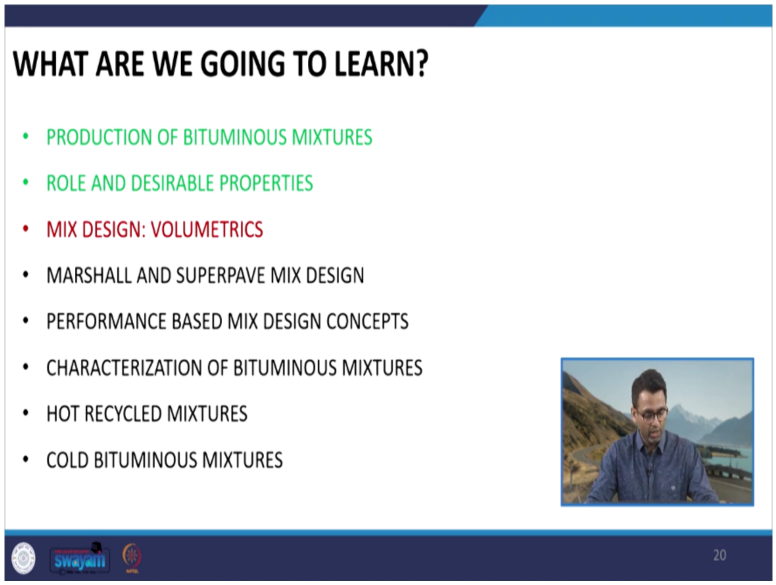
Pavement Materials
Professor Nikhil Saboo
Department of Civil Engineering
Indian Institute of Technology, Roorkee
Lecture 38
Volumetrics in Mix Design (Part-4)

(Refer Slide Time: 00:46)



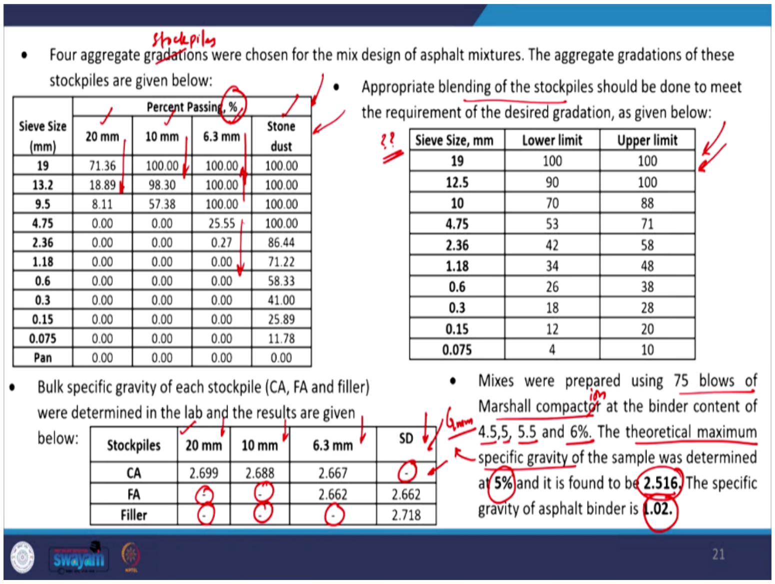
Hello everyone, in the last presentation, we were discussing about the concepts related to the volume matrix of bituminous mixtures. We have derived various expressions that are required during the mixed design process and we have also understood the definition, and the fundamentals of these volumetric parameters.

I hope that by now you all are familiarized with most of the concepts that are required to solve a general mixed design problem, especially the calculations involved during the mix design process. Though we have not discussed specifically about the steps of any mix design process until now but these concepts which we have learned, which we have discussed will remain same, irrespective of any mixed design process we adopt.

So, today what we will do we will try to solve a detailed problem and this problem has been made in such a way that, if we are able to understand this problem, and if we are able to solve this problem, we can expect that we will be able to solve any other problem related to the mixed design of bituminous mixtures. And this problem which we will be discussing today is basically drafted by one of the research scholars, and I am really thankful to him.

So, let us first see the problem, and I will go slow in this presentation, so that we can understand each and every step. And in fact, let us first try to understand the problem itself, and then we will try to think upon that which are the logical steps or that will be required to solve this problem in a systematic manner. So, the question in front of us is that, four aggregate gradations were chosen for the mixed design of asphalt mixtures the aggregate gradations of these stockpiles are given below.

(Refer Slide Time: 2:37)



Sieve Size (mm)	Percent Passing, %			
	20 mm	10 mm	6.3 mm	Stone dust
19	71.36	100.00	100.00	100.00
13.2	18.89	98.30	100.00	100.00
9.5	8.11	57.38	100.00	100.00
4.75	0.00	0.00	25.55	100.00
2.36	0.00	0.00	0.27	86.44
1.18	0.00	0.00	0.00	71.22
0.6	0.00	0.00	0.00	58.33
0.3	0.00	0.00	0.00	41.00
0.15	0.00	0.00	0.00	25.89
0.075	0.00	0.00	0.00	11.78
Pan	0.00	0.00	0.00	0.00

Sieve Size, mm	Lower limit	Upper limit
19	100	100
12.5	90	100
10	70	88
4.75	53	71
2.36	42	58
1.18	34	48
0.6	26	38
0.3	18	28
0.15	12	20
0.075	4	10

Stockpiles	20 mm	10 mm	6.3 mm	SD
CA	2.699	2.688	2.667	-
FA	-	-	2.662	2.662
Filler	-	-	-	2.718

So, I think it should be just written as four aggregate stockpiles were chosen for the mixed design of asphalt mixtures and the aggregate gradation of these stockpiles are given below. So, you can see that we have 4 stockpiles here, the first stockpile is designated as a way we designate any stockpile based on the maximum size of the aggregate present.

So, 20, this is a 20 mm stock pile, this is a 10 mm stock pile, this is a 6.3 mm stock pile and this is a stone dust stockpile, so we have 4 stockpiles here. And we have the aggregate gradations in terms of percentage passing for these individual stockpiles. The next part of the question says, that appropriate blending of the stockpile should be done to meet the requirement of the desired gradation as given below.

So, this is the desired gradation, so this gradation might have been given by this the highway agency that we have the lower limit and upper limit. And then, appropriate blending of the stockpiles, which means these 4 stockpiles which we see on the left-hand side is to be blended in such proportion that the final gradation should follow these upper bound and lower bound limits.

So, the next part of the question says that, so you can see that we have a problem to solve here itself that is the first part will be the proportioning. Further, the question says that the bulk specific gravity of each stockpile and for each individual stockpile for coarse aggregate, fine aggregate, and the filler were determined in the laboratory and the results are given below.

So, for each individual stockpiles, the coarse aggregate were separated or taken separately, the fine aggregates were taken separately, and the filler that is material passing 75 microns were taken separately, and each of these stock pile they have determined the specific gravity of the aggregates. Now, you can see there are few blank cells here, this is because this 20 mm stockpile does not have any fine aggregate and filler content.

Similarly 10 mm stockpile does not have any fine aggregate and filler content, similarly this stone does not have any coarse aggregate content, and that is why it is just left blank, and in fact we have solved a similar problem previously, but this question is combining, so many different aspects, and then let us see that how step by step we can approach to solve this question, okay.

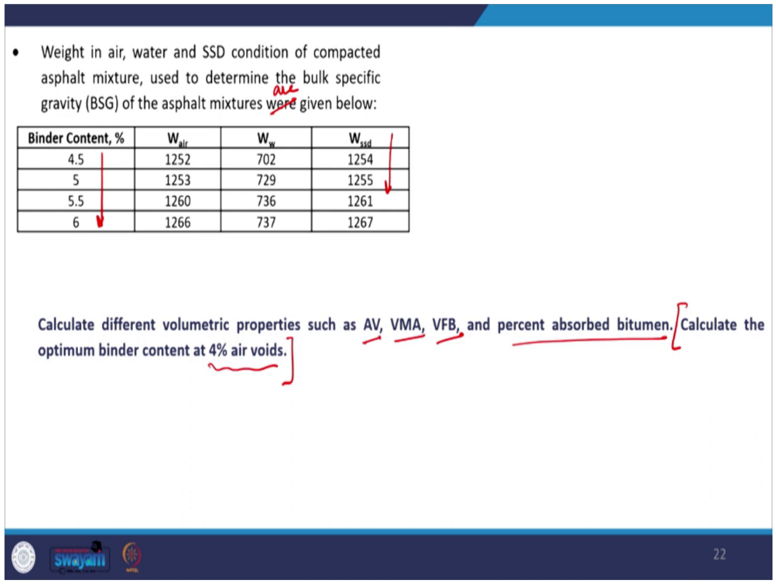
So, this was about the aggregates, then the question says that mixes which means asphalt mixtures or bituminous mixes were prepared using 75 blows of martial compaction. Though as I said we have not specifically discussed about the steps involved in the Marshall mix design but let us say we have adopted a compaction process, so that is an impact compaction.

So by now we know that we can have different types of compactions, and the finally we will have some cylindrical mixtures which we prepare in the laboratory. So, using the Marshall compaction and giving 75 blows on each side of the specimen, we have prepared bituminous mixtures at different binder content, so the binder content chosen are 4.5 percent, 5 percent, 5.5 percent, and 6 percent, so all are at a gap of 0.5 percent.

The theoretical maximum specific gravity, so as I say theoretical maximum specific gravity, so in the back of our mind I should remember that this is indicating about Gmm. So, the theoretical specific gravity of the sample was determined at 5 percent, and this is to be noted here that only 1 binder content they have determined the theoretical maximum specific gravity and it was found to be 2.516.

This is the value which we got after laboratory measurement. The specific gravity of the asphalt binder is 1.02, so this is again 1 of the input.

(Refer Slide Time: 06:58)



Further, the question says weight in air water and saturated surface dry condition of compacted asphalt mixture used to determine the bulk specific gravity of the asphalt mixtures are given below. This is what the question says that we have, we prepare the sample as at 4 different binder contents.

So at all the binder contents when we have the compacted specimen, the weight in air of that specimen, the weight in water of those specimens, and the saturated surface dry weight of those specimens are given here all right, so these are the different weights that we have recorded in the laboratory.

Now, the final question is that we have to calculate different volumetric properties such as air voids, voids in mineral aggregates, voids filled with bitumen, and percentage absorbed bitumen, so these volumetric properties we have to calculate in fact at all the different binder contents at which we are preparing the mixture. And then finally, we have to calculate the optimum minder content at 4 percent air voids.

Now, this last part of the question is something which we are yet to discuss, but till now very easily we will be able to calculate this optimum binder content. So, though we have not very explicitly defined the optimum binder content in any mix design process but you see it the question itself asks calculate the optimum binder content at 4 percent air voids.

So the question says that at 4 percent air void whatever is the bitumen content that they are considering as the optimum binder content and we have to calculate it. So, this is the entire problem and you can see this is a big problem comprising of so many parts in the equation, so let us move ahead and let us try to solve this question.

So, in any mixed design problem which we will do in the laboratory, the first part is always of course after selecting the appropriate materials like aggregates and binders, the next important step or I consider that as the initial steps towards volumetric is to blend the stock piles, is to find the specific gravity of the blended aggregate gradation, and then further prepare the mixtures and determine other volumetric properties.

So, the first step in the problem is that we do not know till now, that in what proportions these stockpiles should be blended, so that our final gradation should fall under the specified limit of the highway specification which was given in the initial part of the question. And, then the next part which we have to calculate is the specific gravity of the combined blend, so this is this is also something which we do not know.

So, here again someone can opt to use step 2 as step 1, that can be done but this is 1 way in which I have tried to solve this question, that the first step is to calculate the percentage retained. Now, the question is why we are interested in the percentage retained, because in the question if you remember, which I already showed you, we had the specific gravities of different sizes of aggregate which means coarse, fine and filler.

And then we had various stockpiles whose individual gradation in terms of percentage passing we knew. But using percentage passing, we do not know that in individual stockpile, what is the percentage of coarse aggregate, percentage of fine aggregate, and percentage of filler. For example, if I go back to the question, so this was the table which was given to you, so this says percentage passing, so it tells you about the gradation, but let us see this stockpile or this stockpile, and this stockpile, let us say 6.3 mm.

Here, you will see here that we also we have fine aggregates as well as we have coarse aggregates, so first we have to find out that what is the proportion of coarse aggregate and fine aggregate in this stockpile and similarly in other stockpiles, so that we can calculate the appropriate average specific gravity which about which we have already discussed previously.

(Refer Slide Time: 11:25)

Step 1: % retained

Sieve Size (mm)	Percent Passing, %	Percentage Wt. Retained %	Percent Passing, %	Percentage Wt. Retained %	Percent Passing, %	Percentage Wt. Retained %	Percent Passing, %	Percentage Wt. Retained %
19	71.36	28.64	100.0	0	100.00	0.00	100.0	0.00
13.2	18.89	52.47	98.30	1.70	100.00	0.00	100.0	0.00
9.5	8.11	10.78	57.38	40.92	100.00	0.00	100.0	0.00
4.75	0.00	8.11	0.00	57.38	25.55	74.45	100.0	0.00
2.36	0.00	0.00	0.00	0.00	0.27	25.29	86.44	13.56
1.18	0.00	0.00	0.00	0.00	0.00	0.27	71.22	15.22
0.6	0.00	0.00	0.00	0.00	0.00	0.00	58.33	12.89
0.3	0.00	0.00	0.00	0.00	0.00	0.00	41.00	17.33
0.15	0.00	0.00	0.00	0.00	0.00	0.00	25.89	15.11
0.075	0.00	0.00	0.00	0.00	0.00	0.00	11.78	14.11
Pan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.78

Step 2: Proportion of CA/FA/Filler

Stockpiles	20 mm	10 mm	6.3 mm	SD
CA %	100.000	100.000	74.447	0.000
FA %	0.000	0.000	25.553	88.222
Filler%	0.000	0.000	0.000	11.778
Specific Gravity of coarse aggregate	2.699	2.688	2.667	-
Specific gravity of fine aggregate	-	-	2.662	2.662
Specific Gravity of filler	-	-	-	2.718
Average specific gravity	2.699	2.688	2.666	2.668

$$\frac{100}{\frac{74.447}{2.667} + \frac{25.553}{2.662}}$$

So, here I am calculating percentage retain to estimate or to calculate the proportion of coarse aggregate and fine aggregate in and filler in individual stockpiles. So, you see this is the gradation which is given to you, so this is already known the 1 in black these are different stockpiles, stockpile 1, stockpile 2, stockpile 3, and stockpile 4.

So, using percentage passing, I can calculate percentage weight retained very easily, so this is what I have done, this is just 100 minus this value, so I get this, and you deduct this, you get this, you deduct this, you get this, so I am just calculating the individual percentage weight retained in each sieve.

So, I hope by now we understand the calculation at least, so I am not repeating that while solving this problem, so you deduct you subtract this you get this. So, this is what I have done and I have all the values in front of me, similarly for stockpile 2, stockpile 3, and stockpile 4. So, for example you can see here this is 100 minus this, this is 100-100, 100-100, 100-25.55, 25.55-0.27, 0.27-0 an, so on.

So again, I hope that you understand this calculation. So, now you have the percentage weight retained. Then using this percentage weight return very easily we can calculate the percentages of coarse aggregate, fine aggregate, and filler in each of the stockpile. So, I will just see percentage weight retain and I will calculate, for example if you see stockpile 1, we only have the material which are retained on the 4.75 sieve, nothing is passing 4.75 mm sieve.

So the coarse aggregate fraction is 100 percent, and rest is 0 percent, 0 percent. Similarly, the 10 mm stockpile, you can see in front of you, let us see 6.3 mm stockpile, so you have 4.75 mm, and then you have things here. So, 25.553, which is this plus this are the total amount of fine aggregates, and whatever remains that is amount of coarse aggregate.

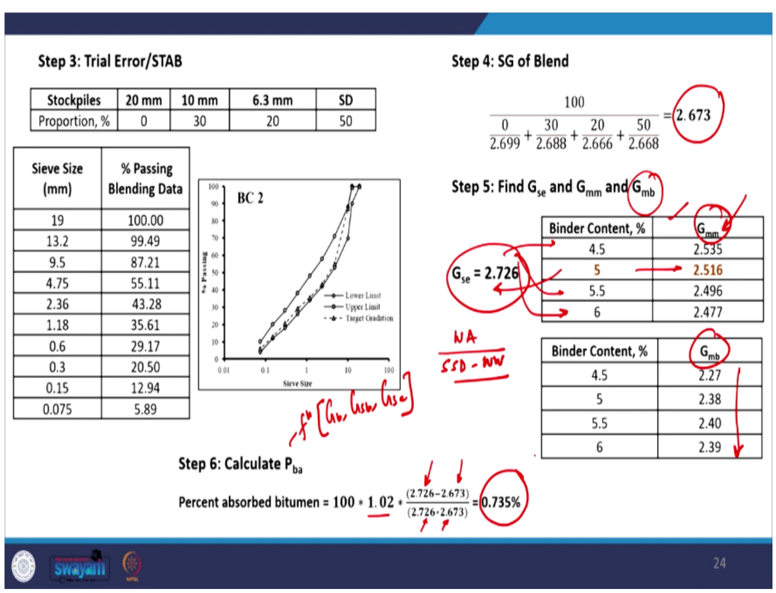
Similarly, if you see stone dust, you have nothing above from here to here, just add everything, you will get the total amount of fine aggregate, and finally 11.78 which is, which you can see here is the percentage of filler in the stone dust stockpile. So, just before taking the average, this part of the question is already given to us, that what is the specific gravity of individual sizes of aggregates in each stockpile, so this was given in the question.

And then, we will take the harmonic mean, and we get these values corresponding to different proportion. For example, let us see this, this will be equal to, I am just repeating but we have already discussed everything here, $\frac{70.447}{2.667} + \frac{25.553}{2.662}$, and we do not have any filler here, and similarly you can do all the calculations, so this is first calculation which we have done, the average specific gravity for each stockpile that is given to us.

This is for individual stockpiles, till now we have not determined the specific gravity of the final gradation, but of course we cannot determine it at this stage, because we do not even know what is the final gradation, because we do not know in what proportion we have to blend these individual stockpiles.

And as we have to arrive at a range of values, that is upper bound and lower bound, and we have discussed it in detail that there can be many solutions of blending this stockpiles, so either you can do a trial and error method, for example you can just use a simple excel sheet, keep on changing the values of the proportion of individual stockpiles which you want to take in the final blend, and calculate the percentage passing each sieve or each sieve size corresponding to that proportion, so that is one method.

(Refer Slide Time: 15:58)



Another method, which is also an iterative process is to use any available software, for the example, we have discussed about the simple tool for brigade blending where you get all the different possible ways in integral solutions for blending these stockpiles. We already did that exercise, and then out of various different options which we got using this step, we chose this proportion which was falling within the specification of upper bound and lower bound.

So, you can see this was the specification which was given to us and the middle-dashed line which you can see is the final gradation and it is within the limits, so this is what we have chosen. We have chosen that we will not use any aggregate from the 20 mm stockpile, because it is not really necessary, we will use 30 percent of 10 mm aggregates, 20 percent of 6.3 mm aggregates, and 50 percent of stone, so this is what we have decided finally.

Of course, there as I said, there are various solutions to this and the designer can choose any of the solution based on his comfort or his requirement. So, if you choose 0 percent of 20 mm, 30 percent of 10 mm, 20 percent of 6.3 mm, and 50 on stone dust, and do the calculation corresponding to each sieve, you will get this solution, which is basically shown it through this graph here.

So this is the percentage passing for the blended stockpiles for the combined stockpiles. Now, we know in what proportion we are blending these individual stockpiles, and we also know for individual stockpile, what is the average specific gravity. So, we will take another harmonic mean and we will calculate the specific gravity of the blend.

So this is what we are doing here, these values I have already shown you in the previous slide, the average specific gravity of each stockpile, so therefore the final average specific gravity is 2.673. Just remember here, the moment you change these values, these proportions, the specific gravity of the blend will change.

Next step is to find the effective specific gravity, G_{mm} and G_{mb}, so how to do that, because by now we also know that, in order to calculate the volumetric parameters, we will require these specific gravities as an input. So, if you can again remember we have discussed even in fact in the last presentation that Gse is a parameter which basically depends on the aggregate source, however the formula of Gse.

So I am just writing here the formula of $G_{se}=\frac{1-P_b}{\frac{1}{G_{mm}}-\frac{P_b}{G_b}}$, so this was the formula. Now, you see this is something which you have to understand here basically, before you can think of doing what we are going to do. You know that we cannot measure Gse, so we have to calculate and for this calculation we need G_{mm}, G_{mm} can be measured in the laboratory.

And the question says here very clearly that they have determined the theoretical maximum specific gravity at 5 percent binder content, so at P_b equal to 5 percent, the value of G_{mm} is given to us as 2.516, so this we already know. So, let us use this input which is already given in the equation to calculate the value of Gse corresponding to the G_{mm} at 5 percent.

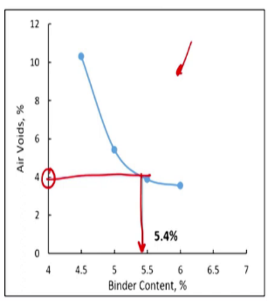
This is what I have done, so this value is given in the equation, only this is given in the question, using this and the formula I have calculated Gse. So, let me write down the formula once again, okay, so this is the formula which you see here, so P_b is 5 percent, G_{mm} is 2.516, Gse you calculate as 2.726. Now, for this aggregate source and this particular binder which we are using in the mixed design, Gse is not going to change, irrespective of any binder content.

(Refer Slide Time: 23:36)

Step 7: Calculate Volumetrics

Binder Content, %	AV, %	VMA, %	VFB, %
4.5	10.31	18.77	45.06
5	5.41	15.43	64.98
5.5	3.87	15.17	74.47
6	3.54	15.97	77.83

Step 8: Calculate OBC



So, at all the other binder contents, so P_b is known to us, every time, once P_b is 4.5, 5.5 and then we have 6, so using these 3 values of P_b, and using the value of Gse as 2.726, you calculate the value of G_{mm}. And again, G_b has been given to you as 1.02 in the question. So, what we have done here, first using the G_{mm} at 5 percent, we have calculate Gse, and now using Gse and different P_b, we are calculating the value of G_{mm} using the same formula.

So, now you see we have the value of G_{mm} at different binder content, so this is done, because this is an important input or calculate other volumetric parameters. Now, what we will do? We will calculate G_{mb}, so calculation of G_{mb} is easy because we have all the necessary inputs. So, what are the inputs required for G_{mb}? We have the weight in Air.

we have the weight in water and we have the SSD, so $G_{mb}=\frac{\text{weight in Air}}{\text{SSD}-\text{weight in water}}$, so just do it for all the different binder contents and calculate the value of G_{mb} which you see here, just using the same formula, $G_{mb}=\frac{\text{weight in Air}}{\text{SSD}-\text{weight in water}}$, okay, so G_{mb} is also calculated.

So, now we have G_{mm} and G_{mb} at all the different binder contents, and we have the effective specific gravity of the aggregate source, we also have the average specific gravity of the final blend, so we have almost all these specific gravities that are required to calculate the volumetric parameters, so it is good.

Now, what we will do if you again remember our derivations in the last presentation that we have calculate P_{ba}, which is the percentage of absorbed bitumen, and the percentage of absorbed bitumen just a recap is defined with respect to the weight of aggregates in contrast to the value of P_b, which is defined in terms of weight of the total mix, so the formula for P_{ba} is a function of, I am not writing the formula here, is a function of Gb, is a function of Gsb, and is a function of Gse.

So if you know all these 3 values, you can calculate the value of percentage of absorbed bitumen. So, you can calculate the percentage of absorbed bitumen, so you can see this is $\frac{100\times G_b\times(G_{se}-G_{sb})}{G_{sb}\times G_{se}}$, so this is 0.735, so the percentage of absorbed bitumen is 0.735 percentage, okay, so I hope this is clear to you.

We can finally move to calculate different volumetric parameters, now this becomes very simple because we have put in our efforts to determine all the necessary specific gravities that are required. So, at different binder content since we have the value of different specific gravities we can calculate air void, so air void is dependent on G_{mm} and G_{mb}.

So this is the formula. VMA is a formula which we have discussed, so using this formula again you can calculate the value of VMA, and VFB is a function of VMA and air voids, so again very simple it is VMA minus air voids by VMA, so again using the formula you can calculate VFB at all the binder contents.

We are done with all our calculation here as asked in the question, and then finally we can calculate the optimum binder content, so the question is how do you calculate the optimum binder content. The question already said that calculate the optimum binder content corresponding to 4 percent year void, so if we know the variation of air void with respect to binder content, we will just plot it, and then we will mark a 4 percent air void here.

And we will calculate that what is the corresponding binder content to achieve 4 percent air void, so this is 5.4 percent, and this curve we will discuss later when we discuss about mix design that with increase in binder content, the air void usually decreases. And this is very obvious, because we have some void which we are filling with additional bitumen every time, and so the amount of air void decreases.

So, I hope that this was pretty much clear to you, and I also hope that by now you are confident with the necessary concepts that are required to understand and solve any volumetric related questions, I will not say mixed design related questions now, because we are yet to discuss, but when I say volumetric related question, it also means that any mixed design related question, because our mix design presently relies mostly on the volumetric calculation.

So, thank you everyone, and in the next presentation we will conclude the concepts on the volumetric of mixed design by understanding the critical parameters like voids in mineral aggregates, air voids, and voids filled with bitumen. Thank you.