Concrete Technology
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Lecture - 15
Mix Design of Concrete: General & IS Method

Welcome to the lecture two module four of concrete technology. We will start from where we have stopped in the previous lecture.

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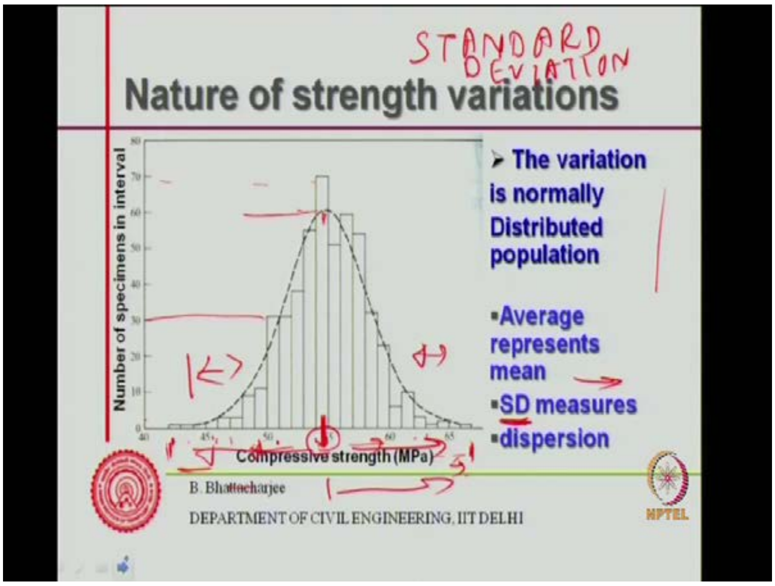

In the previous lecture, we are looking at nature of variation of strength of concrete. Now, what we are mentioning; what we mentioned yesterday is that, let us say a concrete we design for a mean strength or let me call it as an average strength of 55 or let us say 54; somewhere here. What one would find is that large number of specimen or samples would exhibit strength lower than that mean; and again, similarly similar numbers of specimens or samples would exhibit strength higher than that. This is so because cube strength of concrete is governed by number of factors. For example, while batching, that is, you know proportioning or weighing the material; weighing the material for putting them in to the mixer machine; if I was expected to put in let us say 185 liters of water per meter cube of concrete in a given batch, sometime it may be 180 and sometime it may be 190. So, it is very difficult to keep same amount, putting same amount time and again; there is a variation.

Similarly, the quantity of cement going into a batch; batch to batch there will be a variations; batch to batch there will be variations. And thus, water cement ratio would vary. It will never remain constant. And as we have seen, RDR; and also, we will see later on, when we look at the factors affecting strength, we will see that water cement ratio governs the strength. So, if there is a variation of water cement ratio, there will be variation of strength. Similarly, batching process can introduce strength variation. Similarly, mixing process can introduce variation. For example, you take material from first 15 percent of the discharge of a mixer machine and make cubes. And similarly, you take last 15 percent of the discharge of the mixer machine and make concrete cubes. They are unlike people show same strength. Initial discharge will content more of the aggregates; later discharges are likely to contain more of the paste. Thus, it is unlikely that both would show, exhibit same strength or same property. So, mixing also introduces variation.

The properties of the material from one batch to another would again vary. For example, aggregate in one batch will not be exactly same as another batch. So, there is variation due to the aggregate properties variation; variation because of cement properties should vary. And that way one would see that, large number of factors would be affecting the concrete cube strength. The cube that is made, casting of the cube, compaction there, curing condition – they are very unlikely to be identical in all cases. Therefore, strength of the concrete varies. You might have targeted it at some value of 50 or 55. But you might find that, it actually varies from somewhere around 41 to about 67. So, there is a variation. And this variation if I plot the number of specimens in the interval; for example, 50 to 51 here; this is the number of specimens; say about 30. From 46 to 47, you have about two numbers of specimen. And similarly, here if I look it at 62 to 63; again, two numbers of specimen exhibited that strength. So, these are the number of specimen showing strength within that interval. 54 to 55 has been shown by majority. And this pattern if I join by the smooth line, this varies like a bell. This variation is called a normal variation; or, concrete cube strength is said to be varying normally or distributed normally.

And, we from the law of statistics, we know that, when there is a random variable like cube strength, which is controlled by number of factors such as the proportioning, mixing, properties of the material, etcetera; under such circumstances, cube strength is likely to be varying in this manner; distribution of the cube strength would… is likely… Do you know that, cube strength is likely to vary in a normally distributed manner; normal distributed manner as shown here through the bell curve. The testing process, the casting process, curing, mixing, everything contributes to this variation. And therefore, it is normal distribution, normally distributed according to the central limit theorem of statistics. And such a distribution is a two parameter distribution. So, concrete cube… The variation of… is… Concrete cube – population of concrete cube strength is generally normally distributed. That is what we say.

And, such a distribution is characterized by two parameters: one is called the mean, which is the average – arithmetic average of all the data, which you can find out. For example, you know this strength, one sample; this strength, one sample. You know class 45 to 46. You have got two samples. So, 45.5 will be the representative class value multiplied by the number of samples. And if you sum them up for all samples in the histogram and find out say arithmetic average; that represents the mean. So, average represents the mean. And in case of normal distribution, the mean which is central tendency, is also the mode. That is where you find the maximum number of samples showing that particular… maximum number of samples showing strength at this range. So, that is called mode, the peak of this distribution. And also it is the medium; that means 50 percent of the samples would show strength lower than this; and 50 percent of the strength samples would exhibit strength higher than this. So, the mean in case of normal distribution is same as the mode and also same as the medium. And concrete cube strength therefore behaves normally. So, mean strength corresponds to the mode of the distribution and it also is the medium; which means that, 50 percent of the cube would exhibit strength lower than the mean. And another 50 percent would exhibit strength higher than the mean.

The second parameter through which this distribution is described is the dispersion; how wide this is. For example, if I am mixing process, do not introduce… or it introduces less variation; batching process introduces less variation; properties of the aggregates from batch to batch vary less; then this range will be smaller; this range will be smaller; this will tend to be smaller; this will get reduced. So, this range of 41 to 67 as seen here could be different depending upon the control that I have. If my batching process is a computer controlled batching process, automated batching process, where all ingredients are weighed within their tolerance limit; mixing process – the mixer machine is so good that it does not exhibit too much of variation of the concrete from RDR discharge – initial discharge to the final discharge. I have a quality control system, where I test every ingredient. Under such circumstances, this dispersion will be less, because as you can understand, the water put in a given batch – it is very less; I was talking about 185 liters and 180 liters and 190 liters in 1 meter cube of concrete.

Now, supposing the batching process is better; instead of 180 to 190, if the water variation in the water is simply 178 and 182; instead of 182; I mean 185 I said, so 183 to 187 instead of 180 to 190. Then in such case, the water cement ratio in the final mix is very less and the strength is very less. We shall see that, strength is governed by water cement ratio when you talk factors affecting strength. So, if I have better control, this dispersion will be less. So, this dispersion is a measure of control I have. Now, how do I quantify this dispersion? This dispersion is quantified in terms of a parameter called standard deviation – standard deviation – SD. So, standard deviation is a measure of dispersion. And as we understand now, better quality control means less standard deviation; better quality control means less standard deviation. So, two parameters: the average, which represents the mean – the central tendency and the median and the mode, same thing, and thus standard deviation.

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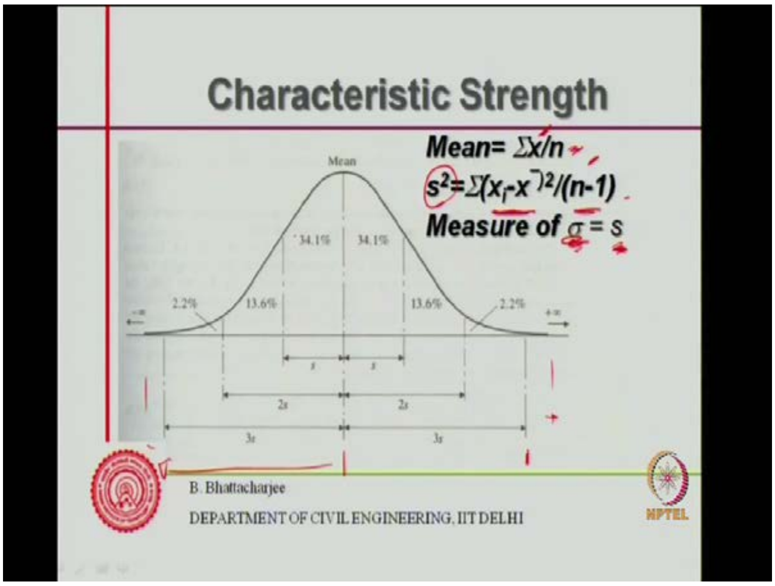

And, we calculate the mean is simply all values of the cube strength; sum it up; divided by number of samples. We can calculate it out; possibly, we would have learned in statistics, how to calculate it out when you divide the total range of the samples into various class intervals, take the class representative value and the frequency as we call it, which we are shown RDR; number of samples interval, that is, the frequency. So, if you know the frequency or relative frequency – the frequency divided by total number of samples. So, relative frequency multiplied by the class values – class representative values will give us the mean. Or you can have all individual cube strength divided by total number of samples – that will give you the mean. Standard deviation is measured in this manner.

Deviation of individual samples from the mean; square it up, sum it up and divide by n minus 1 if n is small. But if n is sufficiently large – more than 30, then n minus 1 and n will be nearly same and this will not be affected. So, s square is called variance, which is the standard deviation square. And square of s is called – is the standard deviation usually meant for small number of samples. So, standard deviation square is given as deviation of individual samples from the mean; square it up, sum it up. So, root mean square in a way except that we have taken n minus 1 when it is small samples.

Now, if I find out s – standard deviation of population that we denote by sigma; measure of standard deviation of the population is less. So, s represents the standard deviation of the population; population means all cube of belonging to the same category. Now, that may not be possible to measure all cubes of population; actually denotes to infinite samples size – infinite number of samples, not sample size; infinite number of samples. And standard deviation is measured by this formula. So, what we have seen is that, standard deviation is the parameter, which governs this dispersion. And it has been observed that, 99.9 percent of the data – you can show it by even calculation, because there is a curve that can be fitted to this Gauss – Gauss’s distribution. So, the Gaussian distribution curve is available, equations are available.

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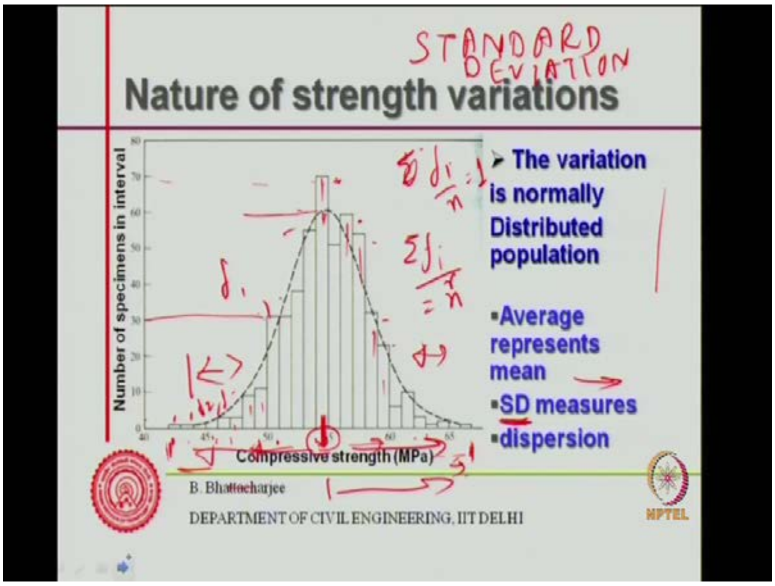

And, if I divide by even RDR – histogram; if I divide by the total number of samples, that we can understand if I go back to this curve again. If I go back to this curve again; if I divide by the total number of samples, this will be fraction, this will be fraction, this will be fraction; all these will be fraction. This is called relative frequency. And sum of all these fractions will be equal to 1, because sum total of this number of samples here, number of samples here, number of samples here, number of samples here – all these is a… Sum total of all those number of samples is the total number of samples that is equals to m. So, total number of samples – sigma f i is… f is the frequency is equals to n. And relative frequency is given by f i by n. So, f i is this one. If I call this as f 1, f 2, f 3, etcetera, etcetera; f i – any i f 1… This is f i. Sum total of f i divided by n is equals to 1, because sum total of f i divided by n, because sum total of f i is equals to n. So, this equals to 1. So, if I sum up all these fractions, I get 1. So, area under this curve is therefore can be approximated as 1.

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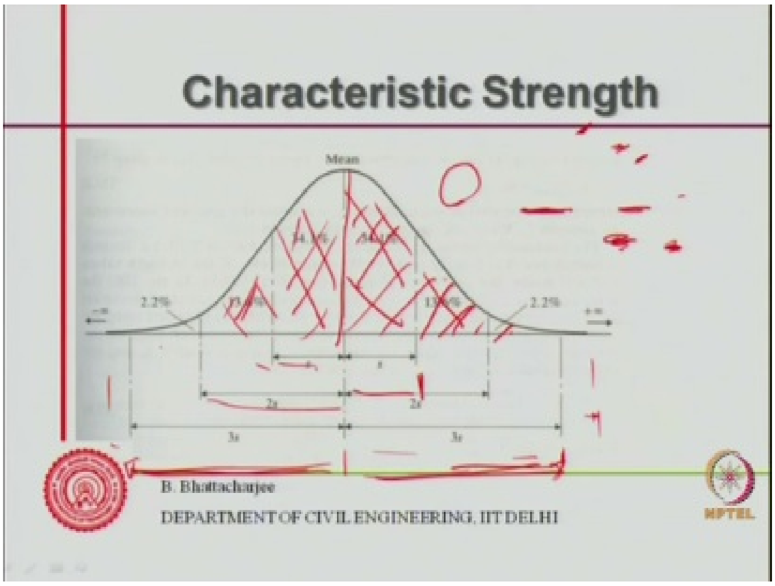

So, total area under this curve is 1; total area under this curve is 1. And since it is symmetrical, this area must be 50 percent – 0.5. This area must be 50 percent of the total area. And this area must be 50 percent of the total area. And it has been observed… From the equations, one can show that, this 99 percent of this area is contained within plus 3 standard deviation and minus 3 standard deviation. So, if I go three standard deviation, because total dispersion – standard deviation is the measure of dispersion. So, everything is contained within plus 3 standard deviation and minus 3 standard deviation. And if I go one standard deviation away, there is 34.1 percent of the area, is contained here; another 13.6 percent of the area is contained here; another 2.2 percent area is contained here. Similarly, 34.1 percent area is contained within this 1s, and within this 2s and 1s, 13.6. Since it is symmetrical, same thing is valid.

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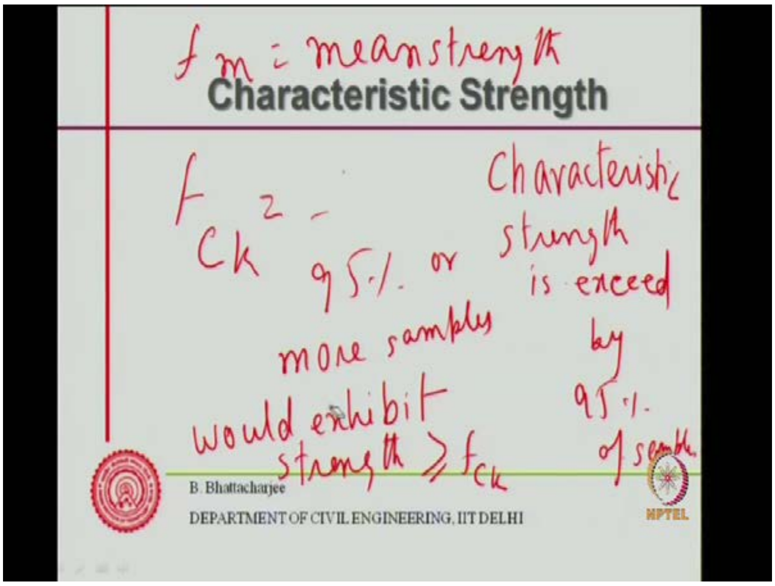

Now, as far as concrete grades is defined, we define characteristic strength. If you remember, we define characteristic strength. How did I define characteristic strength? Characteristic strength is that strength, which is exceeded – is the strength exceeded by 95 percent of sample – strength that is exceeded by 95 percent of the sample. Strength that is exceeded by… Just let me write it. f c k – we denote it by f c k is strength more than 95 percent or more samples would exhibit strength greater than equals to f c k. So, that is how we define.

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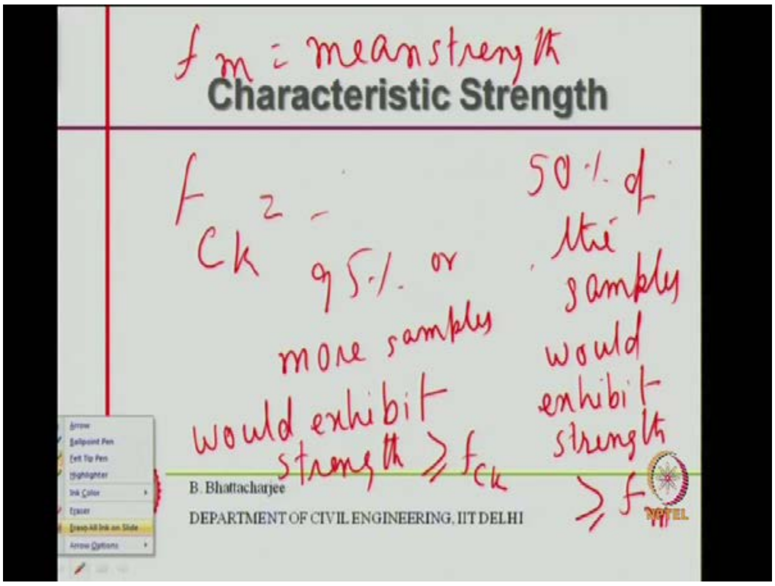

Now, mean strength – if I call it f m as the mean strength – I call f m as the mean strength, 50 percent of the sample will exhibit strength more than f m. So, 50 percent of the samples would exhibit strength greater than equals to f m, because we said mean and median is same. And at median, 50 percent of the samples would show strength more than the median; and 50 percent shows below by definition. Therefore, mean median coincides. Therefore, 50 percent of the samples would exhibit strength more than mean.

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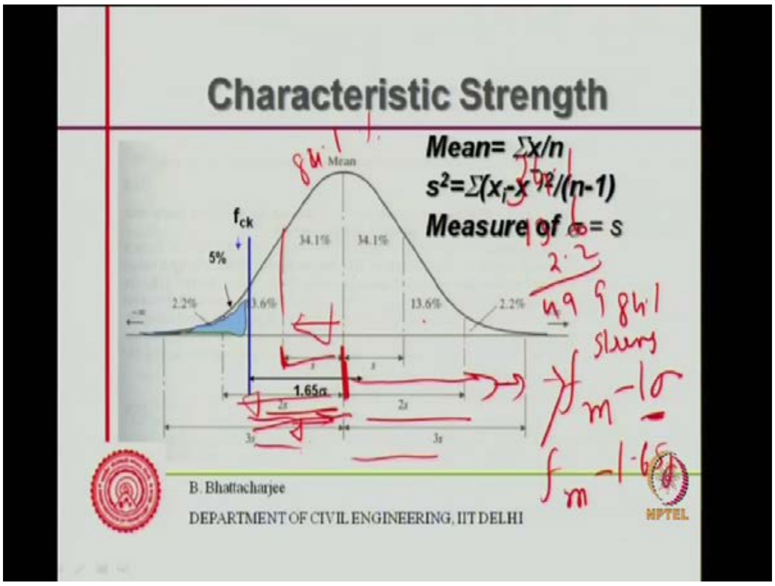

So, if I now go to this curve, this strength will be… 50 percent of the sample will exhibit strength more than this; 34 plus 13.6, 2.4… 34.1, 13.6, 2.2 – if you see, 9; and this is… 49.9 percent. And would show strength more than that… And 49.9 percent or 50 percent will show strength less than this. Now, I want a strength that would be exceeded by 95 percent of the samples. So, it will be somewhere this side. It would be somewhere on this side; it would be somewhere here; it would be somewhere here; f c k is here. 50 percent of the sam… 95 percent of the sample would be showing. For example, you come here; 50 plus 84.1 percent of the samples would show strength more than this. So, for 95, it would be somewhere here. 5 percent of the area would be here and 95 percent of the area would be on this side. So, this is what is f c k. And corresponding to this, we know that this… For example, we have to minus distance, 84.1 percent of the sample would exhibit strength more than mean minus 1s. So, f m minus 1 standard deviation. This strength would be exhibited. 94.1 percent of samples would exhibit strength greater than this. 95 percent of the samples would show strength… This is related to 1 sigma. So, f m minus

1.65 sigma, because from statistics, we know the 95 percent of the area corresponds to 1.65 sigma – 1.65 sigma here. Therefore, 95 percent of the area is on this side. Therefore, f c k is somewhere here.

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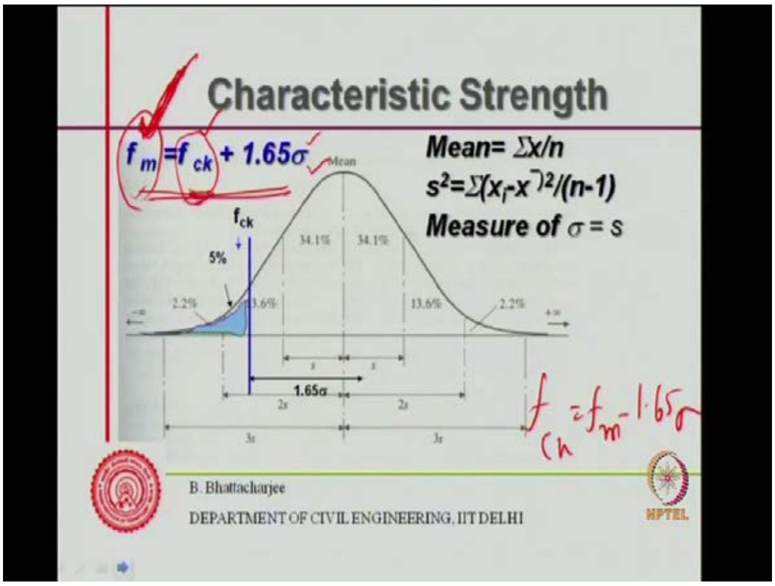

f c k will be equal to f m minus 1.65 sigma; f c k is equal to f m minus 1.65 sigma. Thus, f m is equal to f c k plus 1.65 sigma. This is an important aspect. Therefore, you can see, if the standard deviation is higher, then target mean strength will be high for the same strength, same f c k; same f c k, standard deviation is higher. Mean strength for the same strength grade or f c k; mean strength will be higher if standard deviation is higher. This is an important issue; we shall discuss this sometime later on when we talk of quality control. So, mean strength is related to grade strength in this manner.

Now, while testing or making trial mixes, I can verify this. It is very difficult to verify this. To verify this, I got to test large number of samples, which is almost impossible to do. So, we test small number of samples and get an estimate of f m; which we call as target mean strength. So, we do mix design for f m, because it is possible to get an estimate of f m from testing small number of samples. Let us say 6 samples or 3 cubes, 3 specimens making a sample. Or, number of samples if I test, small number of samples if I test, I can get a measure of f m. But it would be difficult to get f c k directly. So, we design the concrete mix for target mean strength, that is, f m. This will be clear when we talk something about quality control later on. So, we design the concrete for target mean strength, that is, mean strength, because in the laboratory, I can get an estimate of mean strength easily by testing smaller number of samples. If I want to get f c k, I require lot more cubes to be tested from a large number of data. Then I have to establish this curve and obtain this. So, first step in all mix design procedure is to come with a mean strength.

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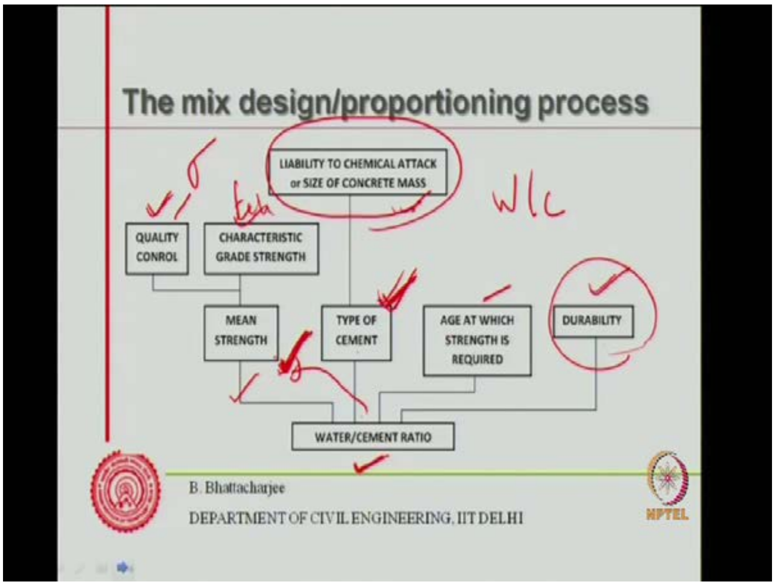

So, mix design procedure first step would be to get a mean strength – mean strength. Characteristics grade strength; quality control, that is, sigma, f c k, and this gives me mean strength. That is the first step. So, we can look into the procedure of mix design. First step is to get the mean strength. Then strength is governed by water-cement ratio. This is an empirical observation; first, by D. A. Abraham sometime during 1920s. And this is still valid. We consider it… If this is acceptable at all level, although there are other kind of approach is available; but generally, strength verses water-cement ratio relationship has been accepted. And it is understood that, strength is largely governed by water-cement ratio. So, in mix design procedure, we have now got the strength. Therefore, we can determine the water-cement ratio.

From the strength, we can determine the water-cement ratio, because water-cement ratio governs this strength; but when all other things remaining constant. So, this all other things involves type of cement based on the chemical, type of cement and age at which the strength is required. This is the other factor. So, age strength and age – both decides water-cement ratio. But we have also mentioned RDR in the previous lecture that, durability of concrete also control through prescription of water-cement ratio depending upon type of cement. Now, for example, if you have an application or else site, where sulphate attack… There is a possibility of sulphate attack. You might use the slag cement or sulphate-resisting cement, where you respect mass concreting to be done; heat of hydration is a problem; you might use low heat cement. So, if you use let us say sulphate-resisting cement, the water-cement ratio for sulphate-resisting cement from durability point of view might be given or must be prescribed in the code. So, use the water-cement ratio prescribed in the code for durability for given type of cement which you choose depending upon the liability of chemical attack or size of the concrete mass.

For example, as I said, if it is a marine environment, possibly, you will prefer a slag cement. And environment, where sulphate attack is prominent, maybe sulphate-resisting cement together with slag cement. Of course, if sulphate and chloride both are there, sulphate-resisting cement is not good. So, once depending upon the kind of chemical attack you are likely to have, you will choose the type of cement. Also, mass concrete, you select low heat cement. If you want quick strength, then you might select rapid hardening – RHPC – Portland cement – rapid hardening cement; Portland Pozzolana cement for low heat for mass concrete and also for better durability; for example, alkali-aggregate reaction, etcetera, etcetera. You might also select low alkali cement if it is alkali aggregate reaction. So, type of cement depends upon liability of chemical attack and size of concrete masses.

Now, water-cement ratio is also prescribed from durability and from strength required at a given age, you find out water-cement ratio. For these two conditions together, durability, type of cement that is used for durability and water-cement ratio prescribed for the given exposure condition, you find out the water-cement ratio; finally, select the water-cement ratio selected from least of the two. First, you see what is the water-cement ratio required for strength, also the water cement ratio required for the type of cement for durability purpose; whichever is lower, you select that water-cement ratio. So, first step in mix design is to find the mixed mean strength; second step would be to find out the water-cement ratio. These are conventional mix design. Most of the mix design method follows this method. Second step would be to find out the water-cement ratio. First is the mean strength; water cement ratio from the mean strength and durability concerns for the given type of cement; and age at which the strength is required.

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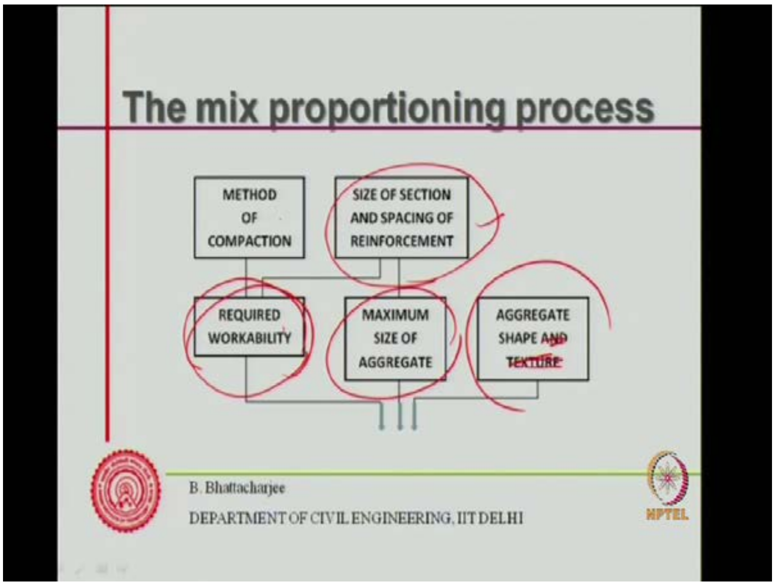

Then, followed from this water-cement ratio being known, second step; third step would be to determine the water content or paste content. You see method of compaction, size of the section and spacing of reinforcement. See method of compaction decides workability. Size and spacing of the reinforcement also defines workability; that is what I said; which is specified normally. So, required workability specified from method of compaction; the section itself and spacing of reinforcement. And then this workability is controlled by maximum size of aggregate and aggregate shape; not really texture much, but shape – mostly the shape. Remember, when we discussed about aggregate, we said that, maximum size of aggregate reduces, improves the packing density; rounded aggregate or aggregate shapes improved the packing density. And therefore, the amount of workability or mobility, mold-ability required for concrete; which is a function of the paste content. So, the paste content would govern the workability. That is what we mention in the previous class. From the required workability, type of aggregate, maximum size of aggregate and aggregate shape, etcetera, etcetera including grading of aggregate, we can determine the paste content.

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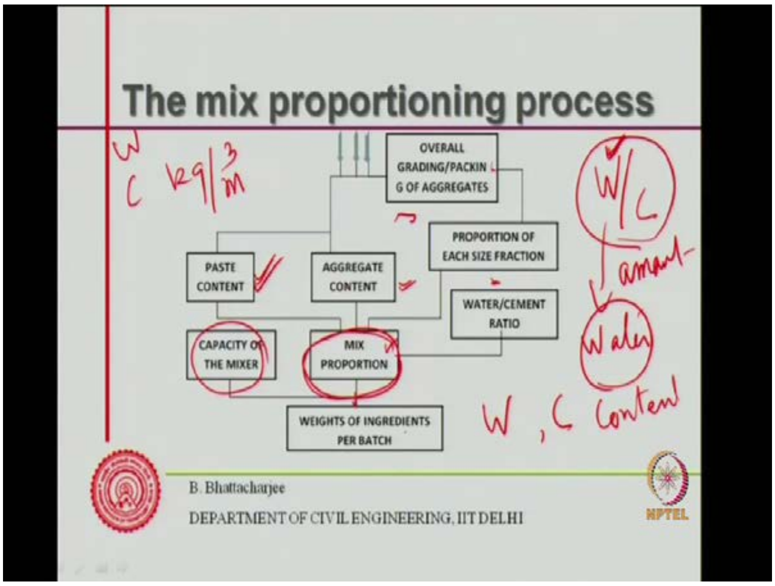

So, overall grading and packing – packing of aggregates, we can determine the paste content; and also, either the paste content or the water content of the mix, because water-cement ratio being fixed, if I chose water, amount of water; if I fix the amount of water, cement content will get automatically fixed. So, most of the mix design method, what do they do? Based on the workability requirement, maximum size of aggregate, shape of the aggregate and overall grading determines the water content, which essentially ensures a required paste content. If I know the paste content, if I know the water content; then obviously, I can find out cement content. And if I know the cement content and water content in one, all the contents, cement content, water content – these are all expressed in terms of mass per unit meter cube of content. So, in unit volume of concrete, how much of water, how much of cement I need – that I can find out.

First, I find out the mean strength; corresponding to the mean strength, I find out the water-cement ratio and also look at the durability part of it. Whichever controls the water cement ratio, from that, I fix the water-cement ratio. Then if I can fix the water content, I have got the cement content also. The water content is fixed from… Water content per meter cube of concrete is fixed from workability, maximum size of aggregate, shape of the aggregate and overall grading. In fact, that governs the paste content required, because the packing would be depended upon the grading per proportion of the sizes, relative proportion of the sizes and also shape and maximum size of aggregate. So, this will depend the packing.

And, depending on the packing characteristics or packing density of the aggregate, the paste content required for a given workability would be… Paste content required will govern the workability. So, if I know the workability, I can actually find out paste content. But most of the… Many mix design method, what is does? They fix the water content, because automatically, water-cement ratio being known, paste content will be controlled. Therefore, once the paste content is known; or, in other words, water content, cement content is known in k g per meter cube, rest of… If I know the total density of the material, then I can find out… With density of the material, I can find out the aggregate content. Or, if I know the total volume is one meter cube; if I no volume of these two component, rest of the volume is the aggregate content. So, total aggregate content. Therefore, simultaneously, I can find out.

And, if I know proportion of each size fraction, aggregate content; then I can find out mix proportion; that is, every size fraction I should be knowing. So, water-cement ratio is come from RDR. Paste content and aggregate content being known, proportion of the size being known, I can find out the mix proportion. Then I use this; knowing the capacity of the mixture, I find out weights of ingredients per batch. So, that is the overall mix proportioning process or mix design process as conventionally it is called. But actually it is… Truly speaking, it is actually mix proportioning; that is all we are doing. Design is conventionally used. Perhaps it is more appropriate to call it mix proportioning process. So, this is the overall mix proportioning process.

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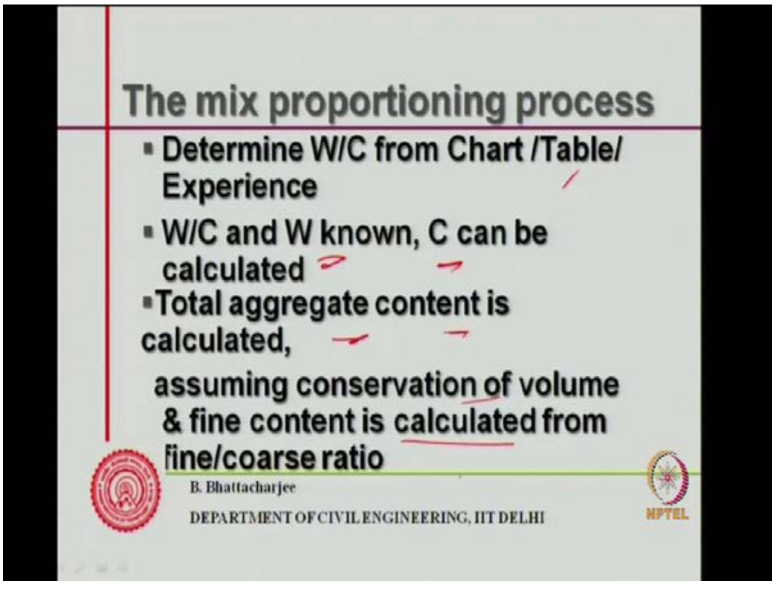

To look at it again, first, determine the water cement ratio from chart to table. This will be from Indian code of course. But let me method just see; overall process looks like this. And total aggregate content is… Determine the water-cement ratio. So, if you look at overall process, we determine water-cement ratio from chart table or experience depending upon the method. Water cement ratio and water content being known, cement content can be calculated. Total aggregate content is then calculated assuming conservation of volume; and fine content is calculated from coarse to fine ratio.

Let me look at it again. First is the target mean strength. Then determine the water cement ratio depended upon the strength from chart table or experience and use durability criteria also. Next step would be water-cement ratio known. Many times you determine the water content from some other table; C can be calculated. And then total aggregate content is calculated, because W and C is known. Rest of the material I can find out. That is the aggregate content. Volumetrically, volume proportion aggregate can be calculated. If I assume that, sum total of all volume will be 1 meter cube. So, that is conservation of volume. And fine content is calculated from coarse to fine ratio, which dictates by packing. So, that is the procedure.

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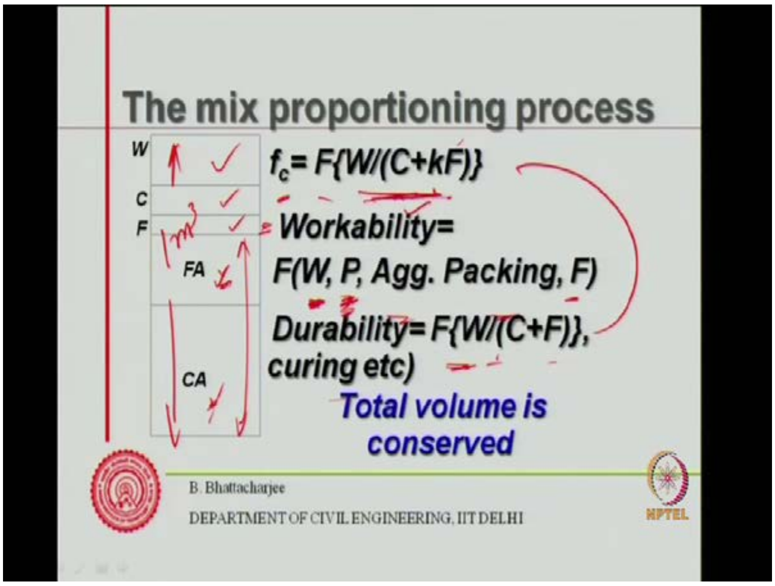

Just to repeat it again, you see this is water; this is cement. It could be fly ash or some other cementitious or filler material or some other supplementary material or mineral admixtures, whatever you call it. This is fine aggregate and coarse aggregate. The strength is a function of water cement or water to cement plus fly ash maybe. It has some factor. So, effective fly ash or effective equivalent cement for fly ash or any other materials, cementitious material. So, water to cementitious material ratio, equivalent cement content, equivalent water-cement ratio; workability is a function of water content; plasticizers if you are using any; aggregate packing characteristics; and also, the filler or fly ash content. So, if I know this, I can find out the paste content. This is the basic idea. Then durability is also function of water to cement ratio and curing, etcetera and cement content. So, based on this concept, first, we find out this; then we find out this in many cases.

Of course, this we do. First, we make a control mix; then we modify this mix with this one. And finalize the water-cement ratio based on these two criteria. And then usually, total volume is conserved. Then therefore, sum total of all materials must be equals to 1 meter cube. So, if I have found out cement, fly ash and… This is equal to 1 meter cube. So, if I have found out cement, water and fly ash, this volume I can find out. And if I know the proportion of these masses and their specific gravities; so this (( )) also I can find. So, that is the overall mix proportioning or mix design process. Now, having gone through the general process of mix design that is used by most of the methods that is used, we can now go to specific method like Indian method.

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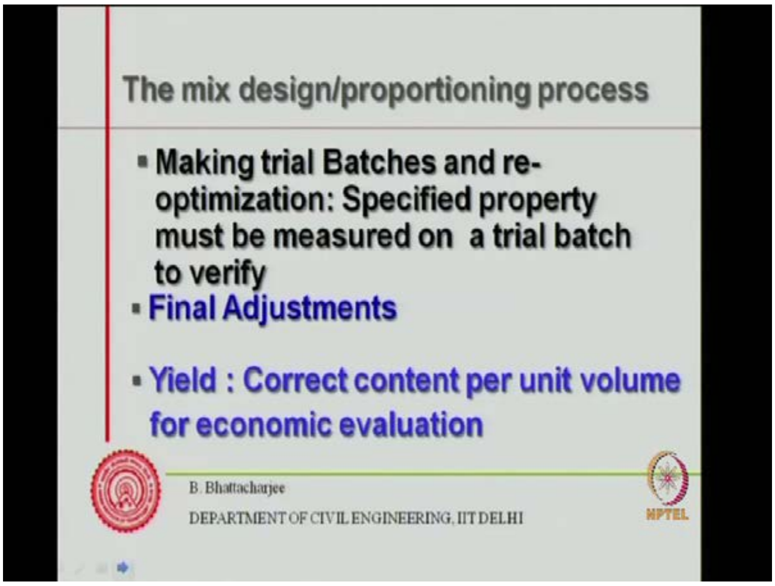

Obviously, in all cases, you have to make trial batches and you have to reoptimize this. Although, specific properties like strength, slump, etcetera should be measured for a batch and verify that you have got it. And if you have not got it, then redo the trial. So, finally, the thing is that, it is final adjustment would be needed. And then you find out the correct content per unit volume for economic evolution. How much quantity you require for 1 meter cube of concrete – final 1 meter cube of concrete? Therefore, that goes for calculating the co-stress, etcetera, etcetera.

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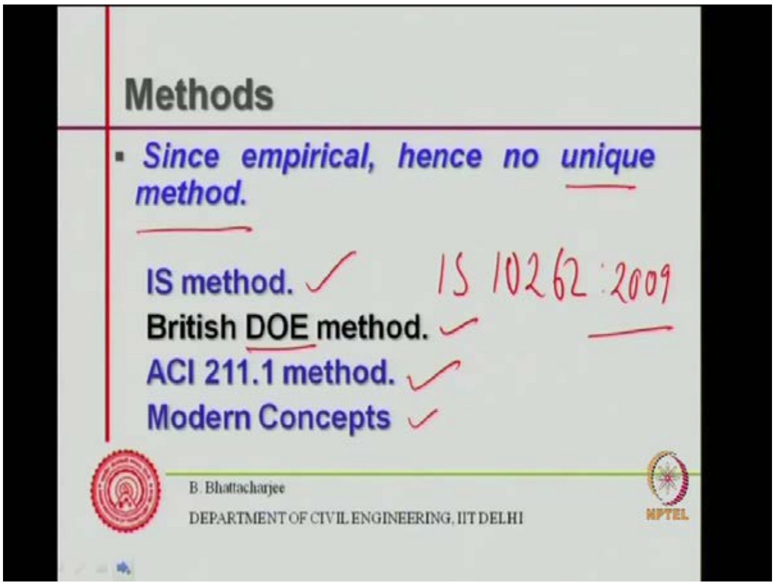

Now, since we said that is empirical and there is some amount of art involved, hence, there is no unique method. We have seen a general procedure that is adopted by most of the methods. But it is all empirical. We can see that. Actually, strength… First we find out from the grade strength and the standard deviation, find out the target mean strength. Up to this, there is no problem. But after that, we find out the water-cement ratio from tables, charts, etcetera, etcetera or from experience. And finally, of course, you have to do the trial mix. So, the method is purely trial and error, laboratory based and empirical in nature.

Then, you find out the water content again from tables and charts, etcetera. And then only I use the concept of conservation of volume to find out the total aggregate content in some manner; we will see that. Actually, here the different method differs a little bit. And if you know the fine to coarse proportion for the packing characteristics or the grading requirement, then you can find out the fine and the coarse aggregate, component of the mix also. So, it is purely empirical. Hence no unique method; no unique method. Method to method differs. And therefore, you have got Indian standard method: IS 10262; yesterday, I mentioned; class lecture I mentioned. Current one is 2009. And then we will discuss also about British DOE method. It is not there in the code, but department of environments – this department of environment method; then ACI method and some modern concepts. That is what we will discuss.

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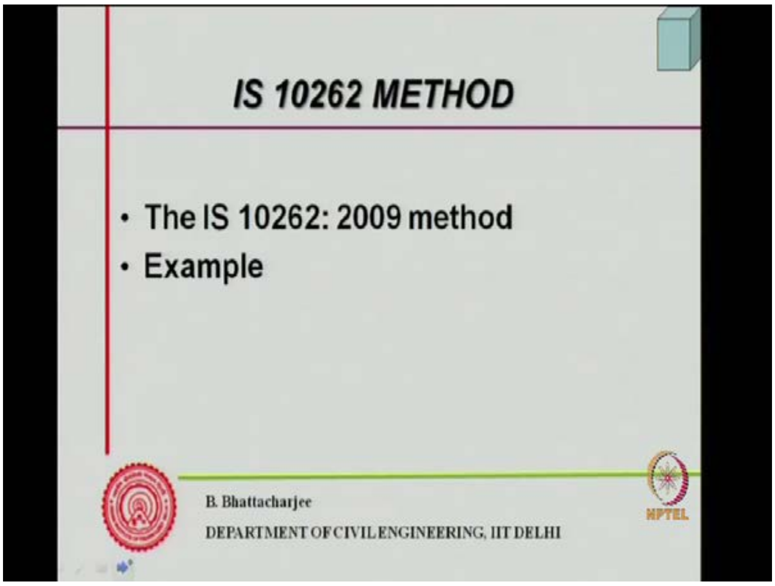

To start with, we will start with the IS method today and follow up with the other methods. We will do an example in the next class.

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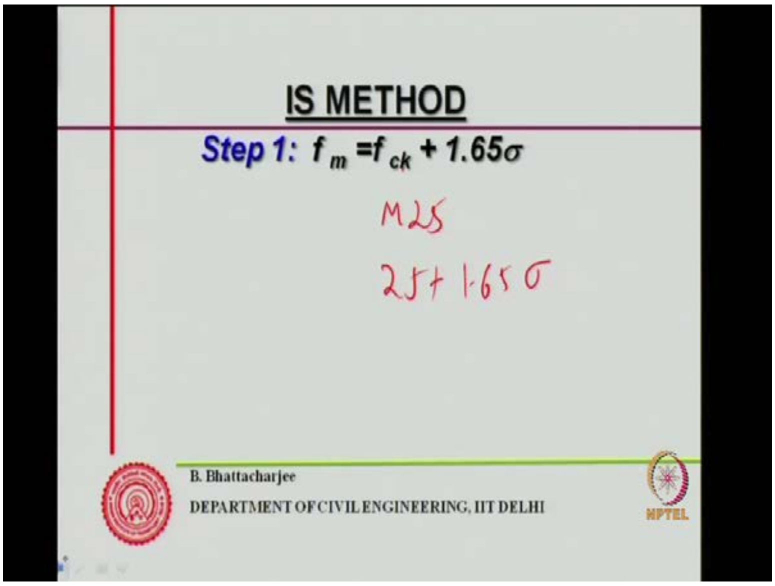

But let us see IS method now. First step is find out the mean strength. And this is the formula. So, if you have 25 grade of concrete is M 25; so it will be 25 plus 1.65 into standard deviation. The standard deviation would not be known to one in the beginning.

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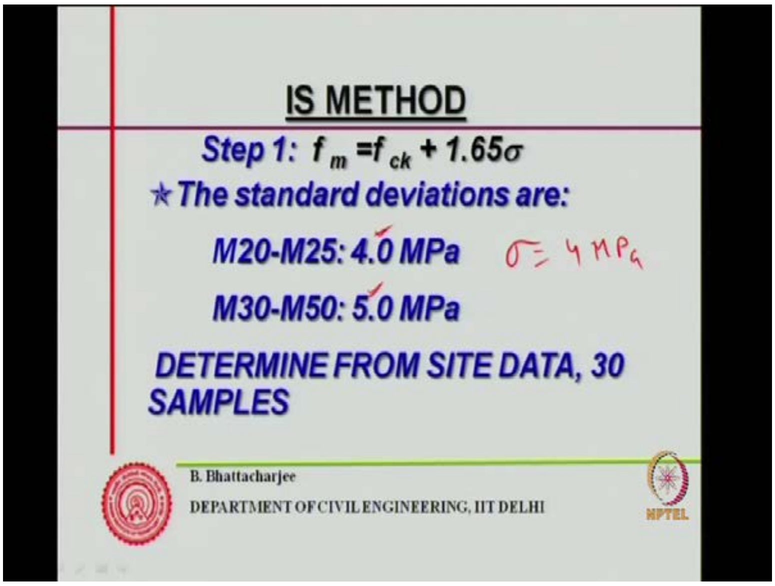

But, once you have done some trial casting, then standard deviation would be known. So, the code says, the standard deviations – it gives you some guidelines to start with from 20 to 25 grade of concrete – M20 to 25; use 4 MPa and sigma. Sigma equals to 4 MPa. For 30 to 50, you can assume it to be 5 MPa to start. But determine this from side data as soon as 30 samples are available to you, because it could be less or it could be more; it could be more or less; this could be more or less. And in such case, the mix design proportion that you are giving is not correct, because it will not give you the right strength. So, determine it as soon as possible from thirty samples. That is the first… However, you calculate out f m.

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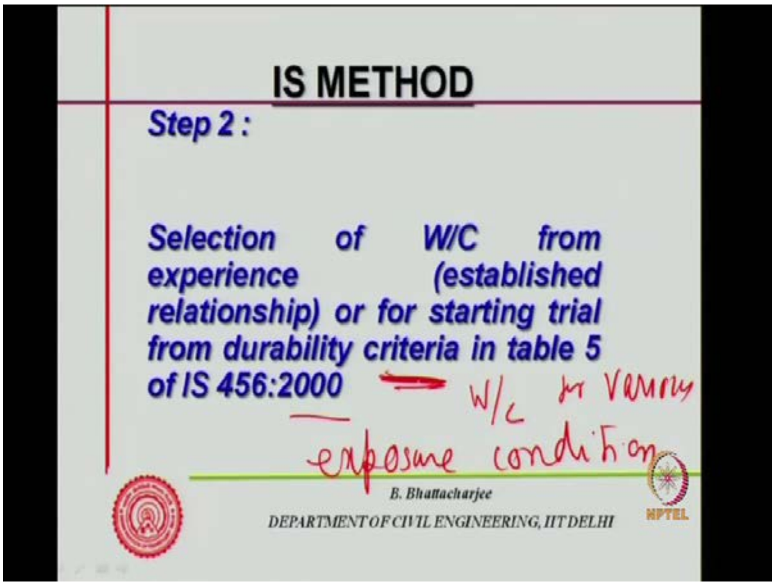

Then, it says you determine… Step 2 – determine the water-cement ratio; selection of water-cement ratio from experience or establish relationship. Now, if you have already done a lot of mix proportioning with the same aggregate, same sand, same cement and same kind of material altogether; then possibly, from your experience, you choose it is M 20 grade of concrete; I need a water-cement ratio 0.55. M 50 – possibly, I need water-cement ratio 0.35 and so on. So, from experience, it can come. If you have nothing, no experience, then go to the IS 456:2000 durability prescription, which gives you water-cement ratio for various exposure condition. Anyway you cannot violate that; you cannot violate that.

For example, if the maximum water-cement ratio prescribes 40 or exposure condition 0.45; and from strength, you find out to be 0.48, you will be always using 0.45. So, your starting trial can be durability criteria. Durability criteria – we will discuss this when we talk of durability of concrete sometime later on. So, durability criteria – this is given in the IS 456: 2000; table 5 I think. So, from that, you can choose the water-cement ratio if it is… You do not have any experience. First time you are using the material and things like that. So, trial – first trial you can use that water-cement ratio. So, it has become actually a simple thing, not complicated, because in any case, you cannot water-cement ratio more than the durability requirement. You can have something less.

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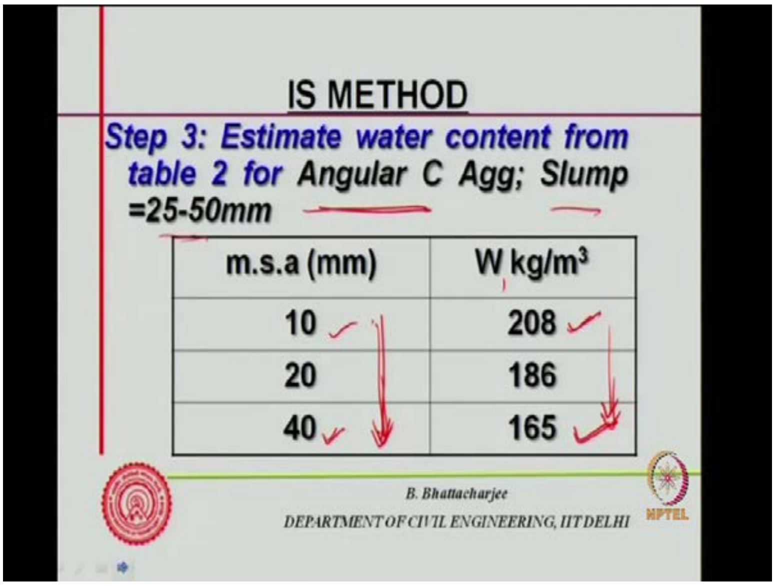

Step 3 – it gives you a table from where you can estimate the water content. This table is meant for angular coarse aggregate and slump 25 to 50 millimeter. For other cases, you apply correction factors. So, you have got maximum size of aggregate – 10 millimeter; then the water required is 208. If maximum size is 40, water required is 165. For angular coarse aggregate and slump, 20 to 50 millimeter. Now, this one can understand. As the aggregate size m s a increases, the packing improves. So I will require less paste. Therefore, less water. Water reduces, because with larger m s a, I will require lesser paste. That is what we have understood when we talked of aggregate in the previous module – previous-to-previous module. So, packing characteristics improves if I increase one more size. And therefore, here compared to this, I have increased two more sizes. So, water content required is less. So, water in kg per meter cube for m s a 20. So, this is the first starting table. But this is meant for angular aggregate and slump 25 to 50 millimeter. But if I have then rounded aggregate and different slump, then I use a correction factor.

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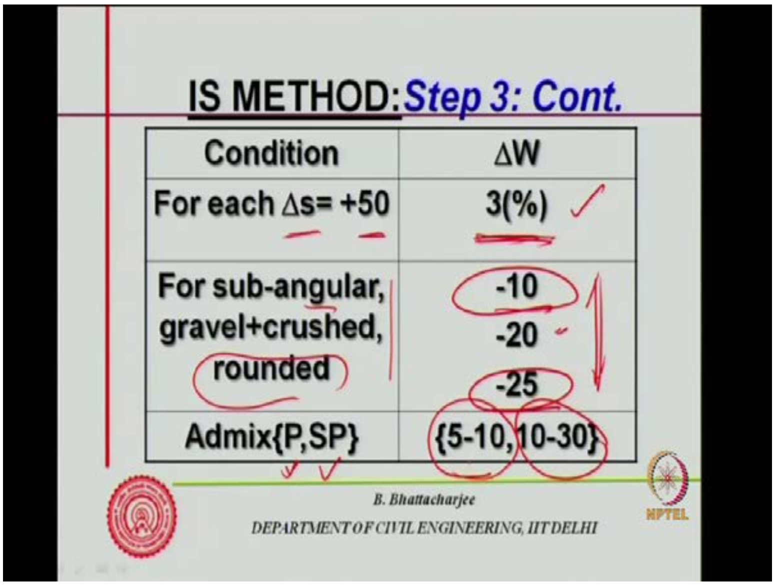

The correction factor is same step continued. I am trying to determine still the water content. For each additional slump, additional slump of delta… 50 plus additional… So, this was 25 to 50. If it is 50 to 70, I mean, 100; then I had increased the water content by 3 percent. So, if you require more slump, you already increased the water content, because paste content you have to increase and workability, is a function of paste content or water content as such also will give you better flow. Now, if you have… That was for thrust aggregate; that was for… If you look at it, that was for angular course aggregate. They did not say thrust; in our code, it is angular.

Now, if you are better shape, for example, sub-angular; then you reduce the water by 10, because sub-angular packs better than angular. And if it is rounded, you can reduce it by 25. So, whatever water you have got, first, this correction; if you have higher slump at 3 percent for each 50 mm increase in slump; and reduce the water content depending upon the shape of the aggregate. If it is gravel and crushed mixed together, then minus 20; sub-angular – minus 10; completely rounded aggregate – minus 25. If you are adding a plasticizer, you can reduce down this water by 5 to 10 percent. And if you are adding a super plasticizer, you can reduce it by 10 to 30 percent.

And, in the last module, we talked of plasticizers and super plasticizers. We have discussed super plasticizers can reduce the water up to about 30 percent; while the dosage is also high in case of super plasticizer; and plasticizer – dosages are less; up to

0.6 to 2 percent is for super plasticizer; and plasticizer dosages are less and it reduce only about up to 12 percent we said. IS code allows us to reduce the water by 5 to 10 percent. So, the water content you can reduce in this manner or increase. Therefore, corrected water content you are able to find it out. That is step 3.

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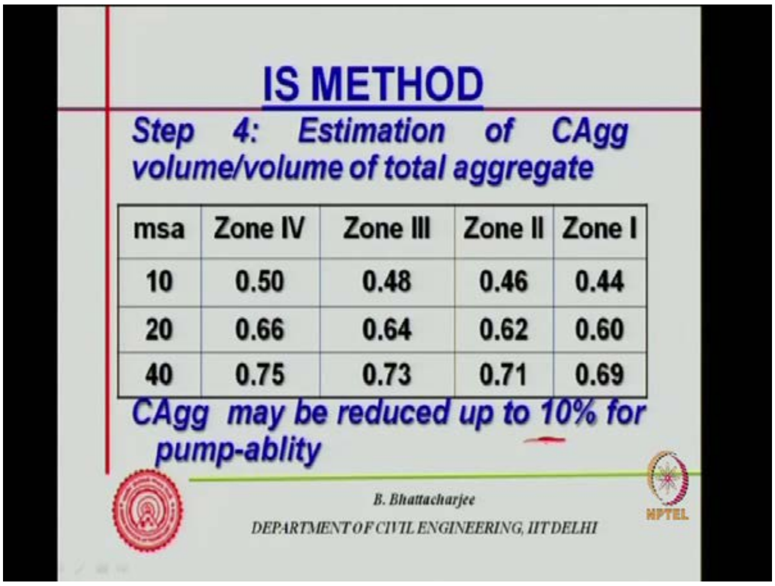

msa	Zone IV	Zone III	Zone II	Zone I
10	0.50	0.48	0.46	0.44
20	0.66	0.64	0.62	0.60
40	0.75	0.73	0.71	0.69

Step 4 – estimation of coarse aggregate volume from a table. And this is… The table looks like this. Depending upon the sand, which we said was… When we were talking of aggregate, we talked of zone 1, zone 2, zone 3, zone 4 sand, which is very fine; this is coarse. So, depending upon the size fraction of the sand or size of the sand, in Indian code, IS 383 classifies the sand depending upon their particle size distribution. Courses sand is zone 1. Zone 2 sand is less coarse; zone 4 is very very fine compared to zone 1. So, depending upon that, the coarse aggregate content would… per unit volume would depend upon that, because packing characteristics would change. For example, this is fine sand. Therefore, coarse aggregate volume would 50 percent of the volume of the total aggregate, will be coarse aggregate; rest 50 percent is fine. Whereas, here it is 44 percent, because you will have better grading; and within this… 44 percent is here.

And, it will also depend upon m s a. Higher the m s a, you can use larger proportion of volume proportion of aggregate. They will have less void in the system. This… They will have less void in the system. In this, they will have less void in the system. And in this, use more coarse aggregate, because fine aggregate – there some materials are missing; some of the larger size will be missing. So, that is filled in by fine aggregate, the sand itself. So, this direction – it increases, because you can use more amount of coarse aggregate, because they will have less voids. If you keep the same voids, this will have… If you use 75 percent, it will have lesser voids in them for the given sand. And as the sand becomes coarser, then this required coarse aggregate volume reduces. So, using this table, you can find out the coarse aggregate volume, per unit volume of total aggregate.

Now, with all this information known, one more additional factor is that, if you are using the concrete for pump-ability, you should reduce the coarse aggregate by 10 percent, because you know coarse aggregates are not pump-able. So, if you want to improve the pump-ability, you must reduce down the aggregate content – course aggregate particularly. And coarse aggregate should be reduced; you should have more mortar to make what is called saturated in pumping situation. Make it more mortar; and mortar should have adequate amount of paste or more paste in pump-able concrete. So, 10 percent aggregate is reduced in case of pump-able concrete.

In another concrete, which is self-compacting, does not require vibration, aggregate content. Coarse aggregate content is even lesser. So, in pump-able concrete, actually, more paste should be flow-able and there is a paste, which flows. So, if you put sand, mortar itself will be flow-able; aggregates are not really pump-able as such. So, that should be less. And they should be embedded in the mortar system rather than just mortar being filling up the voids in the aggregate system and slightly more. Now, aggregate should be embedded in the mortar system. And that is why you have less aggregate – coarse aggregate content in pump-able concrete.

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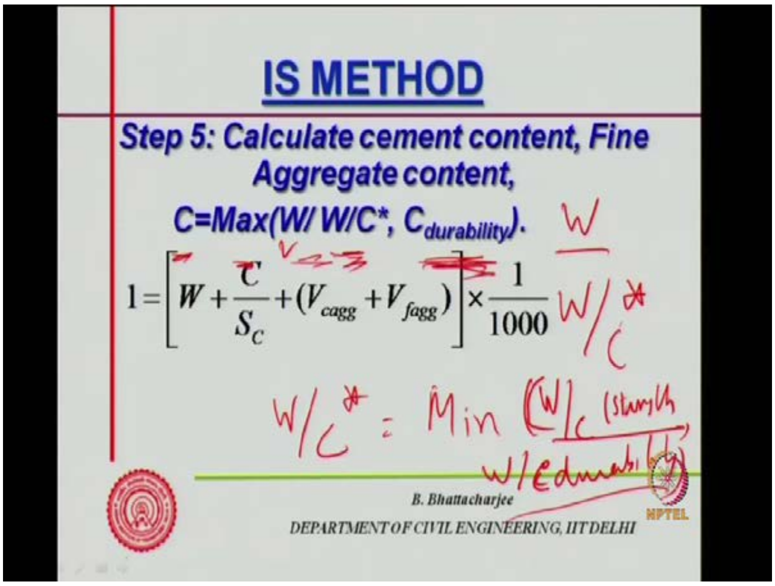

So, what we have got so far, we have determined water-cement ratio; we have determined water content; corrected it accordingly (( )) slump, type of aggregate, m.s.a, etcetera, etcetera. So, I have got water content; target mean strength, water-cement ratio, water content. Therefore, I need to know also the cement content, because water cement ratio is known. And then I know the volume fraction of the total aggregate in the overall aggregate system; volume section of coarse aggregate in total aggregate system. So, once this is known, first thing I do is I find out the cement content, which will be the maximum of water by water-cement ratio. This is known to me now.

And, this is also known to me – water-cement ratio. And C is specified for durability in the code. So, IS 456:2000 – in its table, it gives you C for durability, whichever is greater; either you find out by W divided by W by C; where, W C star is the one which you are using. This will give you cement content; or, C for durability; whichever is greater, you use that. Water-cement ratio – of course, you find out as water-cement ratio; star is equal to minimum of W by C strength comma W by C durability; whichever is lower, you use that; whichever is lower, you use that. So, W by C strength – that you find out from table. And W by C durability – that you have found out from either used… Found out… Or, maybe if you are using a starting criterion, it will be from there.

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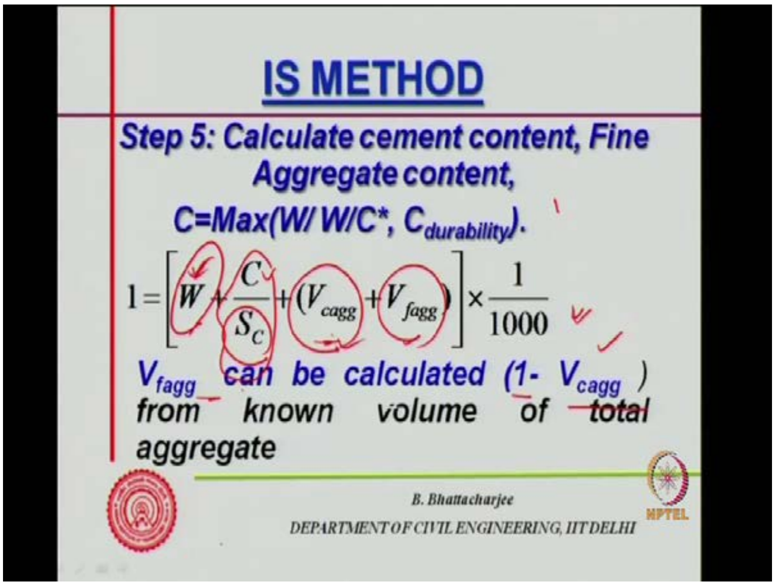

Then, using this formula, that is, volume water divided by 1000, because specific gravity of water is 1000 kg per meter cube. So, water content divided by 1000. Cement content divided by specific gravity of cement divided by 1000; that is, the volume of cement in 1 meter cube; volume of water in 1 meter cube. This is the volume of coarse aggregate in 1 meter cube; and volume of coarse aggregate in 1 meter cube divided by 1000. Anyway, now, this volume can be calculated. Volume of fine aggregate can be calculated, because we know the volume fraction of coarse aggregate from the previous table. So, 1 minus that will give you the volume content of fine aggregate and total, because the total this volume is the sum total of this volume in each individual volume can be calculated, because volume of fine aggregate is equal to 1 minus volume of coarse aggregate, because we have found out the fraction from the previous table.

From this table, we have found out… From this table, we have found out the proportion of coarse aggregate in the total aggregate volume. So, volume of fine aggregate we can find out. And once sum total of all these volume must be equal to 1; there is no air content in this code now. So, no anyone of them is known; one unknown I can find out, because both can be converted in terms of 1 minus V cag’s equal to V fagg. Therefore, this can be written in terms of this and I can find out the total proportion of all, because this is known; this can be calculated out; this can be written in terms of this; this can be written in terms of this; and I can calculate out this one. So, all proportions are known to me. And with all proportions known to me, I can actually now get the complete mix proportion.

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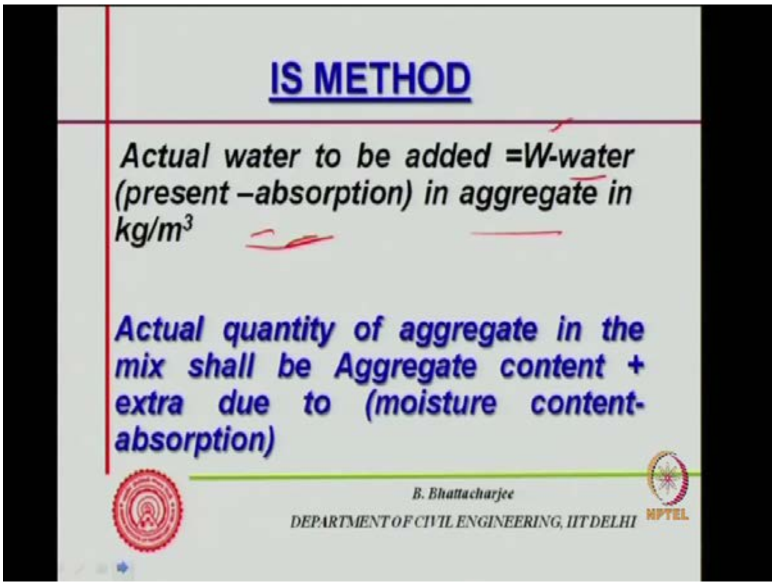

Actual water to be added at the site will be the water that I have calculated minus the water that is present in the aggregate. Now, present minus absorption, because SSD condition I am considering. So, what is required for SSD condition – that I must subtract. So, some correction is needed at the site, because there will be some moister present in the aggregate. And accordingly, I must should do correction such that it is in SSD condition. Similarly, actual quantity of aggregate in the mix shall be aggregate content plus the additional requirement, because there will be some moisture in the aggregate. So, this will be clear when we look into the next example.

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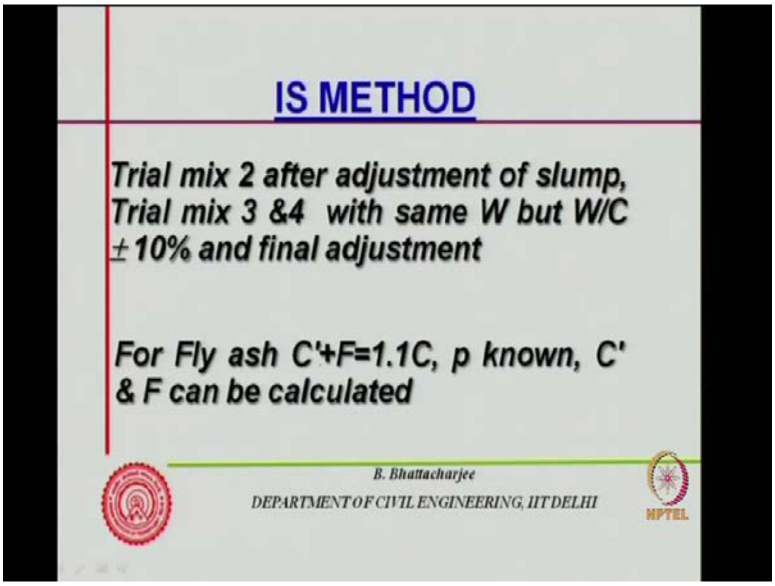

And then trial mix 2 after adjustment of slump; maybe trial mix 3 and 4 with same water. But water-cement ratio plus minus 10 percent and final adjustment. So, for fly ash, you can increase the overall cementitious material by 1.1 C; and C and F dash can be calculated.

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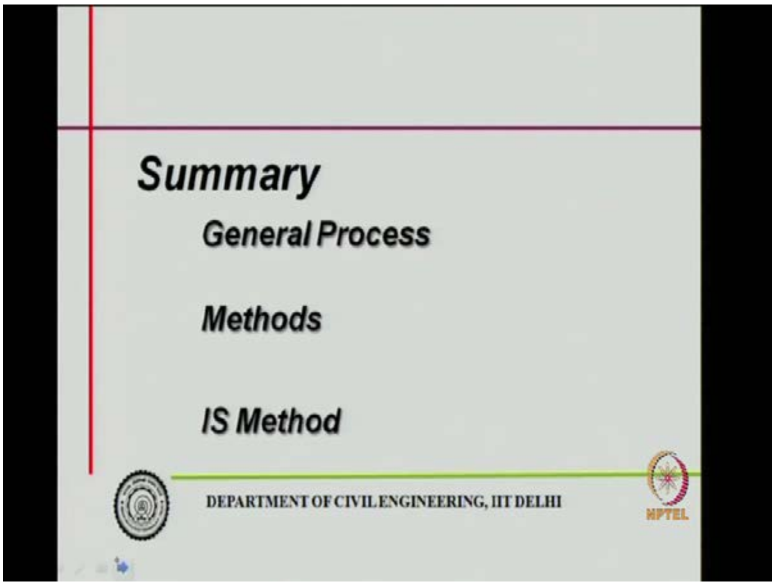

This is… So, with this, we just complete this. Next class, we will start from the same one, the same last end of this particular lecture. And we have discussed about so far general process, we mentioned up methods and we have also discussed about IS method.

So, from the correction of IS method, we will start and go through an example, which will make IS method completely clear. And then in the next lecture, first, we will go through an example, discuss about DOE method.

Thank you very much for your hearing.