Pavement Materials
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Lecture 40
Marshall and Superpave Mix Design (Part 1)

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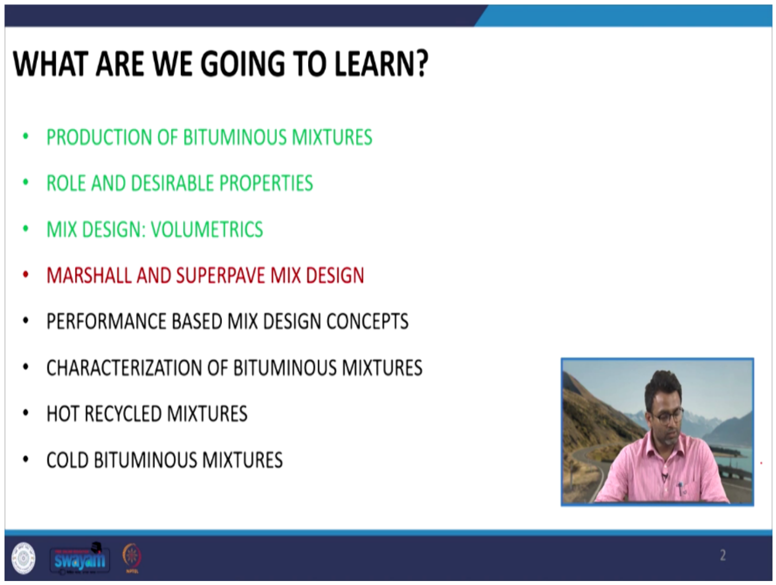

Hello everyone, welcome back. By now, we have completed our discussion on the volumetric concepts of mix design. So, with this we can say that we have completed a major task which is involved in the understanding and in completing the mix design process. So, today we are going to start discussing about the steps of mix design and for this will be discussing about two popular mix design methods which are typically used, and these are the Marshall mix design method and Superpave mix design method.

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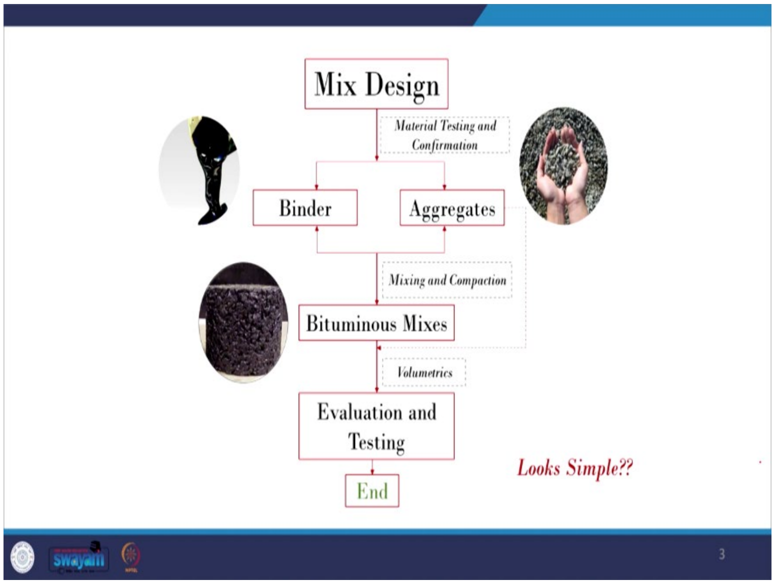

If you remember this picture, I showed you in the beginning of the picture when I started discussing about the mix design concepts, and this is the overall steps which are involved in the mixed design process and the steps will remain the same with some differences irrespective of any mix design method we use. And, as I said the major task here is to understand the volumetric concept which is finally used to complete the mix design process.

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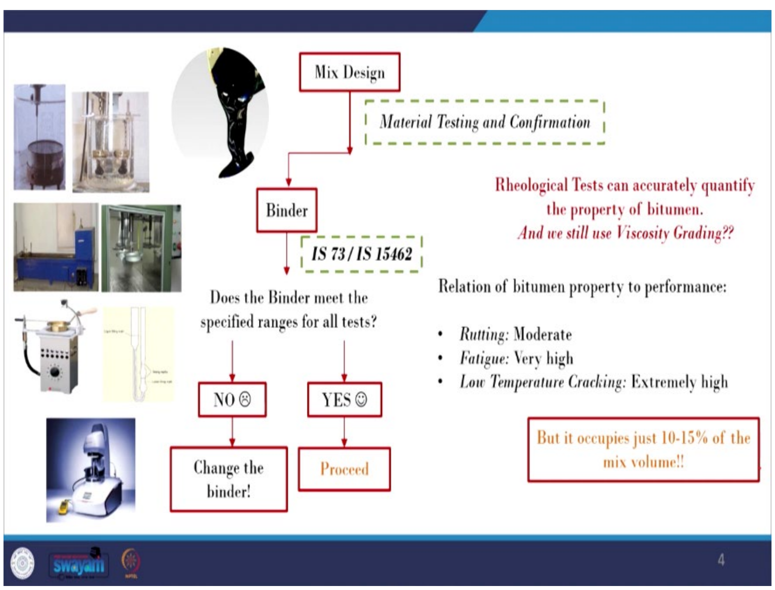

I will start discussing the steps again, few of the concepts may be repetitive, but I have just put it in this presentation just to have a brief recap of what we have already covered. So, coming to the first step in mix design process it involves the material testing and confirmation, so we have 2 different materials using which a bituminous mixture is prepared and these are the bitumen or the binder and the aggregates.

So, once we get the binder which has to be used in the mix design process, we will subject the binder to a series of testing. Now, here I have indicated an example of Indian specification where we follow usually IS 73 when we are talking about unmodified bitumen or the conventional viscosity graded bitumen or IS 15462, which is used for polymer modified binders.

If it is a Superpave mix design method, then we are going to do the rheological test and the pg grading which we have already completed previously. So, once we get the binder we will subject it to a series of testing, this testing given by different highway agencies. So, we can just for now we can just assume that these are a series of tests which are used by any highway agency to confirm the use of binder for construction of the pavement.

So, once we have, once we complete the test we will see if the binder meets the specified ranges or the minimum or the maximum value specified by the codal provision given by the respective highway agency. So, if the binder does not satisfy different criteria's, if they are satisfying only few criteria's and few are not satisfied, then we are going to change the binder.

If it satisfies all the criteria, then of course we are going to proceed, which means we have completed the first task of selecting the bitumen. Now, talking about the importance of bitumen with respect to the performance of the bituminous mixture, if you see the shear of bitumen in corresponding to the distress which is rutting or permanent deformation.

Its role is moderate, because rutting is a phenomenon which is more dependent on the shear strength of the aggregate skeleton. However, the stiffness of the bitumen also plays an important role, and therefore the role is moderate. Coming to the fatigue cracking, now fatigue cracking in the bituminous mixture is more or less controlled by the properties of the bitumen.

Although, there are other factors, such as volumetric factors, such as air void in the mixture, thickness of the bituminous layer etcetera, but coming to the material category bitumen plays a very high role in controlling the fatigue behavior, because it is the presence of bitumen that imparts flexibility to the bituminous mixture.

On the other hand, if you talk about low temperature cracking, the role of bitumen is extremely high because if the stiffness of the bitumen is very high at low temperatures, then the chances of cracking or thermal cracking increases. So, therefore the viscosity or the stiffness or the rheological properties of the bitumen play a very dominant role in controlling occurrence of low temperature cracking in the hot mix asphalt.

But it is also interesting to note that when we say that the role of bitumen is so high with respect to different aspects, but if you see the amount of bitumen which we use for the production of bituminous mixture, it is very low, it is a, if you talk about in term in terms of volume, it is approximately 10 to 15 percent of the total volume on the other hand, the aggregates occupy more than 80 percent of the volume in the mix.

So, since in India we are mostly using viscosity grade bitumen, and previously we have discussed what are the demerits of viscosity graded bitumen, it does not give us a complete idea about the viscoelastic properties of the bitumen for a very wide range of temperature to which bitumen is actually subjected during the service period. So, we still use viscosity grading in India, so it is important that bitumen being an important material in the bituminous mixture we move for more advanced form of testing to quantify the properties of bitumen.

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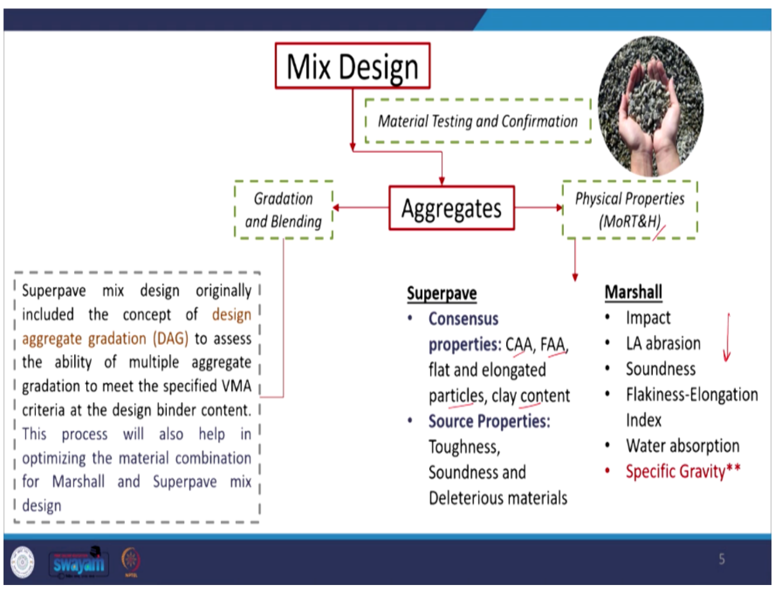

Moving on to the next step, we have to confirm the aggregates which we are going to use for the production of bituminous mixture. So, with respect to aggregates there are two tasks which has to be performed, one is to measure the physical properties of the bitumen and to confirm whether the physical properties of the bitumen, it satisfies the criteria given by the highway agency.

And the next is to perform the grading of bitumen, to select a grade that which sizes will be present in the mix which we are going to produce, and then when this gradation has to come from different stock piles, how these different stockpiles are to be blended in order to produce the aggregate skeleton.

Talking about the physical properties, let us because we will be discussing Marshall and Superpave mix design, so I have planned to take both the mixed design concepts together, so that we can understand these steps as well as differentiate between the 2 steps in the mix design method. So, if you see the Marshall mix design method, so conventionally we will use the typical test as given by the highway agency.

For example in India we use the specification outlined by ministry of road transport and highways and it says that we have to perform tests like impact Los Angeles abrasion, soundness flakiness, and elongation index, we have to measure the water absorption, and of course specific gravity is something which we have to measure or calculate irrespective of any mixed design process, so this remains same in both the mix design process.

So, in the Marshall mix design which we follow in India these are the some of the tests which we have to perform to select the aggregate particles or aggregate source. Coming to the Superpave mix design method, they have divided the test on aggregates into two parts, the first part is termed as determining the consensus properties, so consensus properties are properties which the agency feel is more important and should be met by aggregates from different sources, irrespective of whichever highway agency is using it.

So, these are not very local type of properties which we are determining rather than these are global properties which should be satisfied, because these properties are found to be related directly to the performance of the bituminous mixtures. So, these are coarse aggregate angularity which we have already discussed, fine aggregate angularity, flat and elongated particles.

So you can see that they are giving more importance to the shape attributes of the aggregate particles, because it is found by many previous researchers that these properties are actually related to the performance of the bituminous mixture, and they also evaluate clay content under the consensus property and they use sand equivalent test to do so.

On the other hand, they also perform test which comes under source properties, which are more of local material properties by different state agencies which they can adopt, and these include test like toughness, soundness, and deleterious materials. And again, the details of this, test we have already discussed previously, so I am not repeating the same here again.

Coming to the gradation and blending, we have discussed in detail about how the gradation is selected based on the maximum density line. We have also discussed about how the blending can be done usually trial and error method is used. We also saw the demonstration of stab which is simple tool for aggregate blending which can be used to select the different possible options of blending the stockpiles to meet the desired gradation.

Under the gradational blending an important concept which Superpave mix design originally included is the use of design aggregate gradation. And design aggregate gradation is useful to assess the ability of different or multiple aggregate gradation which meets the criteria of the lower bound and the upper bound limits, but within this gradation, which gradation is more suitable or will specifically meet the VMA criteria can be evaluated using the design aggregate gradation.

Design aggregate gradation can also be very useful for optimizing the material combination irrespective of the mix design process, so the same can be used in Marshall mix design process and in Superpave mix design process also. So, but typically when we talk about the Marshall mix design process in India, we really perform a step called design aggregate gradation to select appropriate gradation, but as we will discuss today this can be a very important step.

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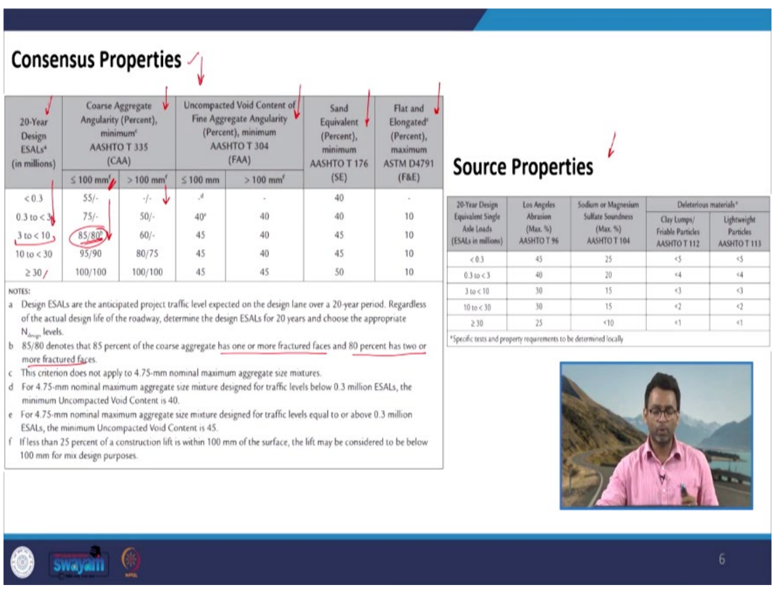

Before we start discussing about the design aggregate gradation this slide is in reference to the previous discussion which we have done. So, this table is given by asphalt institute in ms2, so you can see that what criteria they have put on the consensus properties. Here, one important thing about Superpave mix design which should be mentioned at this stage is that, we have different levels of traffic corresponding to be used in the mix design process.

So, you see here they mentioned that the traffic is the 20-year design equivalent standard xl load which will dictate that what should be the limit of the material properties to be used for the production of hot mix asphalt. So, traffic is basically divided into 5 categories, we have traffic less than 0.3 msa, we have traffic .3 to 3 msa, we have traffic between 3 to 10 msa, 10 to 30 msa, and more than 30 msa.

Coming to the consensus properties as we have discussed, we have coarse aggregate angularity, fine aggregate angularity, sand equivalent which is the clay content, and flatten elongated particles the details of these tests, we have already covered previously. And here you see that they mention that when the aggregates are used in the bituminous mixture which are within the first 100 mm of the bituminous layer they have some different criteria's.

In comparison to the aggregates that will be used on the lower side, that is beneath 100 mm from the surface. So, the question is why they have considered the material properties corresponding to the depth of the pavement? Because the here the logic is that the materials which are kept on the upper layers they will be subjected to higher stress levels, so they should be of superior quality in comparison to the material that are at lower depths.

Therefore, they have considered less than equal to 100 mm, and more than 100 mm and the criteria's are listed here. Here again, a few more important points, for example you can see two numbers here, so if you say that the aggregates which are used let us say at a depth of 50 mm should have a coarse aggregate angularity of 85/80, when the traffic design traffic is in of the range of 3 to 10 msa.

So these 2 numbers indicate that 85 percent of the coarse aggregate has one or more fractured faces, whereas 80 percent has two or more fractured fetches, so this is the significance of 2 numbers in the same category. So, I think others are very straight forward that they have put limiting values to different material properties.

Coming to the source properties, they have the source properties include the Los Angeles abrasion, sodium or magnesium sulphate soundness, and deleterious material which includes 2 different tests, that is the clay alarms of friable particles, and light fit particles, and the limits are given in this particular table, so this is from the super pave mix design process.

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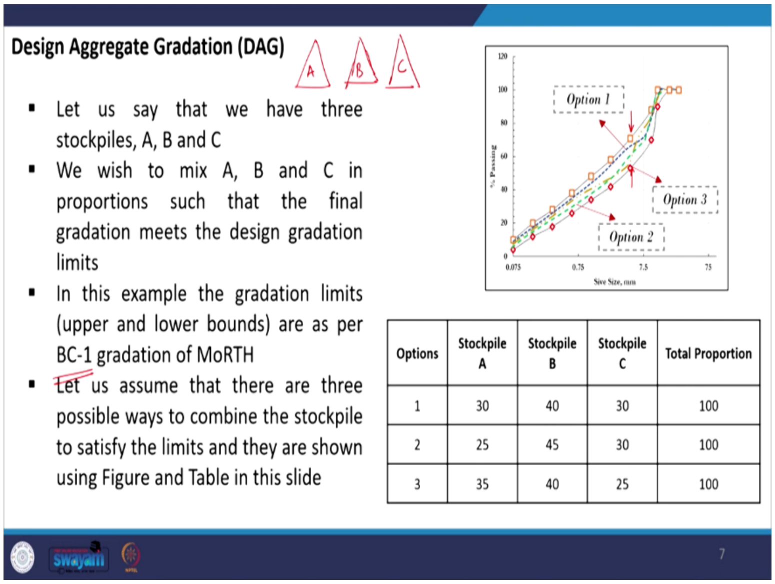

Options	Stockpile A	Stockpile B	Stockpile C	Total Proportion
1	30	40	30	100
2	25	45	30	100
3	35	40	25	100

Now, we start discussing about the design aggregate gradation. And, as I mentioned this is a very important step to be performed to select appropriate gradation from different available options. So, let us try to understand the design aggregate gradation using an example which will make it more clear that what we mean by design aggregate gradation and how these steps are actually performed.

So, let us say that we have 3 stockpiles, A, B, and C, so these definitions stockpiles, everything we have already covered, so I hope you will be able to understand it now. So, let us say we have 3 different stockpile A, B, and C, which have to be blended to meet some desired criteria. So, we may wish to mix A, B, and C, in proportions, such that the final gradation meets the design gradation limits.

In this example, this design limits has been taken from Indian specification given by ministry of road transport and highways and we have selected a bituminous concrete one gradation which is typically used in the wearing course. So, let us assume that there are 3 possible ways to combine the stockpiles A, B, and C, so that they satisfy the gradation criteria.

So, this is the gradation criteria, the one, the line, the marker in orange and the red, they indicate the upper bound, and the lower bound limit for the gradation and you can see some dotted lines within this band including option 1, which is shown using a blue line, option 2 using a green line, and option 3 using an approximately brown line, which means that these three gradations.

Now, what are these three blending proportions? so option 1 it includes 30 percent of A, 40 percent of B, and 30 percent of C. Option 2 it includes 25 percent of A, 45 percent of B, and 30 percent of C. On the other hand, option 3 includes 35 percent of A, 40 percent of B, and 25 percent of C, and you can see the summation for all is 100 percent, and all the options are satisfying the upper bound and the lower bound criteria.

So, the question is which option should we select and as we are discussing we will perform a design aggregate gradation, so that we make a rational choice of choosing the appropriate aggregate gradation.

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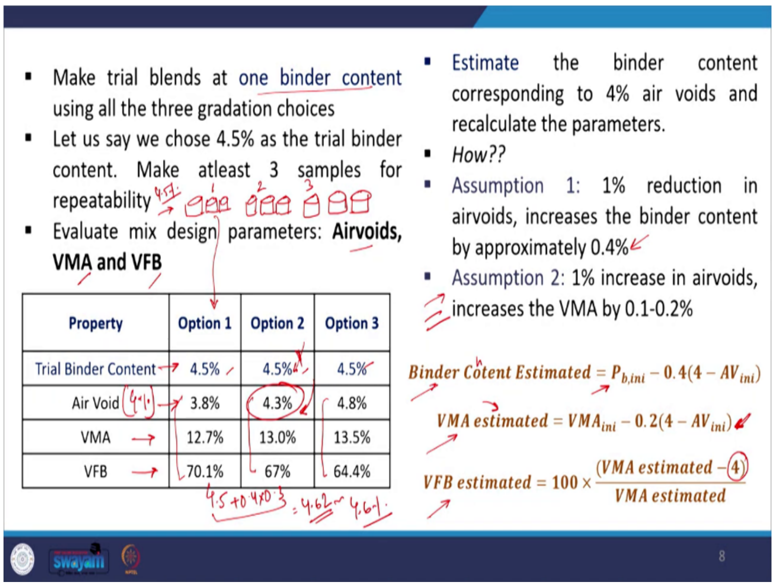

So, the steps include, the first step is that will make trial blends at one binder content. Now, this is again very important that here you have to realize that we are only making the samples using the 3 gradations at a single binder content. So, let us say that we choose 4.5 percent as the trial binder content, now this trial binder content can be chosen by the engineer based on his local experience.

Based on the type of mix we are targeting, this can be very close to the anticipated optimum binder content, so let us say we are choosing 4.5 percent as the trial binder content. We will make at least 3 samples for repeatability, so that we can take the average with more confidence, then after making the samples we will evaluate the mixed design parameters.

So for all the gradations option 1, 2, and 3, we have made bituminous mixtures, cylindrical bituminous mixtures. And they are all made at 4.5 percent binder content, and now we are evaluating them and we are assessing the volumetric parameters such as air voids, voids in mineral aggregates, and voids filled with bitumen.

By now, we all know that how these parameters are evaluated for a given mixture, so I am not discussing about that in detail again. So, this is our trial binder content, so for the mix the option 1, when we evaluated the mixture, we found that these are the values. Similarly, for option 2, we found that these are the values, and for option 3 these are the values, and you can see they all are different from each other.

So, all the options 1, 2, and 3, though they satisfy the gradation criteria their volumetric parameters at 4.5 percent binder content are different. Now, what we are going to do? we are going to estimate the binder content corresponding to 4 percent air void. Now, here you have to understand that first we have made mixes at a single binder content.

And now we are using the results to predict that at what binder content in each of the 3 options, we will get 4 percent air voids. And why are we actually doing this step? Because we will see later that our mixed design is done corresponding to a target air void content of 4 percent.

So, to estimate this there are 2 assumptions which have been suggested by ms2, and about these suggestions again we have discussed previously using an example which you can recall. So, the first assumption here is that 1 percent reduction in air void increases the binder content by approximately 0.4 percent.

And we have previously discussed this with an example, and then we all agreed that it is approximately correct to say that 1 percent reduction in air void increases the binder content by approximately 0.4 percent, so this is the first assumption. And, the second assumption is 1 percent increase in air void increases the VMA by 0.1 to 2 percent.

Now, though we have not discussed this particular concept or aspect, I leave it to you to ponder upon it using a pen and paper, and try to figure out whether this statement holds true or not. And, since now you understand the volumetrics of bituminous mixtures, I am sure you will be able to appreciate or agree upon the statement which is made that 1 percent increase in air void approximately increases the VMA by point 1 to 2 percent.

So, using both these assumptions, we can very easily interpolate and calculate the estimated binder content corresponding to 4 percent air void, so the binder content estimated corresponding to 4 percent air void is given by this simple interpolation formula. Similarly, the VMA estimated corresponding to 4 percent air void and using this assumption can be written using this particular formula.

And, as I said that this you can easily derive using the simple interpolation, just by drawing plotting a graph. And then similarly, since we have the estimated binder content and VMA estimated, VFB estimated can be similarly calculated, and you can see that for VFB estimated we are using 4 percent air void as the final criteria.

Now, using the first table which is shown, and these assumption and formulas, we can calculate that what will be the binder content corresponding to 4 percent year void. So, if this entire row has to be 4 percent, then what will be this particular row and correspondingly other rows.

If you see for example, let us say we are looking at option 2, here at 4 percent we are getting 4.3 percent air voids, so at 4.5 percent binder content, we are having 4.3 percent air void, so to get 4 percent air void, if I want this air void to be 4 percent which means point 3 percent reduction in air voids from what we have now, the binder content should be how much.

Using the assumption, which we have taken it should be $4.5+(0.4\times0.3)$ I think this is very simple to understand, so this is 4.62 percent or you can say 4.6 percent. So, if we increase the binder content by 0.1 percent if you see here the air void reduces by approximately 4.6 percent.

So, now again what we have, let us take another example just for VMA also, so in case of VMA, let us assume that 1 percent increase in air void increases the VMA by approximately 0.2 percent. So, if we see option 3 here, and in option 3 at 4.8 percent air void, at 4.8 percent air void, the VMA is 13.5 percent, so what should be the VMA at 4 percent air void.

So, it should be how much using the same assumption, 13.5 which we have now, we are taking that 0.2 percent it will increase into 0.8, so this gives us around 13.3 percent. So, similarly the VMA can be estimated for other options too. And once we have the estimated binder content and the VMA, the voids filled with bitumen can also be calculated using the simple equation which is shown.

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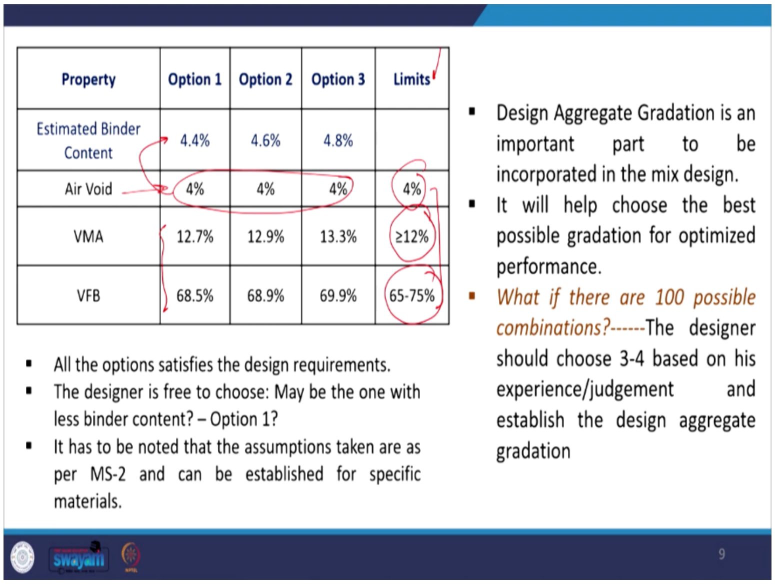

Property	Option 1	Option 2	Option 3	Limits
Estimated Binder Content	4.4%	4.6%	4.8%	
Air Void	4%	4%	4%	4%
VMA	12.7%	12.9%	13.3%	≥12%
VFB	68.5%	68.9%	69.9%	65-75%

So, if you see this table, it presents the final results. And here, if you will see that this row all the values are 4 percent, these 3 values, we have estimated the binder content to achieve the 4 percent air void, and similarly we have calculated other parameters.

And these are the limits which is given by the highway agency, that for the particular mix, for the dense graded mixture, the air void is 4 percent, that is fine, the VMA corresponding to the nominal maximum aggregate side should be greater than equal to 12 percent, and the VFB should be in the range of 65 to 75 percent.

So, in this example, interestingly you will see that all the options satisfies the criteria of VMA as well as VFB. So, this indicates that all the 3 options are good enough, but what do we do now, so at this stage we can also look at the economy or the cost of the mix and you will see that option 1 has the least binder content and also satisfies all the criteria, and therefore the cost of this mix will also be lower in comparison to option 2, and 3.

So, a designer can choose option 1 as the design aggregate gradation and then he can proceed to the next step for completing the mixed design process. So, as I mentioned that design aggregate gradation is an important part to be incorporated in the mix design, it will help to choose the best possible gradation for optimized performance.

And in case for example, we are using stab, and this stab tells there are 100 or 200 possible combination, in that case it is suggested that the designer can choose 3 to 4 of those option based on his experience or judgment considering that he is taking a coarse gradation, a fine gradation, a gradation which is somewhere in the middle of the band.

And then he can perform the design aggregate gradation on these mixtures, and finally select one for the mixed design process. So, we will stop here today, and we will continue discussing the steps involved in the Marshall and Superpave mix design in the next presentation, thank you.