Concrete Engineering and Technology
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Lecture - 7
Proportioning of concrete mixes (Part 1 of 3)

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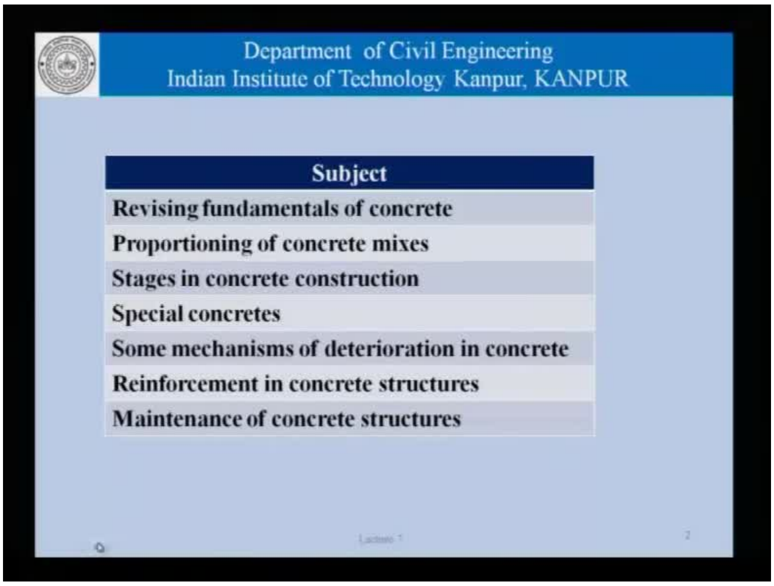

And welcome back to this course on concrete engineering and technology, where we are trying to work with revising the fundamentals of concrete proportioning of concrete mixes, concrete constructions, special concretes, mechanisms of deterioration, reinforcement in concrete and maintenance of concrete structures.

Now, having completed our discussion of the revision of fundamental concrete, let us begin the exercise of proportioning of concrete mixes. In the previous lectures or discussions, we have covered the basic ingredients of concrete; that is cement, fine aggregates, and coarse aggregates. Then we have also covered the basic properties of fresh and hardened concrete, in terms of workability which is largely measured in terms of slump and compressive strength, which could be measured using cylinders or cubes depending on the a misspecifications or the countries in which we are working.

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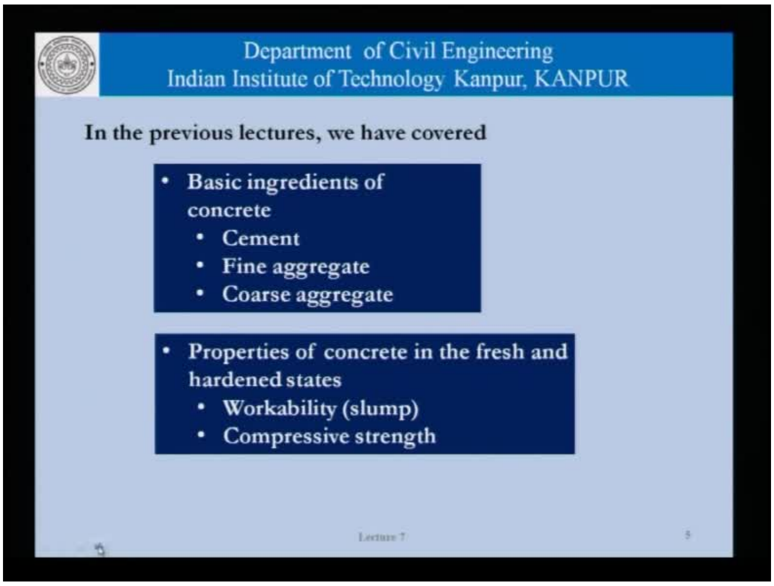

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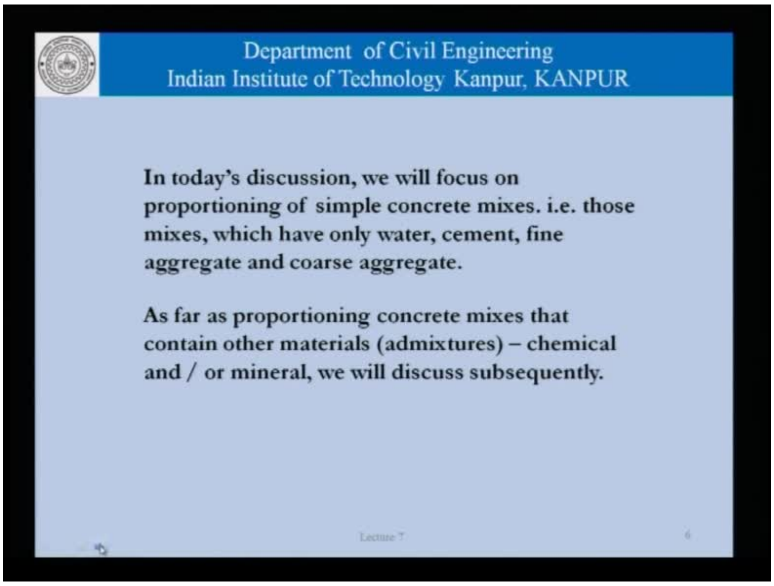

Now, in today's discussion now beginning today's discussion, we will focus on proportioning of simple concrete mixes, that is those mixes, which have only water cement, fine aggregate and coarse aggregate; that as we have always asserted in this course is the basic concrete. As far as proportioning of concrete that contain other materials, which is admixtures whether they are chemical or mineral or combination of both that subject will be taken up in a subsequent discussion.

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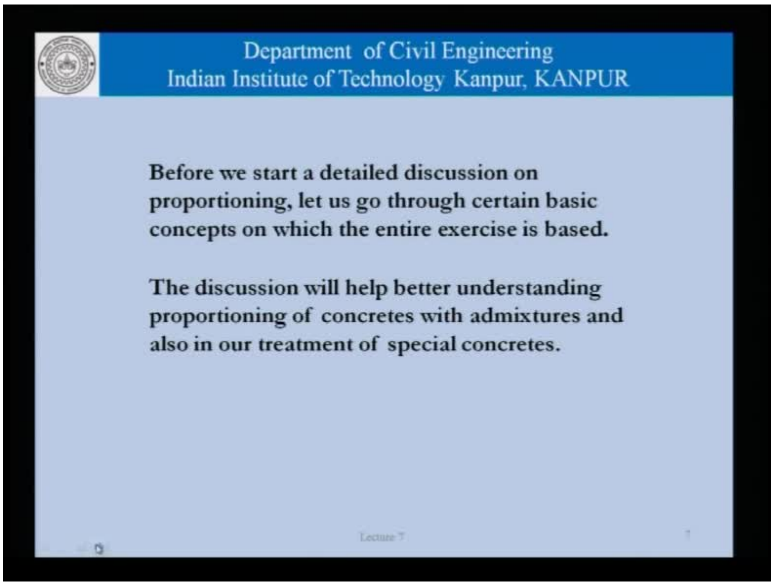

How and before we start detailed discussion on the proportioning of concrete mixes, let us go through certain basic concepts, fundamental concepts on which the entire exercise of proportioning concrete mixes is based.

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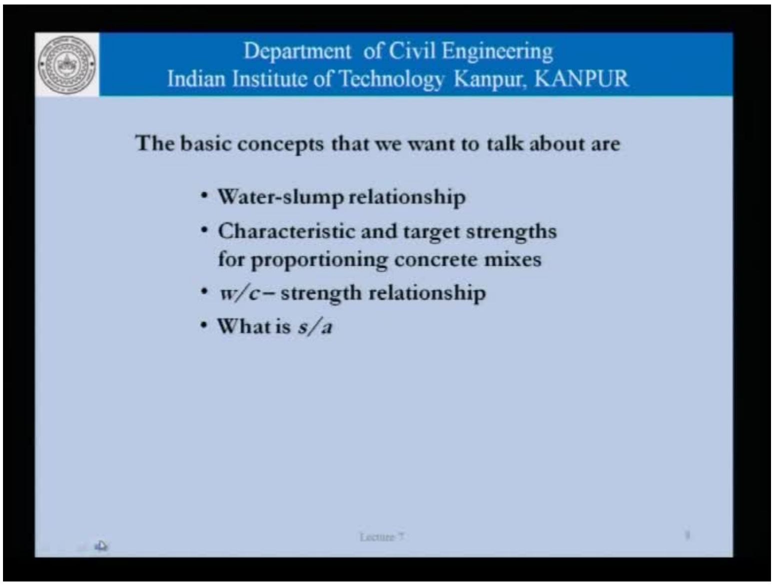

This discussion will help us better understand the proportioning of concrete with admixtures. Also in our treatments of special concretes in subsequent discussion and the basic concepts, that we want to talk about in the discussion today are the water slump relationship. What is the fact of water content, the unit water content that is the k v's of water but cubic meter of concrete on the slump of concrete? That is how water content affects the slump or for the given slump, how we determine the water content?

Then we will talk about characteristic and target strengths for proportioning of concrete mixes. Characteristic strength is what the designer basis, his discussion or his design on. He wants, the designer wants the concrete structure, that designer wants the concrete in a beam or a column or a slab to have a certain characteristic strength and he basis is design on that strength. A concrete engineer or person whose responsible for providing that concrete at site make sure that the, characteristic strength is obtained and for that he uses a target strength for the designing of those mixes.

So, we have a characteristic strength and target strength and we use both of these to proportion concrete mixes. Then we talk about the water cement ratio versus strength relationship water cement ratio is the primary factor, which effects the strength of concrete. We have seen that when we are talking about the properties of concrete. Now, how this strength is affected that is something which we must have a clear picture on and we will revise that concept today. Another concept that we need to look at very carefully is that of s by a. Now, what is s by a? We will talk about it later in this discussion today, but in principle it is the saint component of the total aggregate. So, the concrete comprises of cement, water, fine aggregate and coarse aggregate. So, the fine aggregate and the coarse aggregate together are the inert materials in the concrete mix.

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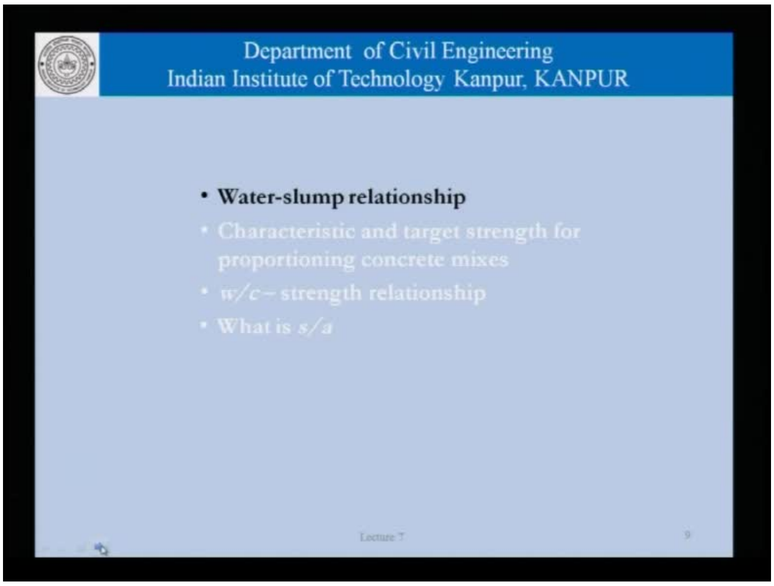

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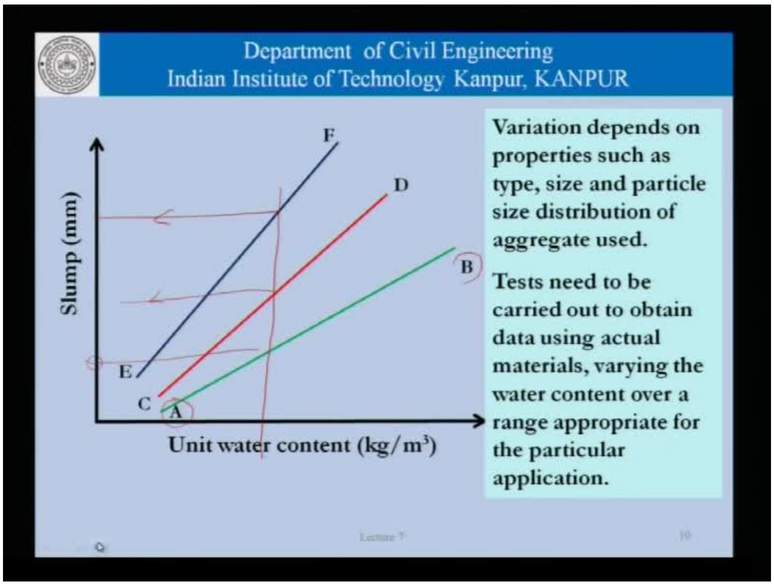

Now, among that inert materials what is the proportion of sand? That is the fine aggregate that parameter is s by a. Now, let us begin our discussion with the water slump relationship. If we keep on increasing the unit water content as show here from something like a to b, it can be expected that the slump which is measured in millimeters, will keep on increasing and the simplest way to represent that relationship is by a straight line as shown here.

Now, this is not a unique straight line and the line or the variation between slump and the unit water content could be a b or it could be c d or it could be e f. Now, what determines for a given unit water content, what determines this slump that we will obtain? Whether we will obtain something like this somewhere here or we will obtain something like this here. Now, what determines this slumps value? This variation depends on the type of aggregate, the size of the aggregate, the particle size distribution that we use, as far the aggregation is concerned, for aggregates which are smaller, we may expect that certain amount of water will give you a certain amount of slump. If the aggregate size becomes larger, then for the same slump we may require a same water content and so on.

So, even though in principle, it can be said that the slump water content relationship is largely linear. The variation actually depends on the type size and particle size distribution of the aggregates used also and the type of cement used the properties of the cement and so on. We need to carry out tests to obtain actual data using the actual material at site to determine the unit water content for slump relationship, for a given material set. We need to varying a water content over certain reasonable range to get the kind of slump, that we get for a particular material which will be used at a particular site.

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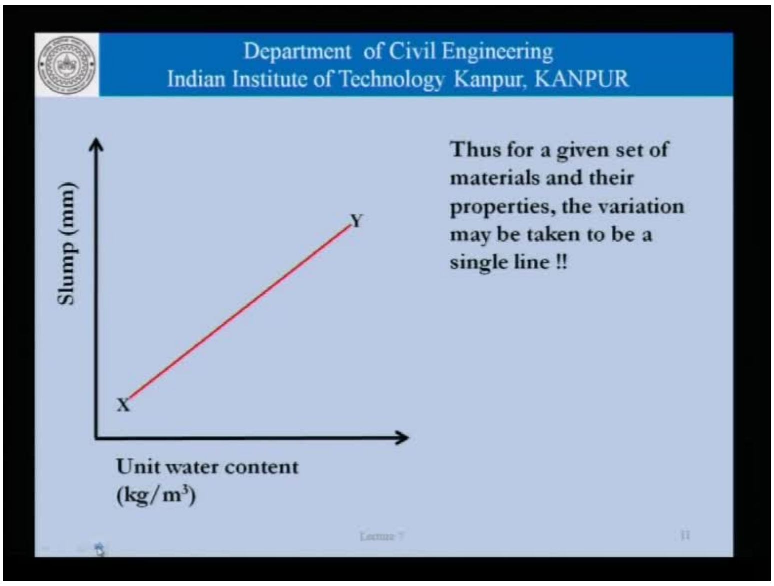

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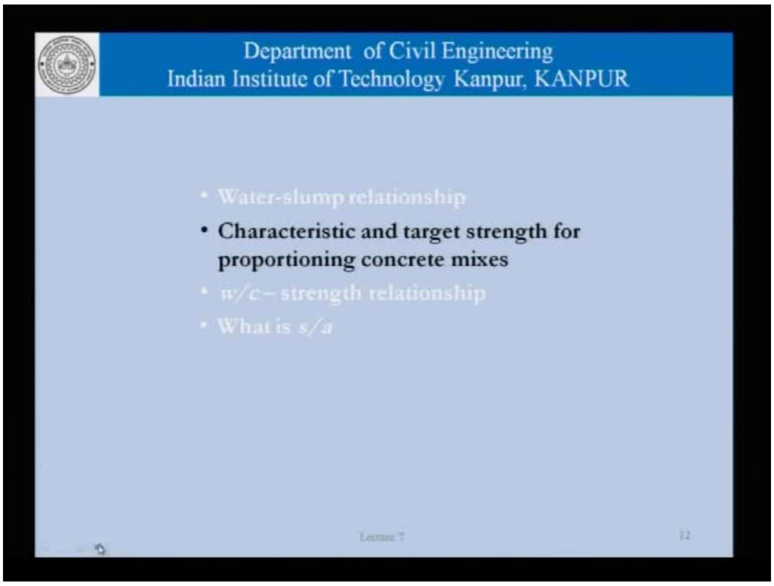

What can we said, therefore is that for a given set of materials and their properties the variation will be taken to be a single straight line, which is given here as x y coming to the second thing, which is the characteristic strength. The target mean strength, which is useful or which is required when we have proportioning concrete mixes.

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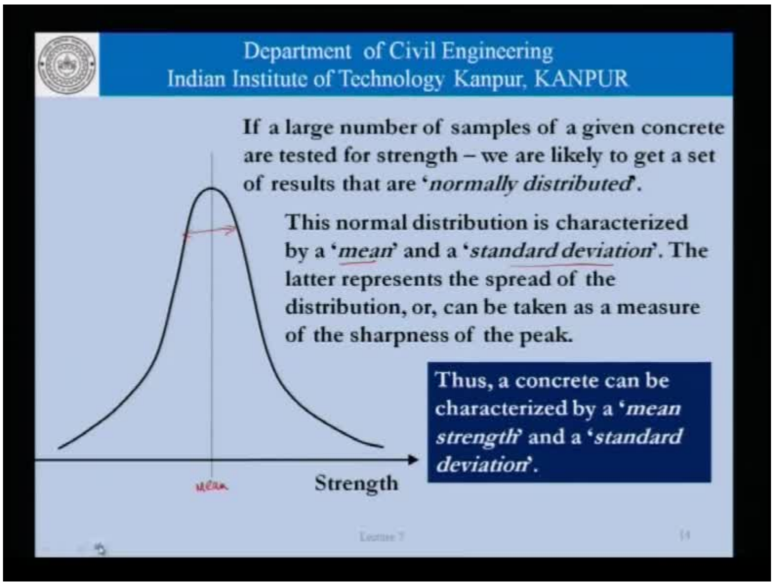

If we test large number of samples of concrete, what we will get is the results will be normally distributed, that is for the different cubes or cylinders. That we test the strength will not be a single unit value, it will vary in a manner. That will give certain average and certain standard deviation, which is what is associated with a normal distribution and I am not getting into the details of statistics, the normal distribution is what is largely assumed and let us leave it at that.

This normal distribution as I said is characterized by a mean, so this is the mean of the normal distribution and a standard deviation, which essentially represents the spread of the distribution. It can be measured or qualitatively understood in terms of the sharpness of the peak of the distribution. So, these two parameters the mean and the standard deviation, they characterize a normal distribution that is the statistics. What we are saying is that if we test large number of concrete cubes, we will get a strength distribution, which is normally distributed. That is that strength distribution, we will have a mean and a standard deviation, which you can determine using a knowledge of statistics. That is what I have said a concrete can be characterized by a mean strength and the standard deviation.

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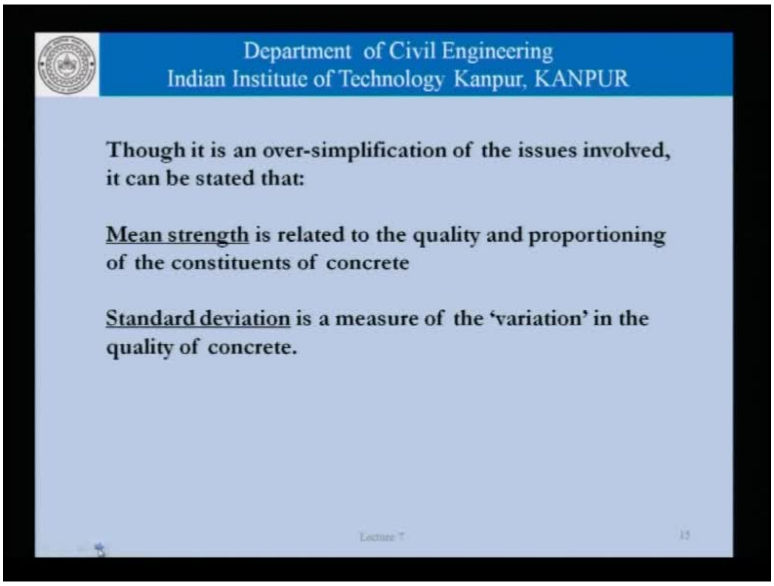

Though it is an over simplification of the issues involved, it can be stated that mean strength is related to the quality and proportioning of the constituents of concrete. Standard deviation is a measure of the variation in the quality of concrete. See the concrete strength is determined by the quality of the meta material that we have used, that is cement, fine aggregate, coarse aggregate and each of these materials has its own variation. We will not get the cement, which is exactly identical all the time. Similarly, we will not get the fine aggregate and the coarse aggregate, which is exactly the same all the time.

We keep changing over time that is from time to time for a given site, it will keep changing. Not only the properties of the raw materials, effect the strength of concrete, but it also dependent on the proportioning. How much cement, how much water, how much fine aggregate, coarse aggregate, has been put into the concrete mix? So, the mean strength is largely determined by the quality and the proportioning of the constituent of concrete. Standard deviation is a measure of the variation of the quality.

So, if we have a site or if we have an experiment where the properties of cement the vary over a large range, then what we will be expect we will expect that the strength of concrete also shows a much larger spread. It will also be spread over a large range of values that is the standard deviation will be larger. Similarly if the proportioning depending on how we are carrying it out, if the balance that we use or any other method that we use to measure the cement, measure the fine aggregate, coarse aggregate, if that measurement changes because of whatever reason over a period of time, we will again get a variation in the strength of concrete. That variation is understood in terms of the standard deviation.

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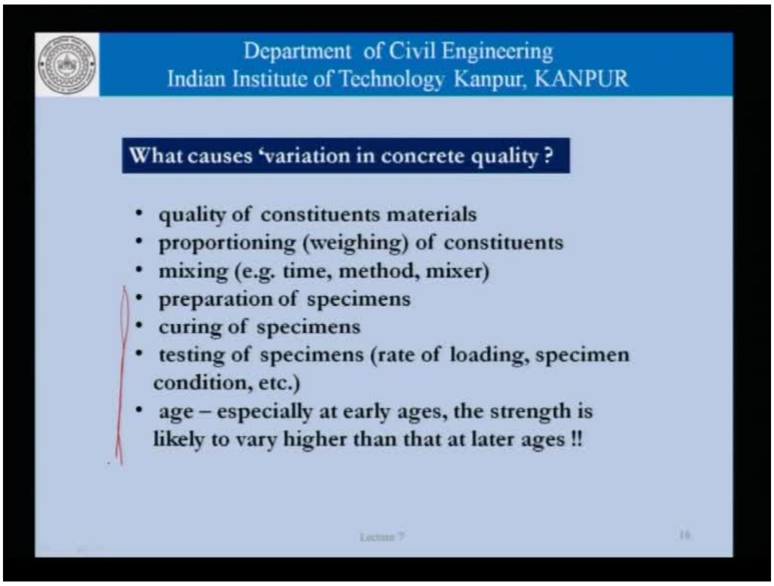

So, it is an over simplification, but we must remember or we can say that the mean strength is related to the quality and proportioning of concrete mixes of or of the constituent of concrete. We can say that the mean strength is related to the quality and proportioning of the constituent of concrete and standard deviation is a measure of the variation in the quality of concrete. I have listed some parameters, which cause variation in concrete quality, it could be the quality of constituent of materials, it could be proportioning, which is weighing of constituent, it could be mixing. For example, the time the method, the mixer, if we mix a certain concrete mix, let us say for one minute.

Another concrete mix for one and half minutes, it is likely that the extent of mixing the extent of homogeneity, which is achieved is different and that will affect the strength of concrete it will not affect the strength of concrete to the extent. That it will become very noticeable and change the mean of the concrete mix the mean strength of that mix, but it is it may be sufficient to cause some amount of perturbation, which will be measured in terms of the standard deviation. Preparation of samples, we prepare samples; that is cubes or cylinders and how we prepare them?

How many layers do we fill the concrete in? Whether, we vibrate each layer, whether we vibrate the entire specimen, the method of vibration and so on. All this effects the strength of concrete as determined from that particular specimen, curing of specimens. Usually specifications require that the concrete is stored under water, what is the temperature of that water misspecification give you certain ranges? Now, within that range what is the actual value and so on. The testing of the specimen that is the rate of loading specimen condition specimen is tested.

After it is taken out from water, whether the specimen is tested while it is wet or is it allowed to dry out and so on. At what rate is the load applied to this specimen? Whether we are using load control or displacement control machines? What is the stiffness of the machine that we are using to determine the strength of concrete? All these parameters will cause a small perturbation in the extent or in the strength that we determine, from one specimen to another. Each especially at early ages the strength of concrete is likely to vary much more than at later ages.

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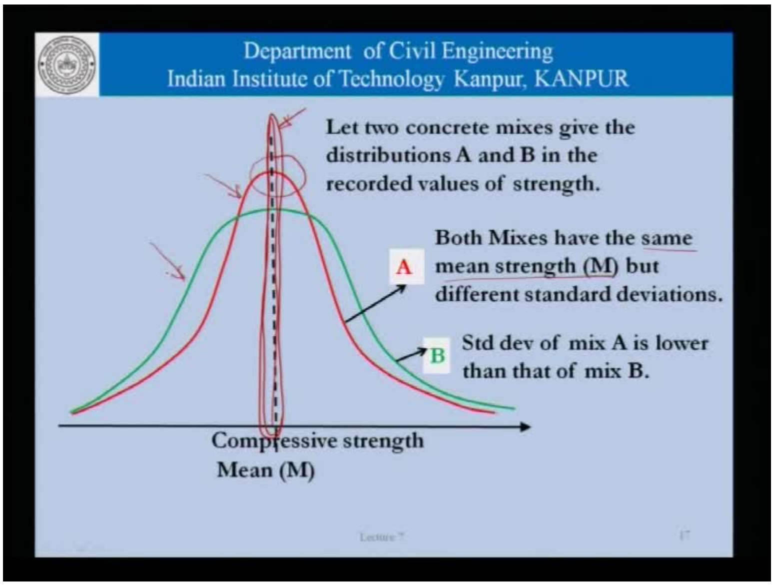

So, all these issues which cause variation in concrete strength are addressed in a misspecification or in a test method, where it is said that well we will test specimens which are prepared in a certain manner at a certain age queued in a certain manner and so on and so forth. But having said all that it is virtually impossible to ensure that all those conditions we will be met all the time, for any project or any concrete construction. All this needs to the variation in concrete strengths. What happens therefore, is the situation like this, there are two concrete mixes which give distributions A and B in the recorded values of strength.

Now, what can we say about the mixes A and B? What we can say is that both mixes have the same mean strength M, that is their strength distribution that we get is distributed above the same mean, that is more the mixes have the same average strength. But having said that the standard deviation of mix A is lower than that of mix B, how do we say that? Because the peak that we get here in the case of mix A, is sharper, in the extreme case for example, if there is absolutely no variation in the strength of concrete or very little variation in the strength of concrete, what do you expect will happen to this distribution that we are plotting?

We will get in the extreme case, a situation where all the time we are hitting, this mean value and there is no deviation. That is the absolutely extreme case of no standard deviation, no deviation, absolutely repeatable quality of concrete. That does not happen and therefore, from this extreme or ideal condition, we come down to the mix A, which shows a certain variation and the mix B, which shows a variation which is more than that of A. Therefore, we can say that the standard deviation of B is higher than that of A. We can calculate these numbers through knowledge of statistics and proceed further.

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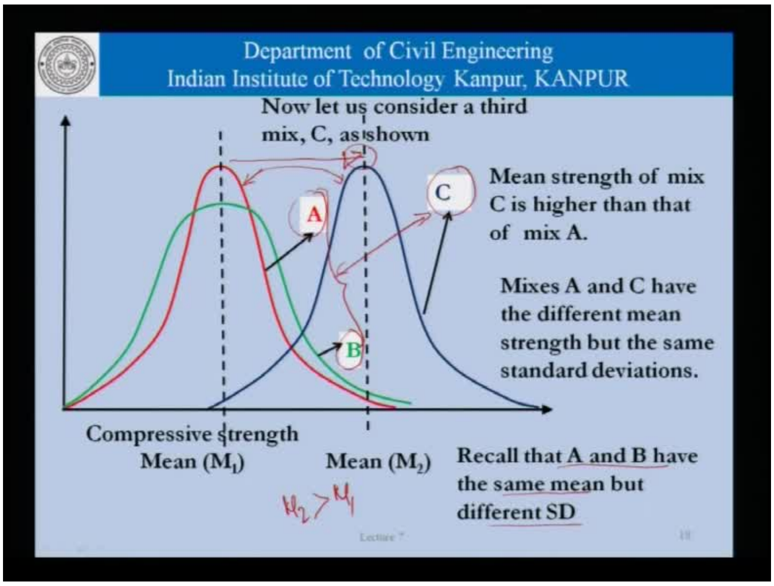

Now, let us consider the another mix, C. Now, what can we say about the mixes A, B and C? The mean strength of A of C, that is this mix is higher than that of A or B. So, what has happened to the C is that we have something whether we have change the proportions, whether we have change the quality of material or whatever we have done, what we have achieved is a higher strength.

That is the mean M 2 is greater than M 1, but mixes A and C have virtually the same standard deviation. The way I have plotted it this standard deviation and this standard deviation is virtually the same. We should recall that we have already discussed enough, we stating that A and B have the same mean, but different standard deviation. That is as far as A and B is concerned and now we are comparing A and B with C and that is what we get from here.

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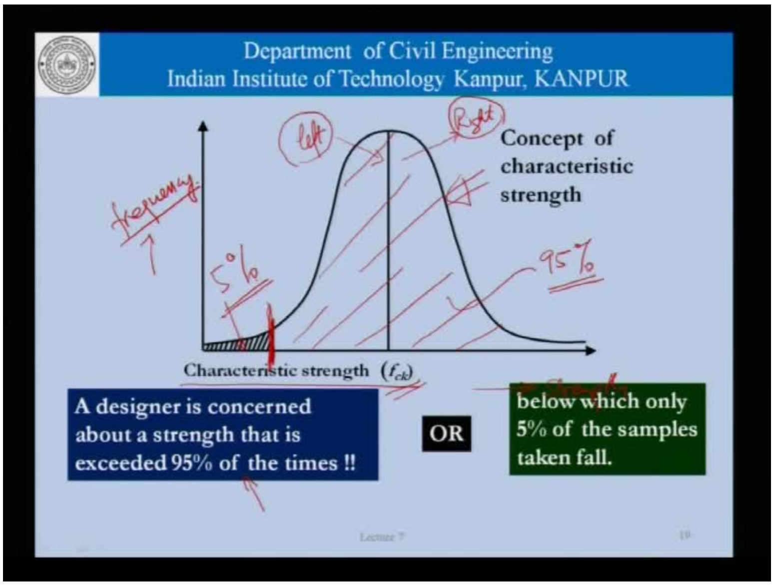

Now, let us try to understand the concept of characteristic strength. So, far we have discussed how the strength of concrete will vary and how we will try to understand the variation in concrete strength, the mean strength and the standard deviation. Now, what are the concepts of characteristic strength? If we plot this, this access is strength and this is frequency. So, if we plot a given variation of concrete strength, then characteristic strength f c k that is the normal symbol that designers and concrete engineers use to address characteristic strength is a strength which is somewhere here.

Now, what is special about this particular value? A designer is concerned about a strength that is exceeded 95 percent of the times or below, which only 5 percent of the samples taken from what we are saying is the following. If this is the variation, that we get then fundamentals of statistics, will tell you that the number of specimen is to the left of the mean that is the number of specimens, which are falling below the mean. The number of specimen falling to the right of this mean that is those specimens, which show a strength, which is higher than the mean that will be the same that is 50 percent of the specimens are more than the mean 50 percent are less than the mean. These are the properties of the normal distribution itself.

Now, given the fact that concrete strength varies and assuming that it varies in a normal manner a designer is concerned with a strength here, such that the strength that we get from the distribution is such that this area here is 95 percent or this area here is only 5 percent. 5 percent of the cubes or specimens fall below the characteristic strength or all allow falling below the characteristic strength and 95 percent should exceed the characteristic strength, so that is the whole concept of characteristic strength.

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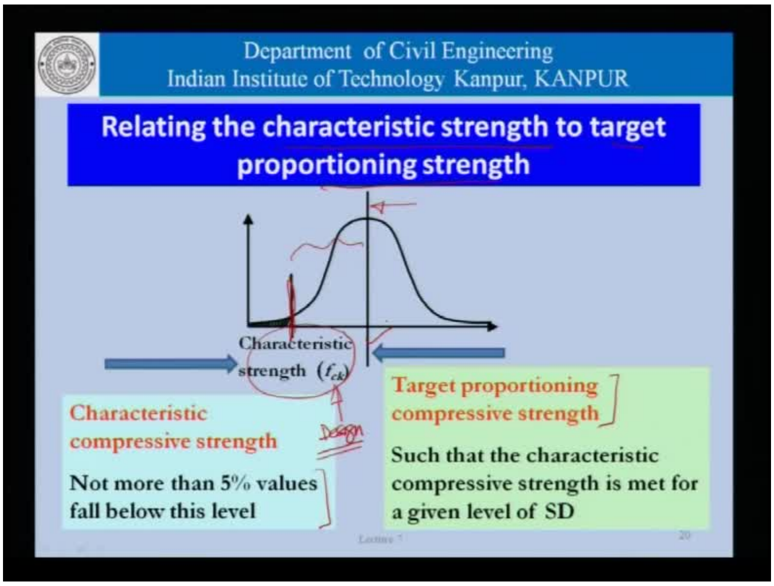

So, the designer has to ensure that for as his design calculations are concerned or the designer carries of the design process in a manner, that whether it is a beam or slab or a column or wall whatever it is he’s assuming that the strength of concrete in that particular element or in that particular member will be higher than the assumed characteristic strength, 95 percent of the time.

Now, how that is implemented in terms of quality control quality assurance and so on? That is a slightly different matter and we will take it up subsequently. So, once again now let us try to understand, how to relate the characteristic strength to the target proportioning strength in order to get this characteristic strength? That is the strength below, which not more than five percent of this specimen are allowed to fall. A designer works with a target proportioning compressive strength, such that the characteristic compressive strength is met for a given level of standard deviation.

So, basically what we do is or what we need to do is that we need to have the characteristic strength value and we should target our proportioning exercise that is the concrete should be proportioned in a manner. That it gives you a mean strength, which is much higher than the characteristic strength. Now, how much higher should that be depends on the standard deviation, if the standard deviation is very small? Then we can proportion a mix, which is having a mean strength pretty close to the characteristic strength.

On the other side if the standard deviation is large or the expected standard deviation is large, then we need to proportion a concrete mix in a manner that that the mean strength or the average strength of that particular mix is much larger than the characteristic strength. So, this is something which we must keep in mind that as far as the designer is concerned, the whole design exercise is concerned is based on the concepts of characteristic strength and the risk of being repetitive. I will once again say that the characteristic strength is the design basis for concrete structures.

I had the strength which is exceeded 95 percent of the times, the mean strength here is the strength of the concrete mix for c average strength of that mix. That is higher than the characteristic strength by an amount, which is determined by the standard deviation, which is likely to be faced at site. Like I have stated earlier, the standard deviation is related to the amount of quality control or the extent of quality control that we have. If we have very good quality control on our materials proportioning exercise testing and so on, we will have a low standard deviation, if we do not have a very good quality control system in place we have a larger standard deviation.

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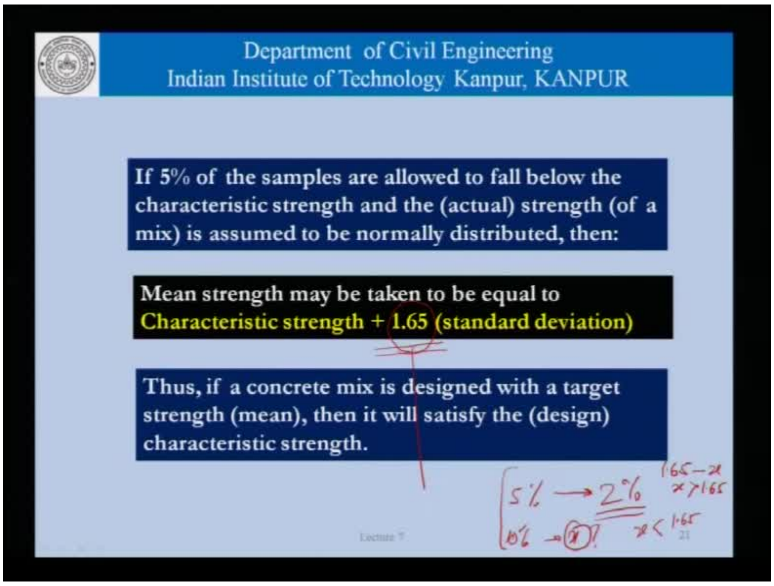

Now from statistics, if we have 5 percent of the samples being allowed to fall below the characteristic strength and the actual strength of the mix is assumed to be normally distributed, then the mean strength can be taken to be equal to characteristic strength plus 1.65 times the standard deviation. Thus if a concrete mix is designed with a target strength, which is the mean target strength or the mean strength of that concrete mix, then it will satisfy the design characteristic strength. Where does this factor 1.65 comes from?

It comes from the property that the strength is normally distributed and the fact that only 5 percent of the specimens or the values are allowed to fall below the characteristic strength. If that value of 5 percent was to be reduced to 2 percent that is we have a a structure being constructed, where we do not want more than 2 percent of the specimen tested to be below the characteristic strength. What will happen to this factor? 1.65 will become some x, which is larger than 1.65. Similarly, if we have a structure where we allow for whatever reason more than 5 percent to fall below the characteristic strength, 10 percent. If we allow 10 percent of the specimen tested to be below the characteristic strength.

Then what will happen to x? x will become less than 1.65 and this discussion you can see when you look at table of the normal distribution and I am leaving that as an exercise for you to do your own and see how we get this factor 1.65? How this factor one 1.65

changes? If we allow the value of 5 percent to vary, so may get 2 percent may get 7 percent, 10 percent and so on.

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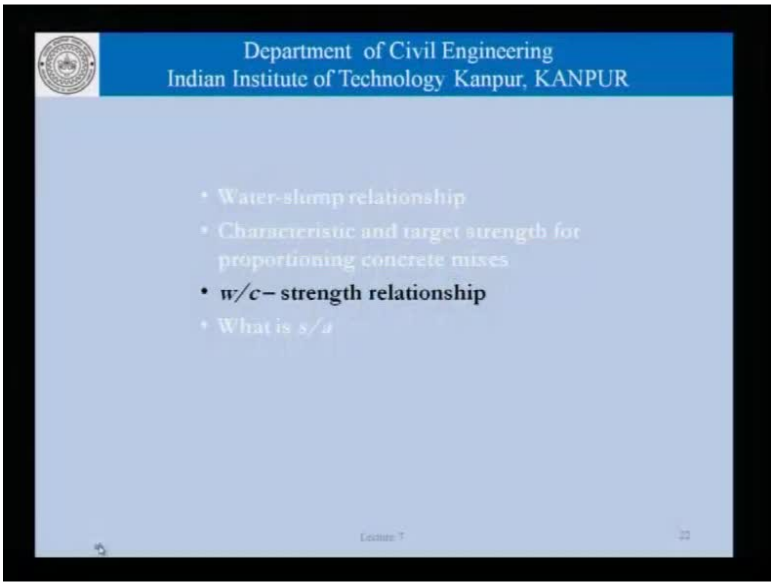

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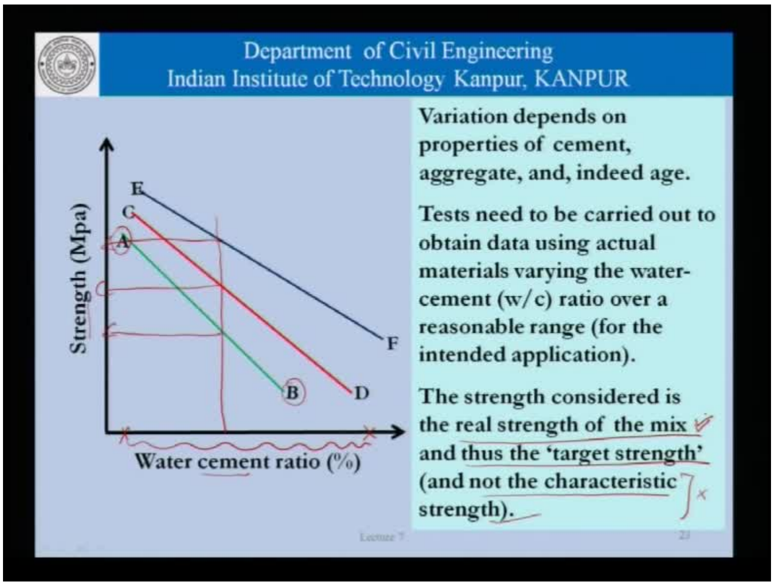

Now, let us come to the next concept which is the water cement ratio versus strength relationship, much like the discussion that we had in terms of the unit water content and the slump. Here too we have a variation of water cement ratio and the strength of concrete, which could be the compressive strength of concrete determine using queues or cylinders. We can have a variation a b and again to simplify things, we can connect down the straight line and make it a, b it could be b c d or e f. That is for a given water cement ratio, we can have this strength or this strength or this strength or this strength depending on all kinds of factors including age.

If we test the concrete at one day, the same concrete at 7 days, the same concrete at 28 days, we will keep getting different values of strength for the same water cement ratio except that as the hydration. The strength development sees as the changes in strength over time will become smaller and so on. So, having said that this variation whether it is a, b, c, d, e, f it depends on the properties of cement the aggregate. Of course, age and we need to carry out test using real materials and real data to get the variation of the water cement ratio and strength over a reasonable range of values. It makes new sense to try to determine the water cement ratio versus strength relationship in the neighborhood of 30 35 percent water cement ratio.

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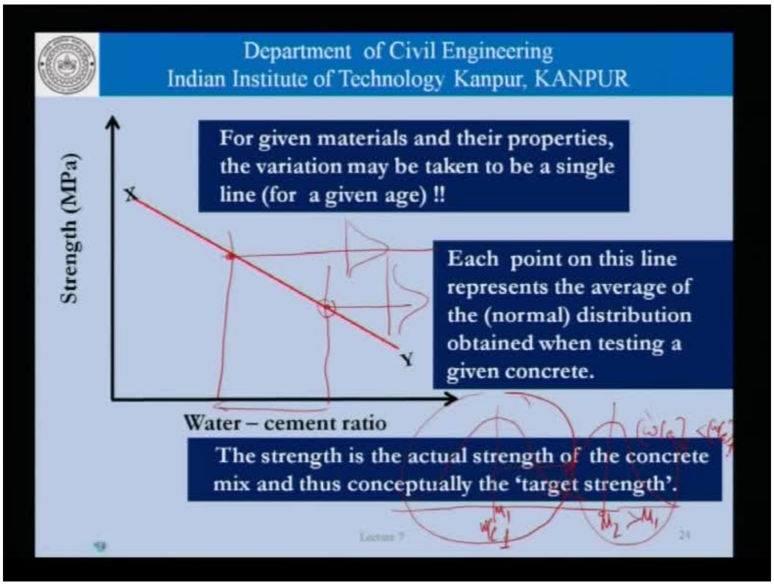

If the strength required is such that a water cement ratio in that mix will be 50 percent, so we have to choose a range here, what water cement ratio range is chosen depends on the strength that we want. With that range we have to carry out experiments and narrow down the variation, that we want or the water cement ratio versus strength relationship. We must remember that this strength considered is the real strength of the mix and thus we are talking more in terms of the target strength of that mix. Because it is not the characteristic strength of the mix, no we are not talking here of the characteristic strength. We are talking of the target strength that is that strength, which will be actually obtained, when we test the concrete cubes or we test the concrete specimens.

The characteristic strength is an independent parameter that extent. Therefore, simplifying the picture, we will have for a given material as set of materials and that properties the variation may be taken to be a single straight line for a given age age is not really a big issue. Because depending on what we are working with, what kind of specifications, what kind of construction, we can specify the age. We can say that we want to do to our quality control, we want to have a concrete, which will satisfy the strength criteria at a given age.

We must remember each point on this line, whether its point here or point here or a point here actually represents the average of the normal distribution obtained, when testing a concrete. So, what we are really saying here is that for a given water cement ratio, if we test a lot of cubes, what will we get? We will get a distribution and strength, which is something like this. That is what we talked about and this will be for water certain, water cement ratio. This means, if we change the water cement ratio to a value which is lower. That is if you lower the water cement ratio, we are using water cement ratio one here, if we choose a water cement ratio two, with which is less than the water cement ratio one, then the mean will move on that is we will have higher strength.

But that does not mean that we will have higher or lower standard deviation. So, we will get distribution which will get something like this. This mean here m 2 is higher than this mean. Here m 1 simple because we have move the water cement ratio, that is what we have understood from our discussion so far. What this point really represents is this entire distribution, if we have reduced this water cement ratio and we carry out this exercise here again, then this point here represents this entire distribution. So, what we are getting is distributions like this and once we understand this concept then we are invest this. We know exactly how could we handle this, strength, water, cement ratio. As I have been stating this strength is the actual strength of concrete mix and the conceptually the target strength.

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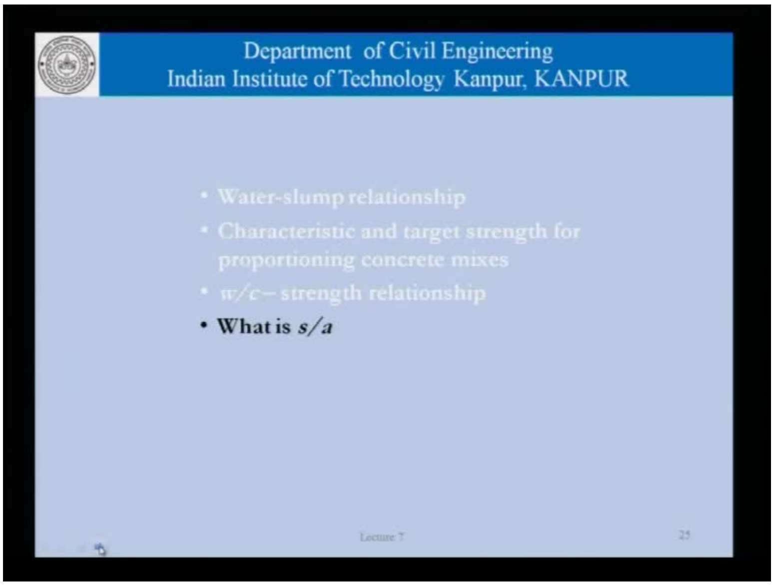

Now, coming to the last item, that we have for the discussion today as a concept in proportioning concrete mixes is the s by a. That is the sand to aggregate ratio or the sand in the aggregate ratio.

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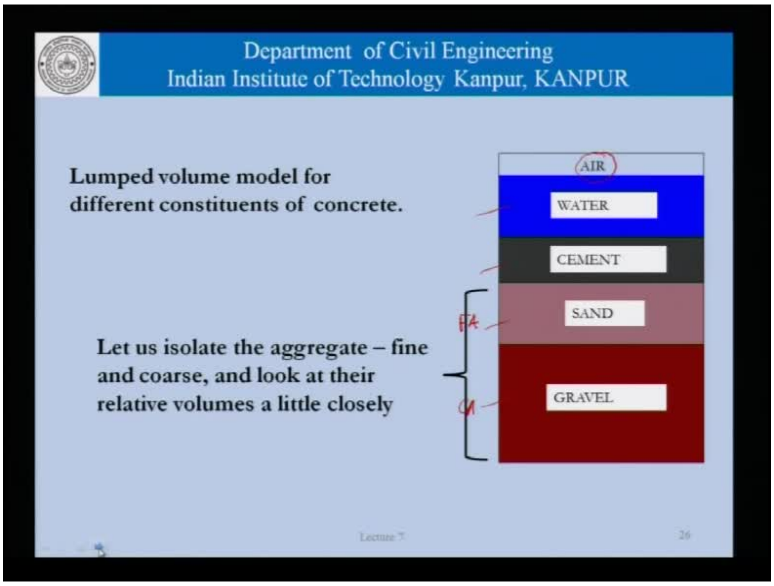

We have considered this lumped mass model or lumped volume model. I should say for the different constituents concrete, we have said that this is water, this is cement, this is sand, this is gravel or this is what I call coarse aggregate, this is what I call fine aggregate. This is what have considered that a given volume a cubic meter or 1000 liters or whatever that volume is is comprising of certain amount of water, certain amount of cement, certain amount of sand and coarse aggregate, with some air whether it is entrained or its entrapped sitting in the concrete mix.

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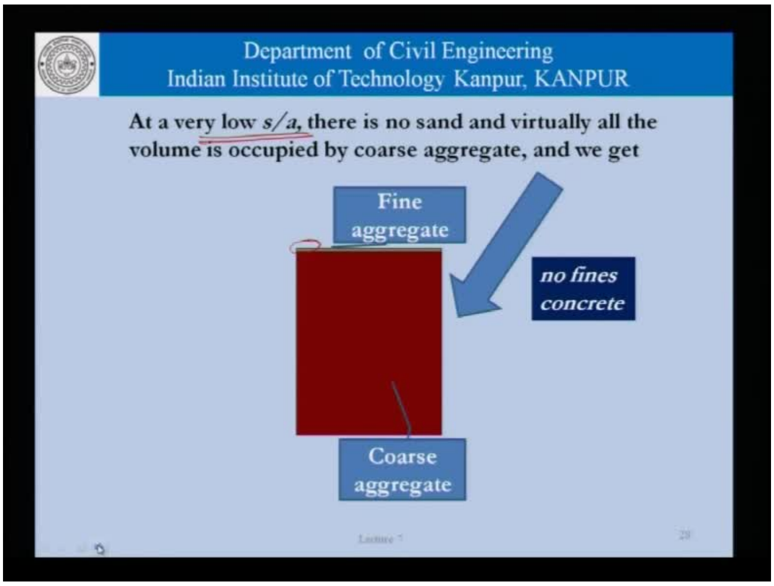

If we isolate the aggregate that is the fine and coarse aggregate and look at their relative volumes a little closely, what we will find is that s by a representing the share of volume of the inert part, this is the normal distribution case, where we have a certain amount of fine aggregate a certain amount of coarse aggregate.

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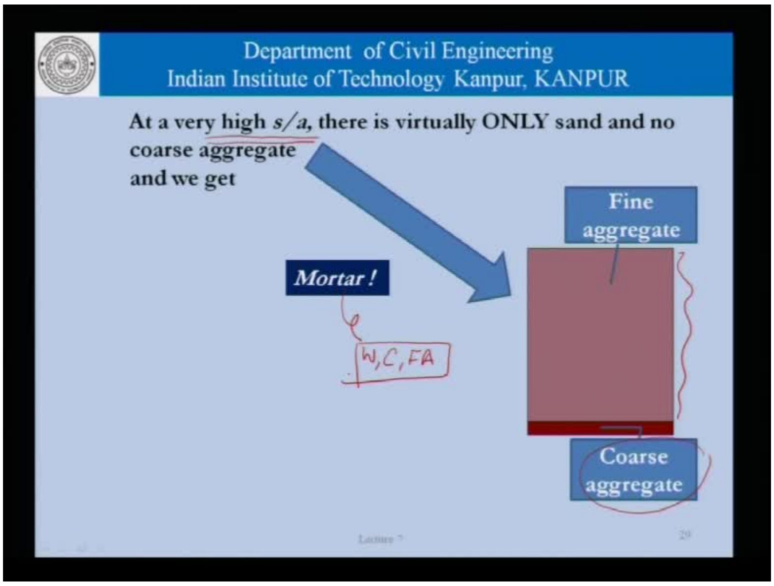

In another case if the s by a is very low, that is we put variedly fine aggregate in the system another lot of coarse aggregate, then we have what is called a no fines concrete. That is concrete which does not have any fine aggregate. So, we have basically the air water cement very little fines and lot of coarse aggregate can you picture that kind of concrete in your mind.

On the other side, if we have working with a very high s by a that is we are working with a system where we inert aggregate has a lot of sand compared to the coarse aggregate then what we are talking of is this we have a lot of fine aggregate and very little coarse aggregate. Extreme case, what do we get in the extreme case? What will happen, is that if the coarse aggregate from the system simply vanishes? We get water which comprises only of water cement and fine aggregate not counting. Of course, the air which sits in the system anyway and this air is the part of the mortar component.

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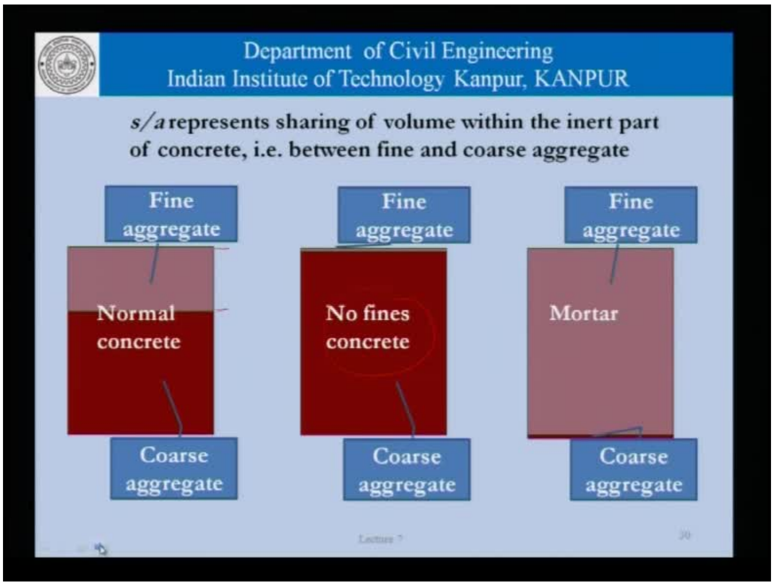

So, if we have s by a representing the sharing of volume within the inert part of concrete, that is between the fine and coarse aggregates, then if we have normal concrete like this where there is a reasonable amount of fine aggregate, a reasonable amount of coarse aggregate in the system. If we have very low s by a, we have a no fines concrete and if we have a very high s by a, we are virtually working towards mortar.

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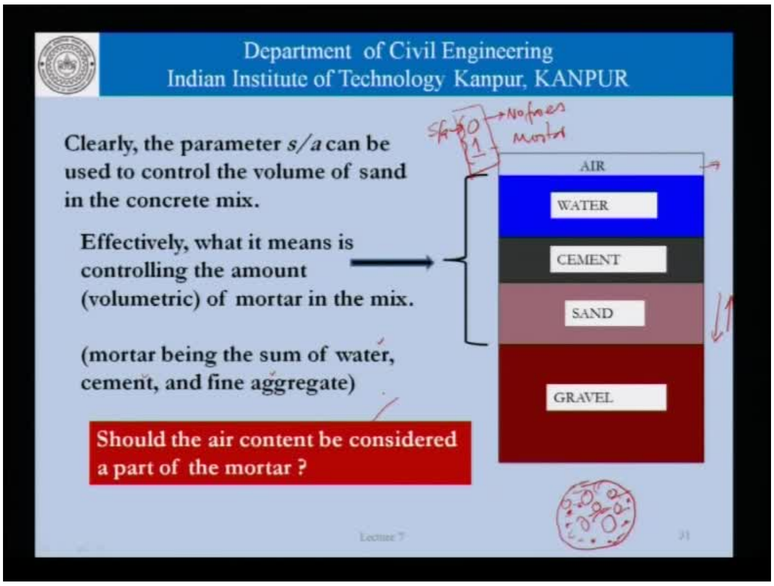

Now, if the s by a can be used to control the volume of sand in a concrete mix, we will see this in the proportioning exercise. How s by a is used to control it? But in principle we can imagine that if s by a is taken to be 0, then we have a no fines concrete and if s by a taken to be one then we have mortar. So, if I vary this s by a in this range, then I can control the volume of sand in the concrete mix effectively, what does that mean? It means that we are able to control the mortar in the concrete mix, then we control the s by a because if I control my sand, if the sand is reduced or it is increased, what is happening?

The mortar content which is the sum of water cement and fine aggregate reduces or increases in no fines concrete. The mortar component is only the water in cement in mortar, we have only mortar, we do not have any coarse aggregate. So, we have moved towards and s by f, one should the air content we considered a part of mortar. The answer from my side is yes because given a concrete mix and actual concrete mix where we have aggregates and so on. Suspended or embedded in a matrix of mortar, we have air particles sitting within the mortar. So, no matter how we consider the lumped volume system, as I shown here air actually is distributed over the entire air is actually distributed over the entire mortar.

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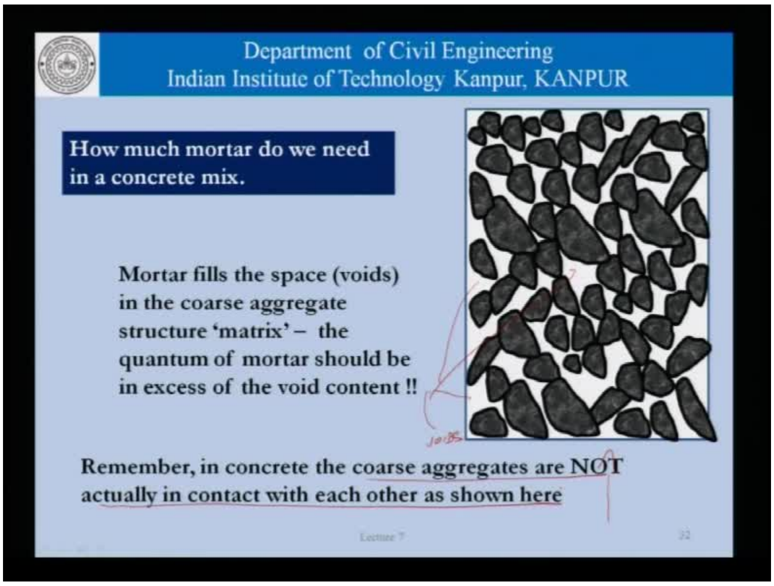

So, therefore air is a part of mortar as far as the discussion in this course is concerned. Now, the question is how much mortar do we need in a concrete mix? A concrete mix really look something like this, where we have a lot of aggregates and mortar really is required to fill this space, the void in the coarse aggregate structure or the matrix and the quantum of mortar should be in excess of this void content. So, given a mass of coarse aggregates, we know that is arranged that coarse aggregate mass in a certain space. We will all been contact with each other and this and this here is the voids and mortar should be such that it is able to fill all the voids.

So, we have effectively a mix we effectively have a measure of the minimum amount of mortar, that we need in order that we are able to create a concrete. However, in a concrete the coarse aggregates are not actually in contact with each other as shown here. Therefore, what will happen? Some of these coarse aggregates will not be there, that is the way to look at it if the aggregates are in contact with each other, then we get a certain minimum amount of voids. It also depend on how much packing you do? But in principle it gives you the minimum amount of voids and that is the minimum amount of mortar that we need in a concrete.

If we do not have aggregates in concrete, if we do not have aggregates in contact, then we need a certain higher amount of mortar in order that that mortar is sufficient to fill all this space for a given volume of concrete. Now, that is the kind of give and take that is we try to maximize the volume of coarse aggregate in the system, try to minimize the amount of mortar in the system because if we minimize the mortar in the system, we also minimize the cement which is the most expensive part of our constituent.

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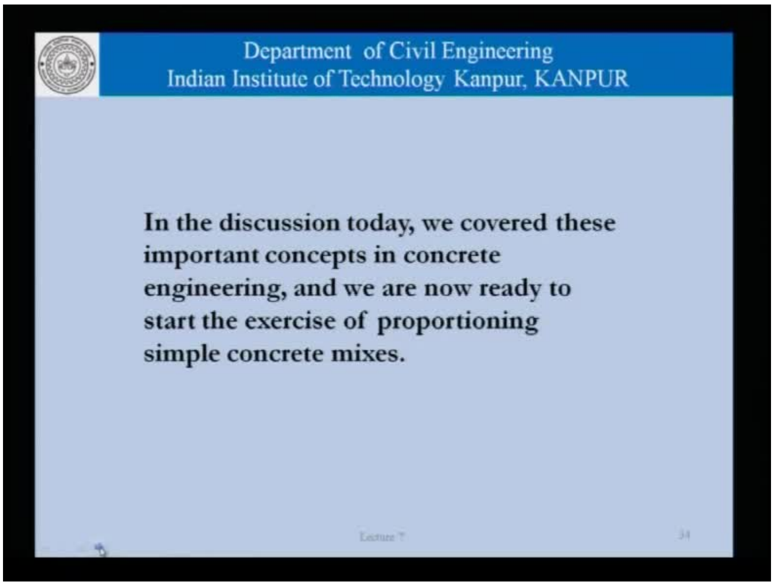

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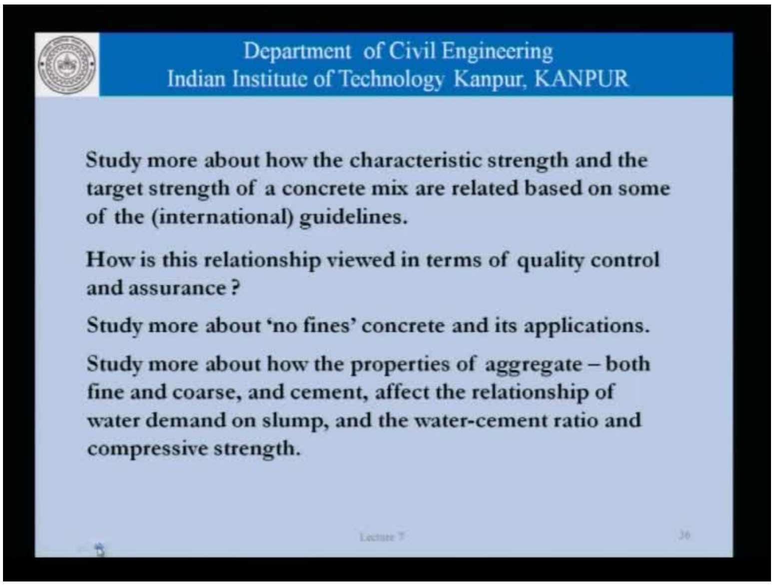

So, that exercise of determining what is the minimum amount of cement required? What is the optimum amount of sand required? That is the kind of exercise, which is part of the proportioning of concrete mixes. I do not completed the discussion on all these topics, we are ready to embark on the exercise of actually proportioning simple concrete mixes, which we will take up subsequently.

Now, as usual some things that you should think about, I would like you to study more about characteristic strength and the target strength of the concrete mix and related. How they are related based on some international or national guidelines? We talked of the relationship of 1.65 times, the standard deviation added to the characteristic strength to get the target mean strength, there can be other ways of relating the two. How is this relationship between the characteristic strength and the target mean strength viewed in terms of quality control and assurance? I would like you to study more about the no fines concrete and its applications.

That is the concrete where we have an s by a of something very closed to 0, that gives us no fines concrete, where is it used? How useful it is and so on. You can study more about the properties of aggregates, both the fine aggregate and the coarse aggregate and cement. How these properties affect the relationship of water, demand on slump and the water cement ratio and compressive strength.

Thank you.