Pavement Materials
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Lecture 54
Mix Design of PQC – Examples (Part – 1)

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Hello friends, in the last class, we were discussing about the mixed design of pavement quality concrete and we have learned several steps that are involved in the Mix design process. We have understood various parameters that should be considered for designing a payment quality concrete.

Let us solve few problems today too, so, that we are confident when a problem is given to us. The first problem we will take up corresponding to the design flexural strength, we will also solve a problem corresponding to the design compressive strength and we will also see when there are criteria's for example, we have to use certain pozzolanic material like fly ash in the mix, then how the calculations should change.

And then, we will also solve a problem on high strength concrete. Though the steps of high strength concrete remains the same and additional difference with the conventional mix design process is that we have to use certain admixtures for example, silica fume while we are selecting the materials, so, that the concrete which we design behaves as a high strength concrete. So, let us first talk about the problem which we are going to solve. So, here we have to design a concrete mixture having a characteristic flexural strength of 4.5 Mpa.

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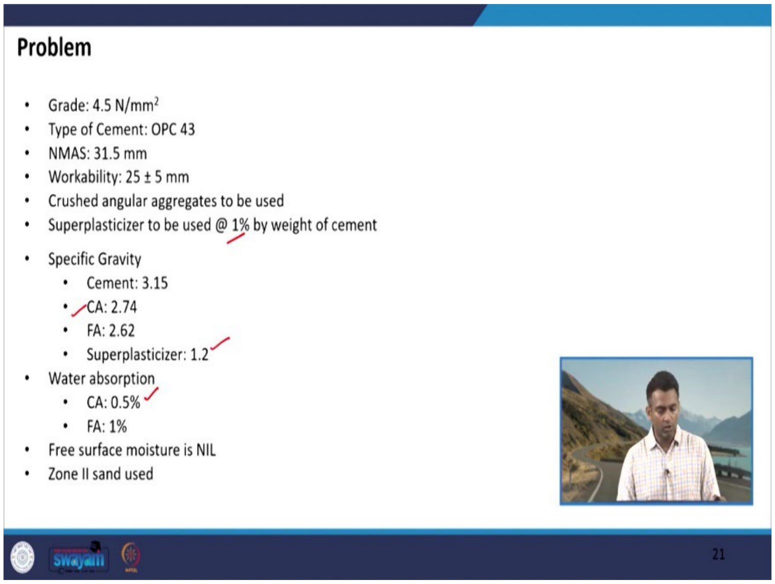

The type of cement which has been given to us is OPC 43. The nominal maximum aggregate size of the aggregate gradation is 31.5 mm, the workability has been defined as 25 $\pm$5 mm, the average workability is 25 mm here, which we have to achieve. The aggregates that are being used to produce the mix are crushed angular aggregates.

There is a provision of using superplasticizer here we will be using the superplasticizer at a dosage of 1 percent by weight of the cement for the first trial and then these are further information for example, the specific gravity of various materials are known like the specific gravity of cement is 3.15, specific gravity of coarse aggregate is 2.74, fine aggregate 2.62 and superplasticizer it is 1.2. The water absorption of coarse aggregate is 0.5 percent by weight of the aggregate and fine aggregate it is 1 percent.

And in the present problem which we are solving there is 0 percent moisture in the surface of the aggregates. The free surface is moisture is equal to 0 here, in the fine aggregate the problem states that we are using zone II fine sand. So, these are the inputs that will be required or these are the parameters that will be required to complete the mix design process.

So, having defined the problem, let us see the steps which we have already discussed yesterday, but today we will try to solve and get the proportion of various constituents. So, let us see the various steps which we have to follow to solve this problem.

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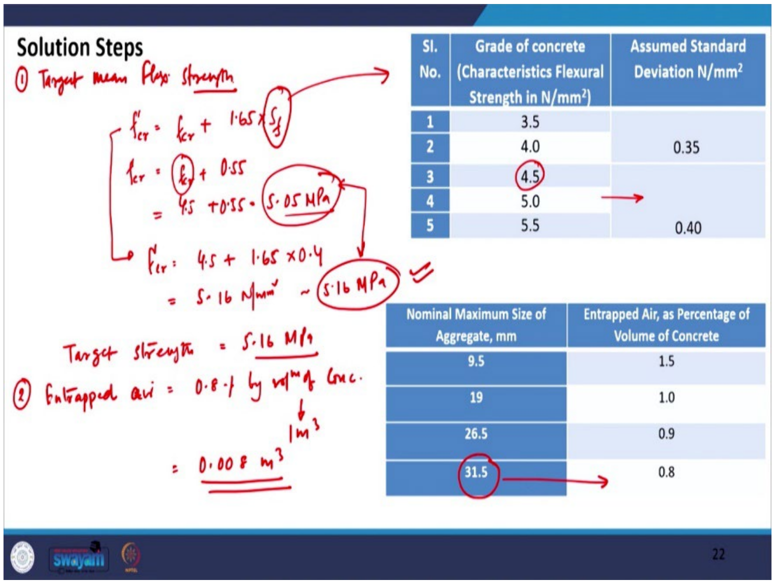

So, the first step as we discussed yesterday is that we have to calculate the target mean flexural strength so, we have to calculate the target mean flexural strength. So, if you remember that there were two equations corresponding to the flexural strength, one was that the value of f'cr = f cr which is $F_{cr} + 1.65 \times S_f$ and the second equation was that f'cr should be equal to $F_{cr} + 0.55$.

Well, this is very straightforward. So, if I just put the value of F_{cr} which is 4.5+ 0.55 what we get? We get the value is 5.05. And then, if I try to put the values so I will need the value of S_f so, we can refer this to this table that S_f is a function of the characteristic flexural strength in our case it is 4.5. So, the value will be 0.4. So, f'cr with this formula becomes equal to $4.5 + 1.65 \times 0.4$. So, if you just calculate this, we will get the value is 5.16 N/mm^2 or 5.16 Mpa.

So, this is a one value, this is another value the question is which value we should take? So, we have to take the maximum of these two values. So, in this case we will proceed with 5.16 Mpa. So, our target strength becomes equal to 5.16 Mpa. So, this is the first step which we have completed.

Now, in the second step we have to note down the entrapped air content and entrapped air content is a function of the nominal maximum aggregate size which in our case is 31.5. So, the entrapped air becomes equal to this we will use not now, but while we are doing the proportioning by volume. So, entrapped air is equal to 0.8 percent by volume of concrete. So, the standard volume of concrete which we take is 1 meter cube for the mix design purpose. So, this becomes equal to 0.008-meter cube.

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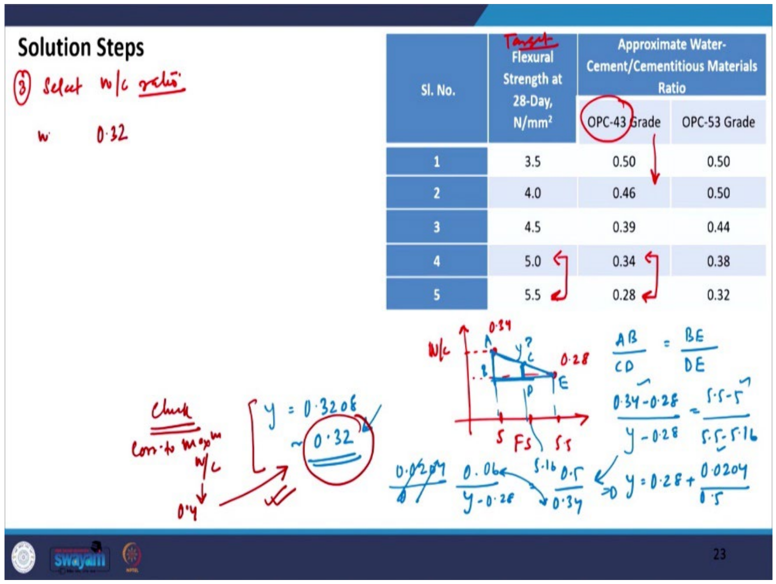

Now, let us move to the third step and the third step is to select the water cement ratio. So, in the third step we will be selecting water cement ratio. Water cement ratio is a function of the target flexural strength please remember that this is target flexural strength and the grade of cement. So, we have to look in this column because we are using OPC 43 here, our target strength was 5.16 which is somewhere between these two values. So, we have to interpolate accordingly.

So, if I just do the interpolation, I hope we understand that how do the interpolation? So, if this is the water cement ratio this is the flexural strength. So, corresponding to the value of 5 the flexural strength is 0.34, corresponding to the value of 5.5 it is 0.28 and we have to find corresponding to 5.16. So, this is what we have and this is what we need, we do not know this.

So, we can just do the interpolation you can see this triangle, these two-triangle let me call this as A B C D E. So, A B E and C D E they are similar triangle. So, therefore, I can write that AB by CD is equal to BE by DE. So, AB = 0.34-0.28, CD becomes equal to this value is y. So, I do not know the value of y, y - 0.28. BE = 5.5 - 5 and DE = 5.5 -5.16.

So, if you further solve this what do you get? We have in the numerator equal to $\frac{0.06}{y-0.28}$. This is equal to $\frac{0.5}{0.34}$. If I further solve this y = 0.28 + 0.0204 which is multiplication of this and this in divided by 0.5. So, y here becomes equal to 0.3208 or 0.32.

So, the water cement ratio which we have to select is equal to 0.32, but remember here there is a check which we have to apply, when you select the water cement ratio. So, there is a check, what is that check? Check corresponding to the maximum value, to the maximum permissible value of water cement ratio.

So, if you remember that the maximum permissible value is 0.4. Since this is less than 0.4 so, this is okay. So, which means we can select this as the design water cement ratio. So, in our case the design water cement ratio is equal to 0.32.

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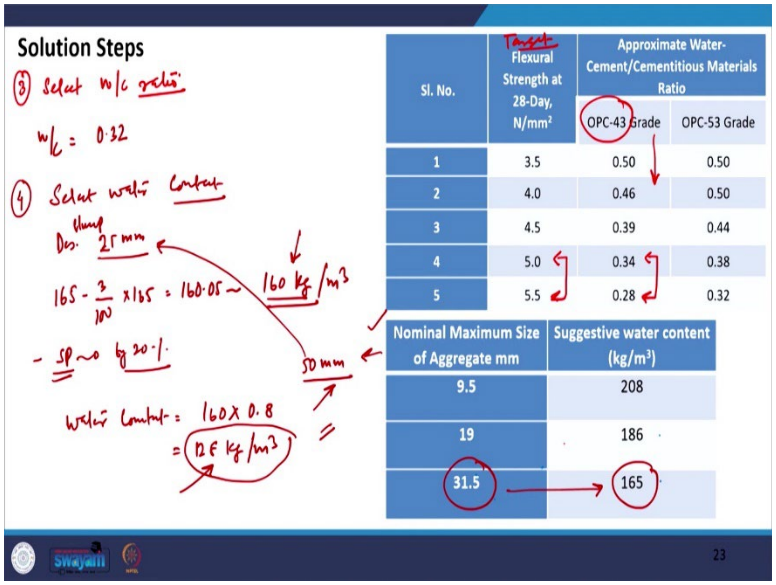

So, now, we go to the next step that is the fourth step and in the fourth step we have to select the water content. So, the selection of water content as per the suggestive table is a function of the nominal maximum aggregate size and you see we are using 31.5. So, the water content to be selected is 165. But if you remember again there was a few conditions here that this table is for a slump of 50 mm and we are not considering the use of any admixtures here. So, our design slump is 25 mm.

So, the correction again if you remember was that for every 25 mm increase or decrease in slump, you have to increase or decrease the water content by 3 percent. So, here we have to decrease the slump by 25 mm, 50 - 25. So, we have to reduce the amount of water the suggestive water by 3 percent. So, if I just do the calculation, it is $165 - \frac{3}{100} \times 165$. So, this becomes equal to 160.05 or let us say 160 kg. So, 160 kg per meter cube of water we will need after applying the slump correction.

The second correction is for the use of any admixtures in our case we are using superplasticizer. So, if you use superplasticizer you have to further reduce the amount of water required by 20 percent which means you will use 80 percent of this value. So, now, the water content becomes equal to 160×0.8. So, this is 128 kg per meter cube. So, this will be the water content which we use.

Again here, if in our problem we are using crushed angular aggregate in case you are using any other types of aggregate you can further adjust the water content accordingly for the required workability. So, please note down that we have got 128 kgs per meter cube, and we will proceed further with this value.

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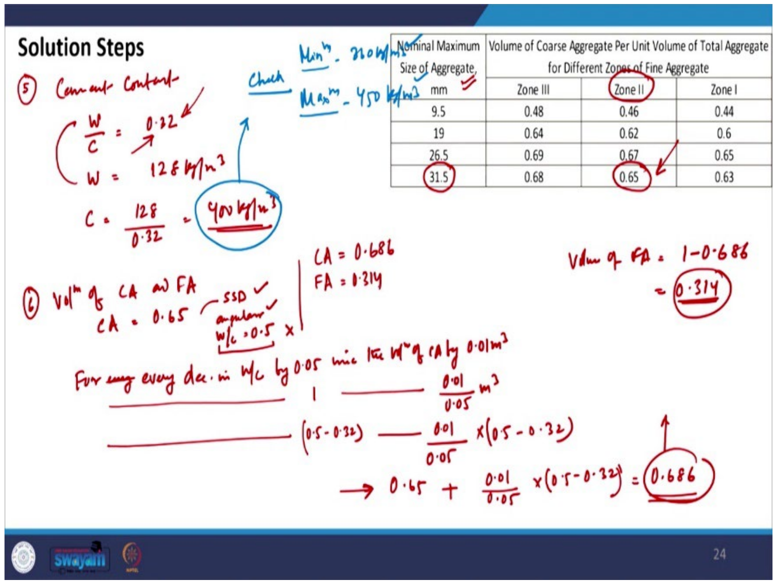

Now, let us go to step number 5. In step number 5, we have to now calculate the cement content. Well, this is a very straightforward step, our water cement ratio which we got was equal to 0.32, water content which we got was equal to 128 kgs per meter cube. So, I will just put it here. So, the cement becomes equal to $\frac{128}{0.32}$ which is equal to 400 kg per meter cube.

Now, again we have to apply a check here corresponding to the minimum and maximum value of cement. So, the minimum value of cement is 360 kg per meter cube, well it satisfies these criteria. So, that is not a problem. The maximum value is equal to 450 kg per meter cube. Again, it said despise these criteria as well. So, there is no issue which means we can select this value and we can proceed to the next step.

So, we now go, let us now go to the sixth step. And in this sixth step we are going to find out the volume of coarse aggregate and fine aggregate. So, if you see this table which we discussed in the last class, that the volume of the coarse aggregate by the volume of the total aggregate is a function of the zone of sand which we are using and the nominal maximum aggregate size.

So, nominal maximum aggregate size is 31.5 the question it was said that it is a zone II sand. So, therefore, the volume of the coarse aggregate by the proportion of the coarse aggregate is equal to 65 percent by volume of the total aggregate. So, the coarse aggregate volume is equal to 0.65 and this is in SSD condition. The criteria for this table we are considering that the aggregate is angular, this table is valid when the water cement ratio is equal to 0.5. So, well these two criteria are all right in our case. But our water cement ratio is not equal to 0.5. So, try to again understand it in this way that our water cement ratio is 0.32.

Since the water cement ratio is less than 0.5, which means that we will have to reduce the amount of fine content, because final materials have larger surface area. So, the requirement of water in that case will be more. So, since our water content is now the water cement ratio is 0.32, we have to increase the amount of coarse aggregate and reduce the amount of fine aggregate. So, that the proper wettability of the surfaces is ensured. So, the criteria which we saw yesterday was that for every decrease in water cement ratio by 0.05 you increase the volume of coarse aggregate by 0.01-meter cube.

So, it is very straightforward now, for every decrease in water cement ratio of 1, you have to increase by $\frac{0.001}{0.05}$ meter cube. For every decrease in water cement ratio in our case it is 0.5-0.32 you have to do 0.01, 0.05 × (0.5-0.32). So, if you do this calculation, in our case it will be equal to 0.65.

So, we have to increase by this value, and you get the value is 0.686. So, 0.686 means 68.6 percent by volume of the total aggregate will be coarse aggregate and therefore, the volume of fine aggregate is (1-0.686) so, this becomes equal to 0.314 by total volume of the aggregates. So, this is what we got let us note it down. So, here we have got that the volume of coarse aggregate is equal to 0.686 and volume of fine aggregate is equal to 0.314.

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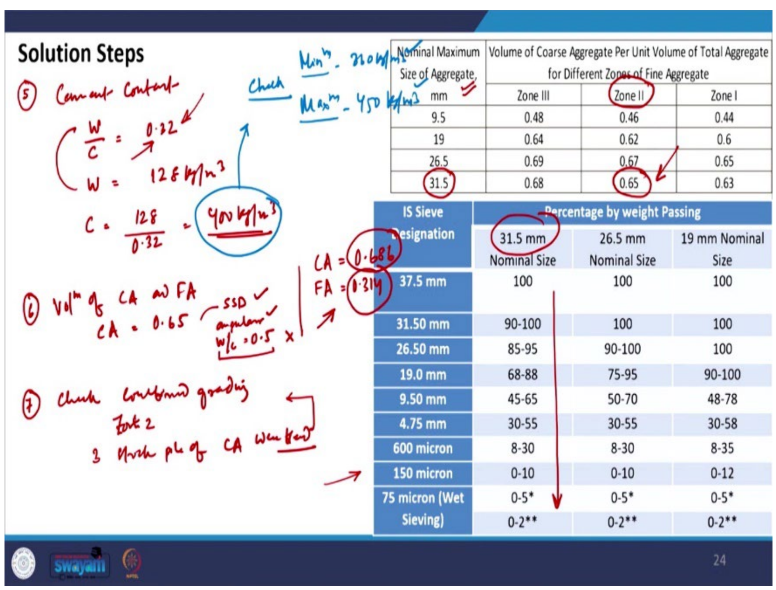

Now, our seventh step should be to check the combined grading I mean to ensure that the aggregate stockpiles check combined grading. So, the problems said that we have zone 2 sand. In the problem, they actually blended 3 stockpile I forgot to mention these 3 stockpiles of coarse aggregate were blended.

To achieve the coarse aggregate gradation criteria, and in this step, we have to ensure that the combination of this coarse aggregate and fine aggregate falls under the required combined gradation. So, we will have to see the gradation corresponding to the nominal maximum aggregate size of 31.5 mm and we have to ensure that our gradation falls here.

If let us say our gradation does not fall here, then we have to do some adjustment in the volume of coarse aggregate and fine aggregate and we have to come within this particular range. So, some iteration again some adjustment may be required, even after doing the, this calculation which we have just done. So, I am assuming that with 68.6 percent by volume of coarse aggregate and 31.4 percent of fine aggregate we are within the prescribed range.

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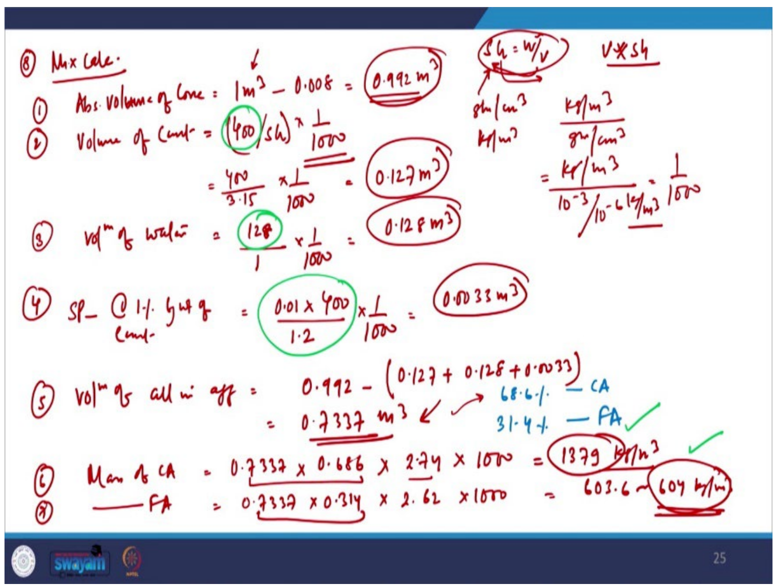

So, we will move to the next step that is the eighth step that is the calculation mix calculations. So, in the mix calculation coming to the first one, let us see the absolute volume of concrete it is 1 m^3, this is what we considered. But if we remove the amount of entrapped here this will be 0.008 as we calculated. So, this becomes equal to 0.992 m^3.

So, this is the amount of solid volume that remains in the concrete which has to be filled by the available materials like coarse aggregate, fine aggregate, cement, sand, water and admixtures. So, now, let us proceed to see the volume of cement so, what we did we calculated the mass of cement and the mass of cement which we calculated was 400 kg/m^3.

So, we can divide this by the specific gravity again I am just writing the formula here this is weight by volume. So, in order to calculate volume, we have to divide the weight by specific gravity and then we multiply it by 1 by 1000. Why we do so, because, you see that the unit of specific gravity is gram per centimeter cube. And the weight which we have calculated here is kg/m^3.

So, we have a ratio kg per meter cube divided by gram per centimeter cube. Let us say I want to convert this in terms of meter cube finally, that the numerator remains the same. So, gram is 10^{-3} kg centimeter cube, will be 10^{-6} m^3. So, this becomes equal to 1 by 1000, this is kg/m^3. So, here therefore, I am multiplying it by 1 by 1000. So, if you do so, you have $\frac{400}{3.15} \times \frac{1}{1000}$. So, we get here is 0.127 m^3.

So, this is the volume of cement then we also have volume of water I will do the similar calculation 128 kg/m^3specific gravity of water is $1 \times \frac{1}{1000}$. So, this is 0.128-meter cube, then we also have superplasticizer and we are using it at the rate of 1 percent by weight of cement. So, if I do that it is 0.01×400 kg/m^3, this is the weight if I want to find the volume, I have to divide by the specific gravity which was 1.2 and then I have to multiply it by 1 by 1000. So, this becomes equal to 0.0033 m^3if you do the calculation.

So, now, we have the volume of all the materials and then we also have the volume of coarse aggregate and fine aggregate, but that is not by the volume of concrete but that is by the volume of the total aggregate. So, now, I have to divide the remaining volume to those aggregates. So, volume of all in aggregate next step is volume of all in aggregate. So, our bulk volume was absolute volume is (0.992-summation of all the other volumes) so, this becomes equal to 0.7337 m^3.

So, now, we go to the next step that is mass of coarse aggregate because we have got this volume here, just to mention here that 68.6 percent of this volume belongs to coarse aggregate and similarly 31.4 percent of this volume belongs to fine aggregate. And now, we are trying to find out their respective masses in the total concrete. So, the mass of course, aggregate becomes equal to 0.7337 × 0.686. So, this is the volume of the coarse aggregate by the total volume of concrete with respect to the total volume of concrete I want to convert it into weight.

So, here if you see now, I have the volume and I want to find the weight. So, volume if I multiply by specific gravity, I will get the weight multiplying it with the specific gravity which was given in the problem is 2.74. But again specific gravity is in terms of g/cm^3, so, the conversion is in 2000 there it was 1 by 1000 so, here it becomes equal to 1000. We do this calculation we get this value is 1379 kg/m^3.

Similarly, mass of fine aggregate 0.7337 × 0.314 this is the volume × 2.62 that was given in the problem multiplied by 1000 so, we get as 603.6 or let us say 604 kg/m^3. So, now, we have got all the proportions. So, let me just use a different colour to just mark the weight. So, this is one weight this is another weight here, this is the weight for cement, this is the weight for water and this actually is the weight for the superplasticizer. So, remember that this proportions let me just erase this and write down the proportions in a fresh page.

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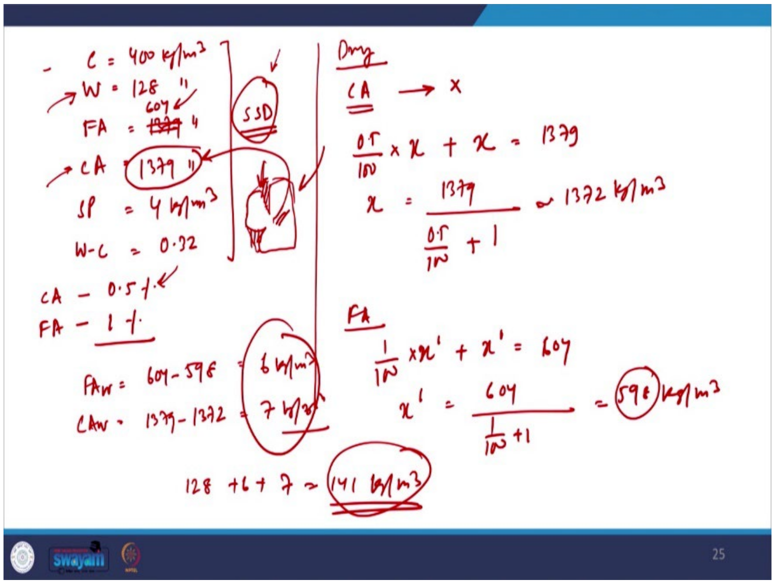

So, now finally, the proportions are let cement is equal to 400 kg/m^3 water is equal to 128 kg/m^3, fine aggregate is equal to 604 kg/m^3, coarse aggregate is kg/m^3, superplasticizer is 4 kg/m^3 and then water cement ratio which wType equation here.e have taken is 0.32. But this is in an SSD condition.

If you remember in the problem, the problem stated that the coarse aggregate and the fine aggregate had a certain level of water absorption as well. Let me write down what was given? It was given that coarse aggregate has an absorption of 0.5 percent and fine aggregate has an absorption of 1 percent.

Now, you see this is an SSD condition. This is an SSD conditions. So, if I want to find out the proportion in dry condition, I have to first subtract this water which was absorbed inside the coarse aggregate from the mass of the coarse aggregate because this mass comprises of the dry mass of the aggregate as well as the water absorbed because what is the state here let us say this is coarse aggregate. So, this is the bulk volume. Here we are assuming that the water is already absorbed. So, this weight is equal to the weight of the solid part plus weight of the absorb water.

So, let us say that the dry weight let us say we are trying to find out for coarse aggregate let us say the dry weight is x. So, what does this actually mean? $\frac{0.5}{100} \times x + x = 1379$. So, therefore, if I want to calculate the dry weight this is equal to $\frac{1379}{\frac{0.5}{100}+1}$. So, this gives us the value is 13 approximately 1372 kg/m^3.

Similarly, if I want to find out for the fine aggregate. So, $\frac{1}{100} \times x' + x' = 604$. So, $x' = \frac{604}{\frac{1}{100}+1}$ and this becomes equal to 598 kg/m^3. Now, this difference 598 with 604 is the amount of water that is present in the SSD condition.

So, amount of water in the fine aggregate is (604-598). And which is actually equal to 6 and amount of water in the coarse aggregate is equal to (1379 -1372), which is equal to 7 kg/m^3. Which means in the dry state we have to do this adjustment in the total water content. So, the actual total water content in the dry state becomes equal to (128 +6 + 7), which is actually equal to 141 kg/m^3. So, I think you understand that this will be the new proportion of the new weight of water which we have calculated.

In the dry state, you also have to remember that you are making no adjustment in the water content. So, if you are making adjustment in the water content, the corresponding this cement content for a given water cement ratio will also change and those adjustments can be made very easily.

So, in the previous step, which we have done to calculate the proportion in the dry state. So, since, we are now changing the water content, so, we are adding the additional water content which are present in the fine aggregate and the coarse aggregate. So, for a given cement content which is already fixed that is 400 kg/m^3, the water cement ratio will change accordingly and the calculations can be done.

But the mix design does not stop here. Now, we have just calculated the weight of different materials, the proportion of different materials that has to be used to produce the concrete mixture.

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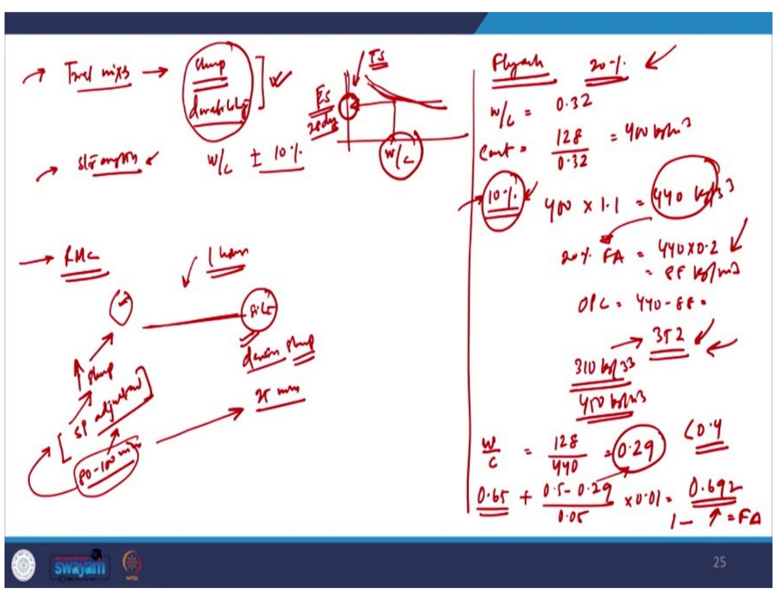

So, now, we have to make trial mixes. In the trial mixes for the calculated proportion, you check the slump requirement again and you also check for any durability criteria if there is any. Once these two criteria's are satisfied for the given proportion, then we will further check for strength. If let us say the initial proportion which you got that does not give you the required slump or durability some adjustments need to be made and accordingly the values will change.

And once you satisfy all the requirements keeping in consideration the different checks of maximum and minimum values. We will further proceed to make sample at the chosen water cement ratio and plus minus 10 percent water cement ratio. And then what we do at different water cement ratio we will determine the compressive strength or in this case flexural strength that is 28 days.

We will see that how with increase in water cement ratio our value is changing or with let us say with increase in water cement ratio the value reduces the flexural strength decreases, then you select the water cement ratio such that the target strength which for which you have designed is achieved.

So, this target strength should be achieved and this will be our final design water cement ratio. In the same situation if we are making a ready-mix concrete, which means we are making it in a plant and that has to be transported to the site, then we have to again further do some adjustments.

So, there we have to first understand that what is the distance between the plant and the site, let us say if the transit distance is so long that you will need let us say no more than 1 hour or 1 hour time to reach from the plant to the site. In that case, the initial slump which you require here will be higher, and by the time it reaches this site and is being placed it should be at its desired slump. So, in order to increase the slump here again several measures can be taken and commonly the value of superplasticizer is adjusted or is increased to get the required workability.

So, let us say the design slump is 25 mm here. So, maybe you will need a higher slump of 8200 mm at the plant. So, that by the time it reaches this point you get a slump of 25 mm and in order to increase the slump value you can adjust the quantity of admixture or the type of admixture which you are using to produce the mix.

Another consideration in the same problem which we can see is that in case we are using, let us say certain mineral admixtures like flyash. Let us say we want to produce the mix with 20 percent fly ash in the same problem. So, in our problem the water cement ratio which we got was 0.32 and the cement content was equal to $\frac{128}{0.32}$ which was 400 kg/m^3.

Now, if you remember that when we were discussing in the first lecture that when we are using admixture, we have to increase the cementitious material content by 10 percent. So, again this 10 percent is a suggestive value based on the experience and based on previous experience with the material or previous trials that has been done the same 10 percent can be increased also or reduced accordingly.

So, say we are increasing the cementitious material by 10 percent presently it was 400. Now, it is increased by 10 percent, so, 1.1. So, 440 kg per meter cube, in this 440 kg per meter cube 20 percent is fly ash. So, 20 percent is fly ash. So, that becomes equal to 440 into 0.2 which is equal to 88 kg per meter cube and the remaining is OPC. So, OPC becomes equal to 440 minus 88 this is 352.

Here also we have to exercise those checks which we have discussed for example, you have to ensure that this is more than 300, this is more than 310 kg per meter cube, so, this is fine and this should be less than 450 kg per meter cube, so, this is also fine. So, we can select this proportion of this amount of OPC here. So, now, since, we have also increased the cementitious material content to 440 kg our water cement ratio will change.

So, the new water cement ratio becomes equal to 128 by 440, which is 0.29 again this is less than 0.4. So, this is fine, we can proceed ahead. So, now, all the other steps will remain the same for example, when calculating the proportion of coarse aggregate, it was 0.65 as per the table. But now, you have to do the adjustment corresponding to 0.29 and not corresponding to 0.32. So, this will become equal to (0.5-0.29) now, earlier, it was $\frac{0.32}{0.05} \times 0.01$. So, this becomes equal to 0.692.

Similarly, you calculate just 1 minus this value will give you the fine aggregate and then all the other steps will remain the same, which we have discussed and you can calculate the proportion in SSD condition as well as in the dry condition.

So, we will stop here today by understanding this example. I hope this was clear to you. And in the next class again we will solve two more problems, we will try to see a problem corresponding to the design compressive strength and we will also solve one problem which is related to the production of high-strength concrete. Thank you.