Building Materials and Construction
Dr. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Module - 9
Lecture - 1
Mix Design of Concrete: General Principles

Well having seen the material selection and discussions on properties of concrete. Now we are in a position, to finally design a concrete mix. We are looking at normal concrete, normal strength concrete mixes and not high strength or special concrete. So, this module 9 will look into mix design of concrete. And in the first lecture we will look into general principles of concrete mix design.

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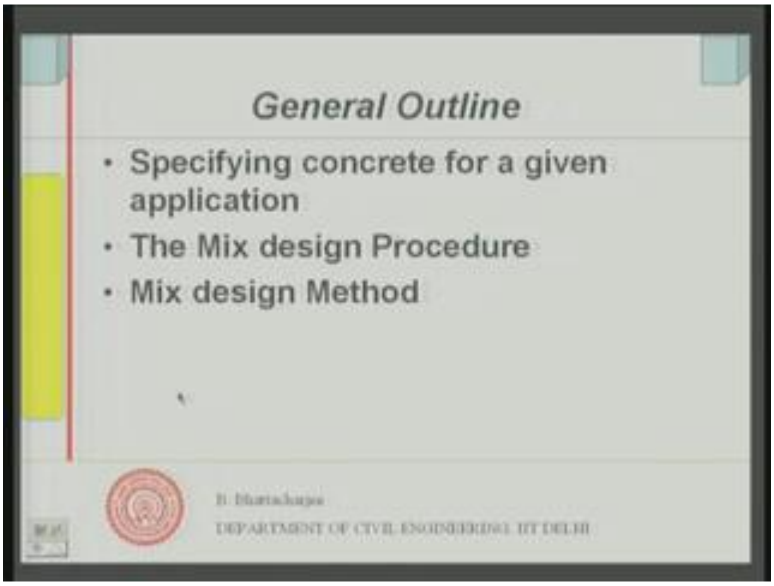

So therefore, first of all we will just you know remember try to remember what are how do we specify the concrete for a given application and also look into the mix design procedure. And we will just mention about the method today when finally, in the next 2 lectures we will take up examples of mix design and mix design methods specific methods.

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So, that is what it is right; first of all let us understand what is the objective of mix design? First of all to find a combination you know of constituents this is important. We must find out the combination of constituents that would give concrete properties complying to certain specifications. So, mix design basically is a you know is a process by which i find out the combinations of ingredients, which I should mix together to make the concrete such that I get the properties of concrete or performance of concrete according to certain specifications.

Now, I can get this mixes by various combination of ingredients. But when I am doing a practical mix design I must do it economically is a combination. This is process of finding a combination of constituents, that would give the concrete properties complying to complying to certain specifications. And I should find it out you know find this combination which is economic, so that is the idea, that is the mix design procedure right.

Then, what are the characteristics of concrete that we are talking about? Well, these are concrete properties in fresh and hardened state; you know we have already discussed about the performance of concrete. So, various fresh and hardened state properties; those are the characteristic that we look into right properties at the fresh and hardened states, so that is what we look into alright.

So, that is what it is and then how do I select the properties? So, first that is that is we are going to look into how do I select this properties, this will depend upon the application. So, the properties are selected depending upon the application and on expected performance; properties are selected based on the application that I am going to use the concrete you know the site or the structure where I am going to use it.

What is the performances expected out of that? So, properties of concrete materials we select based on performance. Then, proportion of those materials also again we select based on performance. This performance specifies in terms of fresh and hardened state properties and we will find out that combination which will satisfy, those properties in fresh and hardened state or performance parameters and it must we must find out the comb- combination which is economic.

So, first is a criteria specification you know this comes from the owner or the client or the user well my concrete as to be in marine environment. So I need the performance accordingly, so environment it must carry so much of load, so grade of concrete is selected accordingly etcetera, etcetera. So, this properties are selected depending upon the application and the expected performance in service that is what it is.

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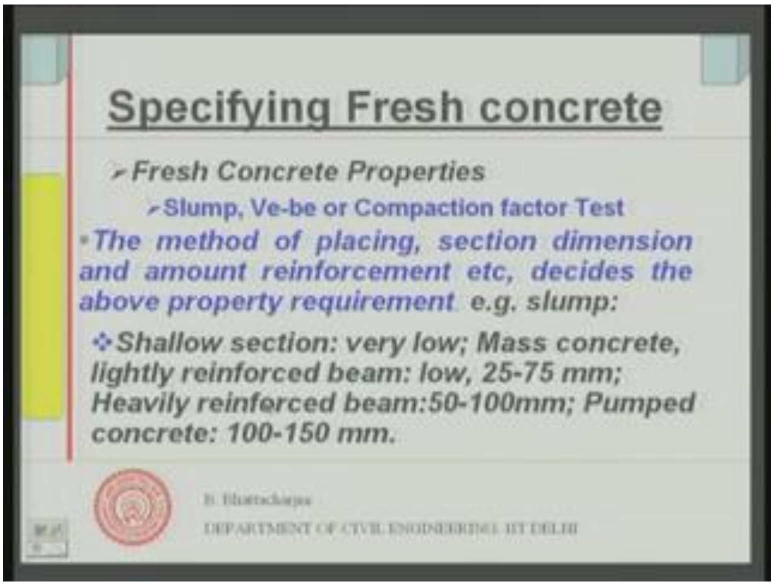

And we know we specify fresh concrete in terms of many many properties we discussed earlier. But while coming to mix design of normal strength concrete, we cannot look into logical properties I have mentioned you earlier when we were talking about properties of fresh concrete that things like etcetera. At the moment I cannot relate the workability to them so therefore, I cannot really measure.

Practically I stick for measurement of workability or something like, slump, Ve be or compaction factor, so these are the results. So, fresh concrete properties are measured in terms of this. So, what does 1 do? 1 specifies the concrete that I require this much of slump right. So, specifies the concrete in terms of well I need this much of slump depending upon the need at the site, need of the structure. For example, it is a heavily reinforced concrete then I would possibly need more slump. We shall see, this how do we select this right.

So, this is the first thing fresh concrete properties and then the slump that I require depends upon placing, method of placing how I am going to place it? It depends upon section dimension; it depends upon amount of reinforcement and you know structure that where I am going to place. So, all this put together decides how much the slump should be.

So, the method of placing section, dimensions and amount of reinforcement, etcetera decides the slump. So that is the idea now some example and this is again available in the court. Some examples shallow section is a very shallow section you require very low slump, mass concrete you will require very low slump. Because, mass concrete you require very low slump; you do not have to compact it and then you do not have to reinforcement in it. So these are all the ones, where you need very low slump, and therefore they are special cases

Now let us see, the structural grade of concrete normally used in structures like: Beam, column, bridges, you know or slab or similar elements or even domes, curved section, and things like that. So there lightly reinforced structure you will use 25 to 75 millimeter, so in such structural grade of concrete the recommended slump is 25 to 75 millimeter. This as per IS: 450 62000, heavily reinforcement section you would need more.

As I said it depends upon method of placing, because somewhere we will see the concrete now concrete would require a very high amount of as a special case. Now, pumped concrete it is a method of placing, so it is based on of placing pumped concrete. This would require more slump than other places, so this require 100 to 150 millimeter.

If you look at heavily reinforced section dimension thin section would need more, so thin sections and then amount of reinforcement.

So you can see that, heavily reinforced require 500 to 100; light reinforced requires 25 to 75 millimeter. So based on this kind of requirement, the slump of the concrete is specified. Usually from this at the time of structural design or even during the time of construction, 1 may consider this slump that would be required. Because, the amount of reinforcement would be known, section dimension would be known, and the way you are going to place that would dictate the slump that is required right. So that is how we actually specify the slump.

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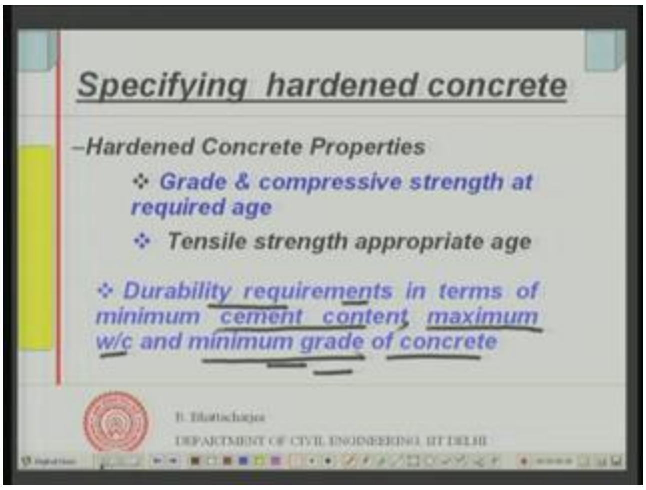

Let us come to hardened concrete. What are the hardened concrete properties? First thing is the strength, but then if we remember the strength is related to grade of concrete. Because, we define grade of concrete in terms of strength, if we recall 1 of the our early lectures on concrete we said, M 25 grade of concrete would mean that its fck is 25 MPa. What is fck? The characteristic strength on, 28 days age of standard cube, standard characteristic, standard cube strength at the age of 28 that's actually 25 MPa.

So, you see when I specify the grade actually I am specifying the strength compressive strength in a manner. But sometime 1 might specify the compressive strength at 7 days or 3 days. Because we said that situations where you need strength it you know you might require high early strength. Some cases you might require high early strength, there you might specify the compressive strength at that required age otherwise, grade does the job.

So, whenever I am saying grade it is actually means I am talking of compressive strength. So, that is the first hardened concrete properties, then we have tensile strength can be other properties some cases I might be interested in tensile strength; you know tensile strength may be interest of my interest some places. So, say I said design is based on tensile strength looking at tensile strength of concrete we have given some example.

For example, is where I do not want any crack those are the places, where I might be interested in tensile strength. Then durability requirement, now this again if you remember that we talked about the durability requirement is specified in code, in terms of some prescriptive recommendation, in terms of minimum cement content, maximum water cement ratio and minimum grade of concrete.

So, depending upon the exposure condition I would need you know my minimum cement content is specified, maximum grade I mean maximum water cement ratio is also specified and minimum grade of concrete is specified. If you remember there is a recommendation, prescriptive recommendation of the code that is how we control the durability; that is how we achieve the durability at the moment.

So, this durability specification or specific regarding this will come from durability requirement. So, you know right all this will come from durability requirement I mean this specification. So, specification comes from the alright so that is specifying hardened concrete. But then in addition to this I need certain information.

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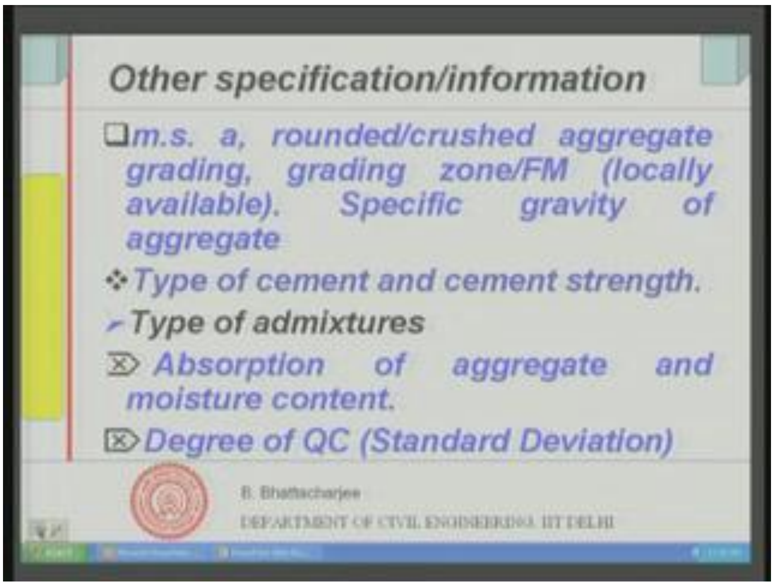

So, these are this is something like maximum size of aggregate, rounded or crushed aggregate. Because, this will be whatever is available to me I cannot go beyond that you know whatever is available to me. So, I will use that crushed aggregate if it is available then I will use that, rounded aggregate if it is available then I will use that, m s a this might come from the section or I might have to take a decision.

Because, maximum m s a I used I can you know whatever is the maximum size of aggregate I can use I will try to use that. Because we have seen that , they may say lesser will be the water demand. But again selection of m. s. a we talked about in material selection, each concrete will require lesser m. s. a, so from those consideration the m s a’s are specified.

Then, grading this information I need my aggregate must satisfy the grading requirement. Then, zones and fine modulus for fine sand or you know sand Fine aggregate that is important. But finally, I have to choose locally available aggregates, so that is the other go I have to use locally available aggregate. So, their characteristics must be known to me, maybe specified by the concrete buyer or the owner. So whatever it is, at the site this must be known before I start mix design right.

So, specific gravity of aggregate I determine them if it is not known I just do test and determine the specific gravity of aggregate. So, whatever is known to me it because finally, I will be using locally available aggregate. So, material selection process I will go to that material selection process.

And the information available from there, that is what is the m s a, what is the grading zone of my sand or its finest modulus, depending upon the mix design method I used. And what are the specific gravity of aggregate? If it is not available I will measure them right. So this information is necessary similarly, type of cement and cement strength. may be necessary some places cement strength, maybe necessary.

But this is not always necessary, because it will depend upon the method that I have adopted. This is not always necessary, it will dependent upon the specific method of mix design for some specific method of mix design like, Indian standard method this requires cement strength. But type of cement might be specified by the owner, because depending upon the environment where it is likely to be exposed I might select the type of cement.

Now, this we have seen how we go about selecting cement ok. This information this is simply information may be necessary, may not be necessary. Necessary if we are using a method which uses cement strength, but all methods do not use it right. If I am using type of admixture, that must be specified and then of course, in the trial mix we will just 1 as to decide the dosage of the admixture and whether it is comfortable or not.

But type of admixture might be already specified for example, 1 might specify that type of admixture; let us say is you know plasticizer. So, plasticizer might be already specified, so this is type of admixture this might be specified or accelerator plasticizer plus accelerator etcetera. So 1 must specify this, might be specified and that information must be available. This is again determined through test, absorption of aggregate; how much is the water absorbed by aggregate.

Because, we assume in the mix design process we actually use saturated surface dry condition all mix design calculations are based on SSD condition of aggregate what you call saturated surface dry. You know aggregate would actually sort of absorb some water.

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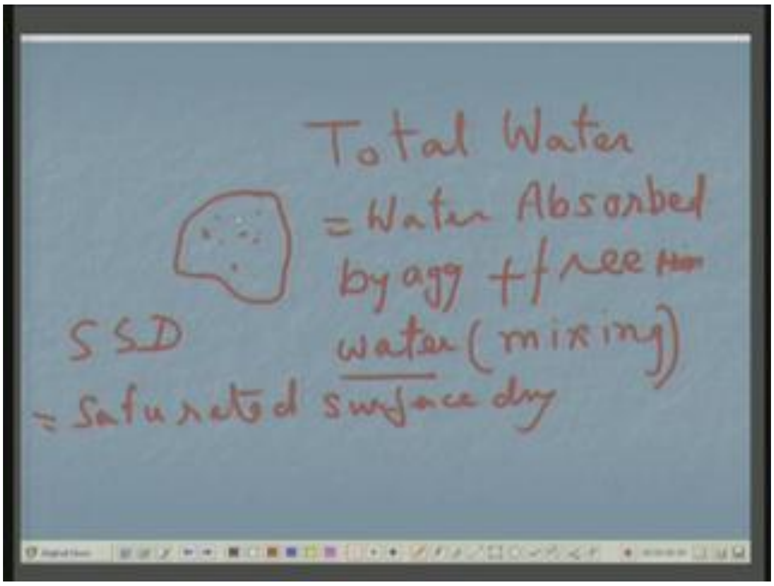

Now, this is your aggregate it has got internal pores and it will absorb some water. So, whatever water you add to the concrete some amount gets absorbed by the aggregate itself. So, you have free water available for your mixing and workability purposes is less than total water that you have added right.

So, total water you add total water that is sum total of that is equals to sum total of water absorbed. Water absorbed by aggregates plus free water available for mixing if I may call it free mixing water. Let me put it as here; mixing water free mixing water. Now, this absorbed water I must know what is the water absorbed absorption.

So, free water is 1 which you have removed the absorbed water from it. So total water must contain both and the condition of the aggregate we use, we assume is called saturated surface dry SSD saturated surface dry. So it means, the water internally absorb that is already there, but surface is dry that means, when I use aggregate in this condition it will not absorb further water It will not absorb further water.

So, to make it saturated surface dry how much water I need that means, I must add to the free water to calculate out my total water required in the total water required. So, to know the total water required, so therefore absorption of aggregate is this information I must have and this I determine through testing that means, I do an absorption test on aggregate and find out how much water it absorbs.

And that much of additional water I have to add to the mixing water finally, while actually doing the casting. Another important issue is degree of quality control that is available at site; you know it is related by what is called standard deviation. We will define this standard deviation of standard deviation at the site of cube making we will define this somewhat later on,

So, these are the information that is necessary before we start let us say our mix design process. 1 is the specifications then additionally in addition to the specifications, I need some more information. So, both this information and the specification; the information that come directly from the specifications both are needed to go for you know to faintly go with the mix design process. Let us see, then what the process are, so we looked into the specification and the information that is necessary.

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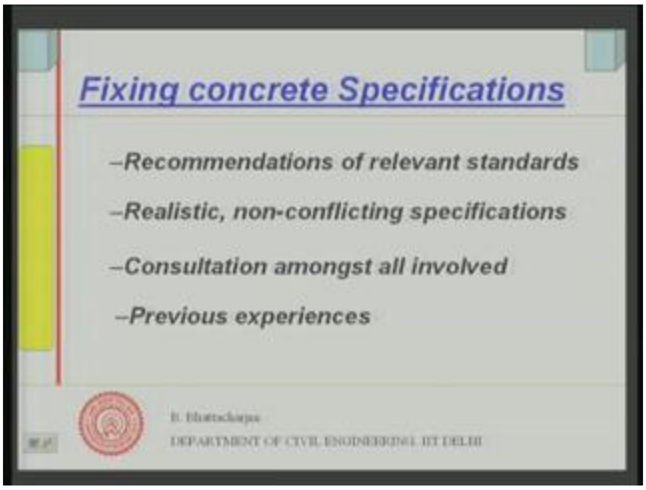

Now how do I fix this specification? Before I come to the actual process of mix design let us see, how should I fix this process of fix this specifications. First thing we can look into recommendations of relevant codes you know I have been always mentioning IS: 456 to 1000, IS: 269, IS: 8112, IS: 383 and etcetera, etcetera, this is the codes of practice. The codes of practice similarly, we have got British standard let us say BS: 8110 or CP you know etcetera, etcetera.

The code of practice so there are several 800 CP so on so forth. So there are several codes of practice and recommendations this specification are fixed from the recommendation of standards. So, when I said I fix the durability standard minimum cement content, maximum water cement, ratio from durability We fix- it from the standard. So, we fix- it from the standard, but most important it as to be realistic and non-conflict conflicting specifications.

So, you know you cannot have something which is contradictory to other requirement. So, 2 specifications you give for example, you want less heat of hydration at the same time you want possibly early de-shattering; that may not be possible example. So, specification should be such, that there are not conflicting with each other.

If you require high strength and you also you know possibly require high strength and you say that, well I cannot use too much of cement my cement content should be maximum something like this; this could be a conflicting specifications. So specifications from the relevant standard, as per the performance requirement and 1 as to see that, they are not really conflicting most realistic and not conflicting. As put it in your specification that will not right.

Obviously, to avoid contradictions during the time of concrete production consultation amongst all involved which means, the owner, the client, the designer, the contractor or the construction agency, then the users. As many people are as possible I mean you make of course, who matter not anybody from the roadside. Supposing the user is such that he has given a job and he is not knowledgeable about civil engineering construction, well he may not be interested in getting involved in this process.

But those who matter consultation among all involved those who matter that create conflict specifications in any stage and that is true for concrete mix also. Previous experiences help for example, if you know a particular aggregate do not create alkali aggregate reaction, so that is to be used. That is 1 thing, so that is how we can fix particular aggregate that you are using.

If you know that that particular aggregate normally, you know I mean it is qualities are such that possibly it does not it has got sufficient strength; you know it has got sufficient strength potential in concrete. So, previous experiences help or if you know that particular cement and aggregate system gives you a strength that a given water cement ratio. So, first experience we have been constructing with this helps very much. So, based on this actually 1 fixes the specifications.

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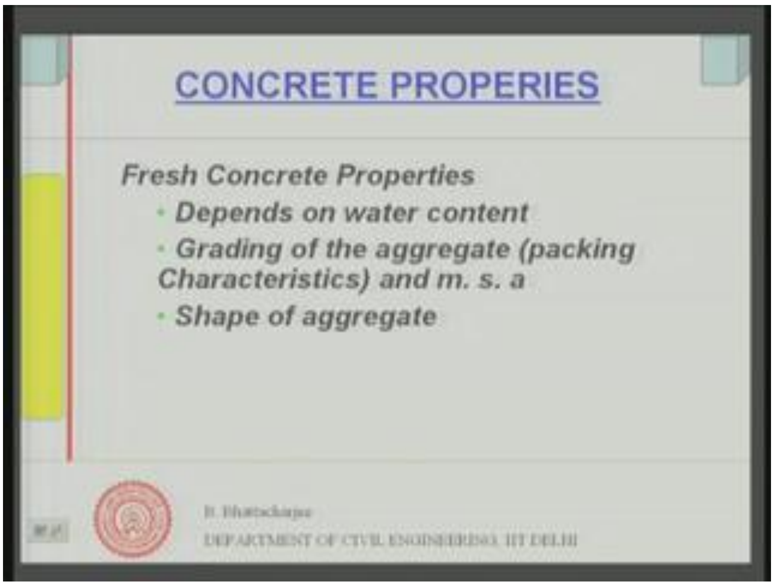

Now, let us see on what does properties of concrete depends. We have already discussed this at length, but we are just going through this again in connection with mix design. Because, mix design procedure is based on this factors; what properties dictates the fresh concrete properties. We have seen that, when I fix my water cement ratio, water content. Once I fix my water cement ratio, it is water content which will dictate my fresh concrete properties, so that's what we have seen.

Because, we said it is the paste; paste is 1 which is paste content which actually is responsible for all kind of fresh concrete, good fresh concrete properties mainly workability. So, workability once I have fixed my water cement ratio if I increase my water content workability increases; this is what we have seen earlier, so that is what it is.

Water content dictates or governs my fresh concrete properties obviously, grading of the aggregate is important packing characteristics and m s a. If you remember m s a higher the m s a lesser will be the water demand and grading of the aggregate it must satisfy the grading requirement that is the thing. Shape of the aggregate again, we know that shape of the aggregate as a role to play as far as water demand is concerned.

Because, packing characteristics changes with shape; rounded aggregate packs better therefore, you require less water. So, you know should be less in the system, and therefore you will require lesser water to fill in lesser paste in other words and so henceforth less water. So shape of the aggregate this we have discussed sometime earlier.

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Hardened concrete properties let us see what governs the hardened concrete properties. And then I have mentioned you a number of times the strength is by water cement ratio. Well if you are using fly ash then it is water to cement ratio not exactly in the manner that is shown in this particular equation as we shall later on not exactly in this manner.

There is slight deviation from this, but some or other you know it is related to this or this. Strength is mainly governed by water to cement ratio, so this idea goes in mix design process, mix design procedures. And we have also seen that, all other mechanical properties are related to the compressive strength. So therefore, if you a- designing for tensile strength. You actually you can have, if you have higher compressive strength automatically high tensile strength right.

So they are also related to water cement ratio, so tensile strength is also related to water cement ratio. Then durability properties we have seen that, they are controlled by water to cement ratio mainly water to cement ratio and then cement content and of course, our prescription is that. It is you know grade of concrete is also a prescription in this. So what we have seen, if we are looking at the process in concrete properties what dictates.

First of all water cement ratio dictates strength, water content shape of the aggregate and the grading characteristics dictates the water required for given workability. And durability is controlled by water to cement ratio, cement content and grade of concrete. So, this idea goes in mix design process.

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Let us see now, the mix design process itself right before we go to the mix design process. What would have been the best process of mix design? Because, we said that we must find out the combination of constituents that would give me the desired property. So if 1 as to do it very easily through a mathematical exercise and I must do it economically Let me let me put it back again.

So, I must do it economically so what I am trying to do, I am finding out the combination. In other words, I am trying to find out how much cement I need. So, you know like cement content this is what I would like to find out cement content. And how do I express them? Cement content. Expressed in k g per meter cube of concrete right.

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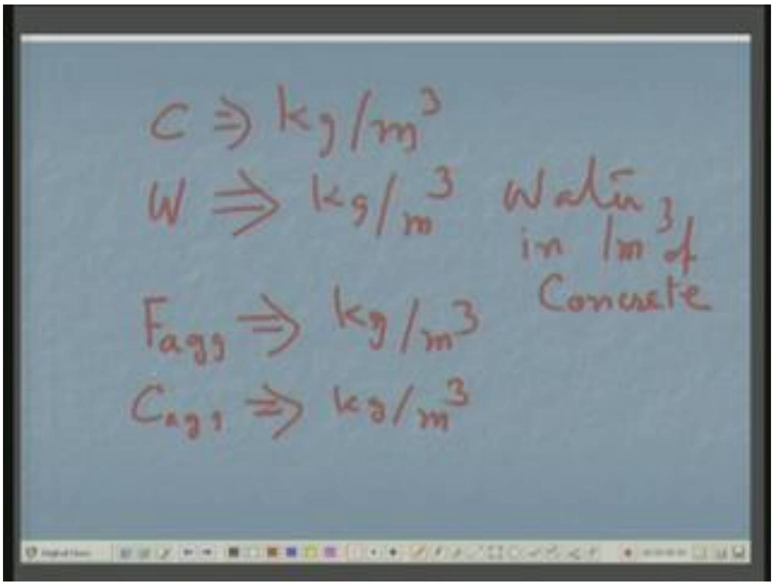

So, C I expressed as k g per meter cube you know I express it in terms of k g per meter cube or in meter cube of concrete. Water w I denote it like this is also in k g per cube is the amount of water in 1 meter cube of concrete of concrete. Then, we might call it as fine aggregate you know Fagg fine aggregate and that is also in k g per meter cube. And then coarse aggregates Cagg let me, put it and this is also in k g per meter cube.

So, right so this is the or if I may you know let me use this notation then throughout right Remember Cagg stands for aggregate content, C stands for cement content. So, all this my variable I want to find out how much is my C, how much is my W, how much is my Fagg and Cagg. That is fine aggregate and coarse aggregate content. Of course, you might ask a question. What about the admixture? Well admixture in the first stage we do not take into account.

What we do? We do a control mix design, then any reduction in water or whatever it is. Due to the admixtures that we do it separately finding out the dosage of the admixtures, so that is additional trial. So, basic mix design procedure, without fly ash or anything the simple case first this is nothing, but finding out the combination of C W Fagg and Cagg Agg Fagg and Cagg. Such that it an satisfies a given requirement or strength.

And also, the cost of my total material is least now, this problem I should be sure be never do formula as in optimization problem. In in mathematics or in you know- optimization is a known field known field. So, formulating an optimization problem would have solved my problem very easily, because then I can just have a software.

And find out how much is the C W Fagg and C agg, but unfortunately to do that what I need? I need strong relationships. Actually what I need is, I need relationships, because I could have created optimization problem.

But if I want to treat it as an optimization problem what I need is, well defined mathematical relationship. At the moment this is not available, not really what is available for example, you know I could not have given you well discussing about the strength of concrete. A relationship between strength of concrete like if, I could give Fc simply as a function of let us say when water cement ratio clearly and maybe something other, something else.

Then, things would have very easy but this will not be universally applicable I can get a relationship for a specific cement by empirical way. So, you know do a large kind of experiments and come out with sort of empirical relationship by regression analysis, by curve fitting and things like that. But such relationship is not universal, might find it out useful in 1 place may not use again. Some other place it may not be and you change 1 of the components this relationship may not be valid.

So therefore, I do not define do not have well defined mathematical relationship this must be understood very well. And therefore, I have to rely on empirical formulae and experience right. Empirical formulae curves, charts and things like that because; I do not have well defined mathematical relationship. If this was there I could have just formulated- optimization problem, feed it in the computer gets the results from the software out and that is it.

So, you mix it and you get the results no, it is not like that. The concrete mix design is not like that, because we are dealing with mostly natural material cement is the processed 1. But it is also process as low as possible to keep the cost low, rest of the material you can say crashing of the aggregate we are doing. So, it is partially processed and there are so much of variability that I really cannot rely on mathematical relationship alone.

Therefore, you have got very large number of mix design procedure There are not 1 2 3 there are n number of every you know there are plenty of most of the codes, many codes or practices not codes necessarily we will have some sort of mix design procedure many organization might have its own mix design procedure. Because, I do not have well defined mathematical relationship therefore, I do not have a unique method as we just discussed.

And therefore, it is not fully science in fact it is science and arts of mix design 1 must recognize this. There is an art component involved, as many time as you do might be doing it better especially when it comes to using the same aggregate, same cement. You know water and ingredients are concerned. So, there is art component in mix design it is not just absolutely single process you say and 1 as to follow that well that does not work out.

Because, highly based on empirical formulae, so this fact must be realized. In fact, you might start up with a mix design procedure, but might evolve your own intuitive way at the site. If the site is continuing for a given long period of time let us say, to change and finally, in all cases you have to do a trail mix. You might use a very sophisticated computer program mix design. But then finally, you have to do a trial mix and see whether it is being satisfied or not.

So, quite often you might find that is not satisfied you have to readjust the mix in order to get the correct proportion to get the correct property. So, this must be understood that it is quite a bit of Arts as well and not purely just you know experience plays a big role that is important, to understand that is important to understand, so that is mix design procedure.

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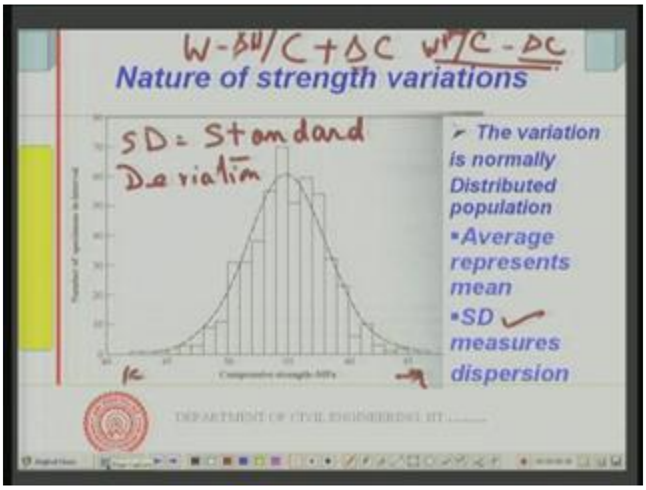

Now before I come to mix design process let us understand few more things. You see supposing I have a concrete let us say like this you know it is cube strength simply concrete cubes some maybe 200 cubes I have large number of cubes I have. For a given concrete I have designed it for a particular strength, I mean let at the moment the value of the strength is not important.

But I have tested a large number of samples; so if i test large number of sample and you might have done in school statistics what is called a frequency plot. So, what I am trying to do is this side x is my strength and I have divided into class interval having 1 MPa. So, the strength here is 45 MPa, it is 65 MPa here and this is 42 MPa. So this is 42 MPa, 43 44, 45, 46, etcetera, etcetera.

So, class interval and this boxes shows number of specimen exhibited strength between let us say 50 to 51. You know, so this is in this case 30 samples I have tested large number of samples, so 30 samples or 31 samples possibly showed exhibited a strength from 50 to 51 MPa. Then large number of you know if I go on plotting this I will get usually a curve of this kind.

The histogram plot as it is called I will get something like this; this inherent to concrete cube strength why? Because, concrete cube strength depends upon large number of factors for example, in your batching plan even if you are doing mechanized mixing. The proportions of ingredients will not be exactly same every time, there may be some differences because of the tolerances limit.

So, if you are doing it volumetrically well then it would be very large difference, because volume cannot be controlled 1 time you have mixed, because volume when you pack-them. We have talked about, batching and at that time we mentioned volume we packed differently. Supposing I take as sort of a box and try to fill in aggregate here; the mass of the aggregate that I will fill in 1 time and the next time they will not be same they will vary widely.

But even if you have a mechanized batching plan, every time same amount of aggregate will not be there. Because, you have some tolerance limit there are errors here and there and the aggregate itself will not be same. Similarly, cement quantity there will be small variation in the cement quantity, small variation in the water quantity. And properties of the cement exactly will not be same from 1 batch to other.

So, cube and then cube compaction, so several such factor go on contributing to the variation of strength you won't get same strength everywhere, every cube. They cannot be its not possible there will be material differences, testing process differences and differences coming out from large number of factors. And from limit theorem or statistics or ideas of statistics we know that when cube strength like thing which depends upon large number of factors. It is variation is likely to be something like this, what is known as normally distributed.

You know if you plot the histogram frequency histogram like this; you will find there is an unique and other strengths are distributed pick. And it so happens if you calculate out the arithmetic average this will be coming somewhere here; what you call mean. Mean is the central tendency and you will have nearly about 50 percent of the samples showing higher strength then that the mean. And 50 percent of the sample showing lower strength then the mean

So, if you take arithmetic average this is the measure of the mean. So, concrete cube strength shows this kind of behavior what is known as normal distribution so that is what it is. So, in fact this cube as you can see had a mean strength somewhere here; you know 54 between 54 and 55. So, mean strength was somewhere here; and 50 percent of the cube showed strength higher than that.

But interestingly you can see you can visualize something more, you see if this is there the distance from here to here; which is about 67 to let us say 55 makes it 10 12 and from 54 to here 42 it will make it 12. So, it is actually this distances are same and this is real day-to-day experiment experience with cube strength also. You test with large number of cubes you will find that and the plot the frequency diagram you will find this kind of variation.

So, if provided they have come from the single source they will show that kind of variation. So, concrete cube strengths are normally distributed; you see they are normally distributed. So, it is it comes from a normally distributed population as we call it and average represents the mean; the arithmetic average is the mean. Now I said that, there is a distance between these 2 this will depend upon how much control you have onto the variability.

For example, if you do a volumetric batching then the amount of cement you have added in 1 batch and the amount of cement you have added in the next batch could be quite different. The water if you are adding through just simple visual mixing you know sort of you have a can and you just put it like that. By 1 can or half can or something like that, by visual sort of a crude way, not really measured way.

Then, 1 time you will put x amount of water next time you will put x plus delta x and delta x could be quite large. Then, next time you might put x minus delta x where delta x itself could be quite large. So, when you are doing manually the delta you know variations in the material proportion.

1 case you will have something like C plus delta C. And maybe your water is W minus delta W. Other case you might have C minus delta C and water that you have added is W plus delta. Now you can see your water cement ratio is relatively much high here and it is much less here. And it will depend upon, how much is this delta C and delta W value. So, you will get lower strength in this case, higher strength in this case.

So, you will see that strength varies not the same you will get higher strength sometime, lower strength sometime. And since it is attributed to chance, you are there is no specific bias deliberately neither high water is added nor less water is added nor high cement is added it is just the process itself.

So therefore, where there is no deliberate you know or bias is not there you do not add all the time lower cement or higher water and things like that. You will find that, it is dispersed equally on both sides the results queue strength; results are dispersed equally on this side. And in case where your delta Cs are higher or delta Ws are higher the dispersion would be large Dispersion would be large.

So, you have a better control on delta C and delta W dispersion would be less. Now, this dispersion is measured through what is known as standard deviation SD; SD stands for standard deviation; SD is nothing, but standard deviation. So, we are aware of this in our from our school statistics so standard deviation. So, mean average mean represents the you know central tendency; standard deviation represents the dispersion. And both this factors are important for our consideration, and let us see how do we calculate them.

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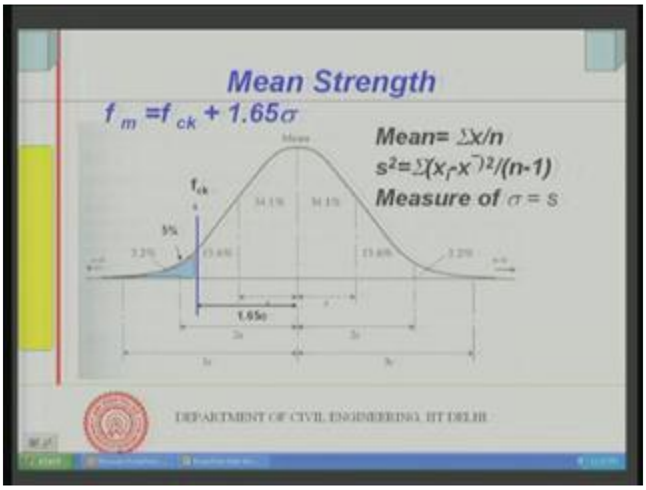

Mean we calculate like this Mean is sigma x, so if you know all x values all those strength values if I take I sum it up. These are the x values you know the strength value all the x values of course, you have of doing it from statistics. There are other simple ways of doing. I am not interested in those, but I am just defining them. You can look back into statistics if you have more curiosity on the subject, but mean is simply found out where x represents the strength.

So, all x values I sum up find out whether the total number of samples that gives me mean, so that is the mean; that is the central tendency that is the mean. And the dispersion is measure of dispersion if I am calculating from sample I calculate in this manner find out the deviation individual deviation from the mean X bar is nothing, but mean.

So, you know this is x bar, so x bar is the mean so find out each individual deviation of each individual from the mean square it up sum it up for all the samples and divide by n minus 1 for n minus 1. Because of degree of loss of degree of freedom 1 degree of freedom again, you can go back to statistics.

So, from sample supposing I have determined it from small number of samples something like, 20 20 20 odd samples, then possibly I will use this calculation. And s square is I find out from here and this s under root of this 1 is called is a measure of the standard deviation sigma is standard deviation. So, s is a measure of standard deviation and that is how we calculate.

And you have seen that it is symmetrical about both sides, the law of statistics would tell you that most 99.9 percent of the results you will find between mean plus 3 standard deviation and mean minus 3 standard deviation.

And that is what we have seen in the previous graph also, our mean strength was something like 54.5 plus something like 12.5 and minus all results were within this. 54 all results were within 54 you know they range from like something like 42 to 67. So, 12.5 is nothing but 3 sigma in my previous case 3 s2 standard deviation, so both sides its symmetrical 3 standard deviation both the sides, right.

And if i divide by the total number of samples in earlier case, I can plot this diagram such that the area under this curve is equals to 1 ok. So such that the area under the curve

I can plot what is called relative frequency instead of plotting the frequencies I talked about divide by the total number of samples you will get relative frequencies. And this can be fitted. The total area under such relative frequency curve would be 1.

And when it is fitted to the normal distribution you know area under this normal distribution curve is 1. More if I go 1 s1 standard deviation away from this mean The area on the right hand side is 13.6 plus 2.2 which means, 15.8 percent. And area on the left hand side is 50, because at this 0.50 percent. You see if you sum this up 34 13.6 plus 2.2 would make it nearly you know 8 9.

So, 15 plus 449.9 so 49.9 is you know total area I mean nearly about 1. Because, will be small on that side also so within 3 sigma you get double of 49.9 percent area. So, left hand side we said was 50 percent area, right hand side from the mean will have 50 percent of the area which means, that 50 percent of the queue strength belongs to more than the mean strength 54.5 in our previous diagram.

And 50 percent of the results will have 50 percent queue will exhibit; queue strength less than 54.5. This is important issue, but supposing I go to this line 54.5 plus 1 standard deviation away, which in my case would be 3 standard deviation will be equals to 12.5. So, my standard deviation in this case is 12.5 divided by 3 something like 4.17.

So, this is you know 1 s means 4.17 so 54.5 plus 4.17. So, if I go to 58.67 so this line will correspond to 58.67 in the previous diagram. And if I you know I can see that I have 15.8 percentage of the total cube results is above you know that I have just calculated 58.5 or whatever it is. So, above that above that strength similarly, 54.5 minus 4.17 you know below that there will be 15.8 percent of the results.

So, I can find out how much percent of the result will be above let us say same calculation let us do again you know 54.5 plus 2 into 4.17. Because, my sigma is sigma equals to 4.17 or s you know which is s equals to sigma equals to this 4.17.

So this is nothing, but 62.87 so this above 62.87 I will find only above 62.87 MPa I will find only 2 percent of the cube results. Similarly, below 54 minus 54 minus 2 into 4.17 you know this will correspond to this point. Below this strength I will find only 2.2 percent of my cube strength results. So, that is the idea you know that is the idea that is important for us.

Now higher the standard deviation it means, my degree of quality control is poor. the dispersion is more; when smaller is the standard deviation that means, my degree of quality control is better. Now this has got some relevance, because if you remember we defined our characteristic cube strength as that strength which will be exceeded 95fpercent of the time.

So, fck lies somewhere here; only 5 percent of the cube strength will be lower than that 95 percent should be higher than that. And we have found out that at you know in this case 50 percent will be higher from 54.5 or the mean 50 percent of the cube would show higher results than higher strength result than the mean 50 plus 84.6 you know 80 50 plus 30 84.1 percent of the cube strength will show results higher than mean minus 1 standard deviation.

So, if I want to find out what is this value? You know above which 95 percent of the cube would show higher strength results than that. Because, fck I defined by that will be mean minus 1.65 standard deviation. So, fck is mean minus 1.65 sigma this is important. So, mean will be fck plus 1.65 sigma; this is what it transfers from here. So, mean will be equals to you know if this is my mean this fck plus 1.65 sigma. And whenever I test 3 or 4 samples I test for mean; therefore, my mix design should be based on target means strength.

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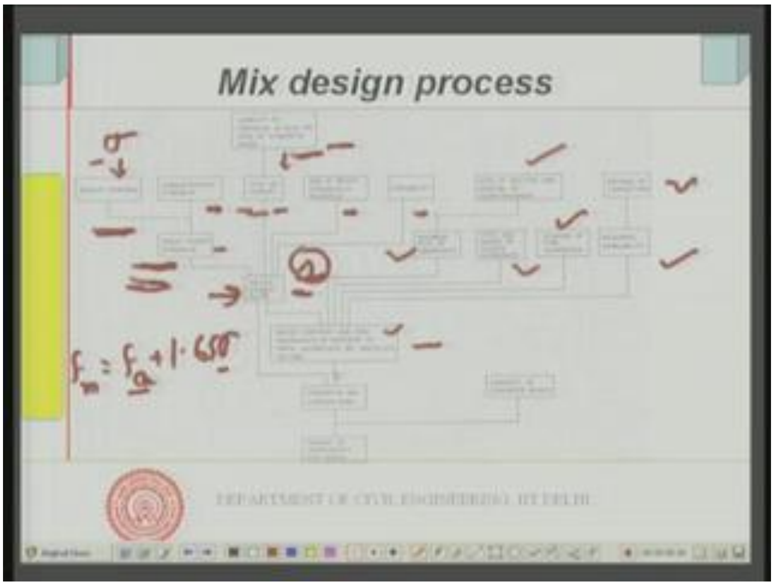

So, mix design process, if I look at now we look at the mix design process, we will see that first of all you see I you know I decide water cement ratio, based on mean target strength so mean strength. Because, I can test 3 4 samples and find out mean strength I cannot find out fck unless I do very large number of measurement, which is not possible. So, I do my mix design with reference to the mean strength right and mean strength I decide from my grade of concrete.

Because, I know fck and I know fck plus 1.65 sigma is equal to target means strength. So, target means strength first I find out and this depends upon characteristic strength and my quality control because this is sigma. If I have higher quality control sigma value will be less, if I have lower quality control sigma value will be higher. And this is said was FM target means strength means strength is fck plus 1.65 sigma.

So I got to know sigma; I got to know characteristic strength; to find out target means strength and now using this formula I find out target means strength. And strength governs water cement ratio so I find out from there. Also the durability consideration actually specifies maximum water cement ratio. So, water cement ratio is decided based on first step 1 decide water cement ratio.

Water cement ratio I decide based on target means strength and durability requirement right durability and type of cement, based on type of cement etcetera. And you know age at which I need the strength that is 28 days, 7 days, etcetera and then durability criteria. So, cement type I decide based on durability criteria etcetera etcetera based on cement type age at the strength I need durability and all this dictates my water cement ratio I can decide all my water cement ratio based on this.

Then, once I have determined my water cement ratio that is the first step step number 1 let me put it this is step number 1 first I decide the water cement ratio. Then what I decide next? I decide my water content, fine aggregate content and percentage of total aggregates based on this principle this is by and large a procedure of mix design as per IS code.

But other mix design procedure also follows almost similar line, so what I do is to decide on this percentage of water content, percentage of fine aggregate and the percentage of coarse to fine what I do is, I find out I size of the section which decides my maximum size of aggregate then shape of aggregate, type and shape of aggregate. And, then you know method of compaction decides my required workability slump etcetera.

So, then grading of the aggregate, so I said that grading of the aggregate then slump required shape of the aggregate and maximum size of aggregates actually decides my overall packing I need and the water I need. So, all this goes on determining water content proportions of fine to coarse and total aggregate content that is what I need from here; I get it from here.

So, once I have decided this water cement ratio comes information from water cement ratio. So, first step I determine this then I determine coarse and water content I need percentage of fines in total aggregate system I need together with water cement ratio i can determine the whole thing.

So of course, we will make it much easy a simple examples will make it much easier we-shall see that. Then, once I have determined this proportion find out the complete concrete mix proportion comes out. Once I have known the water content, fine aggregate content and total aggregate content and water cement ratio known I can find out the concrete proportion. Then, actually find out the capacity of concrete mix and find out what it is. So this is the broad process of mix- design.

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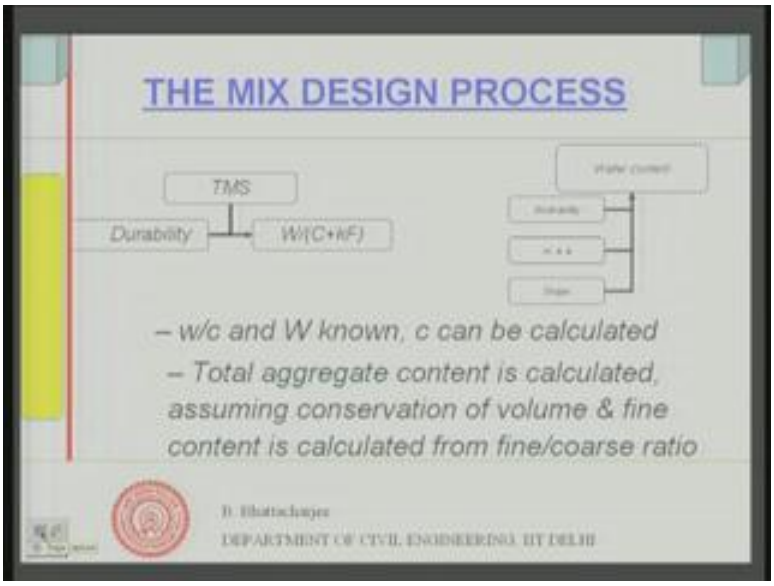

Let us come to more important part of it again. Let us look, the mix design process. You see let me repeat this, because this is most important part. First of all I decide my target means strength based on durability and water to cement ratio. This is procedure followed by almost all mix design process; first I determine my strength required means strength required. And from durability considerations I determine water cement ratio.

The next step would be to determine the water content, based on the workability requirement maximum size of aggregate and shape of aggregate. So, water content is determined based on workability, because you have fixed this first water to cement W to C. F is if you are using a K F you know fly ash. This is if you are using fly ash, in fly ash based mix design K is a factor which is taken about 0.3.

In an example calculation will be made easier, but based on this water to cement ratio or water to cement ratio, effective water cement ratio if I may call it I first thing I do is this. Then, I determine water content based on workability requirement, maximum size of aggregate and shape of aggregate. Once I have done this then since I know the water to cement ratio, I know water content I can find out the cement content.

So, this is known C can be calculated I can calculate out the cement content and once I know the cement content, total aggregate content can be calculated by assuming volume is conserved conservation of volume. And fine aggregate to proportion of fine aggregate content can be calculated if I know fine to coarse aggregate ratio.

So just repeating the same process again of course, when we look at the method, it will become it will become clear when I look at the method the- process will be clear.

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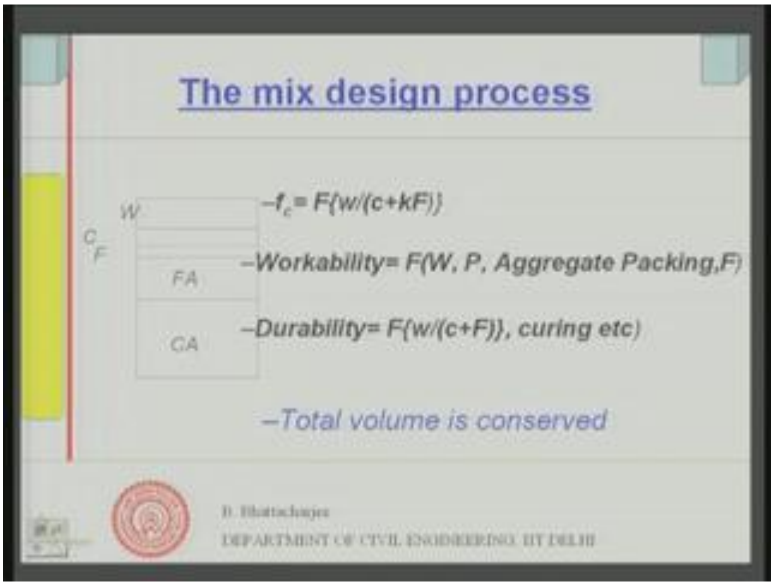

Total volume is conserved what we assume that I have if I have 1 meter cube of concrete in that wet concrete right total volume is conserved. If I have wet concrete then total volume of total volume is conserved that means, whatever coarse aggregate fine aggregate I add up together with the fly ash and cement and water they will form the 1 volume of unit volume of concrete. And use a simple formula to calculate out the quantities.

So, first I determine the cube strength is a function of water cement ratio, so i determine water cement ratio from strength. Then, workability is a function of water plasticizer, but that is not at the moment- of my interest aggregate packing and if it is fly ash I am using. So, water content I determine from workability and aggregate packing etcetera and durability also water cement ratio, etcetera. So, water cement ratio is determined from this 2 and then I assume total volume is conserved and I find out you know proportion of ingredients.

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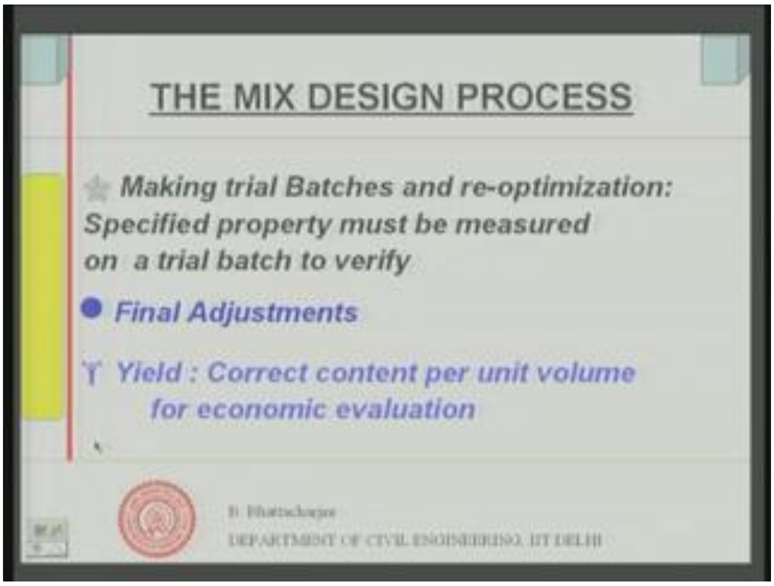

So therefore, mix design then you have to make trial batches and re-optimize your mix for specific property final adjustment you do. And, then you look at the correct yield content per volume for economic evaluation.

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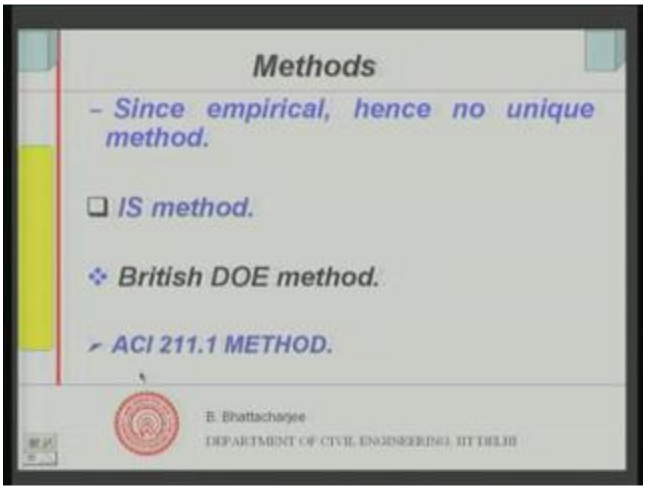

So, that is the mix design procedure I think we will take up 2 methods. There are several methods in empirical there is no unique method I mentioned earlier there are large number of methods. So, we take up 2 methods IS method and British method, there are other methods like ACI method, but that uses cylinder strength.

So, it will be difficult for us to deal with ACI method, but we will do 2 methods in next 2 consecutive lectures and that would make the process also more clear.

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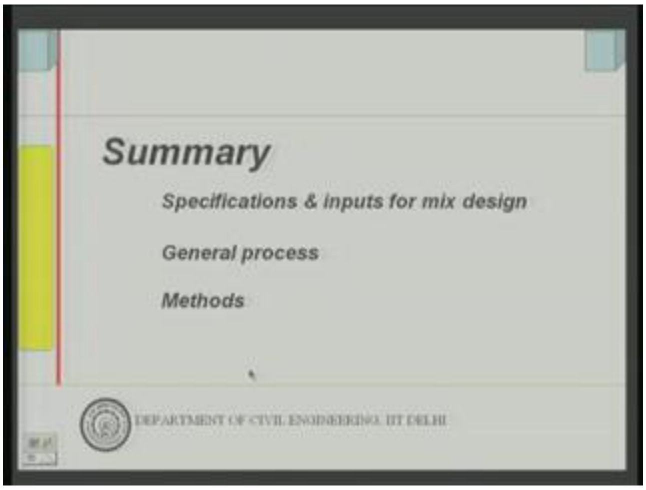

So, summary we have looked into specifications of and inputs for mix design, then we have looked into general process of mix design, and we just mentioned the methods. I think with this we finish the introduce discussion on mix design procedure. We will look into 2 methods and corresponding example in the next 2 lectures.

Thank you.