Concrete Engineering and Technology
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Lecture - 40
Review of the course

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Welcome to this lecture in our module on concrete engineering and technology. Now, this is lecture 40, the significance of it is that it is the last in this series, they were different ways of doing this discussion at the end of this course. And I thought the best way or one way perhaps would be to go back, today we started in lecture 1, and try to see what we set out to achieve, and to what extent we have accomplished it. Now, this is a slide from the first lecture, we share that the subject that of concrete engineering and technology is acquiring tremendous significance, as we continue to use more and more concrete in diverse conditions more challenging environments, we are using new materials and new technologies in the different processes, which are related to concrete construction or construction of concrete structures.

We have a lot more experience from previously built structures, in terms of observed deterioration, in terms of their structural performance, and so on. One of the biggest things that has happened is that we now realize that concrete is not a maintenance free material; it requires periodic maintenance, and the structures need to be monitor, they need to be evaluated from time to time in order to make an assessment, whether any

corrective action is required, while the structures are in operation or in service. We find rising concerns about the quality and durability of concrete construction, there is a lot more pressure from all sides, the users, the regulators, to build durable concrete structures; and all that has contributed to making the subject of concrete engineering and technology, a lot more challenging, and has invoked the lot of interest.

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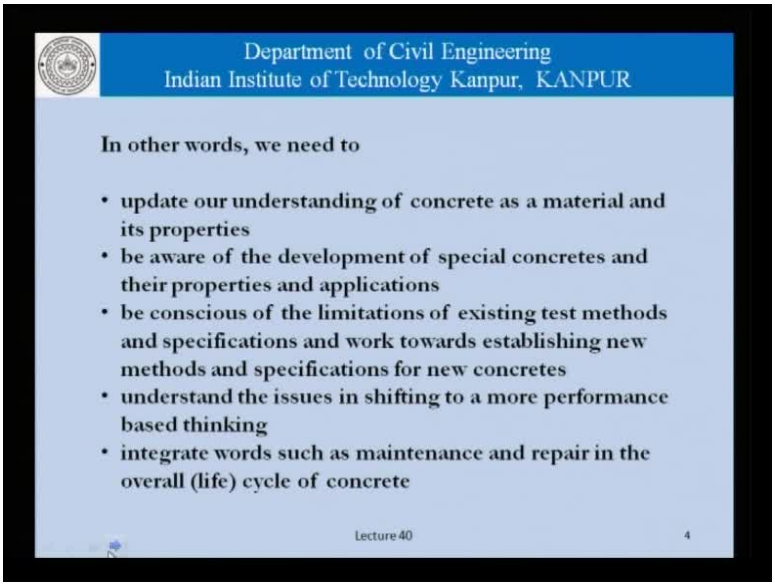

Then we had also set out saying that, we need to understand or update our understanding of concrete as a material and its properties; be aware of the development of special concretes and their properties applications, they conscious of the limitations of the existing test methods, and specifications, and work towards establishing new methods and specifications for new concretes, more challenging environment, different kinds of materials being used.

Understand the issues in shifting to a more performance based thinking, the thinking in our present codes in specification is in terms of a prescription, that is if the concrete has to be done in a certain environment, it has to be done, it has to be done in a certain way. Then well do this, keep the water cement ratio to be, a maximum of 40 percent 45 percent, have a certain minimum cement content, have a maximum cement content, and so on. That is not really performance based thinking, because the properties of concrete as we have seen in this course, are not related to that single parameter alone, there are

several other things, they contribute to the performance of concrete in a particular situation.

Integrate words such as maintenance and repair, in the overall life cycle of a concrete, we have not touched upon the cost component, but at the end of it finally, at some point in time, there will be a discussion on the life cycle cost of structures, if a structure is cheaper to build, but it is more expensive to maintain, and more expensive to get rid of at the end of its service life. Then is that really the best structure is the present cost, the only consideration, these are questions which we need to answer to ourselves, and to the society, when we design and construct concrete structures in this day and age, so that was the motivation of designing and delivering this course.

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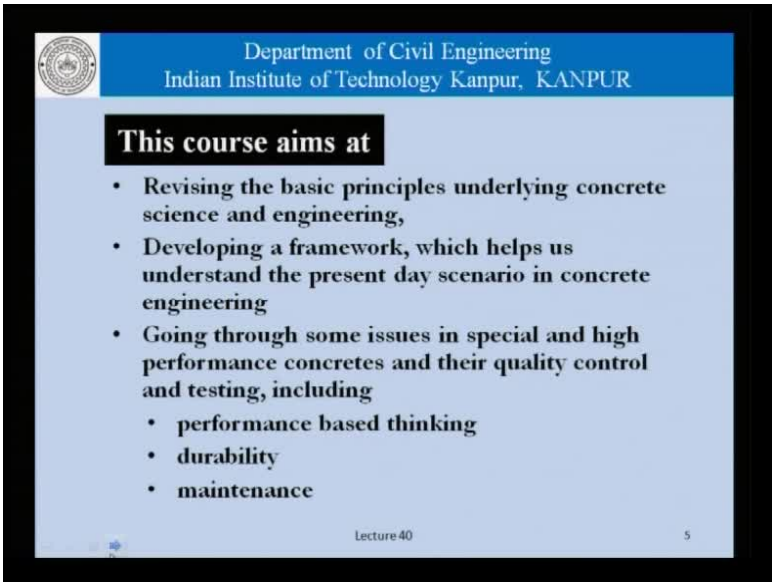

We have set out the aims at revising the basic principles underlying concrete science and engineering, developing a framework which helps us understand the present day scenario in concrete engineering, going through some issues in special and high performance concretes, and their quality control and testing including, performance based thinking, durability, and maintenance. In this we among all the keywords on this slide, we spend a considerable amount of time talking about special concretes, and high performance concretes. Defining, what is a special concrete in terms of materials being used, the technology being used the properties of the concrete, and so on and so forth.

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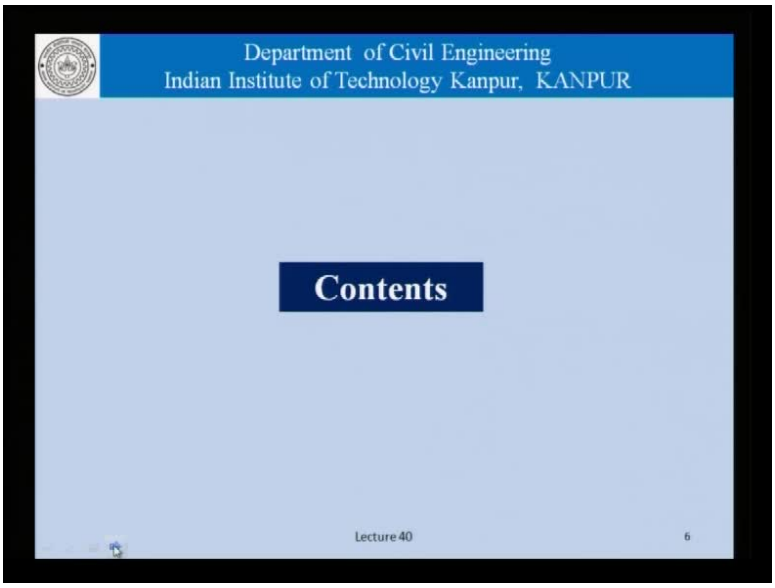

Now as far as the contents are concerned, that is quickly run through the contents, as they were laid down in the first lecture.

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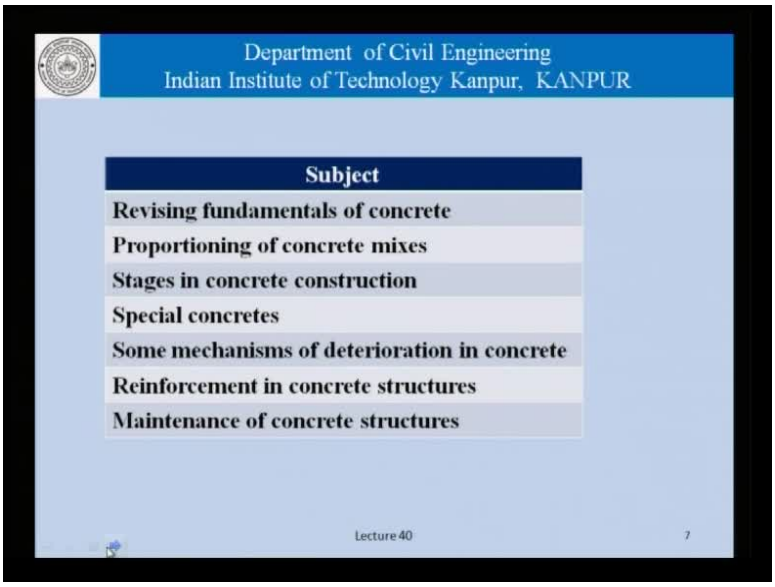

We said revising fundamentals of concrete, proportioning of concrete mixes, stages in concrete constructions, special concretes, mechanisms of deterioration, reinforcement, and maintenance.

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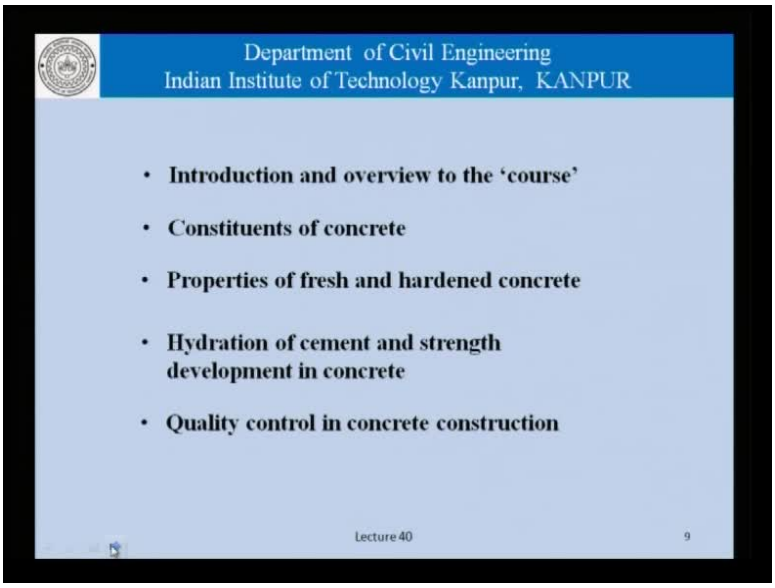

As far as fundamentals are concerned, we said that we will talk about the overview and introduction to the course, which happen at the very outset talk about the constituents of concrete, properties of fresh and hardened concrete, hydration of cement and strength development, quality control issues.

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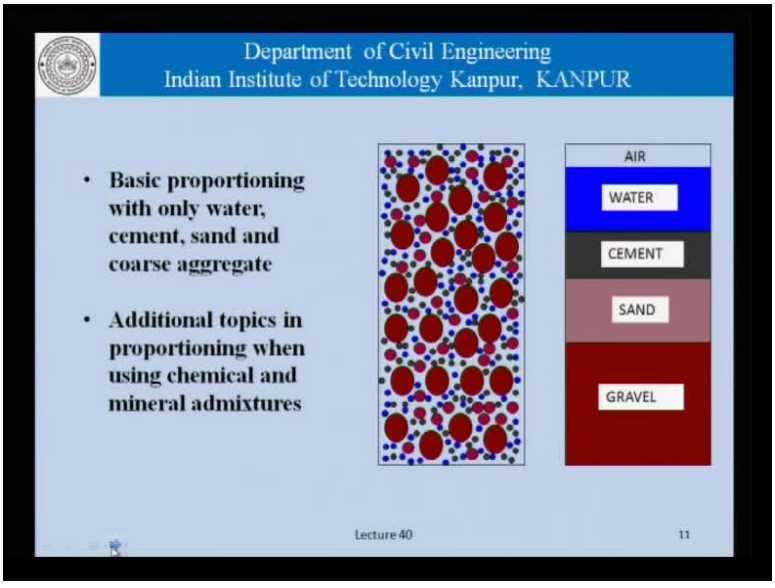

As far as proportioning of concrete is concerned, we spend a considerable amount of time, at this picture which shows, the essential volumetrics of concrete. That is at the end of it a certain volume, a cubic meter, let us say has to be made up of certain ingredients,

coarse aggregate, sand, cement, water, and air, that is normal concrete. But, if you want to add mineral admixtures, use some other kind of aggregate, whatever we want to do, fibers. In all these cases the volumetric balance has to be maintained, that 1 cubic meter box is fixed, so we must keep that in mind, when we talk of proportioning concrete mixes, and that is what we did at some length.

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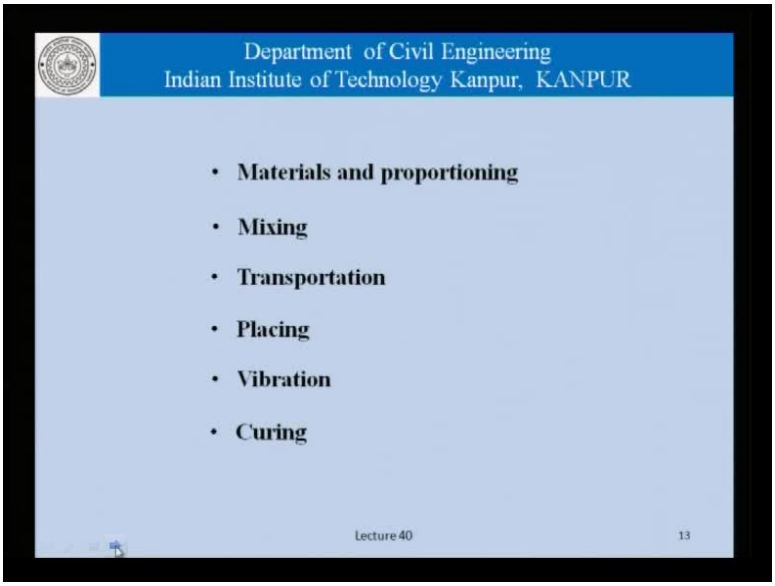

As far as stages in concrete construction is concerned, we had laid out materials and proportioning, mixing, transportation, placing, vibration, and curing.

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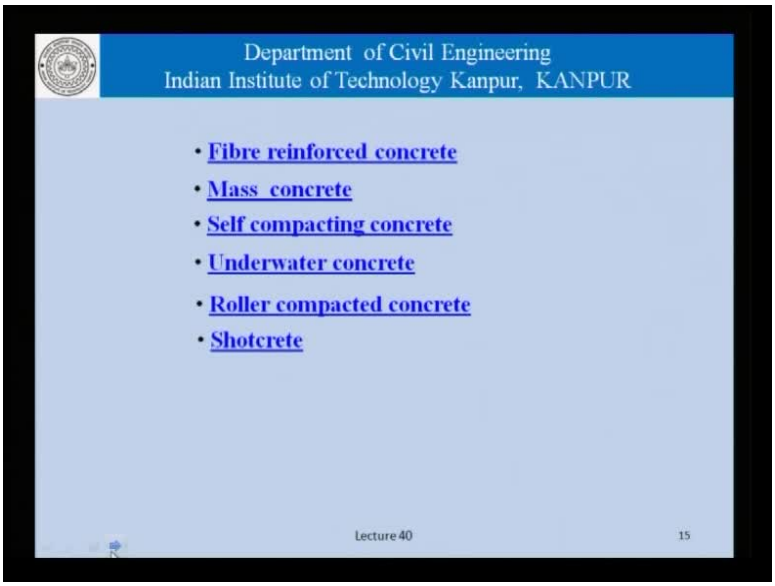

As far as special concretes is concerned, we had laid out, fiber reinforced concrete, mass concrete, self-compacting concrete, underwater concrete, roller compacted concrete, and shotcrete has some examples of special concrete; based either on the use of materials or the conditions of placement, and method used in placement, the environment of placement, method in vibrating the concrete, and so on.

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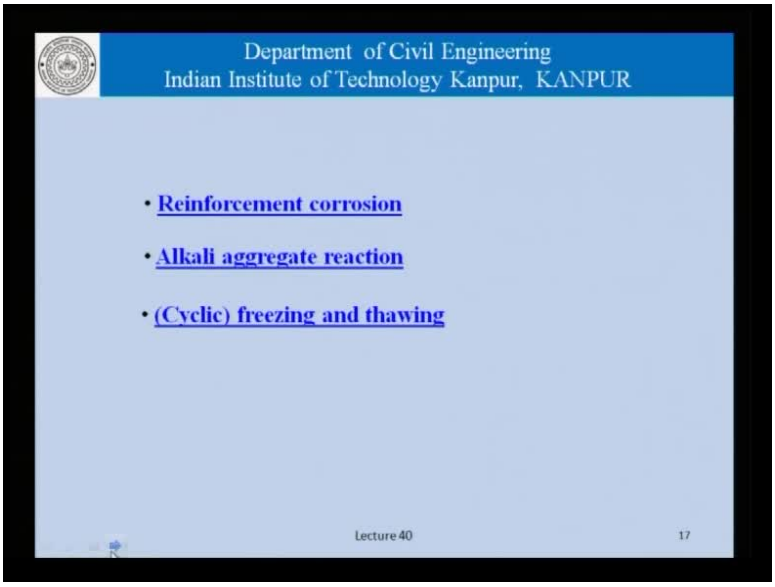

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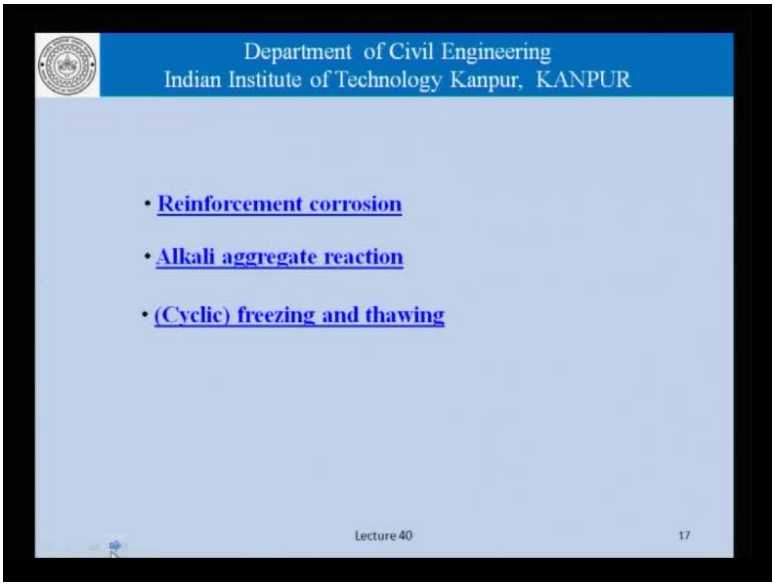

We had said that, we will talk about some mechanisms of deterioration in concrete structures, and we had promised to talk about reinforcement corrosion, Alkali aggregate reaction, and cyclic freezing and thawing.

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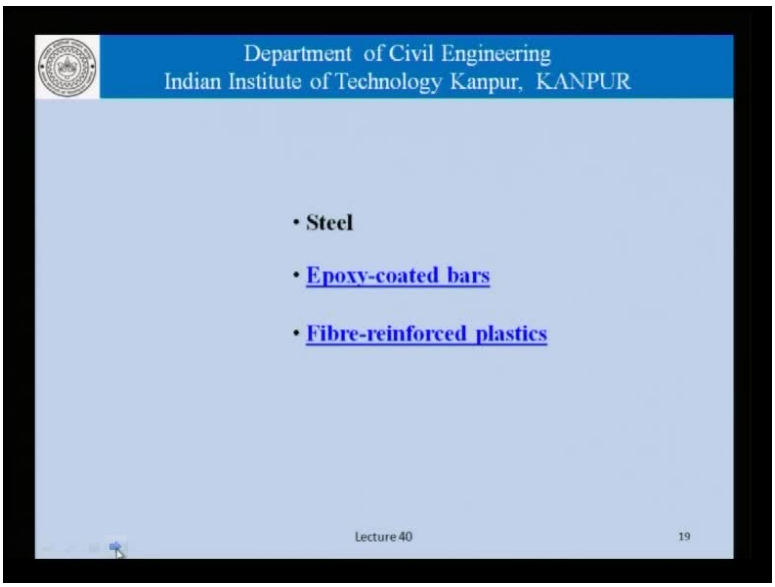

As far as reinforcement is concerned, we had said that we will not talk about steel, because that is a material which is very commonly understood, and is not to that extent a part of course, or a discussion of concrete engineering, at this point in time epoxy coated bars, and fiber reinforced plastics.

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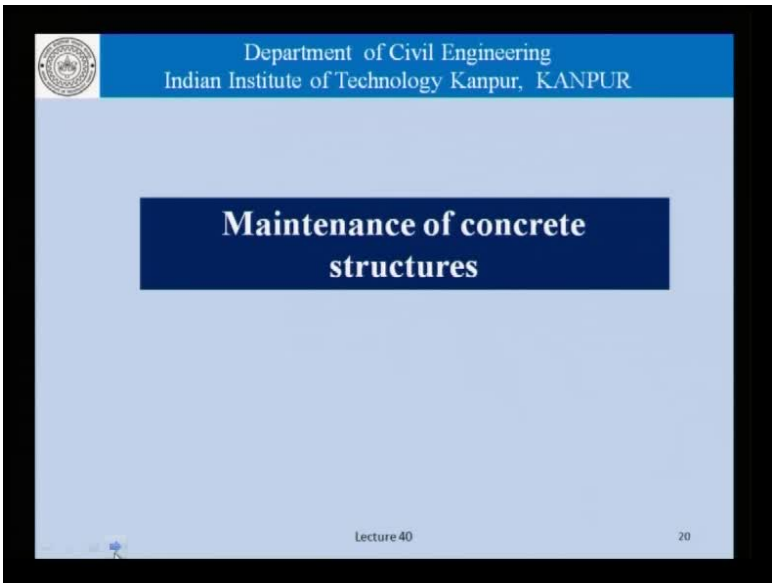

As far as maintenance is concerned.

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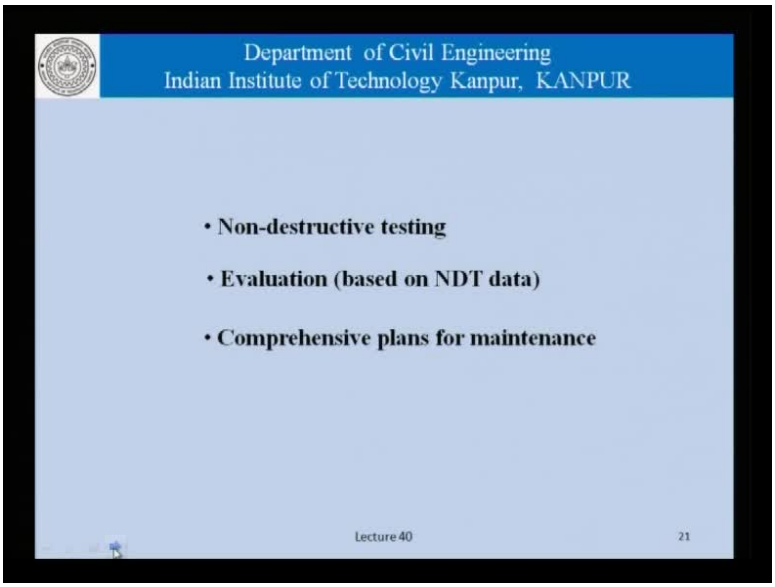

We had set out to talk a little bit about non-destructive testing, evaluation of structures, based on non-destructive testing data, and a comprehensive plan for maintenance.

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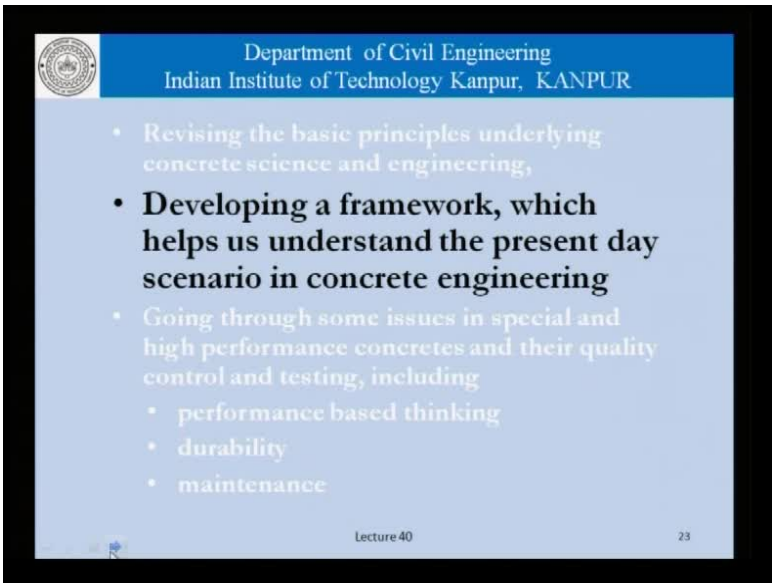

With all these keywords, that we set out to discussing this course, to my mind, if we have succeeded in developing a framework, which helps us understand the present day scenario in concrete engineering; I think the purpose of this discussion in the last 38 39 lectures has been well served.

We have I hope a better understanding of materials, we have a better understanding of the methods of placing, we have an understanding of special concretes. Basically, what makes the concrete as a material, and a concrete structure special or important; we are basically set out to achieve some understanding, as to what makes concrete different today than it was let us say even 20 as ago, and if that purpose is been achieved, I think we have achieved this goal.

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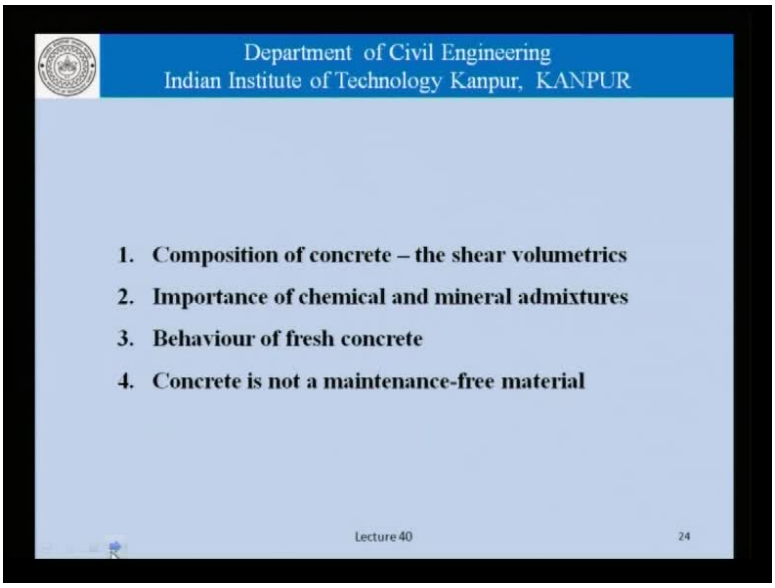

Now, let me focus a little bit on some of the central keys, that ran through all the lectures, or all the discussion, that we had about concrete different aspects throughout this 38 39 lectures, one was the composition of concrete - the shear volumetrics. And I said just now, when we basically looking at when, we were briefly looking at the slide on proportioning, that at the end of it is a cubic meter of concrete, that has to be proportioned; whether we fill it only with coarse aggregate, or we can fill it with only sand, or cement, or water, that is all right, but that would not make concrete the way, we want the concrete to be in terms of its properties, whether it is fresh properties, or the properties of hardened concrete. And therefore, we need to proportion the different ingredients, add mineral admixtures to it, add materials such as fibers, and so on to it.

So that the properties of concrete are who are lightly, but the shear volumetrics of it is something which is very very important, and we must remember some of those things, then we talked in terms of the importance of chemical, and mineral admixtures, and how a judicious choice of these admixtures, and their uses, the doses of these admixtures can be used to engineer, the properties of concrete, whether it is workability, whether it is strength, whether it is setting time air content temperature rise in mass concrete place ability, and so on.

The behavior of fresh concrete, now fresh concrete is not something which a lot of codes, a lot of books, lay a lot of emphasis on. Slump, air, temperature, Segregation, these are

some fundamental properties, which we must remember to record, when we are doing concrete construction. Because these are the properties that help define, what that concrete is going to be at the end of the hydration process, at the end of the curing period, and so on, and so forth. As far as, fresh concrete is concerned, it is also important to understand, that water is the modified as a fluid, and it is fluid properties by the addition of cement as a powder.

Even, if you forget about the hydration, that goes on so there is the paste that forms, that paste has certain properties, and that get modified, those properties get modified, when we add sand to it; and that is how we get mortar, and the properties of mortar get modified, when we add coarse aggregate to it or fibers to it. So, we have continuously talked in terms of concrete being suspension of coarse aggregate in mortar, mortar being a suspension of sand and paste, and paste being a suspension of cement and water. It is the volume fractions of these individual components, that are very very important, when we try to study the properties of fresh concrete, and that has been a central thread running through a lot of our discussion in this course. Concrete is not a maintenance free-material, now that is another central theme in the discussion.

Concrete is a porous material, it has certain amount of porosity, whether we characterize that porosity in terms of the total pore volume, or the pore size distribution, how we go about measuring it, all that is fine. But at the end of it concrete is a porous material, the porosity depends upon the water cement ratio, it can be modified to some extent by adding mineral admixtures, and so on.

So, having said all that depending on the environment, in which the concrete structure is located, the environment to which the concrete has a material is exposed to, it undergoes changes, I am not using the word deterioration here, but it undergoes changes for sure. And those changes are not limited to only hydration reactions, there is a chemical change that happens, which could affect the strength, which could affect the cracking patterns which could induce more cracks and so on.

So, at the end of it we must understand, as concrete engineers the different deterioration processes that concrete could be undergoing, or could be likely to undergo depending on the environment, in which the structure is located; and that is something which the

designers must understand because that is because only, then they can design a durable concrete structure.

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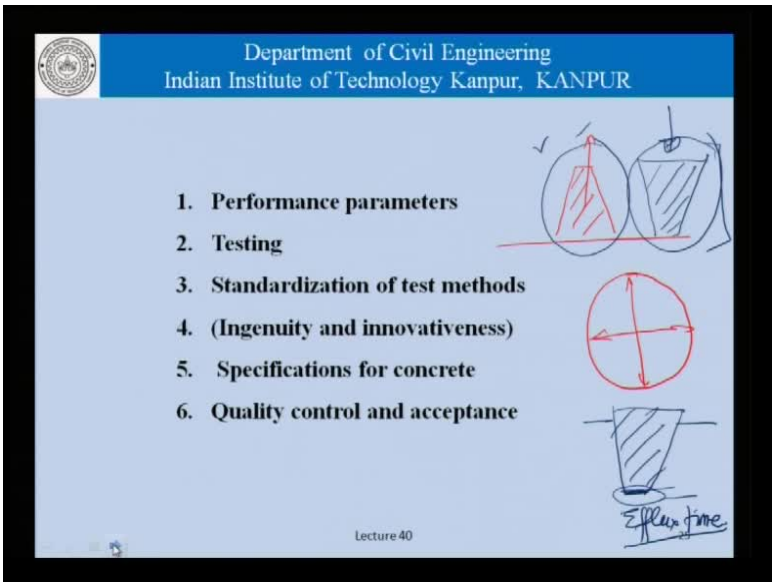

Throughout this course, we are emphasized the need to work with performance parameters, performance of fresh concrete, performance of hardened concrete. Performance of fresh concrete being measured in terms of workability, air content; the performance of hardened concrete being measure in terms of compressive strength, tensile strength, parameters such as the rapid chloride, permeability tests gives us, the coulomb values, and so on.

One of the lectures, when we have talking about freezing and thawing; we talked in terms of the dynamic modulus of elasticity, as being one of the performance parameters specially valid, or specially relevant in the cases, when concrete is subjected to cyclic freezing and thawing. So, the emphasis has been on how do we measure performance, we have tried to define good concrete, good fresh concrete, would hardly concrete; in fact in one of the lectures we talked about using marginal materials, and yet trying to produce acceptable concrete, and then we try to draw distinction between, good concrete and acceptable concrete.

All concrete that we use, need not be good in the absolute sense, what it should be acceptable and therefore, specification writers, engineers should be aware, that in a manner of speaking, there is nothing like good concrete; any concrete that makes a

specifications is good. And therefore, if we have rich specifications, that concrete is as good, as a concrete which meets the specifications, which are not as good.

So, at the end of it, it is the specifications which are very important; continuing with the discussion with parameters and performance parameters, we have always emphasized throughout this discussion, the importance of testing; we cannot determine a parameter unless, we test it; testing does not necessarily involve direct testing, direct testing means testing to get the parameter, that we want to get.

For example, we want to measure the workability of concrete, now workability is an idea, it just says the concrete should be workable; workable means it should be such that it can be placed in molds, takes the shape of the mold, and so on. But how do we measure the workability, as far as measuring is as far as the measurement of workability is concerned, there are tests; there is a clump tests, there is the v b test, there is the slump flow, and so on.

So, we have to have tests, and we have always emphasized that in different conditions, for different concretes, there could be different performance parameters, and if there are different performance parameters, they need to be a different set of tests. One should not be afraid of inventing a new test method; standardization of test methods has been another central theme in this discussion.

When, we do tests, it is important that the tests are carried out in a manner, that is reproduced. By, not only the person, if he carries out the test at one point in time, and other point in time. But also by different people carrying out the test across the world, and that can happen only if the test has certain standards, that is there is an absolutely laid out procedure, by which the test should be carried out.

Sometimes we may laugh, at a standardization or the level of standardization, if you retest methods, such as the slump, if you read the test methods, for example, for the slump test, or the air measurement, or any of the methods, for that matter; there is a lot of detail, but that detail is important, because unless the detail is adhere to you, the test results could be different, and if the test results are different, it is very difficult to compare one result with the other, and you know the obvious problems, that we will follow.

Ingenuity ingenuity and innovativeness, we have not feeling emphasized on this aspect but, it is a very important aspect, one must remember that all these test methods, whether it is the slump test, or the air measurement, or the modulus of elasticity, or the dynamic modulus of elasticity. And whatever test it is, these test have only had a certain amount of history, and depending on the particular condition new test methods always need to be developed.

The other day, I looked at a description of a slump flow test, what we have done in our slump flow test, and that is how I have explained it, the way we have described the slump flow test is we take the slump cone, and lift the slump cone after the concrete has been filled, and we watch how the concrete spreads on this plate, and try to measure this diameter.

Now, there is nothing wrong with this method, except that the other day, I saw a test method for the slump flow, which said that well, we will fill the concrete in the slump cone, but that cone has is helped upside down, in principle, if we were testing a fluid, this configuration, and this configuration are really the same, but not so in the case of concrete. Now, it is completely up to us to adopt, or adapt, any of these methods, so even though we have often in fact, very often talked in fact, very often talked in terms of ASTM, this test ASTM, that test or the British test having a certain number, which may say that the test should be carried out as this, and will not talk in terms of this. But at the end of it, it does not matter. As engineers, if you feel that this is more suitable to me, then this you please go head, and do it except that one must be aware that, then it is not a standard test at least till such time as, it has been excepted by the profession as a standard test.

So, standard tests evolve over a period of time, we saw that, when we talk in terms of self-compacting concrete, all the tests whether it is the u tube fallibility, or it is the l shaped flow, whatever it was those tests are all improvisations, which have happened in the last, let us say 20, 25 years. As engineers, as engineers realize that simply this, or the v b, or the compaction factor, those tests were not good. Enough, when it came to evaluating the performance of self-compacting concretes, or concretes which were highly flowable, whether they were self-compacting, or not as a different story.

Continuing with the discussion, or to give you another example of innovativeness, we can use this configuration of the inverted slump cone, and use it, to measure the efflux time of a concrete, we can hold this slump cone here, have a lead here; fill this concrete up remove the led, and measure the time, and measure the time that it takes for the slump cone to empty.

Now, this is an improvisation on the funnel, we talked in terms of a funnel test, where the funnel is filled with concrete, a certain sized funnel of course is filled with concrete, and we allow the concrete to flow away, record this time, and the time is a measure of its flowability; we can there is no reason why we cannot do it with the inverted slump cone, except that it is only a matter of what becomes more acceptable to the profession, what is more easy to carry out at site, and so on.

Specifications for concrete have been another central theme in our discussion, specifications basically define what we want from the concrete? or what the use of wants in the concrete? or the client wants from the concrete does it have to set very quickly, should it set later, what should be the maximum temperature that is, what is the maximum temperature rise that is acceptable, and so on.

So, depending on where the concrete has to be used? What is the nature of that structure? Where is it located? how important is it not only the design has to be carried out, when I use design I mean structural design, not only the design has to be carried out in that manner, but the concrete engineer needs to provide a concrete mix, which meets that specification.

One of the problems, that I have seen, when I talk to concrete engineers in profession is that, we do not specify the concrete properly, and if we do not specify the concrete properly, there is no way that you will get good quality concrete; when it comes to food, when it comes to clothing, we are very choosy, we know exactly what color we want we know, exactly how much salt we want? But, when it comes to concrete workability, we mat say well anything is alright, but that is not the way, concrete engineering can be done for two longer time, we need to learn to write specifications property. As, I said before, any concrete that meets the specification is acceptable and therefore, if we want a higher grade of concrete, we should write it in their specifications, we have to specify it as such.

So, that is why testing methods, and specifications have been the core, or one of the core items on our agenda, as far as this course is concerned. Quality control and acceptance, that is something which we have talked about in all cases, and that is related to this specifications, that is related to the test methods. Because, once we write specifications, we cannot write qualitative specifications, if we can avoid that, we have to write specifications in terms of performance parameters, we have to write specifications in terms of parameters that can be actually measured, and we have to lay down the rules, as to how the acceptance of concrete is going to be carried out.

We should remember that, concrete and concrete construction is very often, in fact more often, then not public expenditure of funds, or expenditure of public funds and therefore, one has to be very careful when dealing with acceptance criteria, and acceptance of concrete, we cannot accept unacceptable concrete, or sub standards, sub specification concrete, and that can be determined, only if the tests are carried out, and not only the records have to be kept. Records have to be maintained to show, what kind of concrete was used in different segments of a large structure? that is all part of a comprehensive plan of quality assurance, and quality control, when it comes to construction of concrete structures.

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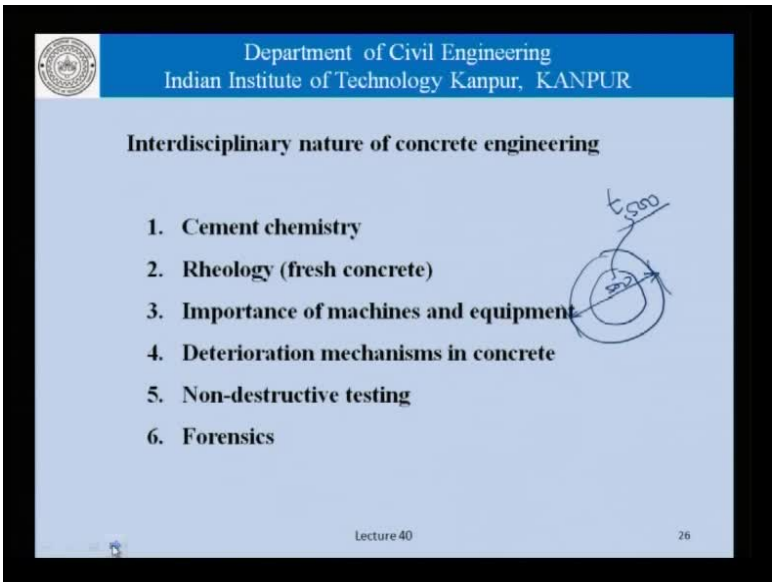

We have tried to emphasize through this course, the interdisciplinary nature of concrete engineering, as it has evolved. Let us take some examples of what we have talked about,

cement chemistry, and the chemistry involved in the hydration. Including the fact that chemical admixtures, and mineral admixtures, alter this part of concrete engineering, or are a very integral part, or important part of concrete engineering. When we use mineral admixtures, or chemical admixtures, we alter this cement hydration, and that is something if you want to get to the bottom of it, we need to know a lot more chemistry than civil engineers generally do.

Continuing with that, we need to have some background in Rheology, and we are talking of the properties of fresh concrete, how the concrete flows? What is the viscosity of the concrete? What is cohesion? What is adhesion? So, these are terms that are common in other disciplines of engineering, but not so common, as far as the understanding of concrete is concerned. But when we use these terms, we have to have test methods to evaluate it, we have not talked in terms, we have not talked in terms of a test method which evaluates the viscosity of concrete, or the cohesiveness of concrete, and that actually leads us to another discussion, and that we have done that in this course.

Sometimes we may not be able to measure the parameter, that we want to measure like we talked in terms of workability, and we are not able to measure workability, we are measure, we are measuring something which we think is related to workability, slump test is the example of that, we talked about that just now.

Similarly, when it comes to viscosity, and the cohesiveness of concrete, we talked in terms of a test called T 500 or T 50 which is the time, that is takes for the slump flow to reach the level of 500 millimeters. As, the slump cone is been lifted, and the concrete flows out, the time that it takes for this diameter to become 500 m m is what we had talked of as T 500.

Now, a concrete that has a lower T 500 than another concrete, basically means that in common parlance, we will say that, that concrete is more viscous, and that is why it is taking more time to deform. We are using these words, but once we are using them in engineering parlance, in an engineering sense, we had better be able to measure them. And if we are not able to measure those properties, we should be able to at least measure properties which are related to them, we have not had time to dwell too much on the kind of equipment that is used in concrete construction, the mix the batching plants, or the pumps, or the agitator trucks, the vibrators, the different kinds of vibratos, and so on.

But, let me show you that, that is an integral part of a site engineers job, if you are working at site with the lot of concrete, it will be expected that you know a lot about the construction equipment, and the lot of construction equipment is related to concrete construction.

Coming to deterioration mechanisms of concrete, we talked in terms of the reinforcement corrosion; now corrosion is not something, which civil engineers very often talk about of course, with the growing awareness towards durability related issues and the reinforcement corrosion being fairly severe, and a way and visible in different structures across the world, we know what corrosion is but, as engineers what we must know in terms of the principles of reinforcement, corrosion and how they are different from normal corrosion, that we see in a, that we see in everyday life, that is something which we do not have a background in, as far as civil engineers are concerned.

Similar, is the case with alkali aggregate reaction; alkali aggregate reaction involves understanding of a certain kind of chemistry. Now, these areas the corrosion of reinforcement in concrete, or the alkali aggregate reaction are precisely the kind of areas which are in some kind of a no mans land.

Reinforcement corrosion in concrete will not be researched, or talked about by serious corrosions scientists, or engineers. Because, that is a very, very small, that is a very small application, as far as corrosion science is concerned. And as far as civil engineering is concerned, we will not often have the background to study that problem in depth, and the same is the case of the alkali aggregate reaction. It is a very special kind of chemistry, that is involved and therefore, we need to take interest learn certain things about a different field, than what we have been traditionally educated in, or trained in, and try to develop professional expertise in that.

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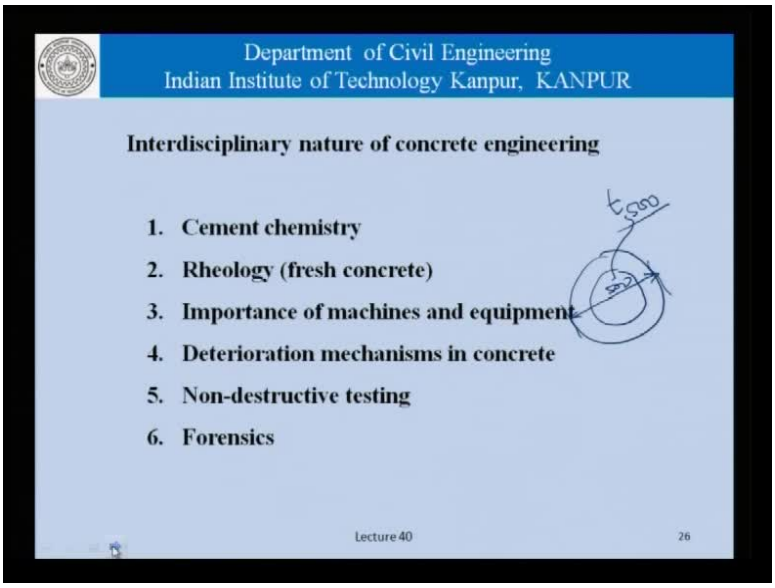

Nondestructive testing, opens another entirely different area of work, measurement of natural potentials, we talked about, we talked about impact ego, or ultrasonic pulse velocities; any of these methods involve the use of very sophisticated equipment's sometimes, and those equipment have their limitations. So, we must understand what the limitations of those equipment's are, somebody comes and tells us, that ground penetrating radar, for example, is a very good tool, to help us locate reinforcing bars within concrete; x y z is a very good tool to measure the thickness of concrete layers, or the thickness of concrete deposited in a tunnel lining. We must understand the principle, that underlies the measurements that we are talking about before, we can say that this equipment, or this method will help us understand, what we want to understand about concrete, but only under certain conditions. If the concrete is wet, then certain methods would not work, if the concrete is absolutely dry, certain other methods would not work and so on, and so forth.

So, basically we need to understand the mechanics or the processes, that are involved in non destructive testing before, we can start using them. Four and six, now this is something which we did not have the time to get involved with, as civil engineers one can often be called upon to carry out an investigation, as to why a building collapsed.

One can often be called upon, to carry out an investigation as to, whether the concrete that was used in construction at a particular place, whether the building collapses or not

is precise the point, the concrete used at a particular place, met the specifications, in terms of let us say the cement content, or the water cement ratio, or whatever it was.

Now, four and six of concrete is a very, very interesting, but an equally complicated story; it is difficult to carry out tests, which will tell us or which will help us recreate the situation, as it was at the time of construction, it could have been raining, it could have been windy, there could have been a certain temperature at which the concrete was placed, and so on; which requires the concrete engineers to keep the records properly. We have emphasized throughout this course, that whatever is carried out each pore each cubic meter of concrete that comes to side must be recorded, where it was used? what were the conditions at that time? What were the conditions of concrete? and so on.

Now, that is something which is very very important to do; as far as the four and six is concerned in terms of a determination of cement. For example, now that is a very very complicated procedure, that has its errors one must understand, what is the range of error? What is the extent of error involved when we measure a certain parameter? Whether it is the ultrasonic pulse velocity, whether it is the strength of concrete, by a u t m, whether it is the natural potential of reinforcement, when carrying out a test for reinforcement corrosion, whether we are trying to measure the cement content in hardened concrete.

What is the accuracy with which we are able to measure it? Or what is the reproducibility of that result? Whether that sample represents that entire concrete mass; all these are questions in order to answer, which we require serious amount of background in diverse fields, so we have talked about different aspects, that are at the inter phase of concrete, and a lot of other areas, as we have gone through different lectures in this course.

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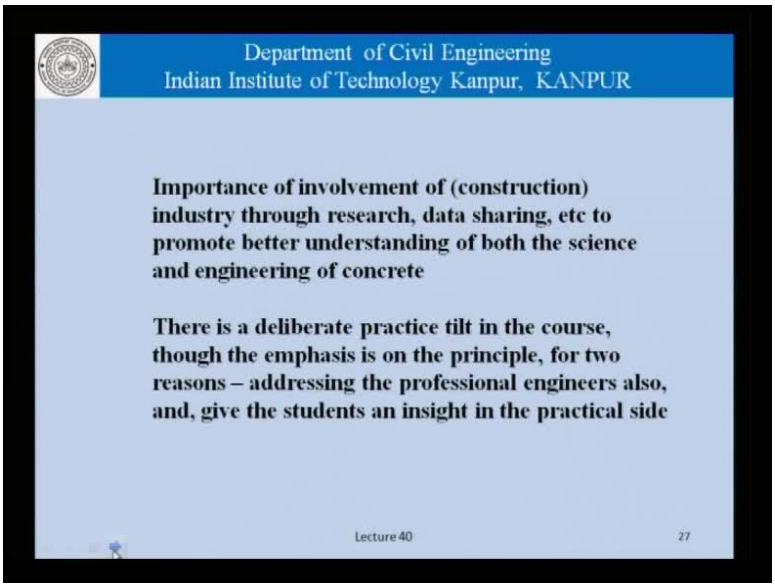

Throughout the discussion, importance of involvement of the construction industry to research data, sharing, etcetera. to promote better understanding of both the science and engineering of concrete has been emphasized; it has been emphasized that producing concrete in the lab using lab mixer, or producing concrete using hand mixed concrete on a small scale; those properties are very different, from the properties, that a concrete will have, if it was mixed in a ready mix concrete plant.

The scale of the consistency of concrete quality, if a road project uses 1000 of cubic meters of concrete, which is all required to be let us say m 25 or m 30, it is a whole lot of data that accumulates, in the construction industry. On what was the variation in the quality of concrete, which was all supposed to be m 30, there will surely be a variation. In terms of the slump that we got for the different concretes, in the air content that we got, in the strength that we got, and that is something which only the industry has; it is not available very easily at least, in academic institutions.

The important of that data, as far as furthering, because of better understanding of concrete science and engineering, that cannot be over emphasized, it simply very valuable. And therefore, it is important, that the construction industry is a major partner, as far as an endeavor to promote better understanding of science and engineering, as far as concrete technology is concerned.

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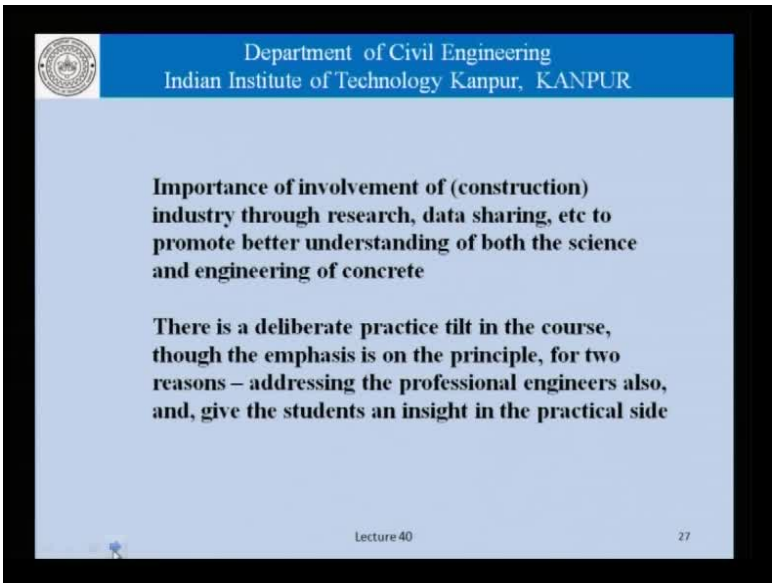

In this particular course, there has been a deliberate practice tilt. Though the emphasis has been on the principle, and at least that is what I would like to believe, for two reasons: one is that I was trying to address the professional engineers, as well in addition to the students in classrooms. And on the other side I wanted to give the students an insight, in the practical aspects of concrete engineering, and construction. And given my believe that concrete is a subject, which is best understood in the field, after a certain amount of principles have been understood in the classrooms, in the laboratories. After you go to the field, or once we have an understanding from field, then we go back to the class rooms, and the principles that we cover there, we have a much richer understanding of how concrete behaves as a material?

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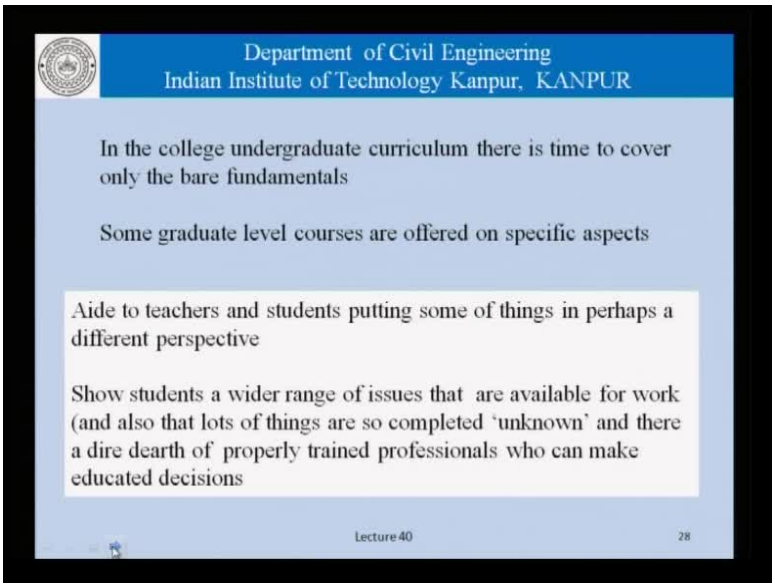

Summarizing that part of the discussion, in the college undergraduate curriculum, there is time to cover only the bare fundamentals, as far as concrete is concerned, in some graduate level courses of course, there are some specific aspects such as, nondestructive testing, or deterioration or repair, and rehabilitation, which are covered. So, what we try to do here was to develop this material, as an aid to the teachers and students, putting some of the things in perhaps a different perspective, and show the students a wider range of issues, that are available for work. And also that lots of things are so completely unknown, and there is a dire death of properly trained professionals, who can make educated decisions.

For those of the students who are trying to go towards graduate studies, or research work; effort has been to identify topics, or show you topics in diverse areas, which are still unexploded, where the understanding is quit incomplete, there are challenges in all areas which could motivate to understand those aspects better, and be able to contribute to concrete engineering.

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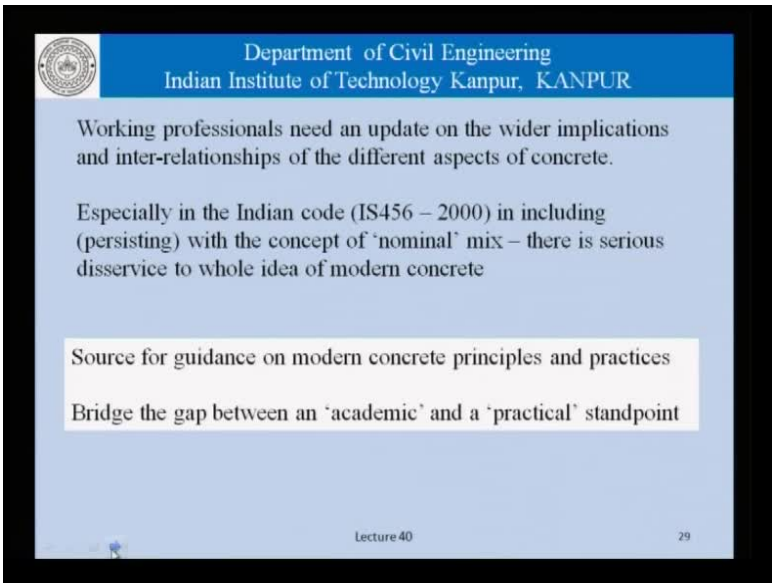

As far as working professions are concerned, they need to update, and understand the wider implications, and inter relationships of the different aspects of concrete. Especially, in the Indian code IS456-2000 in including or persisting with the concept of nominal mix, there is a serious disservice to the whole idea of modern concrete. There is nothing like a concrete prescription, that if we use 1 part of cement, 1 1 by 2 parts of sand, and 3 parts of aggregate, we would get m 20 concrete. That is simply not on, as far as modern concrete construction is concerned.

Even, if somebody does it, it cannot have the sanction of a specification, we should not be writing a specification, because as I said the specification shows what we want, and if we want the concrete, which is simply having the ratio of the materials as 1, 1 1 by 2, and 3, then we are not talking of the quality of the concrete, we are simply saying that you mix the concrete, you mix the ingredients of concrete in this particular ratio, and whatever it becomes will be acceptable to us.

Now, if that is the kind of concrete that we want, then I do not think we will be able to survive too long, as far as serious concrete engineering is concerned. The material in this module hopefully, can service a source for guidance on modern concrete principles, and practices, and contribute to bridge the gap between an academic, and a practical stand point.

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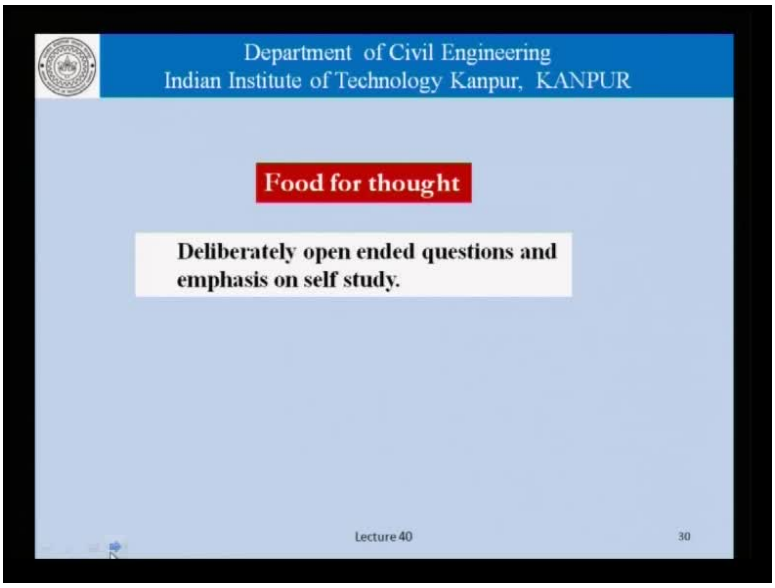

Food for thought has been a central part of our discussion, but of course, in this lecture we cannot talk in terms of an assignment, but I must mention that the questions that have been raised in this section of the lecture, have been deliberately open ended questions to promote self-study.

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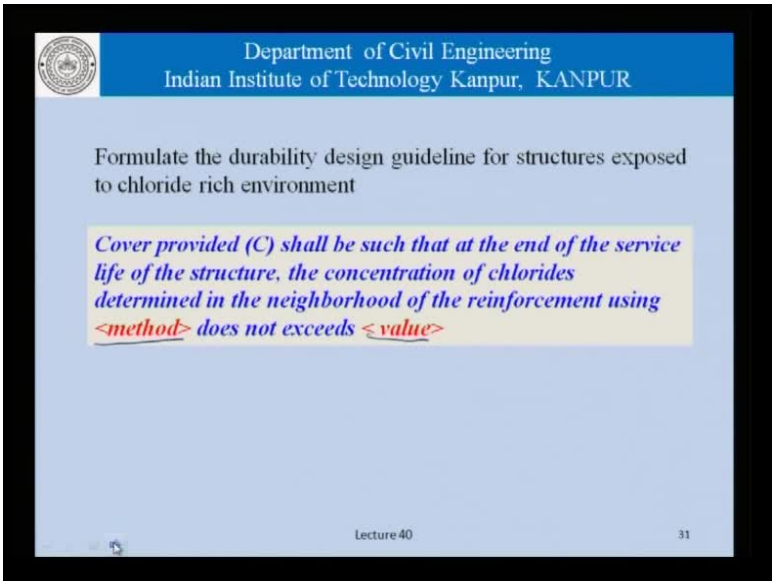

One question of course, which I would like to give an answer to was raised during the question, during our discussion, on durability design, which said formulate the durability design guideline for structures exposed to chloride rich environment, and the answer to

that to my mind would be, the specification should be something like, the cover provided shall be such that at the end of the service life of the structure the concentration of chlorides determined in the neighborhood of the reinforcement using a certain method, does not exceed a certain value. This could be total chlorides, soluble chlorides, whatever you want to include; this value, here could be based on the criticality of the structure, what the conditions of exposure, and so on. And be related to whatever threshold, chloride content has been established for the onset of corrosion, and so on.

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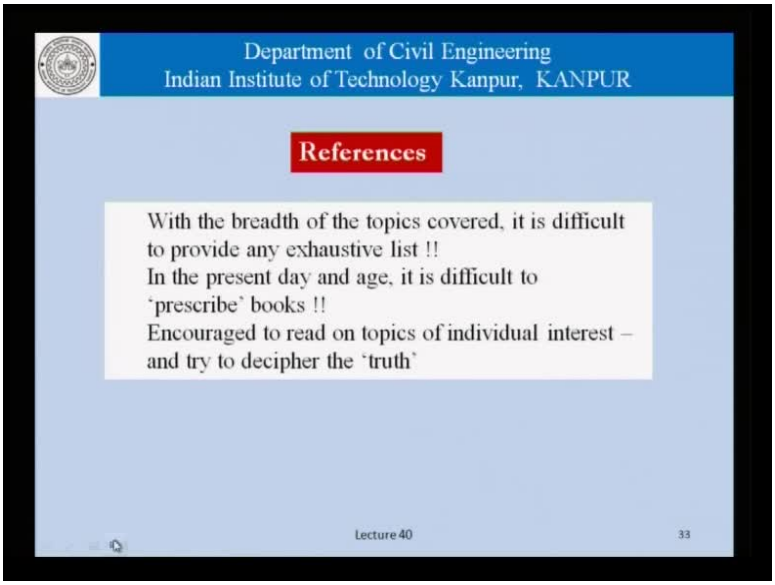

So, with that coming to references, what is a kind of material that needs to be referred, to in addition to the discussion, that we have been having, or to supplement the discussion, that we have been having, with the breadth of the topics covered. In the present day and age, it is difficult to prescribe books, there are so much information available in the internet, the magazines, and so. On that is difficult to prescribe and perhaps, it is not really required to prescribe a set of books.

Especially, if we are talking distance education, because this is not the kind of discussion, where there are exams to be held, and so on. We are trying to talk in terms of motivating self-studies; it is not really required, that there is this particular book, that we follow. In addition to all this, I would rather say that, one is encouraged to read on topics of individual interest, and then try to decipher the truth. Different books, different papers would give us different information especially, when it comes to very specific topics,

what is the amount of water that is required for complete hydration of cement? If this question is googled, if you try to find it on the internet, there will be different numbers that are cited by different researchers.

How is the pulse velocity, how is the ultrasonic pulse velocity, related to the quality of concrete? A qualitative description yes, but any quantitative description will have variations in discussion, and that is something which has matured concrete engineers, one must try to decipher what is applicable in one case and so on, what is applicable in the case, that we are especially interested.

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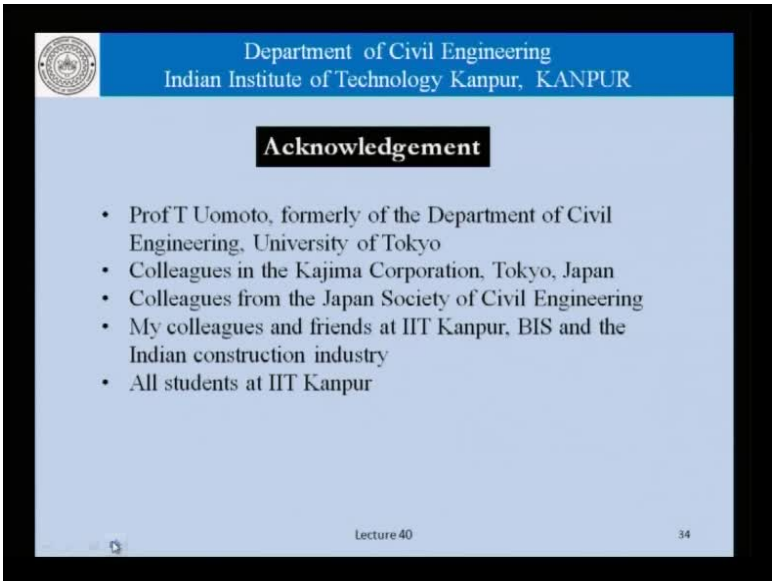

Coming to the end knowledge the support of all the people, who have worked with me; first of all professor Uomoto, who is formerly from the Department of Civil Engineering, University of Tokyo; my colleagues in Kajima Corporation, Tokyo in Japan. Colleagues in the Japan Society of Civil Engineers; My colleagues and friends in IIT Kanpur the Bureau of Indian Standards and the Indian Construction Industry, then all the students at IIT Kanpur, all these people have contributed in different ways, and I must say immensely to my understanding of concrete, and I must say a thank you to them.

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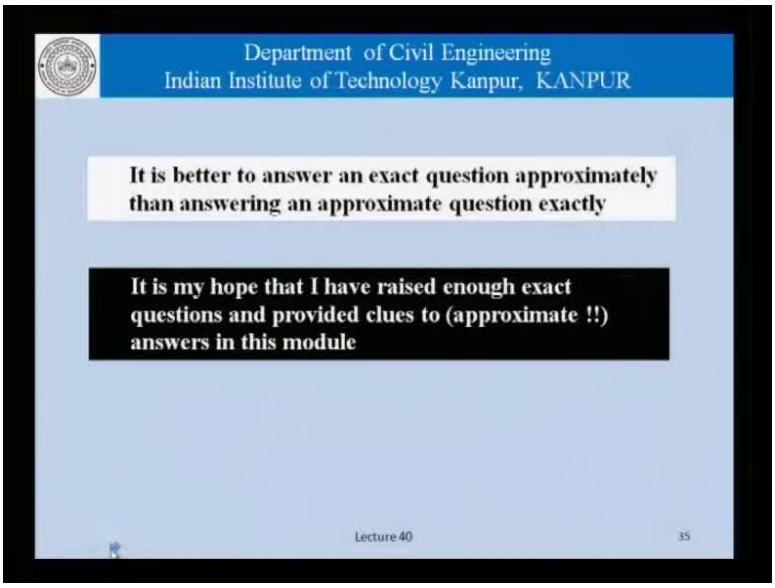

Before, I close I would just like to share this with you, I have read this somewhere, and I have probably paraphrased it, it is better to answer an exact question approximately than answering in approximate question exactly; so it is my hope that I have raised enough exact questions, and provided clues to approximate answers in this module.

Thank you.