Building Materials and Construction
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Module - 9
Lecture - 3
Mix Design of Concrete: British (DOE) Method

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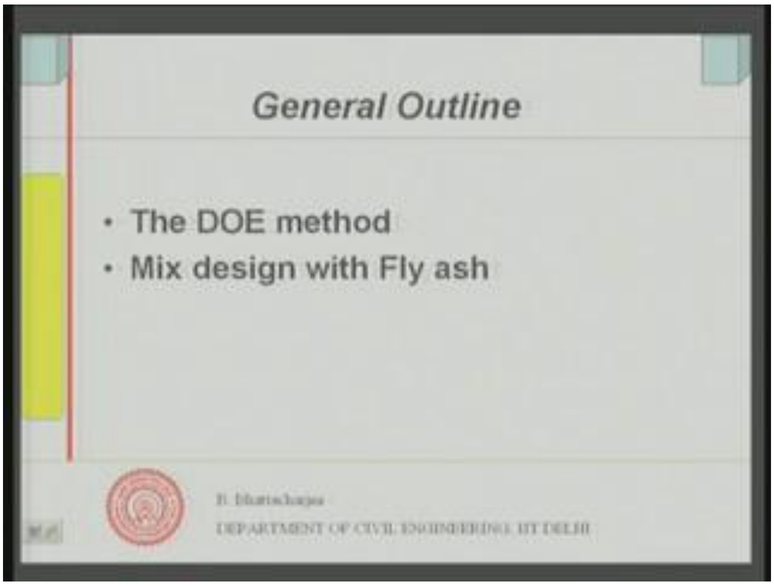

Let us look at another method of mix design today, the British DOE method, so we shall generally discuss about the method itself, and since this method provides us with methodology for designing concrete mix, with fly ash or any kind of. We will discuss that part also right.

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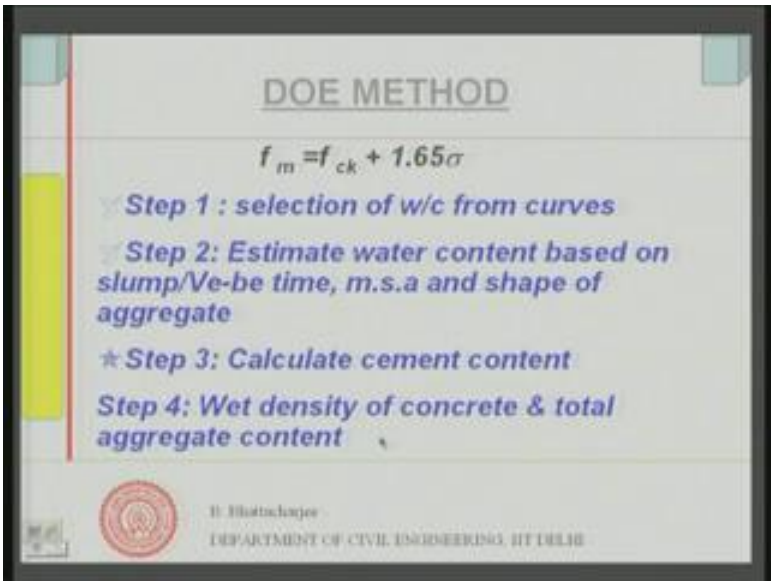

Now this method if you look at it. It starts in the same manner as the IS method or many other similar method. So, what you do we first find out target means; strength. We find out the target means, strength that is TMS. You know TMS target means; strength, in the same manner as characteristic strength plus 1 point six five standard deviation. So, you find out in the same manner as we have done for Indian standard method. And then the step 1 2 3 etcetera follows.

So, let us just talk about the steps same thing the basic philosophy of the mix design remain same in this method as well. Like many other methods. We, select the water cement ratio from a set of curves. Then, followed by that we estimate the water content based on slump be time MSA and shape of aggregate you know we determine the we determine the water content based on slump as well as be time. Now, look at the difference the Indian standard method had compaction factor here. This uses slump and be time MSA and shape of aggregate right.

Now this is a direct from the single table, in Indian standard method what did you do. We first obtained this from the curve, which is as a function of cement strength. You know the water cement ratio versus strength of concrete compressive strength of concrete is assumed to be a function of cement strength as well ok. This similar although here we do not do it that way, but the second step we found out the water content and sand content. First for specific condition of workability that is compaction factor 0.8.

Specific water cement ratio, and then specific grade of you know zone of sand grading of sand.

Then, we applied some sort of correction factor here it is not like this directly we find it out from a single table based on shape of aggregate and maximum size of aggregate and require slump etcetera. So in that sense that this is 1 step method rather than a 2 step method then, we find out the cement content. Because, we know the water cement ratio by this time .through step 1 step 2 we have come to know about the water cement ratio and then the water content. Hence cement content is known to us.

So, with cement content known next step remains to find out cement content is known water content is known. So I can find out the total aggregate content provided, I have some way to determine you know like total wet density as we call it. So, instead of calculating it out in terms of the volume of the solid and water right; where, you know the volume of the cement volume of the water rest of the volume will be occupied by the aggregate. In this case it gives you a curve for wet densities wet densities of concrete right and then that wet density. From wet density we can find out the total aggregate content.

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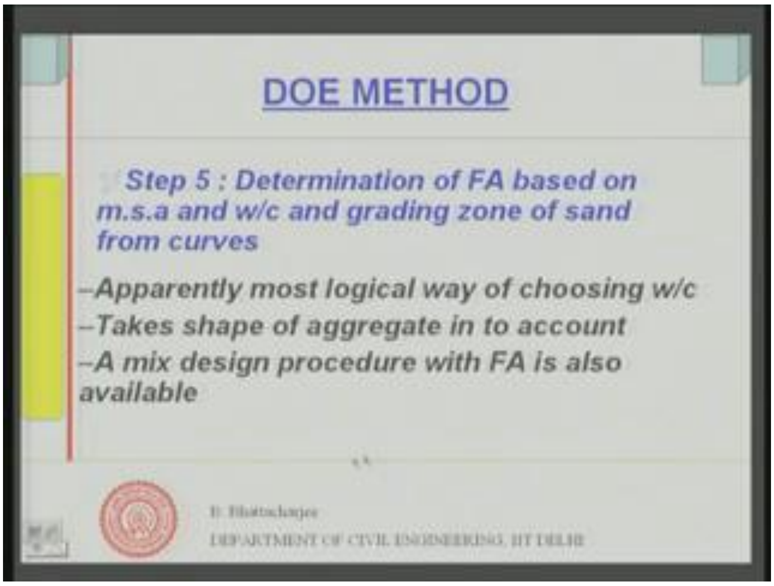

Then, in the last step we determine the fine aggregate content based on maximum size of aggregate water cement ratio and grading zone of sand. Or you know size particle size distribution of the sand from set of curves. So, this is basically the outline of this method, we will just go 1 by 1 each step, we will look into again in details apparently this is the very logical way of choosing water cement ratio. Because, we see it does not assume it to be a function of function of cement strength or something of that kind or specific thing.

It actually, uses water cement ratios or function of function of strength is a function of water cement ratio when all other things; have been constant only thing is starting point might be difficult well, with little bit of modification it becomes very logical as we shall discuss. Then shape of the aggregates is also taken into account in direct 1 table of course, shape of the aggregates is also taken into account in Indian standard code method. Because, we said for rounded aggregate we reduce down the water content by 15 kg per meter cube and we reduce down the sand content by 7 percent.

Then, here there is a mix design procedure with fly ash is also available. And precisely that is why the reason. This seems to be a quite a logical method and seems to be and it is easily applicable to Indian situation also, because it deals with the cube strength and Indian method is almost similar to there is some similarity, So, deals with the cube strength calculates out the target means strength in the same manner. And therefore, that is why I chosen and more importantly it has got it has you know, it makes us it gives us a methodology for designing a mix with fly ash you know this FS stands for fly ash which was not available with other Indian method at the moment, I mean; the code might change.

But, at the moment fly ash based mix design is available to this method and that is the reason why this as been chosen as an second example. There are several other methods, but this can be easily adoptable to Indian condition as well. Now, let us see how this method goes about.

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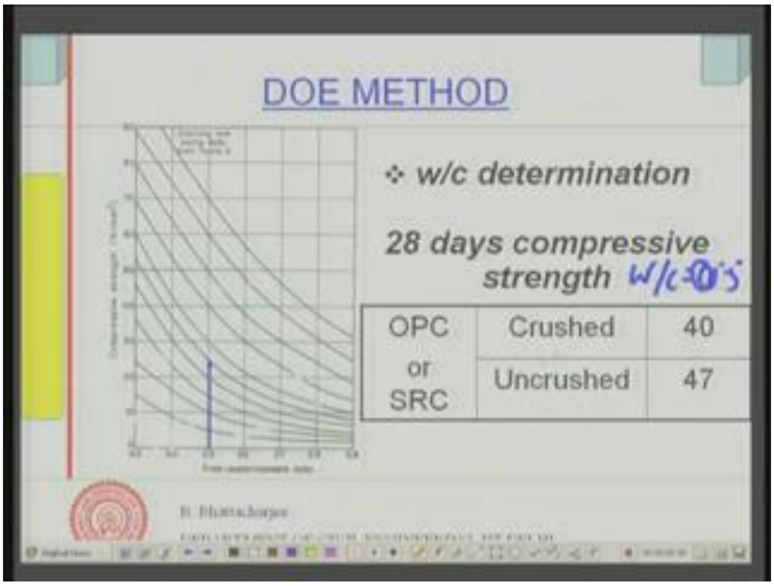

So, we said the first step first step is determining water cement ratio right water to cement ratio. So, FM being known, I know my target means strength. Now, I want to determine the water cement ratio and these are the set of curves in x axis of this curve.

In the x axis of this curve, I have got water to free water cement ratio. Free water cement ratio free W by C. And this side, I have got compressive strength, I have got compressive strength F you know FM may be, I may call it because I will use target means strength on this side. So, this is what the set of curves are there. Now each curve corresponds to a particular concrete that means; aggregate cement all put together. So when every each curve represents to a particular concrete right; not just alone cement, but particular concrete.

Because, strength of concrete is a function of water cement ratio; when all other things remaining constant. It is a main function of water cement ratio. But, other factors do affect that is what we have seen right. So when all other the constant for each case all other things constant. For this case all other things a second constant and maybe constant and so on so forth. So, this corresponds to particular ingredients set of ingredients aggregate cement everything etcetera. And strength would vary like this.

So there are several curves there are several sort of curves. And it tells us a method by which you can obtain by which you- you can you know the starting point could be the strength here. You know starting point could be the strength here ok. First of all let us see what is a guideline of the code itself and then now code since it gives us a guideline. That if you have OPC or Sulphate resisting cement or any other cement. For several cements is given this table is given. It gives you table and corresponding to this table for crushed and uncrushed aggregate.

It gives you the strength 28 days strength this 1, I have chosen 28 days strength actually 28 days compressive strength. The table gives you 1 day seven days I mean; sorry 3 days, 7 days etcetera. Several other strengths are also given and for various types of cement. A part of the table is picked up here. So, this could be the starting point and this is the 28 days compressive strength for water cement ratio. For water cement ratio 0.5 for this line you know. For this line this is for strength for W by C equals to 0.5.

This is W by C equals to 0.5; that is a guideline they have given. Now, this guideline may not be suitable for our condition. So, therefore, this exactly cannot be adopted in our situation. Because, this strength may not be available for our all offices in India with all kind of crushed aggregate is unlikely to be 40. The best way is to do a trial mix and in the trial mix what you do. You cast any workable mix with water cement ratio 0.5. Cast any workable mix.

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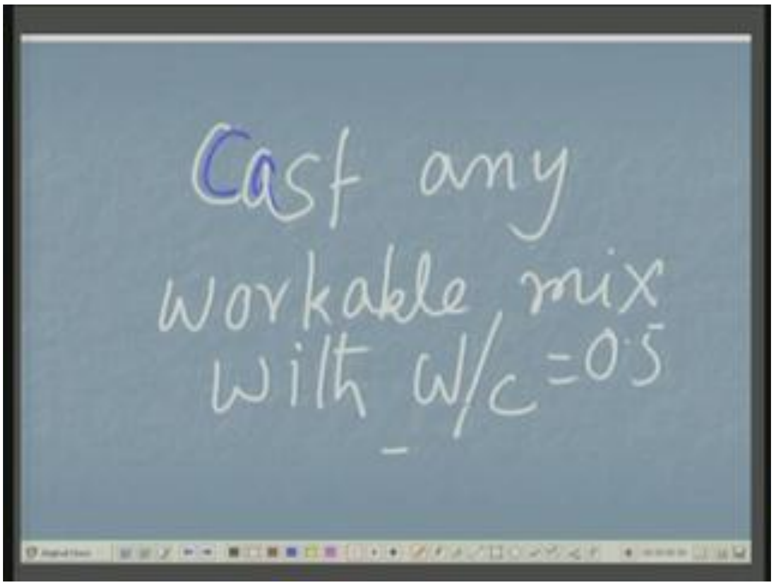

So, cast any workable mix you know the step would be cast any workable mix. Cast any workable mix right cast any workable mix any workable cast any workable mix any workable mix any workable mix you know it should to flow just you should be able to compact mix with, water to cement ratio equals to 0.5 get the results maybe 28 day results. You will have to wait, but that is if you are waiting. If you are you know first time possibly you might take a longer period of time.

But, once some results are available with the set of aggregate and concrete same thing can be repeatedly used very easily. So, that there the advantage of this sort of method comes in supposing, when I want to do monitoring of monitoring of concrete strength in quality control system. So, there is a little bit of change I want to find out, I can use this curves very easily right. So, because this is not dependent on cement strength or anything of that kind.

So, the in case I want to find out in my situation what I will do, I would actually cast any workable mix with water cement ratio 0.5 take that strength for example: let us say for example, let us say my strength comes out to be you know my strength comes out to be something like 25 or, so 24. So, this is the strength that is comes in 25, I find my strength is equals to 25, I find my strength is equals to 25. Now, then this gives me a way to select this curve. So, my curve is now my curve is now, the curve that I will be using for my purpose curve that I will be using for my purpose is this curve.

So, curve selection can be done, 1 way is to take the tabular values, but that will give you only 1 curve. That is not you know that is not really the right thing, because this is meant for some. It has come from some results which have been done UK and will not fit into the Indian situation to fit into the Indian situation, I must have some data. Preferably I mean you know prefer not preferably suggested that, I should have 1 strength 28 days strength at 0.5 with my aggregate cement system etcetera.

So starting point could be that I, start that way and if I know the strength for example, if 0.5 water cement ratio, my strength comes out to be 25 you know 20 and 30. So this is 25 then, I pick up. This is my curve I pick up my curve as this curve then what I do supposing my target means; strength is 32 as shown here. Target means; strength is 32. Target means; strength is let us say 32 then, I go to 32 target means; strength is 32. This is my 32 and I draw a line here come up to this curve and find out the corresponding water cement ratio.

Let me repeat this process again you know how do you find it out. First of all what I do I actually find it out, I actually find it out what is my, I actually find out what is my which is the curve and to do that what I do, I first crush any workable mix with water cement ratio 0.5. Find out the strength and identify this curve. Now I know my target means strength. Since, my target means; strength is known what I can do corresponding to the target means strength I find out the what is my water cement ratio using the same curve.

So, I use this curve to find out what is my water cement ratio. That means I if 32 was my let us say target means strength I draw a line like this and then drop it down to find out my water cement ratio is 0.3 0.4 0.43. Water cement ratio is 0.43. So, that is how we determine the water cement ratio in this case. If you are in UK perhaps you can use this, but in any other situation you any workable mix and choose the curve from the first test results it will take time. Yes, first time it will take time, but if 1 result is available then next time it is not a problem. In, fact in monitoring this curves become very helpful right ok. So following this up is you know following this up with this.

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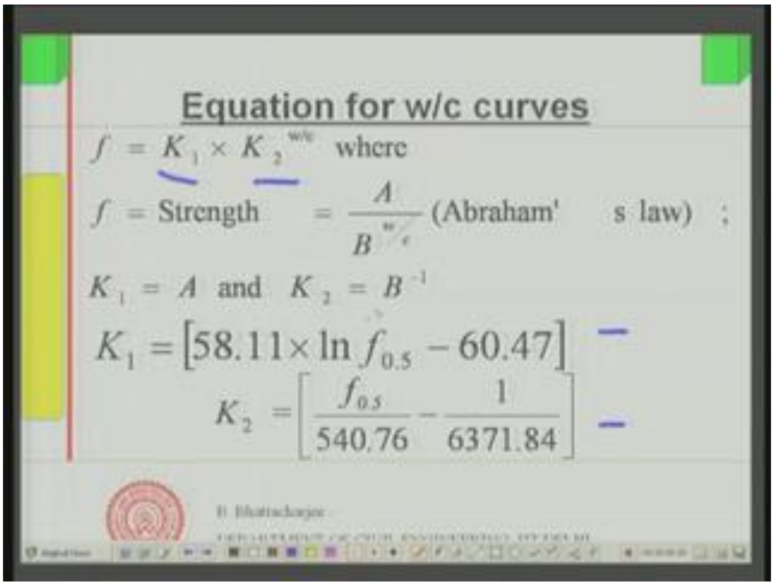

Now, these curves can be easily formed into set of equations. We, know if you remember that we talked about Abraham's water cement ratio law. And which looks like this Abraham's law looks like this you know Abraham's law looks like this. It if f equals to A divided by B to the power water cement ratio that is what it is. Abraham's law would look like this F equals to A divided by B to the W by C and then.

If I write K 2 as B to the power minus 1 and K 1 as A right. A and B to the power minus 1 then my strength can be written like this strength can be written like this F K 1 K 2 W to the power C. So, what we can do. We can actually express all this curves in form of a simple equation like this. So all this curves can be expressed they represent Abraham's law. Now there are 2 constants K 1 and K 2 and by simple regression analysis 1 can determine this K 1, because if you take logarithmic of both sides. We, will find that log f is equals to log K 1 plus W by C log K 2.

The logarithm logarithmically you know if you plot log f. It will be linearly related to water cement ratio. So, all this curves can be fitted into sort of equations like this F 1 is equal f equals to f is equals to f is equals to K 1 into K 2 to the power W by C where, K 1 is given like this and K 2 is given like this. Now, this K 1 is related to 0.5 f 0.5. That is the strength at 0.5 f 0.5. That is strength at 0.5 water cement ratio. So this same thing through exercise can be done for 7 days strength. Or 28 days strength as desired, but the relationship could be like this f 0.5 in case of 28 days strength will be.

The 28 days strength with 0.5 water cement ratio for your materials. And K 1 is related to this in this manner K 2 is related to this K 2 is related to f 0.5 in this manner. This is why all this curve through a regression analysis can be given in this form of in this form of equation K 1 here K 2 here and therefore, strength you can find. So this can be easily worked out in excel sheet also without, going through the curves because these days it is very easy to work on excel sheets and through this equation you can find out well. So, this is how we can determine water cement ratio. This is how we can determine water cement ratio. First from the curves and then same equations can be there.

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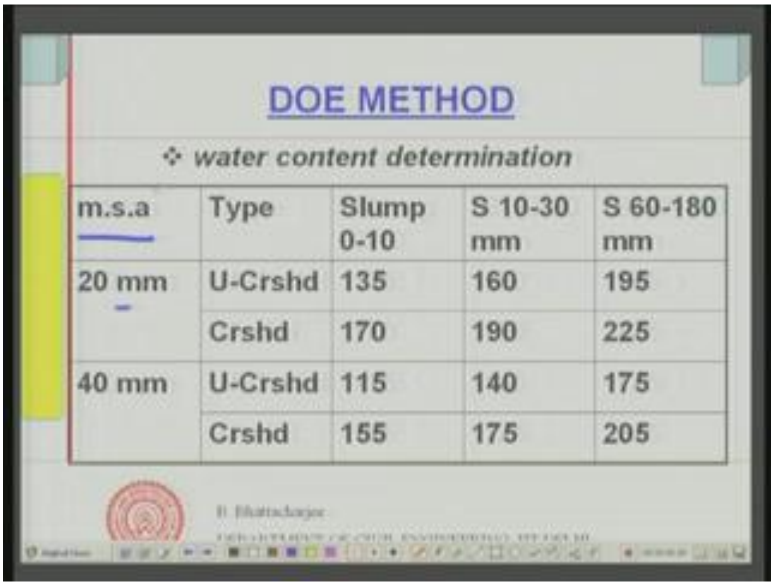

m.s.a	Type	Slump 0-10	S 10-30 mm	S 60-180 mm
20 mm	U-Crshd	135	160	195
	Crshd	170	190	225
40 mm	U-Crshd	115	140	175
	Crshd	155	175	205

Now, having done that having found out that water cement ratio; the next test would be water content determination and this simply done from a table. The table this table looks like this. It is a part of the table again this table will look like this. This is a column for MSA 20 MM, 40MM there is 1 for 10 MM also. So, I have just now taken that it was not really part of the table is required for our understanding. Then, aggregate type is given crushed or un-crushed crushed or un-crushed like un-crushed means natural gravel or natural sand maybe you know or river sand.

So these are all un-crushed crushed means; crushed aggregate crushed sand or crushed coarse aggregate. So, when combined aggregate crushed then for this slump 0 to 10 slump the water is 170. For 10 to 30, 90 60 to 180. In between there are more, 1 more column which I have not put in. So you see the water content can be determined from a table like this knowing the maximum size of aggregate type of aggregate that is crushed or uncrushed, because the shape of the aggregate as been classified into 2 classes crushed and uncrushed.

This is the shape of the aggregate because this is an- this is you know rounded this. So, shape of the aggregate as been taken into account here. And you can see when it is uncrushed it is much less and the water required is much higher when it is crush that is we understand because packing quality is better. So, we require less space and therefore, for a given water cement ratio we will require less water. So this is clearly understandable and as I increase my slump I require more water, as I increase my slump, I require more water. And as my aggregate size increases this will also reduce because my packing becomes better.

So as the aggregate size increases this quantity reduces because the packing becomes better you know, I have a better pack system. So therefore, you can see that the water content can be determined from this table very easily 1 can determine the water content from this table knowing the MSA knowing the slump and corresponding times are also given although, I have not included in the table range of time for example, how much second. This is millisecond or seconds these are given and accordingly 0 to 6 and 6 to 12 etcetera; seconds these are also given.

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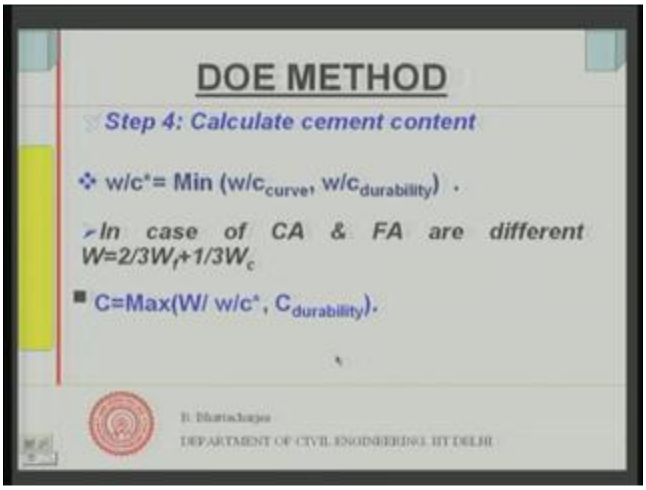

So, water content can be simply determined from this table. Water content being known cement content being known say water cement ratio being known I can calculate the cement content, I know water content I know the water cement ratio. You see water content is known water cement ratio is known, I can calculate out the cement content. And cement content is calculated like this like before like in as in the case of Indian standard method. Water cement ratio water cement ratio you know star.

That means; the what that 1 you will be using is the minimum of water cement ratio determined from the curve and water cement ratio that you have determined from durability recommend same table the table that we have used earlier is the same table. And this is determined from the curve. How I determine from the curve. First I make a trial mix to find choose a curve. And you know from the trial mix, I find out twenty eight days strength and put that onto the curve as we have discussed and when we choose a curve using choosing a curve.

The next step is to find out my water cement ratio required for my target means strength. And that is what we do and then compare this with the durability requirement; whichever is lower I take that then 1 additional thing water content I have determined for crushed or uncrushed aggregate. Now supposing I have got mixed aggregate say sand is natural sand whereas, coarse aggregate is crushed right. Or for that matter I have say natural gravel and crushed sand.

So both ways it is possible then the water content is taken by you know its obtained by this formula, you know where this stand for. W is the water content which is 2 third of the water content for the fines and water content for the coarse aggregate. In other words supposing I have got a fine; I have got the fine as the natural fine. Natural fine say land or river sand whereas a coarse aggregate is crushed. So, water content required for the crushed aggregate will be taken divided by 3 plus water content.

Let us say this value was for the crushed; let us say it was 170. Let us say: W C was 1 seventy crushed and corresponding for the you know for the natural fine aggregate W f was 135. Then, my water content will be given as. Total water content will be given as. You know it will be given as 170 divided by 170 divided by 3 plus 135 into 2 by 3. So 1 can find out the water content, in this manner when you have got mixed aggregate. For single shaped aggregate that is not the problem. For multiple shape you find out in this manner.

So use this water content now together, with the water cement ratio that we have determined. To find out to find out cement content which will be W divided by W by C star W divided by W by C star and C durability whichever is higher. In, other W you know it is just look at this again. Let us look at this again W divided by W by C would give me cement content right. So this star is known to me so I find out the cement content in this manner compare this C with C durability whichever, gives me the higher value I choose that cement content. So by doing this, therefore we have found out the cement content. And we have found out the water content.

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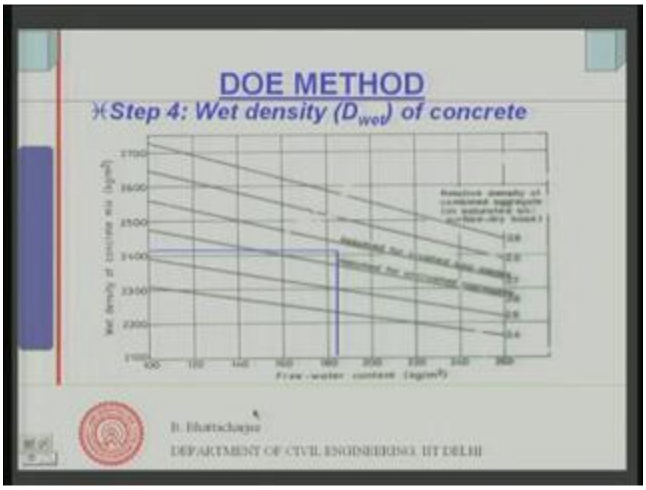

The next step is to is to find out the total aggregate content. This is done using what is called wet density method wet density method. So, instead of calculating volume calculation total volume minus the minus the volume of air this uses a method for wet density which has been empirically established. And you can see the wet density curve this looks like this. The wet density curve has got on the x axis on the x axis it has got. On the x axis it has got free water content, the y axis it has got wet density of the concrete. And there are different specific gravities of the aggregates given here.

So, or the combined aggregate actually. Now, supposing I have got less specific gravity obviously the wet density will be lesser higher the specific gravity of the aggregate wet density is higher and again as the water content, because you see the aggregate as got a specific gravity of 2.6 or 2.7 or up to 2.9 from 2.4 cement has got a specific gravity of 3.15 whereas, water is the material which has got the least specific gravity density. So it contribution towards the wet density will be l. So, as the water content increases the wet density reduces wet density reduces. And it has been plotted against you know for various specific gravity.

Cement specific gravity is by and large same then how do determine. Supposing my water content is 180. Supposing my water content is 180. And my specific gravity is around 2.65 combined aggregate. Then my then my wet density will be somewhere here. Wet density will be somewhere here 2400 and maybe 50 or maybe ten or something like that whatever it is. So, I can interpolate in between and find out. So wet density therefore, I determine in this manner. Total wet density I determine in this manner that is you know; when I know the free water content knowing the free water content. Knowing the specific gravity of the combined aggregate I can determine the wet density and once I have done that once I have done that what I do what I do next.

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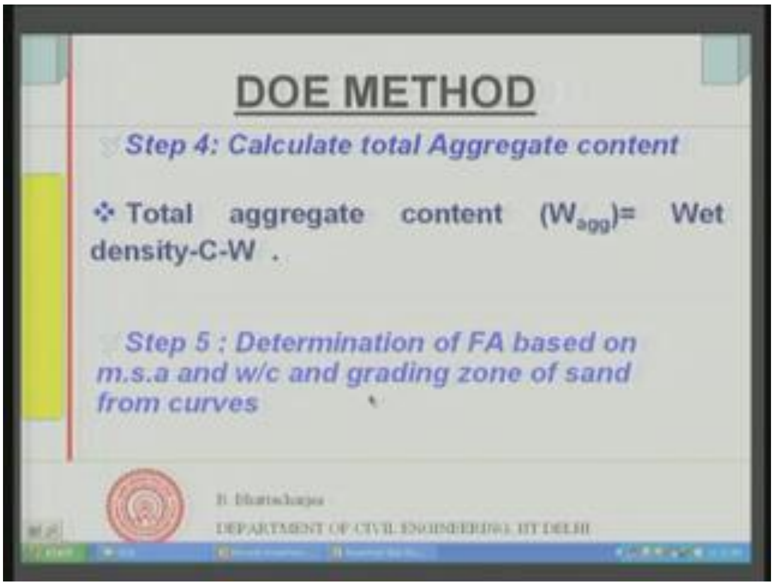

I calculate the total aggregate content using this formula. Total aggregate content is the you know its I express it I express it in this manner I express it in this manner. Total aggregate content is equals to wet density D wet let me call it minus cement content minus water content, so because wet density will be the sum total of material mass of the material. So this is in base of mass straight away no polymetric you know and error due to assumption of air content and all those are actually reduce. So, mass of the cement I know mass of the water I know. And this would be water in 1 meter cube I know and if I know the wet density; which is the total mass in 1 meter cube.

So, in 1 meter cube cement and water I just subtract rest all must be the aggregate. Rest all must be the aggregate because mass will correspond in the aggregate only. So, mass will corresponds to the aggregate only then, the next step will be determination of fine aggregates based on maximum size of aggregate maximum size of aggregate and water cement ratio grading zone of sand from curves. So, that is what next step because so far I have found out total aggregate content, I have found out the total aggregate content.

Now I if I know the proportion of the fines in the total aggregate. Then I found out the coarse aggregate and fine aggregate and that would do my job. You know that would do my job. Let us see how do we do it.?

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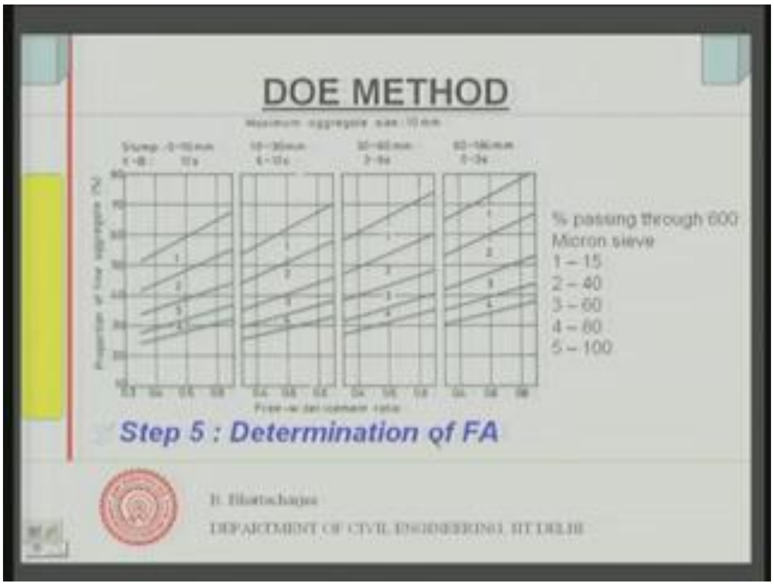

This is done from a set of curves. This curves looks like this set of curves you see this curve would look like this. First of all it will look something like this. In this axis I have got proportions of fine aggregate. And remember this is on mass basis not volumetric basis. Unlike the Indian standard method which had volumetric basis.

There I found out the quantity of quantity of fine aggregate, I mean first I found out the volumetric proportion of the fine aggregate in the total aggregate. This has been plotted as a mass basis total aggregate content right required, because I have fixed my cement content I have fixed my water content. And therefore, I have fixed my total. The moment I have fixed cement and water content, in fact my paste content is now fixed. Total amount of paste in 1 meter cube was fixed. So, rest of the volume is filled in by aggregate. The paste volume should be sufficient enough to fill in the voids in the course and fine aggregate system. So, if I use too much of fines may be the voids would be too large not too may not be the paste would not be able to fill it.

So, therefore, appropriate fine content is required and that is obtained from this sort of curve. So, on this side you have got proportions of fine aggregate and on this side you can see the free water cement ratio. On this side free water cement ratio and here is the slump.

This is for slump 0 to 10 millimeter 10 to 30 millimeter, 10 to 30 millimeter 30 to 60 millimeter and 10. You know 60 to 180 corresponding times are also given you know 0 to 12 second 6 temperature 12 second 3 to 6 and 0 to 3 seconds etcetera you know this increases this of course, will decrease as we have understood earlier.

So and this is for MSA 10MM Similar other curves are available as we shall later on for MSA 20 and MSA 40 we shall see that. Now here look at these curves.0 If you look at this curves there are no lines actually. As the water cement ratio increases. You know as the water cement ratio increases. In fact my fine also increases fine also increases. Because now water cement ratio increase means for a given cement you know given cement content and water content fixed.

Higher water cement ratio means actually higher pace volume and this pace volume must be occupied by larger volumes of fines. And that is why there is an increase as I go along this direction. And this curves each of them represents actually kind of size or grading zone or finesse of the sand earlier of course, they were given in this zone. These are given in terms of zone 1 2 3 4. And this would corresponds to zone 1 of the sand zone 2 of the sand zone 3 of the sand and zone 4 of the sand.

Now, zone 1 sand means which is the coarser sand compared to zone four which is very fine sand relatively finer sand. Now, there is another way of looking at it that line 1 the top line corresponds to passing through. You know percentage passing through 65 600 microns, which means only 15 percent passes through 600 microns. So, it is a coarse sand. This line actually represents a very coarse sand; next 140 percent passes through the second line. So, next 1 this line for example, this line corresponds to 40 percent; 40 percent sand passing through 600 micron. That means; 60 percent is still bigger size. In this case 85 percent was bigger size.

So this is the finer sand. This 160 percent passes through 60 percent passes through. This line corresponds to 60 percent passing through 600 micron. So, most of the and here this 1 corresponds to all being finer than 600 micron; all being finer than 600 micron right. So, as you have finer sands coarser sand you require more quantity of sand in the coarse aggregate system. In the finer sand you require less quantity of less quantity of fine aggregate in the system. And you know how in total aggregate. So, that means if you have something like slump of let us say dealing with slump of 70 or 75 somewhere, in between this. So, 100 millimeter then when you have got this fine sand. For sand let us say I have got the finest of the sand everything passing through 600 micron. And my water cement ratio is somewhere around 0.5. You know something like this 0.45.

Let us say then my percentage of the percentage of the sand in the total aggregate will be around 33 percent. So, I will have 33 percent of the sand in the total aggregate system. If my MSA is 10 millimeter if my MSA is ten millimeter, so this is how I determine the sand content right.

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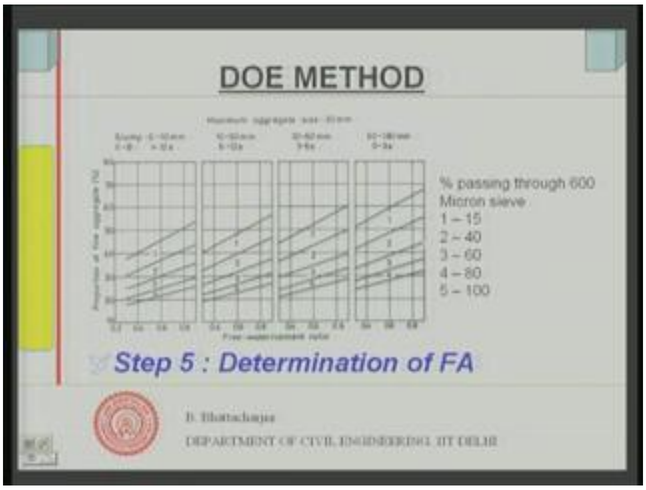

This is how I determine the sand content in total aggregate system same curve similar curve is there for 20 millimeter aggregate. This another curve set of curves for twenty millimeter aggregate. And you see these same thing proportions of fine aggregate. And similarly, here let us say: if 20 millimeter aggregate let us say this was my water cement ratio was 0.5. And let me say let me see say this was 0.5 and I have my slump around 100 I needed. And everything was passing through 600 micron is this, I will need much lesser sand. Now, because my maximum size of aggregate increase.

So, this curve is now coming down because MSA has increased. The void in the coarse aggregate system is lower. So, I will require lesser I will require lesser fines, I will require lesser you know I will require lesser fines right. Now, if I use less fines and less coarse aggregate. It will automatically mean my paste is of course, paste is higher. But at the moment I have already fixed my paste content, what I am trying to do is my paste content is fixed, I am trying to determine the ratio of coarse to fine aggregate.

So in this case this would have been something like 28, earlier case we have seen it was about 32.

Since, my MSA as increased this is reduced down by our 3 four percent for the same sand. If the sand was a coarse sand and same water content, I would have got something like about you know 55 percent for this kind of slump. So, I needed much more fines because you see it is aggregate the mobility of the aggregate, I need more phase more mortar even. So, the more mortar is ensured by this. So, in case of coarse aggregate, so more fines and they would pack into the voids of the coarse aggregate system larger size they are.

So they would have even when, I have this 15 percent. It means; 85 percent is passing through this that means this 1 is better graded sand rather than this, because in this case everything is fine size. In this case the is there is a mixture of everything. There is 15 percent above 600 micron; I mean somewhere here would be a better situation 15 percent possibly above 600 micron. But others are others are somewhere; you know this is coarser side. So, you have got larger size also there in this particular 1. So this curve using this curve then we can determine the fine aggregate content similar curve is available for 40mm aggregate as well.

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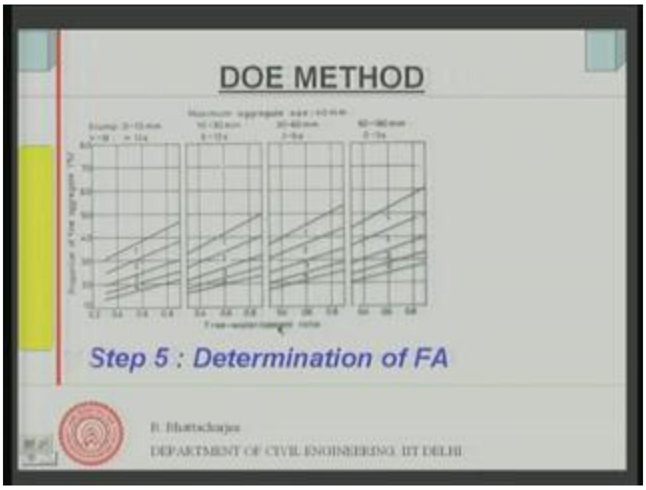

This is the curve for 40mm aggregate. These are curve for 40mm aggregate. So, for different sizes of the aggregate different MSA different MSA and different slumps different workability that and for various water cement ratios once, I know my cement and water and total aggregate content is known the proportion of the fines in the total aggregate content.

Total aggregate system is now determined from this curves this curves. And you can distinguish this from what we did in case of Indian standard. In Indian standard all this were actually calculated first for a specific water cement ratio; depending upon your grade of concrete and for specific compaction factor specific zone of sand. And the grade of you knows zone of sand and shape of the aggregate etcetera. And then we applied correction factors for each of them.

Here of course, fine aggregate content you determine here straight away from this sort of curves. But, then another difference is here I am finding it out in mass basis. That is the proportion of fine aggregate is with respect to total aggregate, both are in mass basis earlier in case of Indian standard it is in volumetric basis.

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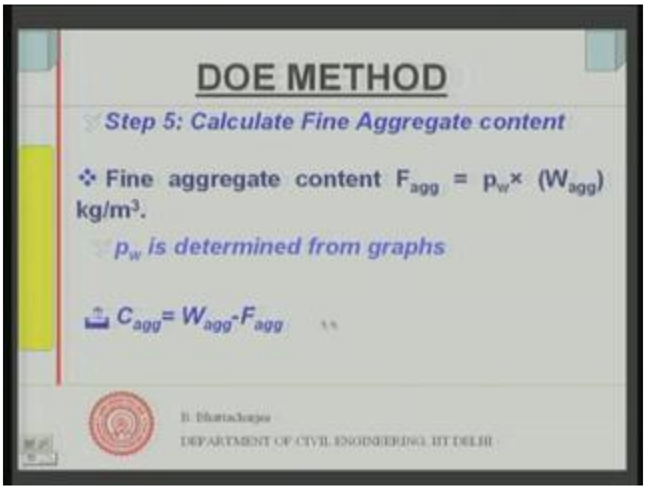

So, doing this after doing this then I know now what my fine aggregate percentage is. So, now I can calculate out the fine aggregate content. And the fine aggregate content is simple. Simply this p value that we have got twenty eight or thirty 2 or whatever we are just looking right. Now whatever, I get p W on the mass basis, I am calling it p W because it is on mass basis multiplied by the total aggregate that is the W aggregate. It is the total aggregate content. This is what I have found out from the curve. This is what I have found out from this you know this total this to find out this, I found out this 1 from the from the you know graphs.

That is the straight line plots that which we have that I have just shown you W aggregate was obtained from wet density minus the cement content minus water content and now I find out a fine aggregate content. So, fine aggregate content is simply this multiplied by total aggregate which I found out as D wet minus W aggregate. If, you remember just for the recollection D wet minus W minus C. So, this being known W aggregate being known multiplied by p W obtained from graph obtained from graph obtained from graph and I just have the fine aggregate value.

So, this is how I determine the fine aggregate having determined the fine aggregate I can find out the coarse aggregate simply W aggregate total aggregate minus the fine aggregate. So, then I have determined water cement coarse aggregate and fine aggregate all this things are now known to me.

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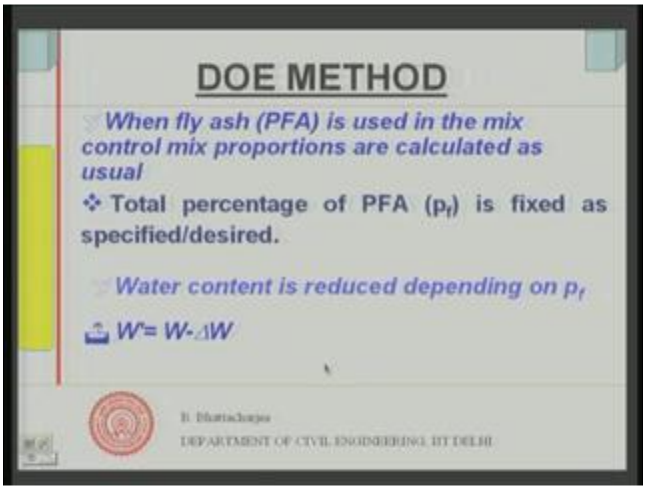

So, this is the procedure meant you know DOE method. But, we will look into the fly ash how we take care of the fly ash. Let us just discuss a little bit.

So what we have seen in this process the stepwise first step of course, the target means strength. Then followed water cement ratio from curves which are not; which are actually you know it is true, I mean a better representation of the Abrahams law. You know strength remaining strength as a function of water cement ratio all other things remaining constant. And they can be fitted easily to equations also; taking F 0.5 that is the strength at 0.5 water cement ratio. As a parameter input parameter you can just determine in form of equations as well.

So input parameter in this curve is again; F 0.5 that is the strength at 0.5. So, you can cast any workable mix which will. Actually any workable mix which will with 0.5 water cement ratio. Find out the strength to pick up the curve. So, you plot this value with 0.5 water cement ratio and the strength you will get 1.0. This point will lie on a line 1 of those curves 1 of those you know 1 of those curvilinear lines. And that curvilinear line represents your concrete.

So, once you know that your concrete correspondingly what is the water cement ratio. For the target means; strength is and find out for all set of mix design. Supposing, you are doing M 25 M 30 M 40, with the same aggregate set of aggregates, you need only 1 preliminary test to choose your curve after it is all same secondly if you are monitoring because it is not. The mix design is not the end. It is the starting point it is the starting point you see mix design doing at some laboratory D serve much the purpose. It has to be done at the site and you do it at the site.

Find out the mix proportion and then once you are actually obtaining the concrete. You continuously test those concrete cubes as a measure of the quality control. So, when you measure them as a means of quality control. You can now find out whether actually whatever strength you are providing or you are expecting. Are you getting it or not? Now, supposing you are not getting which quite often would happen you either you are getting it lower or you might be getting it higher.

Let us say if you are getting it higher then actually you are wasting your cement you can reduce your cement if you are getting it lower you are not giving you are not providing you are not supplying or you are not generating producing what you are supposed to produce. In such case again this curve will come handy, because it is for your set of material the curve has been already identified you can just pick in you can just you know you can just shift. Reduce the water cement ratio little bit using this set of curves. The equation is there from that also 1 can calculate out.

So that is the advantage of this curves you know quite easily adoptable in monitoring the strength also monitoring the cube strength also in quality control. It is much easier to use this curves now that is the first step. Then second step is to determine the water content and which is based straight away on workability maximum size of aggregate and the workability you require, both given in terms of slump and time. And slump is you know is more popular used in site. And therefore, it is a more useful way rather than doing is not very common neither compaction factor.

So, that is another advantage that it is also related to slump. And you do not have to do a recalculation. And then you can straight away obtain the water content for various slump various MSA. And shape of the aggregate and you do not need to calculate in more than 1 step just get from 1 table once you have got it water content is known water cement ratio is known you can find out the cement content and both cement content and water content known, your pace content is fixed and if you know the pace content.

If you know wet density of the concrete which is given in again in you can find out the total aggregate content. Then again the ratio of the fine aggregate is given in mass basis. So, that is again an advantage there is no volumetric basis not calculation based from any equation and things like that simply we can find out. So, this method is quite simplified and looks to appears to be more quite logical and very useful in monitoring. The you know monitoring the cube monitoring quality control and monitoring second point I would like to make is that mix design should be done at the site itself.

It is such a simple method as we have seen and it should be monitored time and again otherwise there is no meaning. Because, you change 1 of the ingredients the mix design may not remain same maybe there are some different some maintenance of the mixture machine or the batching plan- has not been done properly mix design will not remain same. So getting a mix design done once and not that to in somewhere, in the laboratory and not in the site. And then using it in again and again has got not much of a meaning. It has to be continuously monitored continuously monitored and accordingly it has to be changed.

So you know in the quality control system there has to be a way to rectify or you know take kind of action retrospective action on the concrete mix to correct any problem that has taken place. So, monitoring is very important in the quality control system and this sort of this sort of this sort of curves is very helpful in sense. So, mix design has to be done that way. It is not a very difficult job it is simple. But, its emphasis is again that it has to be done at site and time and again it has to be monitored.

Now, I think we can look into the fly ash application of fly ash, in the you know concrete mix design. Now, first thing to do that also I must have a I must have control mix made that means; first without fly ash I have a control mix right. And first I find out the control mix that is the mix without fly ash then I got to take a decision either it should be specified by the client owner or anybody or it is my can be my own decision to use a particular percentage of fly ash, you know P F A is nothing but pulverized ash. Fly ash is pulverized ash and that is what it is.

So I must determine the P F that is percentage of fly ash that I am going to use that should be determined and it should be known determined means it should be known either from specification or make, I make my own decision. Quite often like if it is not a special concrete like high volume fly ash concrete. Normal concrete 1 can use whatever is permitted by the code. Or what are the percentage I can use and take benefit of right. Because as much as I use in the concrete that is beneficial both from environmental point of view and also from economic point of view, so what, but that decision how much I got to use that first must be made. And that P F A percentage of P F A must be known to me then, we have if you remember fly ash acts almost like somewhat like plasticizer similar effect.

Because of its spherical shape if you can recall the discussion we had. The effect of various kind of admixture on workability of concrete, we said that for the same workability same cohesiveness fly ash W reduce down the water demand because of its spherical shapes and generally the sizes being fine we will have some sort of core filling effect and also they can have action and therefore, they reduce down the water content. So, first thing it does is it reduces down the water content.

So I must have a way to find out how much is the water content right and let me say my new water content is W dash and original control mix water content was W. Then, W dash will be W minus delta W you know this is first I did a control mix as I said, I do a control mix right. So, that is called control mix fly ash is used in the mix control mix. So, first I measure find out the control mix calculate for the control mix and from the control mix I find out how much the water I can reduce depending upon this.

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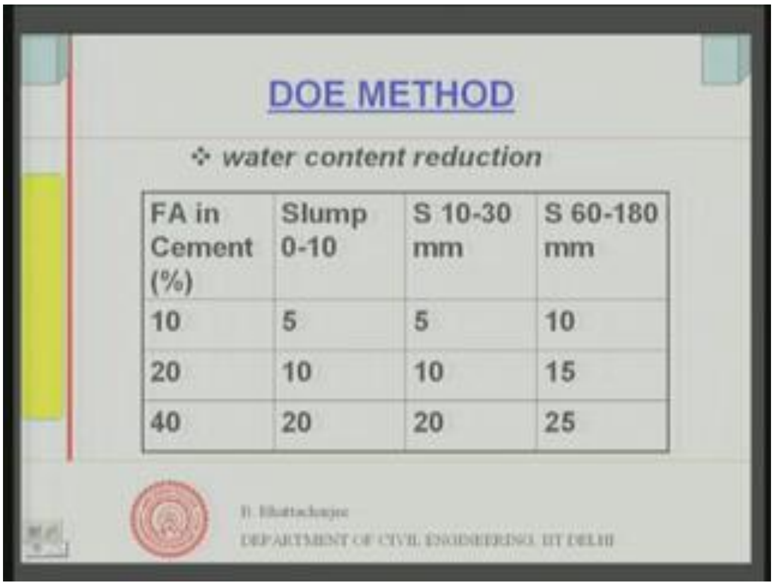

This method provides us a way to do that some sort of guideline. This fly ash must be sufficiently good quality satisfying the relevant standard. And large the specifications are more or less similar to the specifications elsewhere.

So, this sort of table might still be applicable even in our case that means; this table says how much is the reduction delta W how much is the water content reduction in water content is possible. This table talks of delta W. So, this is the water content reduction, these table talks of delta W the water content reduction ok; as you can see as my fly ash content increases. This is the fly ash percentage in cement. So as my fly ash content increases and depending upon the slump I can reduce.

This is the quantity of water that I can reduce. For example: 5 is the delta W here, 5 is the delta W here and ten is the delta W here. So, this is 10 15 25. So, depending upon the amount of fly ash I am adding percentage in the cement material. This is the amount of water reduction that is available. This gives you this given in a form of a table. Therefore, if I know how much is the p f that I mentioned earlier I can find out how much will be my reduction in water content right ok. Now this is this should be p f actually this should be p f this should be p f right.

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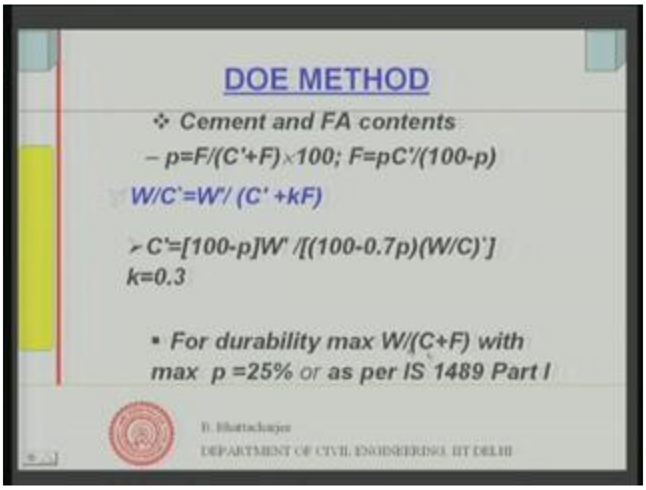

Now, you see you can see that this. This p f is p f is p f is F divided by C dash plus F where F stands for the fly ash. So, p stands for fly ash percentage in total cement where C dash is the cement content F is the fly ash content. So, F divided by C dash plus F that is the percentage of fly ash p represents the percentage of fly ash in total cement percentage of fly ash in total cement. And therefore, from this expression just rewriting you know rearranging I can get an expression for F. F will be given as p multiplied by C dash divided by 100 minus p 100 minus p ok.

So now I have water to cement star which was earlier there. The equivalent thing here given when I am using fly ash is water W dash divided by C dash plus k F. You see all fly ash for example, if I add F quantity of fly ash. All fly ash do not contribute towards the equivalent water cement ratio, I can now define an term called equivalent water cement ratio. Now, equivalent water cement ratio is W dash. That is the water that you are adding divided by C dash that is the cement you have plus F multiplied by k k F you know.

So, this k is less than 1. If, k was equals to 1; that means; all fly ash also behaves like cement. But, k being less than 1 tells us that I have possibly some you know some part of the equivalent cement. The total if F is the total fly ash present in the cement then F into 0.3 k is taken as 0.3. It is a guideline 1 can have his own k his own k from the own test, but k is 0.3 can be a conservative value 1 can start with this, but then determine his own k and find out as it changes.

So, C dash plus k F 1, can take it right and this is the then equivalent cement equivalent cement content and W dash is the water the is a you know water that I have obtained water content I have obtained after reduction. So, my equivalent water cement ratio in case of fly ash concrete will be given by this. And this must be equals to the water cement ratio star of the control mix. So my control mix had water cement ratio star and this must be equals to W dash divided by C dash where C dash is the cement in the new mix fly ash mix- multiplied by k plus F.

By just simply rearranging, I can find out C dash which will be given as hundred minus p because I will put F from this expression. If I will put F from this expression here that is p C dash hundred minus p then p is known to me because p is the percentage of the fly ash in overall cement. And that is the first thing I have decided, in the beginning I have decided what is p, because I said that you want to use thirty percent fly ash in the cement well fine that is what you take 25 percent and so on, so forth. And that decision either as to be specified or 1 has to make the decision in the beginning.

So p is known to us p is known to us p is known to us W dash we have found out. Because, W dash is nothing but original control mix W minus delta W dash which we have found out from the table. So, 100 p minus 100 minus p into W dash divided by 100 minus 0.7 p and also divided by W by C star which is known to us.

So, this will give us rearranging this I get an expression and putting F equals to you know this value I get an expression for C dash. And I have taken k equals to 3 in this expression, therefore it comes out to be 0.7. So, cement content therefore, in the overall mix I have found out and now knowing the cement content I can find out F. Because, C dash is known p is known C dash is known p is known F is known therefore. So F is known you know I can find out p being known C dash being known I can find out F.

So, F is known W dash is known and C dash is known 3 things are known to me. But then 1 more thing I must compare this W by C dash in any case you know W by C dash of course, with the durability whether I am satisfying the, but there is an advantage, I while comparing the durability I need not compare W by C dash. In fact I can compare W by C plus F. So maximum this I can compare and similarly, for minimum cement content I can C plus F I can compare.

So take total cement while taking consideration of the durability. And take water by total water cement ratio instead of cement means; cement plus p- cement plus p. We, just we mentioned this earlier also in connection with the you know in connection, with the types of cement and workability and strength etcetera. And the role of this supplementary cement material, when looked into the micro-structure with supplementary cement material you remember and we said this supplementary cement material actually improves the hmm micro-structures and reduces the permeability. Therefore gives us better durability. So, when it gives us better durability. Therefore, I can take whole of the cement- material into consideration well. So, while calculating the water cement ratio maximum water cement ratio.

Similarly, I can take minimum cement content I can take C plus F complete. But, there is 1 restriction as per our code currently it says that the F value which you can take should be as per you know whatever is permissible in relevant code for p cement allows now, 25 percent as p which would mean; that 25 percent is a of the cement is your p right; which means, that you are using roughly about- 1 third 1 third cement. And its 1 third is added to as p material fly ash. So, that is the of course, this may get modified.

It is likely to be modified 1 might possibly use higher. But, at the moment at 1 four 1 four eight nine IS 1489 part 1 allows p equals to 0.25 25 and therefore, F that you can take should corresponds to p 0.25 only, in this calculation. That is that is what is the stipulations or recommendation of Indian standard code. So, while durability you can use. So therefore, you know at the moment there is not much benefit using p by p more than 25, because in the durability calculation this will not give you an advantage. Although it might give you other advantages heat of hydration many other advantages.

But, durability calculation it is now, going to give you more advantage restricted by the maximum percentage allowable in p cement code that is IS 1489 part 1. So, while calculating the water cement ratio maximum water cement ratio, you can take W plus C plus F, but the F should corresponds to p equals to 0.25. If its if p is more than 25. If p is less than 25 take that value straight away and find out F as you have obtained here. Similarly, calculating total minimum cement content C plus F use that F which can be which is determined from this if p is less than 25.

If p is 25 al- you know if p is more then use p equals to 25 here, to calculate out the F and that F can be used for minimum cement required maximum water cement ratio same thing can be done. So, that is how I can take care of the durability aspect. That is how I can take care of the durability aspect well.

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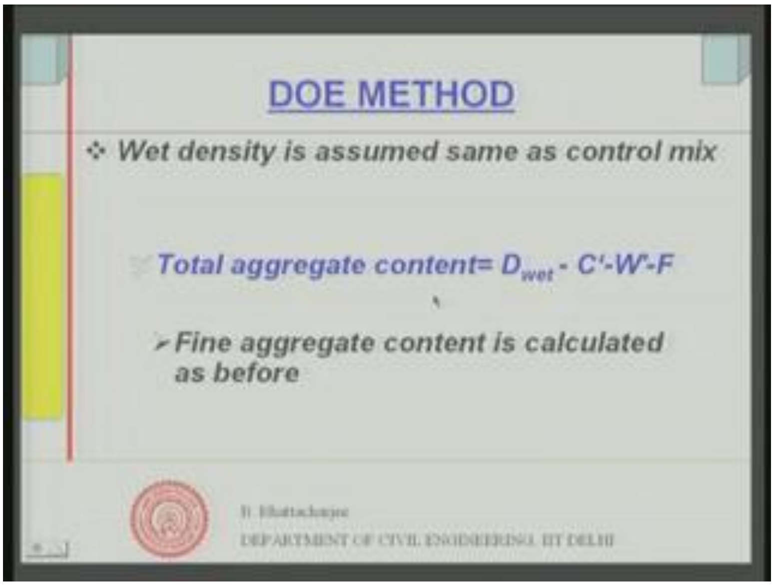

Wet density is assumed to be same as that of the control mix. And therefore, total aggregate content you calculate out in the same manner D wet minus C dash minus W dash minus F. So you have got the wet density and fine aggregate is calculated again in the same manner as. So, we calculate the fine aggregate in the same manner as before and total aggregate content we calculate, in the same manner as before. And wet density from the same curves.

Therefore, I have been able to now find out all the proportions, in this case that is I have been able to find out the cement content, I have been able to find out the water content, which will be lower than the control mix cement content obviously will be lower than the control mix much lower. And then I have been also able to find out the fly ash content corresponding to my requirement. And then of course, I have been also able to find out the fine aggregate content and coarse aggregate content 1 important point here is you see although, we said that the water reduction takes place when we add fly ash. Slumps do not reduce immediately or rather it does may not show you slump reduction. In fact what it shows is with a lesser water content when you add fly ash, you will get same cohesive mix.

So for your all practical purpose of placing compacting we will have same effort required right. But, slump itself may not execute the same thing, in other words when you have fly ash concrete even if you have a lower slump say by 25 millimeter still you can consider it to be as good as the you know same, in terms of workability it is as good as a concrete without fly ash, having 25 millimeter higher slump.

So let us say 100millimeter is the slump of the slump of the concrete without fly ash. Now, I have reduced the water and done the mix design like I have just mentioned. The workability now, I get in terms of slump let us say is 75 still they, will have similar you know like even the slump is 75 still they are acceptable. Because, 25 millimeter reduction in slump is avail slump is allowable. They, give similar cohesiveness .So that is what we do in case of fly ash mix design.

So I think with this we conclude our discussion on mix design of concrete and in general discussion on concrete right. So, we have looked from production of concrete to effect of various materials and looked into finally, we looked into the mix design procedure.

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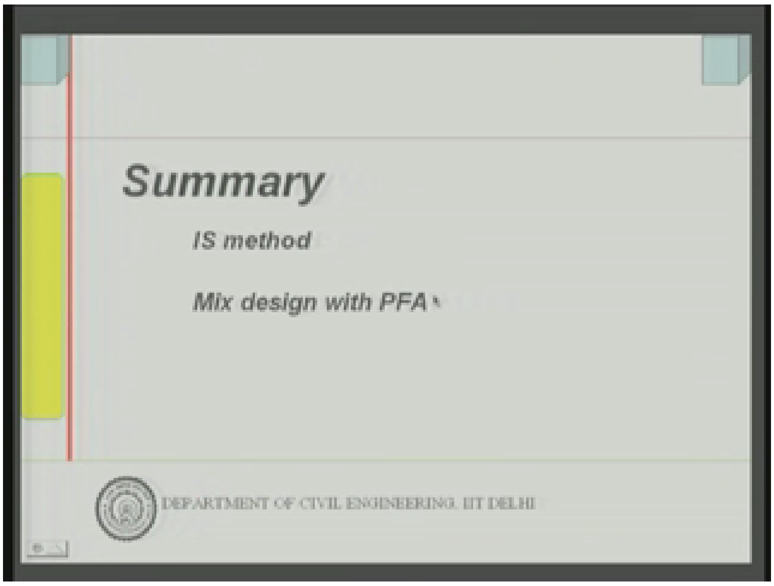

Today, we have discussed. First we have discussed IS method last class. Then, we have discussed now, the DOE method, another method. And lastly mix design with pulverized f ash.

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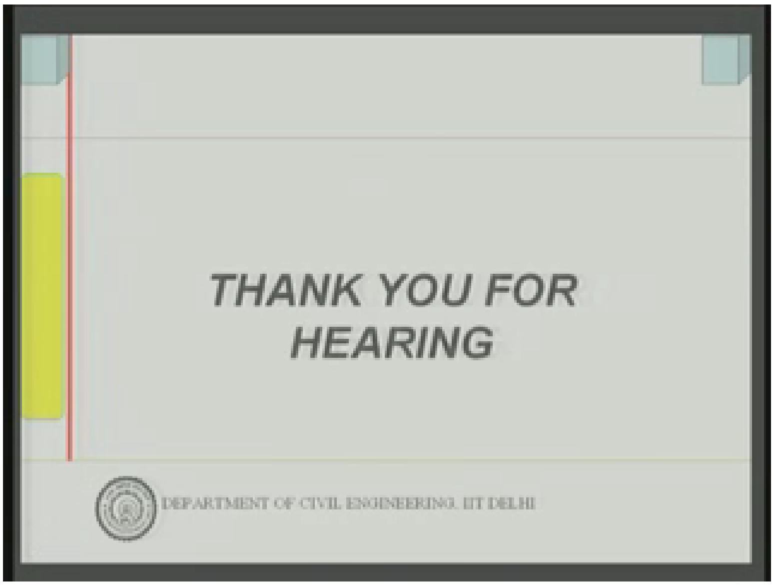

So, thank you for hearing.