Course Name – Pavement Construction Technology
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A very warm welcome to all of you. I am Rajen Chaudhary, a professor in the Department of Civil Engineering at the Indian Institute of Technology, Guwahati, and the instructor for the NPTEL MOOC course, Payment Construction and Technology, funded by the Ministry of Education, Government of India. Today's lecture will be lecture seven, discussing the physical and mechanical requirements of materials for granular courses under module three. In the previous lecture, we discussed the characteristics of the materials that can be used in the construction of pavement subgrade, where we discussed the different characteristics in terms of the Atterberg limits, liquid limit, plastic limit, and plasticity index. We discussed the characteristics in terms of the determination of moisture content and the relationship between dry density and the four different types of soils. We discussed the gradation analysis.

We discussed the measurement of strength in terms of the California bearing ratio and how it is used in pavement design, specifically in the computation of the pavement crust as per IRC 37 through the use of resilient modulus. So these are the aspects we discussed for the materials to be used for subgrade construction. Today, we will be discussing the characteristics of the materials that are used in unbound granular courses. 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.

So when it comes to the characterization of granular coarse materials, there are some standard ways, standard tests, and standard test protocols that are followed to check the suitability of the materials to be used in granular coarse construction. Now, for this particular one, the following parameters are normally evaluated, which you have: the liquid limit, the plastic limit, the plasticity index, and the California bearing ratio. So, this particular part we already discussed when we talked about the characterization of materials for use under subgrade construction. So, in addition to this particular one, granular courses have the aggregates in them. So, the aggregates, as we mentioned earlier, can be classified into coarse aggregate, fine aggregate, and the finest part, which is your filler.

Now, these aggregates need to be evaluated for their suitability depending on which course they are used. So, certain standard test protocols are used for the characterization of these particular materials to understand some of their characteristics. Now, one of those particular values is the Los Angeles abrasion value, which is quite popular for determining the suitability of aggregates used in both granular-bound and unbound courses. Then, we have the aggregate impact value. Combined elongation and flakiness index, which talks about the shape of the aggregates; soundness value, which gives an idea about the weathering resistance of the aggregates; resistance of aggregates to changes in different environmental, climatic, or moisture-related conditions; and the last one is the water absorption value.

Now, all these are under the classification system, which is provided as per IS 2386; different parts exist for these different evaluations of various characteristics. Coming to the first characteristic, that is, in terms of the abrasion resistance or the toughness of an aggregate sample. So, these two characteristics are quite important to judge the suitability of a material for use in any unbound granular course. Now, it states the expectation that whatever aggregate we are using should be tough and resistant to withstand the degradation and breakdown of particles, and when can this happen? This can happen during the construction, that is, when you are drying the aggregate, handling the aggregate, and handling means from the aggregate crushers; the stockpiles are there, and from the stockpiles, they are transferred to the plants. So, the handling of the aggregates is there; then you dry those aggregates during the drying process.

If you have to mix them with some other component, then the mixing is done, and it is again layered in the field, graded, camber is prepared, and compacted. So during all these exercises, the aggregate should have sufficient strength and resistance to bear these different processes from its production to finally laying and compacting in the field. So, thereafter, once construction is completed, the traffic loading will be applied. So again, it should be good enough or suitable enough to bear the abrasion and the wear and tear caused by the movement of traffic. One measurement of the abrasion resistance is when one is rubbed; abrasion normally occurs when one is abraded, and one aggregate is abraded with respect to the other aggregate.

So, there is an abrasion test that simulates how the abrasion can occur in the field and gives us a measure of the abrasion resistance of an aggregate. So, the abrasion test is carried out to test the hardness property of stones and to decide whether they are suitable for different road constructions. These tests will give us some values when measured through different tests, and based on these values, we can convey whether this is suitable for construction in this particular layer or not. The Los Angeles abrasion test is one of the most widely used and investigated methods for assessing aggregate toughness and abrasion resistance. Now, coming to the test procedure, which is as per IS 2386 Part 4, it states that the sample to be tested needs to be graded, and in this particular case, we have been given 7 grades: A, B, C, D, E, F, and G, depending on the sizes present for any particular aggregate source when used in a specific layer.

We have to select grading A or grading B based on the size of the aggregate. So, depending on it, we can choose these different gradations: grading A, which is the weight in grams of the test sample for that grade. So, what if a grade is to be selected? It says that between 40 and 25, you have to take 1250 grams of aggregate; from 25 to 20, you have to take 1250; from 20 to 12.5, again 1250; and from 12.5 to 10, again 1250.

So, this means you have to take 5 kg of material if your material falls under this particular grade for testing. Similarly, it is for B and C; different quantities are given. The grading used shall be those most nearly representing the aggregate furnished for the work. So we will choose one that represents the aggregate in a better manner. So, if grading A represents our aggregate in a better manner, we will choose grading A.

Now, in this test, you need to have some charges to abrade, especially since this abrasion reaction is created at a laboratory scale with the help of some abrasive charges. I will show you in the next slide. So, how much abrasive charge in the form of steel balls is there, which is put along with these aggregate particles? So, the number of those steel balls, or we can say the quantity, is important because a steel ball used as an abrasive charge will have a standard weight. So, depending on the number of steel balls we are going to use, the weight of the charge can be mentioned. So, it says the abrasive charge then selected depends upon the grading you are using.

For that particular grading, it states that if we are choosing A, the number of spheres or balls to be used is 12, which will have an abrasive charge weight of around 5 kg plus or minus 25 grams. So this is again as per IS 2386 Part 4. Now, once you have selected the grading, you have taken the aggregates as per that particular grading requirement. As we mentioned, we will go for, say, for example, if you go for grading A, we require 5 kg of material on 4 different sieves of 1250 grams each, and the abrasive charges are to be taken around 5 kg plus or minus 50 grams. So then that particular aggregate sample, along with that particular charge, is shifted to this drum.

Now, in this particular drum, the dimensions and details of this particular one are available in 2386 part 4. What is important here is that once we put these aggregate samples along with the charges, this aggregate drum is rotated at a speed of 20 to 33 revolutions per minute, and you can see there is a shelf inside it. So there is a shelf inside this standard cylindrical drum, so the aggregate sample, along with these abrasive charges, and this is what the abrasive charge I was referring to: spherical balls are there. So, when these rotate, they go up to a height and then fall from that height along with the aggregate sample. So, this develops a lot of abrasive actions.

So, the aggregates disintegrate and are reduced to a certain amount of fines. Those who are resistant will get converted to a lesser amount compared to those who are weaker in nature. So, it says that for grading A, B, C, and D, the machine is given, and according to the grading types for the first four gradings, it says 500 revolutions are to be given at this rate of around 30 to 33 revolutions, and for the remaining three grading selections, it says 1000 revolutions have to be there. Once this part is over, you are going to stop it, take out your aggregate sample, and sieve it through a sieve of 1.7 mm. So, the final material will pass whatever is retained over 1.7 mm, is washed, and is oven dried. So, your initial weight was the over-dried initial weight that you first inserted into this cylindrical chamber, and the other one, which was retained on a 1.7 mm sieve, was wet-washed and then dried; subtracting this will give you the amount that is finer than this one. So, the more fines generated, the weaker the aggregate is; the less fines generated, the stronger the aggregate is.

So, depending on which layer you are using, there are different percentages given for the abrasion resistance, expressed as a percentage of the fines generated with respect to the initial weight. So, the percentage wear shall be reported as the difference between the original weight and the final weight of the sample. Now, in addition to what we are experiencing, there is a fall of steel balls from a height, and the aggregates rub against each other. So, a good amount of impact, as well as abrasion, is happening. There is another simple test that is known as the impact test.

All these tests, which we normally do for this particular one, have one major concern: these tests should be simple enough to be conducted in small laboratories, and the results should be reproducible on a good scale. When you test it at different laboratories and through different laboratory personnel, there should not be much variability, and you should be able to capture a good feature or good characteristics of the aggregates, which will be helpful to assess their suitability in the field. So now it says the other test, which is the aggregate impact value again. As per IS 2386, it states that this aggregate impact value gives an idea about the toughness of the aggregates, and it is a relative measure of the resistance of an aggregate to a sudden source of impact, which may occur during production, transportation, handling of the aggregates, and laying in the field. Compaction and the impact forces will come over the aggregates.

It gives an idea of the resistance of the aggregate to fracture under repeated impacts. The test sample, and again, now here in this particular one, there were 7 gradings given. Here, it says you take the aggregates that are passing the 12.5 mm sieve and retained on a 10 mm sieve. This aggregate is taken for conducting this impact test, and we will perform the over-drying of the aggregates.

The over-dried aggregates are used for this particular one. Now, here we will have two things: one is that a measuring mold is there; in the measuring mold, this over-dry aggregate is compacted in three layers, and each layer is given a tamping with a standard rod for 25 blows. So we will tamp it, we will compact this aggregate in this measuring cylinder in three layers, and then we will strike off whatever surplus aggregates are there;

this aggregate weight is taken up. And then this is transferred to the cylindrical test setup again, 25 impacts or tamping is given by a standard tamping rod, and then this is brought into this particular setup, where this measure goes here, and you are going to apply this impact load, which is raised and allowed to fall from a height of 380. So, what is done here in this particular case is that you can see there is a standard hammer wing; this particular hammer has a weight of 13.5 to 14 kg and is raised such that its lower face is 380 mm. So, it is raised in such a manner that the lower face is about 380 mm, and then it is allowed to fall onto the aggregate sample. So, we are imparting an impact load over this aggregate sample, and we give 15 such blows. Thereafter, the material in this particular cylindrical cup is taken out, sieved through a 2.36 mm sieve, whatever is retained is washed, and then the weight is recorded, and it is oven-dried again.

We again measure how much fines are generated; fewer fines will be generated if the aggregate is tough enough, but if the aggregate is weak, then a larger amount of fines will be generated. In addition to this particular one, there are many aggregates; this we are doing on the oven-dried aggregates. There are many aggregates that even become weaker when they are saturated with water or when they remain submerged in water for a longer period of time. So in that particular case, before transferring it to give that impact load, we keep those aggregates from the measuring mould submerged in water for a period of 3 days, and then we take them out. We will surface dry those aggregates, remove the surface water, and then subject them to the impact loading.

So, this is what the other process, which is done, is known as the wet aggregate impact value, and what we discussed here is the aggregate impact value. So, for certain, laterite rocks become weaker when these aggregates are submerged in water. So, for certain aggregate types, you may be required to measure the aggregate impact value under wet conditions, especially for softer aggregates. So now we have the material that is retained over the 2.36 mm sieve; it is wet-washed and dried.

So, it says the fraction retained on the sieve can be mentioned as weight C, and if the total weight is the weight that has passed through the sieve and the one that is retained, if there is a difference of more than 1 gram from the initial weight that is taken. So, that means there is some loss of material that has occurred. So, we will discard this particular item. The difference between the material, the sum of the material that is retained on the sieve and below that particular sieve, should not exceed a difference of more than 1 gram compared to the initial weight it has taken. Now, the aggregate impact value, similar to the Los Angeles abrasion value, B is the amount of fines that are generated, and A is your initial.

There was also what we were doing: aggregate abrasion value, the amount of fines that is generated with respect to the total initial weight, and that gives you the aggregate impact value. Now again, for use in different courses, this requirement may be different; in one case, it may be 24 percent, in another case, it may be 27 percent, and in yet another case, it may be 30 percent. What one can understand as one goes up means that as you come closer to the surfaces where the vehicles will actually apply, you require stronger aggregates compared to when they are in the lower layers, because the stresses are dispersed over a wider area and the stress intensity is reduced in the lower layers. So, at lower layers, you can work with aggregates having higher impact values compared to what you would require when you are using aggregates in upper courses. So, there you may require aggregates with a lower impact value.

Now, another important aspect that needs to be worked out for aggregates is the shape of the aggregates. Now, when you see these aggregates, most of the aggregates are produced from the aggregate crushers; big rocks are crushed down to usable sizes. And there are combinations of crushers that are used to bring them from the big sizes to your desired smaller sizes. And this combination of crushers, aggregate crushers, has to work in such a manner that you get good shapes, and the preferred shape is your cubical shape, but you will not always be able to get a perfect cubical shape. So what do you prefer? You prefer to have angular and cubic aggregates.

Angular, the edges are sharp enough, and if it is a cubical shape, then it has a good amount of edges. You will not prefer to have rounded aggregates because, in the case of road construction, especially in these granular courses, they slide over each other; there is less internal friction occurring between the rounded aggregates. So that is not preferred here, especially in the granular courses or the bound courses during road construction. Now, how do you check the shape-related aspects of an aggregate? One index that is used to check the shape is the flakiness and elongation index, which is used to characterize the shape of the aggregates. Here, two important things are taken care of: the aggregate should not have one dimension that is very large compared to the other dimensions, and the second is that one dimension should not be very small compared to the others.

So, we will say the aggregate should not be elongated and should be very thin and flaky. Because that means there are chances that this particular aggregate, if it is more elongated, may break down compared to the other dimensions. If it is thin enough, then it can also break down. So, you can see that the elongated aggregates in one dimension are quite large compared to the other dimensions. These are elongated aggregate particles, and instead of them, there may be other aggregate particles here that are thin enough.

Their one dimension, or their thickness—especially their thickness—is quite less compared to their other dimensions. So, we will not prefer to have aggregates. Now, which aggregate will be called elongated, and which aggregate will be called flaky, is the important aspect. So, here it says that the flakiness index, which I can say is the thinness of the aggregate, is determined in terms of the percentage by weight of particles whose least dimension is less than 0.6 times their mean dimension. So, if I have an aggregate particle whose mean dimension is normally worked out by sieving it through two consecutive sieves. So, if I have an aggregate that is passing through a 50 mm sieve and retained on a 40 mm sieve, I will say that this aggregate has a mean dimension of 45 mm. Now, any aggregate that passes through a 50 mm sieve and is retained on a 40 mm sieve will have a mean dimension of 45 mm. Now, if an aggregate is to be flaky, that means if it is flaky for that particular case, if one dimension is less than 0.6 times 45, then this aggregate will become a flaky aggregate.

If one dimension of this aggregate is less than 0.6 times its mean dimension, and the mean dimension is 45, then this aggregate will be called a flaky aggregate. The other way is when do you call that aggregate to be an elongated aggregate. So, this particular aggregate, whether it will be called elongated or not, what I will check is I will first check for which particular sieve it is passing and on which particular sieve it is getting retained. So, this again, if I work out for any sieve sizes over this particular one, it may be, say, 12.5 mm passing and 10 mm retained, or I can say there may be 20 mm passing and 15 mm retained.

So, 17.5, these are random sieves; there are standard sieves to do this particular analysis. Then I will say 17.5 is my mean dimension. Say I have the same particle, which is again passing through 50 mm and retained at 40 mm.

So, its mean dimension is 45. Now, for any particle in this particular range, that particle will become an elongated particle if one of its dimensions is more than 1.8 times this mean dimension. So, that shows that one dimension is excessively or is quite more compared to the other dimensions of that aggregate. Now, what is the problem that happens with these kinds of aggregates? The interlocking when a mix of these aggregates is prepared and when it is compacted is important; the aggregates must roll enough and get densely packed. But these elongated and flaky particles impede compaction, making it difficult to achieve the desired density, and in some cases, these particles even break down because one of their dimensions is either quite small or quite large.

So, these aggregates break along those dimensions; when they break along those dimensions, they raise a concern regarding the gradation because a gradation change will occur, and second, if there is some presence of binding material over that aggregate, then there will be certain phases that will get exposed without any binding material. So, that raises concerns regarding the durability of those aggregate mixes as well. So, it says that compared to cubic-shaped aggregates, flat and elongated particles tend to lock up with adjacent aggregate particles because they lie flat on the surfaces more readily than cubic particles and resist reorientation. This is important when the compactive effort is applied using rollers.

They should reorient and get densely packed. So they resist this reorientation to form a dense configuration. So that is why elongated and flaky particles are not preferred. Another thing is they can break down. This especially happens more when you have open-graded mixes, where the share of these coarser aggregate particles may be around 90%, as we have seen in open-graded mixes. So, there are more chances that these aggregate particles will break down during production and construction, thus affecting the gradation and durability of these mixtures.

So, this is an important aspect that needs to be taken care of in terms of the flakiness and elongation index. Now, how is it determined? In the laboratory, we have these two gauges. One is your thickness gauge. This is for your flaky particles. Now, as I mentioned, if I have an aggregate that is passing 50 mm and retained on 40 mm.

So, this is the range of my aggregate particle from 50 to 45. My aggregate is this one, so the mean dimension will be 45 mm, and 0.6 of this mean dimension is 27. So, any aggregate particle that passes through this particular slot will be called a flaky particle. If it does not pass through this particular one, an aggregate that is passing through 50 mm retains on 40; if it does not pass this slot, then it is a non-flaky aggregate.

Whatever it passes through, it will be called a flaky aggregate. So, I need to do this particular exercise for a good number of pieces to get a representative figure for them. So, I will at least go for one particular sieve size here: 50 to 40, or say here it is 40 to 25, 25 to 20, 20 to 16, 16 to 12.5, 12.5 to 10. So all different sizes are mentioned depending on which sizes you are using in a particular course; you can work out this particular shape, whether the aggregate particle is flaky or not.

Once you check for this particular flaky, you can similarly check for the elongated part, but for every sieve size, you have to take at least 200 pieces. This is an important aspect because you need to have a good representation of the source, the sample that you are considering for it. The other part is when you need to check the elongation index to determine whether a particle is elongated or not; then again, similarly here, if it is, say, from 50 to 40 mm, the mean size is 45, and it is 1.8 times the main dimension, which will come out to be 81. So, this is my aggregate particle, which I have chosen; if it passes through this slot, then it is non-elongated.

If it does not pass, and the longest dimension of it is not passing through it, if it is bigger, and if it is not passing through it, then I will call that aggregate an elongated aggregate. So, I can count how many pieces are elongated and how many are flaky in a given sample of 200 pieces, and then if I take out the percentage in a manner that shows my flaky part, the weight of flaky particles divided by the total sample can give me the flakiness index, while the weight of elongated particles divided by the total weight of initial aggregates gives me my elongation index. In reference to it, what we commonly use is one way of getting the idea about the elongated particles and flaky particles, but the index that is used or referred to in our MoRTH specifications for aggregates to be used in different layers describes the combined elongation and flakiness index. And what it says is that for determining a combined elongation and flakiness index, you will not determine the flakiness index and the elongation index separately, and you will not do a numerical addition of them for this particular one. First of all, you will take an aggregate sample, which means at least 200 pieces of different sizes, and this will also give you a representative weight.

So you will first do the flakiness measurement, and through that flakiness measurement, you will have flaky particles and non-flaky particles, which can give you the flakiness index. Flakiness index, which will be your flaky particles divided by your total particles' weight, flaky particles' weight, or total particles' weight. Particles mean aggregate here, total aggregates' weight. So you will have the flakiness index, but now, when going for the elongation index, you will use only the non-flaky particles. So, once in here in this case, it says that to determine the combined flakiness index and elongation index, flaky particles are first separated from a representative sample, and you measure the flakiness index.

So, FI is calculated as the ratio of the weight of flaky particles to the total weight of the sample. From the remaining non-flaky particles, we proceed with the elongation measurement of the elongation index. So, this elongation index will be your elongated particles: elongated aggregate weight divided by your non-flaky aggregate weight, because this was your initial aggregate weight, which you have taken from the non-flaky aggregate only, and on the non-flaky aggregate, you have done the measurement of the elongation index. So, this is the elongated aggregate weight divided by the non-flaky. So, the elongation index is calculated as the ratio of the weight of elongated particles to the weight of the non-flaky sample, which is combined to get your combined elongation and flakiness index.

Then, there are different requirements that have been given to control the shape of the aggregates to be used in different layers. So, this is an important aspect whenever a combined elongation and flakiness index is measured: you have to determine the elongation index over the non-flaky materials. It should not happen that you have measured your elongation index because this provides better control over the shape compared to measuring your elongation index and flakiness index separately and then combining these numerical values. So, it is always advised that care is taken to ensure that your elongation index is determined over non-flaky materials to obtain the combined elongation and flakiness index values. So, this has to be taken care of when the laboratory determinations are to be done with respect to your elongation and flakiness index.

Now, another important aspect that is usually considered is the durability of the aggregates or their resistance to different environmental factors, particularly in terms of soundness. And especially, this is done when the aggregates have higher water absorption. So certain aggregates, such as sandstones and laterite rocks, may be present, which have a tendency to have higher water absorption. And they may show good disintegration, or they may break under changes in the environmental conditions. So, that particular thing is usually evaluated or controlled in terms of the soundness test for aggregates carried out as per IS 2386 Part.

What it says is designed to simulate the destructive nature of environmental factors, for example, freezing and thawing, and wetting and drying. In general, wetting and drying means you wet a sample, dry that sample, and wet a sample; this is called wetting and drying. Freezing, if I put that particular one in the water, the water enters the pores of my aggregate particles, and they are subjected to freezing. So it is subjected to temperatures where the water freezes.

When water freezes, ice crystals are formed, and volume expansion occurs. So it will exert pressure on the walls of the aggregates, in the pores of the aggregates, and disintegration of the rock particles may take place. So this particular action needs to be simulated and understood through some laboratory determinations, and that is what is done under the soundness test. So, freezing and thawing are more detrimental than wetting and drying. As a result, most test procedures simulate freezing and thawing. At the laboratory scale, the soundness test involves the determination of the resistance to disintegration of aggregates by using saturated solutions of two salts, sodium sulfate or magnesium sulfate, to develop these crystals in the aggregates and to see how well the aggregates can withstand changes in different environmental factors.

So, this can be an aggregate that looks sound before it is tested for soundness, and when these aggregates are tested with the help of these two salts, sodium and magnesium salts, sodium sulfate salt, or magnesium sulfate salt solution. Later on, you can see how the aggregates may disintegrate. So, it is important to see how good the aggregates will be there, especially when it is checked that they have high water absorption; aggregate samples have high water absorption. So again, the detailed procedure is there in 2386 part 5, but an important aspect is that they say how to prepare the sodium salt solution or how to prepare the magnesium salt solution. For that particular one, it says that for a good amount of salt crystal formations, you should at least take 420 grams of anhydrous salt or 1300 grams of decahydrate sodium sulfate per liter of water.

This is the salt solution that is prepared for magnesium sulfate solution; at least 1600 grams of heptahydrate salt are to be taken per liter of water. Now, in these salt solutions, the aggregates are dipped for a duration of 16 to 18 hours at a temperature of 27 degrees, close to your ambient temperatures, and you need to ensure that these aggregate samples are well below 15 mm from the top of your salt solution. So, they are kept in this salt solution for this period of time, and thereafter they are removed, allowed to drain for about 15 minutes, and then they are again oven-dried. So, this is one cycle where they are submerged in it, taken out, oven-dried, and depending upon the requirements, MoRTH for most cases recommends that this needs to be subjected to 5 cycles. Considering environmental factors, people do try to do this soundness test for a greater number of cycles as well, but the MoRTH recommends that at least 5 cycles must be done for this immersion and drying with these salt solutions.

And then again, what is done here? The loss of weight is being measured. How much weight loss occurs once the sample is oven-dried and sieved? More loss of sample indicates that the aggregate is weak enough; it is less durable, and the requirements are also different when sodium sulfate is used compared to when magnesium sulfate is used. So, depending on the use in different courses, these requirements specify what value of soundness must be present when sodium sulfate solution is used or when magnesium sulfate solution is used, and for how many cycles there are. Five cycles are the standard cycles, which are recommended by MoRTH specifications. Now, let us come and see that we just discussed briefly some of the common tests that are to be done on materials used in different layers.

We will now see what the requirements of those test values are in different courses. So here you can see that this is the granular sub-base course material requirements. Now, first of all, it says what material can be used. Now we have already discussed that this granular sub-base course can be constructed in one or more layers, and if there are one or more layers, there will be a lower sub-base and an upper sub-base, and it can also be constructed in one layer. What materials can be used in it? It says that for the granular course, you can use natural sand. Crushed gravel, crushed stone, crushed slag, or a combination of these can be used depending on the availability of the material in the region nearby the construction site.

Now, certain materials like brick, conker, and crushed concrete, which may be locally available, are preferred for use in the lower sub-base layers specifically. Whenever these are present, you can see that this is how natural sand is formed, this is crushed slag, and this is what you get from aggregate crushers; crushed stone is also present. You will always try to see that there is no other organic matter present in this particular one. Now, what are the requirements that are there? It states that, in addition to the physical requirements given in the table below, this is the table provided by MoRTH 2013 for the materials to be used in the granular sub-base course.

It says that, as I mentioned, the aggregate impact value can be a maximum of 40 percent. So, only 40 percent of fines can be generated; the maximum value is 40 percent. When it comes to the liquid limit and plasticity index, it states that the liquid limit should be lower than the higher liquid limit; in general, this means that your material will have a more plastic nature. So, a liquid limit of a maximum value of 25 percent is allowed for this particular one, and a plasticity index of a maximum of 6 percent is allowed. In addition to this particular one, it says that when you measure, as we discussed in the previous lecture, the CBR is to be determined at a certain percentage; when we were looking for subgrade, it had to be determined that the CBR specimens had to be compacted at 97 percent of the maximum dry density. Here, it says the CBR is to be determined by compacting it to 98 percent of its dry density, and this CBR should have a value of at least 30 percent.

So, the strength in terms of CBR should be more than 30 percent. So, these are the requirements that are given. So, it makes use of your aggregate impact value. And it says that soft aggregates like kankar, brick, ballast, and laterite shall also be tested for the wet aggregate impact value. As I said, this needs to ensure what the wet aggregate impact value is because certain aggregates become significantly weak in the presence of water. They may perform well when they are tested in dry conditions, but when they are tested under wet conditions.

So, that is why we discussed that the wet aggregate impact value may also be required, especially when the aggregates have water absorption of more than 2 percent. So, it says that is given below, and if the water absorption, when determined as per this, is found to be greater, the aggregate shall also be tested for wet aggregate impact value. So, this is for the aggregates to be used in granular courses. Now, in granular courses, there was another mix that we discussed, which was the water-bound macadam. So, this water-bound macadam is most often preferred to be used as a granular base course, or sometimes it can be used in the upper layer of your sub-base course as well.

So, here again, the requirement states what materials can be used for this: crushed or broken stone, crushed slag, or brick aggregates. So, there are places like Mizoram, where a good amount of these brick aggregates is used in different construction applications. And then you can use any other naturally occurring materials, such as kankar and laterite, which all have to be checked for their suitability. Now, what it says is that materials other than crushed or broken stone and crushed shacks can be used in sub-base courses only if this water-bound macadam is used as a sub-base course. If crushed slag gravel is used, not less than crushed shingles and riverbed material are normally crushed.

So, when you are crushing it, these gravels say that 90 percent by weight of the gravel shingle pieces retained on 4.75 mm shall have at least two fractured faces. Now, what are these fractured faces? If I get aggregate from a riverbed, it can be a rounded aggregate. Now, if I break these aggregates at this particular edge, So I will create some projected area; this face will be generated.

Now this is the face that has been formed when I broke this particular aggregate. So this is one area, and there is another area, which is the projected total area of this one. So if one face can be called, there may be, if this is a rounded aggregate, one face; this part may be chipped off. So, one face is created here; this one can also be called a fractured face, or, if I need to say, this one has a small shape. So, whether this one here can be considered a fractured phase or not. So, the important aspect is that any phase which can be considered a fractured phase should have at least one-fourth of the project area; one-fourth of this area of the fractured phase should be one-fourth of its total projected area.

So, it says that the maximum particle cross-sectional area should be, and the one that is there with this fractured face should be at least one-fourth of this total projected area. Then only should there be these sharp edges. Then only can this face be called a fractured face. So, this is very important when we break down the riverbed material, which is rounded, and we use it in different courses. So, when you are using water-bound macadam, you need to ensure that 90 percent by weight of this particular one should have at least two fractured faces, and one fractured face will be considered only if it has a projected area one-fourth of the total projected area of that aggregate.

Now, again, as there is a requirement for the aggregates to be used as water-borne macadam, the Los Angeles abrasion value should be 40 percent, and the aggregate impact value should be 30 percent. As I mentioned when it was there for the granular sub-base course in the previous slide, it was 40 percent; here it is 30 percent. Here, it provides the requirement for the combined elongation and flakiness index; this is very important. You need to check if it is a requirement for elongation and flakiness index separately or a combined elongation and flakiness index, and here it restricts a maximum value of 35 percent. This means that if the aggregates get softened in the presence of water, you should go for the wet impact value.

And along with this, specifically, it says that the flakiness and elongation index is enforced only in the case of crushed broken stone. When you are breaking these industrial waste products or riverbed material, they tend to have more rounded shapes. So, if you are breaking it, you need to ensure the shape, especially the part where the flakiness and elongation index are ensured. In the case of water-bound macadam, the requirements in respect of Los Angeles, and if I am using this as I mentioned, can be used in base and sub-base courses. If I am using water-bound macadam in sub-base courses, the requirements for Los Angeles abrasion value and aggregate impact value will be 50 and 40 percent, respectively, because 40 percent is what was required in the case of the granular sub-base courses.

So, if this material is used in sub-base courses instead, the aggregate impact value requirement will be 40 percent. So, all these things need to be taken care of. The other since, during the water-bound macadam construction, we have seen you need to apply the screening material, and then you need to apply the binding material. So there are also certain requirements that are to be considered for the screening materials.

So the screenings to fill in the voids or shell generally consist of the same material as the coarse aggregates. This is an important requirement. Second, it says that non-plastic materials such as murum or gravel, other than rounded riverbed material, can be used, but it states that this should be non-plastic material. Now, to make it non-plastic, it states that the liquid limit and plasticity index of this material should be less than 20, the liquid limit should be less than 20, and the plasticity index should be less than 6 for any material to be used in screening, and the fraction passing the 75 micron should not exceed 10 percent. So, if you are using the water bond mechanism, the screening material needs to be ensured for the liquid limit, plasticity index, and the percentage that is passing the 75 micron sieve size. In addition to that, when the binding material is used, once the fill screenings are applied, here you can see a WBM construction that is underway, water-bound macadam construction that is ongoing.

If this particular layer is used when you are using a binding material for a WMM layer as a filler material, then again, it states a suitable material, but the plasticity index of this material should also be less than 6. So, we have seen that when coarse aggregate particles are present, there is a requirement for the Los Angeles abrasion value, the impact value, fractured faces, and the flakiness and elongation index. If the water absorption is more than 2 percent, there is a requirement for the wet aggregate impact value. In addition to that particular one for finer proportions, there is a requirement with respect to the liquid limit, with respect to the plasticity index, and with respect to the material that is finer than your 75-micron sieve size.

So, these are important considerations for using different materials in different courses. Granular unbound course, which is used in the construction of flexible pavement, is your wet mix macadam. Now, this is used as a base course. So the requirements should be stricter compared to the requirements we have seen for sub-base courses. Here, you can see that where the aggregate impact requirement for granular sub-base courses was 40 percent, here it is 30 percent.

So, this is another part; the second is Los Angeles' aberration value; it says it should be 40 percent. If an option is given here, you can see that it is mentioned, or you can do a Los Angeles aberration value or an aggregate impact value. It is preferred to use the Los Angeles abrasion value if the water absorption is not more than 2 percent. If you find that there are certain aggregates showing higher water absorption than the aggregate impact value, especially the wet aggregate impact value, it could be quite useful. Otherwise, if the water absorption is within the limits, a Los Angeles abrasion value test is preferred because it, in some manner, gives the abrasive as well as the impact forces during its measurement.

So, this can be preferred if the water absorption is not more than 2 percent. Then there is this combined elongation and flakiness index for the material to be used in the wet mix macadam, which is used as your base course, and it states that the requirement should be less than 35 percent. And what materials can be used? The most preferred option is crushed stone aggregates. If crushed again, it says crushed gravel and shingles are used, not less than 90 percent by weight of this shell, retained on 4.7, and have shed at least two fractured faces; again, this is the important requirement that is there.

When you are using it, when you are crushing it, because the shingles and the gravers need to be crushed down. When you are crushing them down, it is important to consider how many are crushed; when it is done at aggregate crushers from natural rocks, a good amount of crushed faces is generated. But when it is done for these shingles and slags, you need to ensure that a good number of fractured faces are generated, and here it states that 90 percent of the aggregates by weight should have at least two fractured faces, and this is tested for the material above a 4.75 mm sieve size. And the other requirement, as mentioned, is that if they have water absorption of more than 2 percent, then we again need to go here; it says in addition to the wet impact value, it is preferred to go for the soundness test. So, that soundness test can be done because water absorption may be higher; the aggregate may be more susceptible to degradation under your freezing and thawing conditions.

So, you will try to ensure your aggregate suitability through a soundness test as well. So, when these aggregates have more water absorption and more than 2 percent, and are to be used as a wet mix macadam in the construction of your base course, a paver is used for laying the wet mix macadam layer and compaction; we will discuss more about them when we discuss the construction aspects. So, if more than 2 percent of water absorption is present, you can go for the aggregate wet impact value along with it; it has to be checked for your soundness test to ensure that it is durable enough. So, this completes the discussion, especially in terms of the requirements of the materials to be used in your granular courses. Thank you.