensure good stone-to-stone contact.

Now, the other mix that is in this particular category is gap-graded rubberized bitumen mixes. This is again where you are using the rubberized bitumen or the bitumen that is modified through the use of waste tire rubber. So, those are the guidelines for gap graded wearing coarse mixes with rubberized bitumen or bitumen rubber. Here, again, you go for a binder content which is slightly higher. It says that we will go for the binder bitumen binder percentage of at least 7 percent, which is the minimum requirement, and the requirement of Marshall stability is comparatively less for this one, especially for gap graded mixes, and then the voids requirement. So, they are designed in more of the same manner, but their requirements, which are to be met out of the differences, may be in terms of the parameters which is to be checked and the compactive effort that is to be applied.

So, the trial binder contents because based on the experience we can know that SMA mixes will generally require higher binder content, so we can start from a slightly higher binder content in our trials compared to what we do for bituminous concrete mixes. And there in most of the mixes presently, we target the air void content and then try to see whether other parameters are getting met out at our that particular binder content they If they are able to meet out, we will call that binder content as optimum binder content. So, this is all about the design of different kinds of bituminous mixes. Thank you.