

Course Name – Pavement Construction Technology
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A very warm welcome to all of you. I am Rajan Chaudhary, a professor in the Department of Civil Engineering at the Indian Institute of Technology, Guwahati, and the instructor for the NPTEL MOOC course, Pavement Construction and Technology, funded by the Ministry of Education, Government of India. Today's lecture will be a part of the discussion on the characterization of bituminous bond materials under Module 3 of this particular course. 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. In the previous lecture, we discussed the paving bitumen, the importance of bitumen, and what tests are normally used to characterize the paving bitumen. Then there are other forms of bitumen which are also popular: modified bitumen, cutback bitumen, and emulsified bitumen.

So, we will briefly discuss what these binders are and the applications to which they are put in flexible pavement construction. Now, as the term itself says, "modified bituminous binders," you are modifying the bituminous binders or the bitumen, and what is the purpose behind this modification? What do you want to achieve by adding these, I would say, modifiers to your paving bitumen? So, normally, the expectations that arise whenever we make any modifications to the bitumen are, first of all, that we want to improve the asphalt-aggregate bonding because this is very important; if you have a good bond between the binder and aggregate, you will have a durable mix that will perform better under all different conditions. So, your bond between the bitumen and aggregate has to be good enough. If any modification enhances it, that modification will always be better for the performance.

To enhance the aging resistance, we have examined the aging determination in terms of the thin film oven, rolling thin film oven, and pressure aging vessel, and we want the bitumen to age less during the production process and its service life. So, any modification that helps us make a binder age-resistant, or aging-resistant, or I can say resistant to oxidation, will be preferred. To reduce the temperature susceptibility as the binder consistency changes with temperature, the binder becomes soft at higher temperatures and stiff at lower temperatures; however, this is not expected to result in very sharp changes, as soon as the temperature increases, the binder becomes soft, and with a certain drop, it becomes very stiff. So this susceptibility, or I can say the rate of change of consistency with the change in temperature, should be low. So, that is what it is

said that we prefer: that this modification does not make the binder very stiff at lower temperatures and very soft at higher temperatures.

So, this kind of modification that reduces temperature susceptibility will always be preferred. And finally, we want a binder that is resistant to cracking. It may crack when it deflects, it may crack when the temperatures go down, and it may show some deformation under heavy loads when the temperatures are high. So, we want a binder to be edge-resistant, to be resistant to cracking, and to be resistant to any deformation in that case. So, all these requirements are for bituminous resistance towards cracking, especially as it is a phenomenon at low temperatures and deformation when the binder becomes soft at higher temperatures.

Certain modifications are also attempted with some products to add sustainability to these bituminous mixes, such as the addition of waste plastic as a modifier in bituminous mixes. So the binder is modified through the use of waste plastic. So there we are, trying to make use of some waste products. In the binder modification, the product we want to achieve is a good product with higher performance that will be more environmentally acceptable because we are making use of some waste products or alternative materials in its construction. So, these are certain reasons because of which binder is modified.

The most common modification takes place with the use of polymers, and the term polymer is referred to as a large molecule made up of many smaller molecules called monomers, which form large chains and clusters. We have an ISS specification IS 15462 that defines the different characteristics of the modified binder. Under this particular one, there are synthetic products, especially petroleum-derived products, and when they are modified by using these polymers, we call them polymer-modified bitumen. And these polymers are mainly divided into two categories: one is plastomeric thermoplastic polymers, and the second is elastomeric thermoplastic polymers. This is the one that is preferred for binder modification.

A few examples of what types of polymers are under these categories are polyethylene, ethylene vinyl acetate copolymer, ethylene acrylate copolymer, ethylene butyl acrylate copolymer, and ethylene terpolymer. These are some of the polymers that fall under the category of plastomeric thermoplastics, and the quite commonly used elastomeric thermoplastic polymers are styrene butadiene, styrene block copolymer (SBS), styrene isoprene, styrene copolymer (SIS), and styrene butadiene rubber. Many other products, in addition to this, such as waste plastic, which is also a kind of polymer, are available; waste tire rubber is also used for binder modification. But the target is to enhance one or the other characteristics of the paving compared to the paving grade binder when you are modifying it. The test that needs to be conducted specifically for judging the suitability of polymer-modified binder, as given by IS 15462, includes many common tests that we perform in the case of paving bitumen.

In addition to this particular one for modified binders, we need to work out the viscoelastic nature of the binders, and for that, a dynamic shear rheometer is used, and many parameters derived from the dynamic shear rheometer analysis are also used to judge the suitability of the different modified binders. And as we were discussing the viscosity grades of the paving grade binder, similarly, here you have the different grades for the polymer-modified binder as well. You can see one grade is 64, PMB 64 minus 10, the second is 70 minus 10, the third is 76 minus 10, the fourth is 82 minus 10, and 76 minus 22. So, these represent, 64 represents the maximum pavement temperature for which this particular binder is suitable, and minus 10 is the minimum air temperature that can be for that particular region. So, any region experiencing a maximum temperature of around 76 degrees and a minimum temperature of minus 10 degrees, this PMB 76-10 will be suitable for it.

So, this is one of the different requirements in terms of the parameters you have; some of the common ones used for paving are softening point, viscosity, and flash point. In addition to this, there are certain parameters derived from the dynamic shear rheometer to understand the viscoelastic nature because we are now using modified binders that incorporate some polymer sets. So how well it is getting dispersed, how the compatibility exists between the modifier and your needs, and how all these needs must be ensured, so there are different tests and requirements considering the different grades to be used. If we say that the application of these different grades is also for different reasons, as I mentioned, it states that PMB 64 minus 10 has average maximum pavement temperatures of less than 64 degrees Celsius and minimum pavement temperatures greater than minus 10, then the 64 minus 10 grade can be used. If I look for PMB 76 minus 22, having an average maximum pavement temperature less than 76 degrees and a minimum pavement temperature greater than minus 22 degrees.

So, depending on which region we are using, we can select a polymer-modified binder grade. In addition to this particular one, it states that for different traffic levels, there are standard, heavy, very heavy, and extremely heavy traffic conditions. Let us consider one case: when it mentions very heavy conditions, it refers to very heavy service conditions for traffic levels greater than 30 million standard axles or very slow-moving traffic. For that particular case, it is preferred that you select any grade from this specific set. So, this is the requirement here, depending on different regions, and then there is a requirement regarding the J_{nr} value, which is again a parameter derived from the dynamic shear rheometer to understand the binder's resistance to high-temperature deformation.

So, on the basis of this, different modified binders can be selected for use in different regions under different traffic loading conditions as well. Now, the other category of binder is the cutback bitumen. Cutback bitumen is, as the word itself says, something we are cutting back. So, what are we cutting back here? We are reducing the viscosity of the

bitumen. It refers to a type of liquid asphalt produced by blending or cutting back paving-grade bitumen with suitable petroleum distillates.

So, when we add these petroleum distillates, we are cutting back or lowering the viscosity of it, and these petroleum distillates are known as cutter stock or diluents. So, we are bringing this cut back by adding certain petroleum distillates, and we are reducing its viscosity. With this particular one, we can apply it to the aggregates at lower temperatures; otherwise, when you need to coat the binder over the aggregates at ambient temperatures, it is in a stiff, semi-solid state. The binder needs to be heated to temperatures around 150 degrees centigrade, and then the aggregates also need to be heated simultaneously before they are mixed. So, this heating of the binder can be avoided if the viscosity of the binder is already reduced.

So that we can do with the addition of these petroleum distillates. Now, this process reduces the viscosity of bitumen, making it easier to handle and apply at lower temperatures because you do not need to heat your aggregates to those high temperatures, as well as your binder. It is used in various applications; some of them are surface dressing and patch repairs. Small surface dressing is a type of application that we have discussed in earlier courses and lectures. And to apply a coat when we are going over a bituminous course on a granular course.

So then, a layer of this cutback is also applied; we call it a prime coat. We will again discuss this when we discuss the construction aspects of granular courses. Now, application to aggregate or pavement causes the solvent or these petroleum distillates to escape by evaporation, thereby leaving the asphalt residue. So, the process works in this particular manner: you prepare an aggregate mix along with a cutback, or you apply the cutback on a surface where some binder application has to be done. So, the distillate will evaporate with time, and the binder will remain on the surface.

This is shown as an application of a prime coat or an application of a tack coat. Normally, when we want to construct a bituminous course over a granular base course, we will first apply a tack coat, then a prime coat, and thereafter we will proceed with the bituminous construction. And if there is an existing bituminous old pavement and you want to overlay it with a new bituminous layer, then that existing pavement is also treated with a bituminous binder, which we call a tack coat. We will further discuss this when we discuss the construction of the bituminous courses. Now there are different grades, such as viscosity gradings VG10, VG20, and PMB grading 76 minus 10 and 76 minus 22.

Similarly, there are different grades for cutbacks, and they have different applications. For example, this is a rapid-curing cutback where you are using a distillate, which is a naphtha that evaporates very quickly. So, this particular one is used when you have no

fine aggregates available. So, if you want to prepare a mix with rapid curing, it is because the distillate will evaporate very quickly. So, you will get very little time to work with it.

So, that is why you do not want to have very fine aggregates because fine aggregates require a larger amount of time for mixing due to their higher specific surface area. And then there is another grade medium curing cutback, where you are using some diluent like kerosene, and especially here it says that 40 percent of fine aggregates can be used; again, some heavy oils are used to prepare the slow curing cutbacks, and here it says that up to 20 percent of fine aggregates can be used, so in this particular one. So, this says now, you, in addition to this particular one, there are different grades within each rapid curing cutback also. There are RC70, RC250, RC800, and RC3000. What does it represent? RC70 means the kinematic viscosity of this, when measured at 60 degrees centigrade, should be in the range of 70 to 140 centistokes.

Similarly, for rapid curing, the kinematic viscosity when measured at 60 degrees centigrade should be in the range of 250 to 500 centistokes. Now, this gives an idea about the viscosity of that particular grade. And, as I mentioned, different applications are there, like for rapid curing 70 grade and rapid curing 250 grades, it is preferred to be used as a tack coat; for medium curing 30 and medium curing 70 grades, it is preferred to be used as a prime coat. So, it is important to select the right grade for a particular application. Now, the fourth category of binder that is present is your emulsified bitumen or emulsion.

Bitumen and water are two immiscible liquids. Again, here the purpose is how we can bring down the viscosity of the binder so that we can make an application at lower temperatures. So one was adding the petroleum distillates, and the second is this particular process, which is called emulsified bitumen. Now what is done? It is said that mechanical and chemical processes are involved to combine two or more materials that will not mix: binder, bitumen, and water, in general, will not get mixed. So, this is what will exist in different phases.

Now, what is being done here? Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided state in an aqueous medium and stabilized with a suitable material. So, what is done here? You have the two components taken here. You have this particular water along with an emulsifying agent, and you have bitumen. So now you want to mix this particular one; what is done here is that the bitumen is broken down into small globules, and this water, along with the emulsifying agent, imparts a charge on your bitumen globules. So, then the bitumen globules remain in a suspended condition; this helps the aqueous medium, along with the fine globules of bitumen, lead to a lower viscosity, and this emulsified bitumen can then be applied at lower temperatures.

So, hot bitumen and water containing an emulsifying agent are passed under pressure through a colloidal mill. This is a colloidal mill that produces fine droplets of bitumen uniformly suspended in water. This is how it gets suspended; this is how a bitumen emulsion is made. So, the emulsifier, the emulsifying agent that we use, can impart a positive or a negative charge. If it imparts a positive charge, it is cationic bitumen.

If it imparts a cationic emulsion and a negative charge, it is an anionic emulsion to the bitumen droplets, which are dispersed in an acidic or alkaline aqueous phase. Now, one of these examples is a cationic emulsion; the emulsifying agent introduces positive charges on the bitumen globules. So, this particular emulsion will have a greater affinity towards aggregates that are slightly negatively charged or slightly acidic. Most of the siliceous aggregates that are generally available are slightly negatively charged. So, these aggregates will perform better with your cationic emulsions.

And again, a cationic emulsion in which the emulsifier gives the bitumen particles a positive charge while surrounding the water is slightly acidic, and this emulsion breaks when the positive charge is neutralized. So, when you mix it with the aggregates, this gets neutralized, or when you apply it on the surfaces, it gets neutralized, and the breaking of the emulsion takes place, and after some time, the water evaporates and the binder remains over the surface of the aggregate or the existing road surface. Similarly, it is for anionic emulsions where the anion of the emulsifier is at the interface with bitumen, and a negatively charged one is present while the aqueous phase is alkaline. Again, we have IS8887 for cationic emulsion specifications and IS3117 for anionic emulsions. They state certain code provisions and test procedures to check the suitability of whether a particular grade supplied by a refinery or a bitumen modification plant meets the standard.

So, we need to check the requirements of IS8887 for cationic emulsion and IS3117 for your anionic emulsion. And as I mentioned again here, there are five grades. This is rapid-setting grade 1, rapid-setting grade 2, medium-setting grade, slow-setting grade 1, slow-setting grade 2, and they have different applications. Rapid setting 1 can be used for tack coats, surface dressing work, penetration mechanisms, and prime coat applications, and for this, slow setting 2 can be used for producing mixes like semi-dense bituminous concrete mix, which we discussed, or your mixed seal surfacing or slurry seal. So, depending on the grades, there are different applications of this emulsifying agent.

But the concern with most of these binders is that in one case, the distillate is lost to the environment. So that makes sense because we are losing some costly products to the environment; from the cost aspect as well as from the environmental aspect, it is not good. The challenge that occurs with emulsified asphalt is that in both cases, you do not need to heat the binder, and aggregates also do not need to be heated to the high temperatures required for paving bitumen. But in the case of emulsified asphalt, when you are making use of emulsifying asphalt, water evaporates and leaves spaces. So, if you

have a mix in it when the water evaporates, void spaces are created because of the evaporation of water.

So, the density is lower. So, that is why there are certain things that need to be taken care of when you are making use of these emulsified asphalt prepared mixes. Now, with some of the aggregate tests, we discussed the granular course characterization of materials for use under the granular courses, in addition to those requirements. There, we discussed the Los Angeles abrasion value, the aggregate impact value, the wet aggregate impact value, the combined elongation and flakiness index, the soundness test, and other durability tests, which we also discussed. In addition to the water absorption value, the polished stone value is another test that is required specifically for bituminous bound courses in flexible pavements because it is used in the top course; the stripping test, water sensitivity test, cleanliness test, and sand equivalent test are also necessary, as you don't want your surface to have these kinds of issues where you can see the loss of material, which leads to the creation of potholes, as fines are disintegrated and lost in these situations. So, you need to check your binder as well as your aggregates to meet the latest standards available.

Now, first of all, when we are looking at the aggregates part from the bituminous bound aspect, the coarse aggregates, fine aggregates, and the filler are the three proportions that we have discussed. There, we also discussed that when using any crushed gravel, at least 95% by weight should be retained on the 4.75 sieve and have two or more fractured faces. So, this is one important requirement. It says that the coarse aggregate to be used in bituminous-bound courses should be clean, hard, durable, of cubical shape, and free from dust, soft or friable material, or organic or other deleterious material.

So, this should be ensured whenever any source of coarse aggregates is selected. Fine aggregates are especially important when you are using them in the binder and the wearing course. Wearing course is the top course, below which comes our binder course. So, when these two courses of flexible pavements are present, we will not prefer to use natural sand in them. If you take a course lower than the binder course, which will serve as your base course, we can use only 50% natural sand because natural sand does not provide good resistance to deformation.

It is completely rounded. So, there are a lot of chances that the particles do not get interlocked in a good manner, and when the traffic comes over that particular bituminous course or stresses come over it, it gets deformed. So that is why the percentage of natural sand is controlled or limited. It is not allowed in the case of binder and wearing courses, and if you use it in a course lower than the binder course, especially a bituminous bound course, then it can only be used up to 50%. And in addition to this particular one, there is a requirement that the fine aggregate should have a sand equivalent value of not less than 50, because this, in one way or another, tries to ensure the amount of clay content that can

be present, as well as the fineness of that particular material. So, we want to avoid the clay content in this one; this can also be ensured through the plasticity index requirement that is given.

It says that the plasticity index of this material should not exceed; so, this is another requirement that is mentioned for fine aggregates. So, we have the requirement for sand, we have the requirement for the plasticity index, and we have the requirement for the sand equivalent value. Then comes the filler, the finest one, normally the material through 75 microns in the range of 85 to 100 percent should pass through this particular one. Then this is normally referred to as your filler, which usually passes through this percentage from a 75-micron sieve size. And this material can be rock dust, which is produced from stone quarries; it can be hydrated lime, or it can be cement.

And again here, we are going to check for the plasticity index, and it should not be more than 4. And this plasticity index requirement can be omitted if the filler is cement or lime because they are non-plastic materials. Now what is required here? We need to look into the cleanliness aspect, or we can say the grain size analysis aspect. The only requirement is that the aggregate has to be clean. Whenever the aggregates are produced or stockpiled in any crusher plant or hot mix plant, there is a chance that contamination with some local soil, natural soil, or clay may occur, or there may be a lot of dust coating.

So that needs to be ensured. So it says that we need to take samples of different sizes. It says the nominal size of aggregate can be 4.75 or 10, depending on how much material is to be taken up. And then we are going to sieve it, and what we are going to see is that here B is the original dry weight, and C is the dry weight after washing. Wet washing is to be done, and this is to be done through a 75 micron sieve.

So all fines should pass, and we will see what percentage of the fine is to be there. So this percentage needs to be restricted when you are using any material in bituminous bound courses. So, any fines that are stuck to these coarse aggregate particles should be within a given limit; otherwise, if this dust is excessive on an existing aggregate surface, the bonding of a bituminous binder with this aggregate will be affected because of the presence of this dust between the binder and the aggregate surface. Sand equivalent value, as I mentioned, is again to get an idea of how much clay is present here. So, for the sand equivalent value, this test is to be conducted as per IS 2720, and here specifically an oven-dried sample is taken.

We prepare a solution that we will put in this cylindrical measure, and then the sample, your fine aggregate sample, is to be introduced into it. It has to be allowed to settle for a period of time; then you are going to agitate it, and it is again allowed to settle for a period of time. And then finally you are going to see here that the reading is there; when

it gets settled down, you are going to lower it. It says that after which a weighted foot assembly is gently lowered and it rests. This is the assembly which will be lowered and it rests over this particular area.

One where you can see a face; two different layers are there: one is for your sand, and the second is for your clay. So, you are going to measure the sand height and the clay height, and it says that the sand equivalent value is the sand reading divided by the clay reading. So, at least it should be greater than 50 percent; this is the requirement we saw in the previous slide. So, this controls the amount of clay that can be present in your fine aggregates because of the clay, and we are ensuring this through the plasticity index as well, but we are also going to ensure it through the sand equivalent value to control the presence of fine materials. Water absorption in certain aggregates may result in more surface shell voids, which can capture a lot of water, especially when they are left exposed.

So when aggregates are produced at crushers and lie in open spaces during rainfall events, they will absorb some water. So, one is the natural moisture content that is present, and if these surface voids are greater, when these aggregates are used with any bituminous binder, these surface voids will occupy a larger amount of binder as well. So, this will make your mix more costly because the binder that goes into these surficial voids will not help you develop any bonding or strength because it goes inside the surface voids. So, to ensure this particular one, we check the water absorption of the aggregates and how much amount of surficial voids there are. This is how it looks; if this is an exaggerated view, you can see these surface voids are present.

So these surface voids get filled up with water if I keep these aggregates in water for, say, 24 hours. Now, once I take it out, I will gently rub the surface water, and only the water present within these voids will be considered for water absorption. When this is done, this condition is known as saturated surface dry. So, you have saturated the aggregate particle, and the surface is also dried. So, this condition is required, and we want to have the saturated surface dry condition minus the oven dry condition.

Divided by oven dry condition or oven dry weight, this gives you the water absorption, and normally, a limit of 2 percent is given in most cases for water absorption, stating that the water absorption should be less than 2 percent. So, in case there is a oven dry, there will be no moisture. Air drying may leave some amount of moisture present; when saturated surface dry, all surface voids should be filled, and if left in the air, there may also be some extra water present on the surface. So, this is a saturated surface dry to oven dry condition; what you have is surface moisture. So, here in this case, once you submerge the aggregates in the water, take them out, remove all surface water by gently using any

towel or cloth, and then what you get is your saturated surface dry, and these two, over dry weight and saturated surface dry weight, are used to determine the water absorption.

Another parameter that is used is the stripping value of your aggregates. Now this test is used to determine how good the binder is at coating your aggregates, especially because the binder source will generally have a good affinity for the aggregates; however, certain aggregates have a greater affinity for water compared to bitumen, and certain aggregates have a higher amount of water absorption and surface voids. So, we want to see how good that aggregate forms a bond with a given sample of bituminous binder. So, for this one, we will prepare a mix with a given weight of aggregate; we will add binder to it, and this is to be done as per the codal specification. Aggregates are to be heated to a particular temperature; the binder is also to be heated.

200 grams of the aggregate sample, which is around 4 percent of it, and 8 grams of this bituminous material are to be mixed together. Then you need to transfer it to a measure where it will be covered with water, and before subjecting it to this particular one, this mix, which is prepared, is kept in the oven for around 2 hours at the temperature at which this mix is produced. Why is it done? So that all these surface voids, which are there on the aggregates, will absorb the bitumen. So, the surface voids will also lead to a small amount of binder absorption into the aggregate surfaces.

So, this conditioning is done. Once the mix is prepared, the mixture is conditioned in an oven for two hours and then transferred to a beaker containing 500 ml of water, which is then boiled. So, this mixture is kept in the boiled water for a period of around 30 minutes. So, at these high temperatures, if there is water present and the binder film gets removed in due course of time, you may have some binder coming on top of the water; you will keep removing it, and finally, after this 30 minutes of boiling water, you will take out the aggregates, cool them down, and then you will see which aggregates have had their binder film removed. So, this can be seen that the brownish surface, as well as the completely stripped surface, is considered a stripped area. So, this is my portion of the aggregates area, which has binder stripping, removal of the binder, and these are the remaining ones where I still have the coating available over the aggregate.

So, this stripping value is the uncovered area observed; this is a visual examination and total area. So, normally it is expected that this coating should be at least more than 95 percent available. So, this is done through visual observation to get an idea of how good the coating is. Now, one more test is done on polished aggregates specifically for the top courses of bituminous materials, especially the wearing courses, because they are under continuous rubbing action from the traffic. So, we want to see the relative measure of the extent to which different types of road accidents in the varying course will be polished under the traffic.

So, this is one test where we prepare some samples, and we will subject them to some accelerated polishing action. This is a polishing machine; a wheel is there. So, this wheel runs over this aggregate surface, and we will polish it in the presence of water and emery powder so that this aggregate gets polished, and we want to see how much a particular source of aggregate gets polished. We want the aggregate to have good resistance to polishing, and once this is done, the unpolished and polished aggregate will be checked using the British pendulum tester. This is one where a pendulum rubs over the surface of these aggregates, which are in an unpolished state and a polished state.

If they are having an issue because they do not get polished because of this action, then they will generate a good amount of friction. If they are highly polished, the friction generated is less. So, this friction between, or this abrasive action, or the polishing of the aggregates is measured with the help of, or estimated through, this British pendulum tester, or we can call it a pendulum tester. And we believe there are readings given for it; it says that this should have a value of more than 55 percent. So, if you have the aggregates that need good polishing for this particular one, the value of polished stone should be more than 55 percent.

So, this is again a test that is done for aggregates to ensure that they do not get highly polished; otherwise, if they get highly polished, then there is a chance that skidding or friction will be reduced. So, we want aggregates to have good polishing resistance. And then this is one table showing what the requirements are for a mix to be used in aggregate requirements for bituminous macadam, dense bituminous macadam, bituminous concrete, stone matrix asphalt, open graded friction courses, and all mixes specified by different IRC and MoRTH, and there is a requirement of cleanliness that 5% passes the 75 micron particle shape, which is your combined elongation and flakiness index of 35 percent, Los Angeles abrasion value, and impact value. You can see that for different mixes, the requirements may change. In this case, what is that particular mix, what is its purpose? Stone matrix, as well, requires aggregates to have a high resistance to impact.

So, they need to have good tough aggregates; that is why the aggregate impact value has to be less than 18 percent for use in stone matrix asphalt. Then we have the soundness test, water absorption test, stripping value test, minimum coating of 95 percent, and water sensitivity; this is another test which we will discuss when we discuss the mixes. In the coming slides, the polished stone value, especially, says the minimum value should be 55. Now, under this bituminous bound course, we discussed some requirements for the binder and the aggregate to be used. Once you prepare a mix that has aggregates of different sizes bonded together with bitumen, this is the mix that will be laid in the field.

So this mix needs to be ensured for different characteristics, and for laboratory evaluation, we prepared cylindrical specimens using these combinations of bitumen and aggregates. Now these may be 4 inches in diameter or 6 inches in diameter, varying in

height from 2.5 inches to 4 inches or even more than that. The conventional sizes normally used are 4 inches in diameter and around 2 and a half inches in height, or 2 inches in height. So, we will prepare these specimens and try to ensure some properties of these mixes so that they are resistant to this kind of cracking or any deformation that can happen, which is shown as rutting deformation.

They should have a good bond with the aggregate that is there. This binder should not become too soft. So we are finally going to check these mixes because this is the mix for which we have individually ensured aggregates and binder. Now we are going to ensure this mix as well. Two parameters and these characteristics of the bituminous mixes are also used in the design of your flexible pavements. So, it says that a bituminous bond mix is to be strong and durable enough to handle traffic loads and environmental factors like temperature, rainfall, and ultraviolet radiation that will occur during its service life.

So, here it says that the mixed material should have sufficient strength to resist both tensile and shear stresses because there will be some deflection, which will happen, so tensile stresses will also be generated, and there will be compressive stresses as well as shear stresses that will also be generated when the traffic load comes over the surface. So, this is especially true in the bituminous mixes. So, three parameters are mainly evaluated for the bituminous mixes; there are many more parameters, but the three basic parameters that are ensured during the design of these bituminous mixes are Marshall stability. It is in this particular case that a cylindrical specimen, prepared in a laboratory with a specific combination of aggregates and binder, is subjected to a loading. This is a confined compressive loading, which is given here, and we measure it when the sample is inserted in this particular setup, and a load is applied at a standard rate.

And we are going to see how much deformation is happening in the specimen and how much load it takes before the sample actually fails. So, two things: the maximum peak load is measured, and the deformation that happens at the maximum load. So this is one parameter, and there is also a standard for the rate of loading, as well as the temperature at which it has to be done; this we will again discuss when we discuss the design of bituminous mixes. And then, there is a requirement that for a particular kind of mix, the minimum stability, which means the minimum amount of load it should take, is 9 kilonewtons. So, that means it should take a weight load of 900 kg before it fails, and there is also a requirement for Marshall flow.

So, this is one requirement that is necessary to ensure the strength that is checked during the design of the bituminous mixes. Second is the moisture sensitivity test. This is once the mix is prepared initially during the initial period when the mix is not densified to that particular state because, in due course of life, it gets densified by the traffic. So, in that case, we need to ensure the change in its strength. So, specifically, we are trying to ensure the moisture-induced damage in these compacted bituminous samples.

So, this moisture-sensitive test is widely used to measure the change in diametrical tensile strength resulting from laboratory accelerated moisture conditioning, which includes a freeze-thaw cycle of compacted HMA specimens to check the moisture damage resistance. Now that what is done here, we are going to check the indirect tensile strength; here it is again, cylindrical specimens which we use for the Marshall stability. Similar specimens will be used here in this case. And we are going to determine its indirect tensile strength across its vertical diametric plane at a specified location. So, this is how this is a specimen whose diameter will be around 4 inches and the depth may be around 2 and a half inches.

So, this will be loaded along the vertical diameter in this particular instance. So, there is a plate that is kept at the bottom and at the top as well, and from this, a load is applied. You can see that these are LVDTs, which are measuring the horizontal deformation in addition to the vertical deformation. This is a setup that has been shown. So, the loading is done at the diametrical plane for this particular one to get the peak load at which the sample fails. So this gives you an idea about the tensile strength of this specimen, and the expression that is used is $ST = \frac{P}{tD}$; ST is the IDT, indirect tensile strength in kilopascals, where P is the maximum load in Newtons, t is the specimen diameter, which is normally two and a half inches, and D is the specimen diameter, which is four inches.

Here it has to be given in mm, so it's around 101 mm. This may be around, say, varying from 50 mm to 60 mm in that case. So this gives you the indirect tensile strength of a compacted specimen. Now, to look into the moisture damage resistance, this specimen is subjected to different moisture conditioning environments. In one case, what is done for an unconditioned sample is that the mix is kept at 25 degrees centigrade in a water bath to bring its temperature to 25 degrees centigrade. In the second case, the mix is first produced at a definite amount of air void content and then saturated.

So, we are intentionally saturating that mixture with water. So, water enters the mix with an application of vacuum, and then finally, once the water has entered, if the specimen has become saturated in the range of 70 to 80 percent, it is subjected to a freezing action of minus 18 degrees for 16 hours, then again thawed at 60 degrees centigrade for 24 hours. So, this is one way of giving the cycles of freezing and thawing to the specimens when they are saturated with water. So, I am trying to simulate the moisture-related damages that can happen in the bituminous mix. And then finally, this conditioned specimen was also brought to 25 degrees centigrade by keeping it in a water bath for 2 degrees. So, now this is a conditioned set, this is an unconditioned set, and we are going to again measure the indirect tensile strength for both of these conditioned sets as well as the unconditioned test, and the ratio of this particular one will be called the tensile strength ratio.

So, a mix that is more resistant to this particular one will have a higher value, while a mix that has lesser resistance to this moisture-induced damage will have a lower value. For most of the mixes, it states that it should be more than 85 percent; certain requirements may even specify more than 80 percent, and some may say more than 90 percent, depending on different factors. It says that the tensile strength ratio should be more than 80%; in most cases, it says it should be more than 80%. And this parameter, which is the last one, is again very commonly used for judging the strength of bituminous-bound courses: the resilient modulus. The term itself refers to the resilient modulus, which is the elastic modulus, because this is the parameter used in the design of flexible pavements in India, as per IRC 37.

So, here it says the resilient modulus is the parameter that takes into account only the elastic or resilient component of the deformation of the specimen in a repeated load test. So, here again, a specimen in this particular resilient modulus test is subjected to repeated load. This is a specimen, which is shown here, placed in this particular test assembly of resilient modulus, and what is done is that you are going to apply a strain over it, and this particular stress, and you are going to measure what strain is happening. So you can see there is an elastic strain, and when this repeated loading occurs, in due course of time, this mix will experience a certain component of strain that is not recovered. If I load a specimen and then remove the load, when I load the specimen again, some amount of strain will be present, deformation will occur, and when I remove the load, this deformation will be recovered.

Now, there may not be a complete recovery from this deformation. A part of it may recover, and a part of it may remain there, which is the permanent deformation, and a part of it may get recovered. So, here you can see when there is a total strain applied, of which a certain amount is one cycle; when you apply a load, there is strain, and when you remove it, the strain gets reduced, but still at the bottom, some amount of permanent strain remains. The next loading cycle again experiences strain; when removed, it goes back, but in due course of time, some amount of permanent strain will be present, which we will refer to as plastic strain or accumulated strain. Some amount of this recoverable strain exists, and this recoverable strain is what is required to obtain your resilient modulus. So, the resilient modulus is your stress divided by your resilient strain. So, this is the elastic strain, and this parameter is required as a strength parameter when used as an input for your flexible pavement design to compute your cross-thickness.

In this case, this is a diametrical loading that is performed here, and the resilient modulus is computed as the load, P , which is the repeated vertical load. And again, what amount of load has to be given, at what parameter it has to be checked, all must be as per the IS codal provisions, and here we are going to form the ASTM codal provisions to conduct the resilient modulus test. It says P is the repeated vertical load, and H is the total recoverable horizontal deformation. This is what the resilient strain is that we are going

to monitor. h is the mean dimension of the specimen, and μ is the Poisson's ratio, which is a ratio of your lateral strain to the longitudinal strain.

So, for most cases, this is taken as 0.35. This is one parameter again, so we need to ensure the aggregates, the binder, and the mixes as well. There are many more parameters and many more tests that are done on aggregates, bituminous binder, and the mix, especially those of the compacted mixes, to ensure their suitability for road construction or for flexible pavement construction. The ones we have discussed here are the ones that are quite common, specifically the binder part for paving bitumen, the aggregates for most of the common courses, and the one for bituminous-bound, which are as per the design requirements for bituminous mixes. So, this is all for the different tests for the characterization of bituminous-bound courses. Thank you so much.