Development and Applications of Special Concretes
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Lecture-26
Shotcrete

Hello and welcome back to our discussion on development and applications of special concretes. Today we will be talking about shotcrete.

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So, let us begin our discussion by defining shotcrete once again. We have looked at this method of construction in an earlier discussion as well. To recapitulate, this slide shows shotcreting being actually carried out at a site. Now defining shotcrete means this is a concrete which is delivered to the final point of placing in a sealed pressure resistant hose or pipe and is applied by spraying.

So, what we are talking about is that concrete is being delivered through this hose which contains the concrete of course and it is a sealed pressure resistant hose of pipe. So, this concrete is being placed on this surface here under pressure, so that when it leaves this place here it has a certain velocity, how much velocity it has and so on, that is a different story. But it is being placed at this point here through pressure deposition at site.

This concrete requires no formwork and self compacts. Now this self compaction here as you can imagine is a very different concept than the kind of self compacting concrete that we had talked about in our previous discussion. In this case we believe or we want the concrete to compact itself simply because of the speed at which it is deposited. What we must remember or try to think about is that whether this concrete that we get after it is deposited the way it is being deposited here, is this concrete the same as something that we have been talking about here.

In this place here we have been talking about concrete being a suspension of coarse aggregate and mortar and so on. Now once the concrete is deposited here, does it meet the kind of requirement that we have placed here? In the manner of speaking yes, it does because it is the same concrete after all. But in certain contexts, one may argue that well it is not really the same thing.

So, I am leaving this as an open question to you to think about, and see under what kind of conditions or what are the kinds of constraints or limitations that this particular method of placing concrete places on our basic understanding or premise on the definition of concrete structures?

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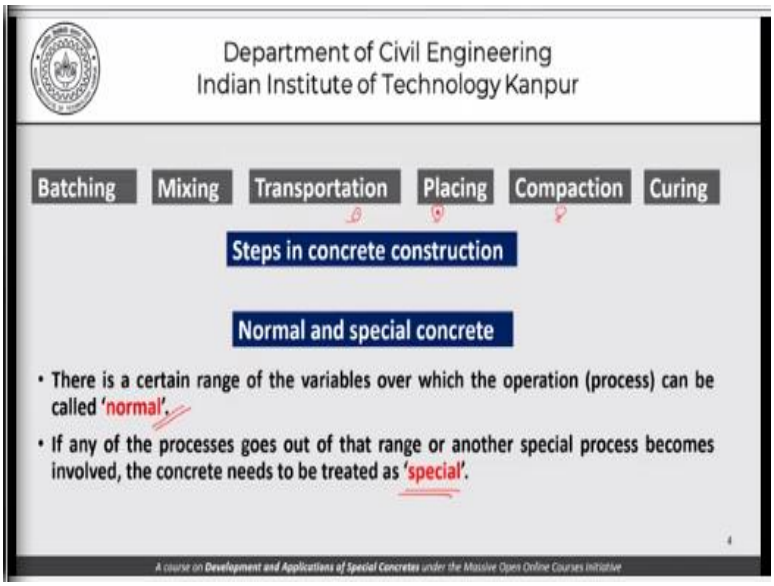

So, having looked at shotcreting operations, let us recapitulate what we have talked about as far as normal concrete is concerned. We have been talking about the fact that batching, mixing,

transportation, placing, compaction and curing are perhaps different processes that go on as far as concreting is concerned. And each of these processes has a certain normal range and once any of the processes or any one or more of those process goes out of that range then the treatment becomes special.

So, as far as shotcreting is concerned, what is the special? The placing method. The placing method is something which we do not use normally. The compaction method, we are not using normal vibrators; that is what I have been saying all the time. So, you cannot alter just one mechanism or one process and think that you have made it special and there other things will fall in place. Transportation similarly as far as shotcreting is concerned is a very different way of working.

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Before we start a discussion on the properties of shotcrete and the material used and so on, I will quickly go through some pictures to show you what the operation is and how it looks like when the concreting is being done in that manner. So, here we have one application where you can see shotcreting being carried out for tunnel linings. And you can see that the lining thickness need not be deposited in a single layer.

It is possible that concrete is deposited in one layer first and then another layer and possibly another layer. What we should make sure when we are trying to do shotcreting in this layered

manner is one thing is about the joints. These joints should be such that the concrete across these 2 joints is not separated, it is just the normal consideration for cold joints, we do not want these joints to become cold joints.

And secondly, we should make sure that this entire mass of concrete does not fall off. Because we should remember that shotcreting is an operation at times is being carried out against gravity. For example, if you are trying to do the shotcreting overhead somewhere here in that tunnel, then the danger of the shotcrete falling off or the deposited material falling off is indeed very real.

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Moving forward, this shows the application of shotcrete in the case of slope protection, which is something very important when we are working with hilly areas where we are trying to stabilize the slopes. And trying to create infrastructure such as roads, canal lining sometimes we use this though that necessarily does not have to come under the slope protection banner. But yes, the application or the condition of application is more or less what is shown somewhere here.

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Moving forward this picture here particularly shows a more complicated form of deposition of shotcrete where the people here the operators, the nozzleman they are being lifted to a position, so that they can reach the place where the shotcrete is being deposited. And you can imagine that these 2 here is you should be able to see that we are trying to do reinforced concrete here. That is there is a certain amount of reinforcement involved.

And the shotcrete is expected to fill this area here somehow move behind the reinforcing bars as well, so that the normal principles that we use for reinforced concrete can still be applied. This picture here is when the nozzleman are at the ground and they are trying to make a deposit on a more or less vertical surface at a lower level.

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This picture is also something which we have seen before when we are talking about special tests or the need to have tests representing the real condition. What is important to understand is the picture here in the context that is shown here. That is whether the concrete deposited here can still be represented using this basic model. So, this was the question that I asked you at the first slide and I am going to reiterate that once again without giving you the answer.

The basic answer that we can have is that no matter what the deposit the fact that here when the concrete is leaving this nozzle and getting deposited here, it is still this concrete. That is we still have mortar covering each aggregate particle and that is being deposited here. So, there is nothing wrong in this model as far as shotcrete is concerned, except that only the method of deposit is very different.

And therefore, we need to be very careful when applying the principles of normal concrete whether it is for proportioning the concrete or it is for quality control, it is for strength development and so on and so forth.

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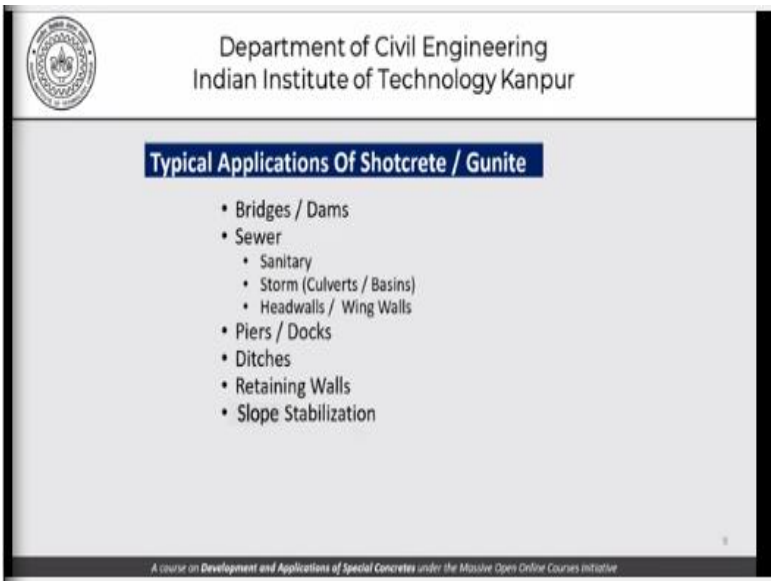

Now the typical applications of shotcrete are what is also called guniting sometimes, the operation is called the guniting and the shotcrete is referred to as gunite. That could be in bridges or dams, repair works especially, sewers, sanitary, storm, headwalls or wing walls, piers and docks, ditches, retaining walls and slope stabilization. These are some of the applications especially in the context of repair works.

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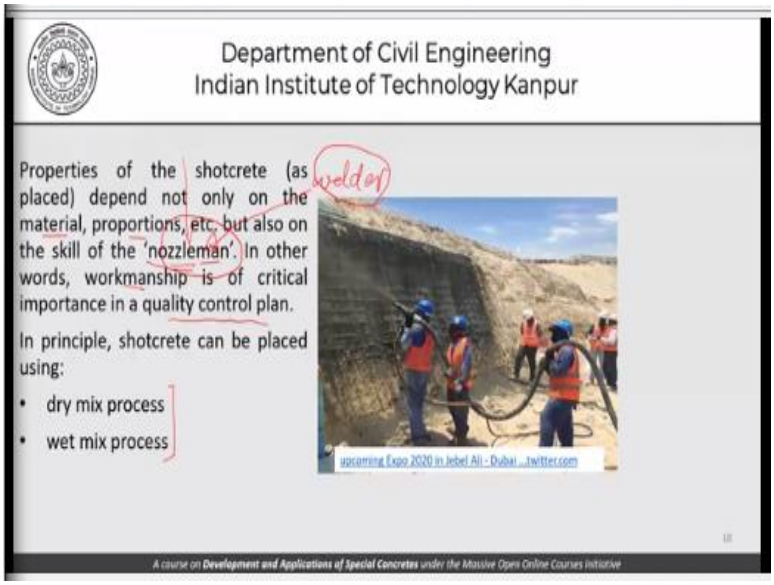

We should remember that the properties of shotcrete as placed depend not only on the material that we use or the proportions. But also, on the skill of the nozzleman, that is the workmanship is of critical importance in a quality control plan dealing with shotcrete. It is much more important here to have a trained or a qualified nozzle man than in normal concrete. I am leaving it to you to

think of a process or processes that have been standardized as far as qualifying and nozzleman is concerned.

Try to think of a nozzleman as a skilled worker working in the construction site and compare the requirements with that of a welder. A welder works with steel, and there are different types of welders there are different qualifications that exist. And I am leaving it to you to think about and look for qualification methods for a nozzleman, how do we go about passing a nozzleman? Stating that, yes, this person has passed the test and is qualified to place concrete using shotcretes as a nozzleman.

In principle shotcrete can be placed using 2 basic methods, the dry mix process and the wet mix process while you are studying the principle of a nozzleman of the qualification of a nozzleman. Try to also think that a nozzleman once qualified, is he qualified for both the processes or if he has qualified using one process? He can still do the shotcreting for the second process.

These are questions which I am leaving it to you to think, and look for in literature, it is not so much of thinking. But it is a matter of looking at the literature and trying to find out from the standards in different countries as to how they treat the qualification of a nozzleman.

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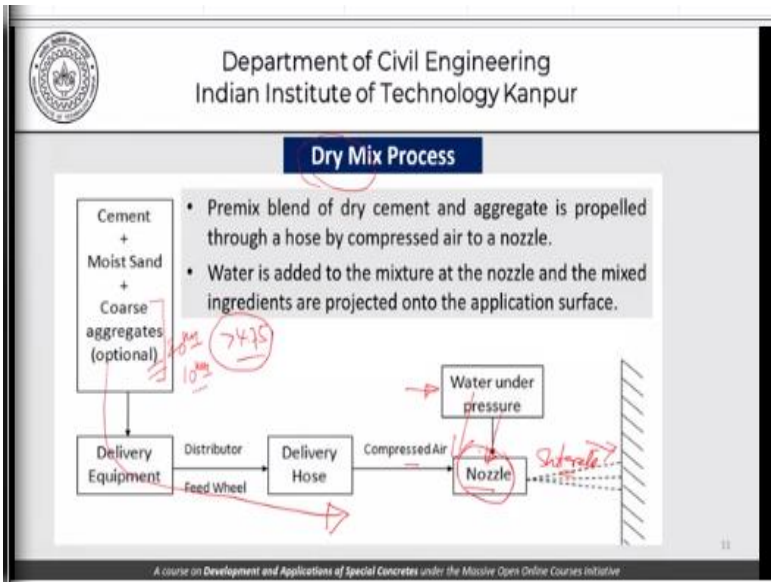

Now as far as the dry mix process is concerned, what happens is with cement, moist sand and coarse aggregate which is optional? Of course, in the context of shotcreting the coarse aggregate does not necessarily have to be 20 mm aggregate. Anything more than 4.75 mm qualifies as coarse aggregate and therefore we will have a lot of examples of shotcrete where only up to 10 mm kind of aggregates are used.

They are surely coarse aggregates because they are not as fine as sand would be, but they are not 20 mm aggregates. So, cement moist sand and coarse aggregate they all go into a delivery equipment for delivery holes, with compressed air we come to the nozzle. And at this point water under pressure is added to this and what we get from here is shotcrete. So, basically the idea is that a premixed blend of dry cement and aggregate is propelled through a hose by compressed air to a nozzle.

And water is added to the mixture at the nozzle and makes the ingredient and water is added to the mixture at the nozzle and the mixed ingredients are projected onto the application surface. So, this fact that water is added at the end and most of this material coming from here is dry, this is what causes this process to be called the dry mix process. So, we are getting dry mix here putting water here or adding water here under pressure and finally shotcreting onto this deposition surface.

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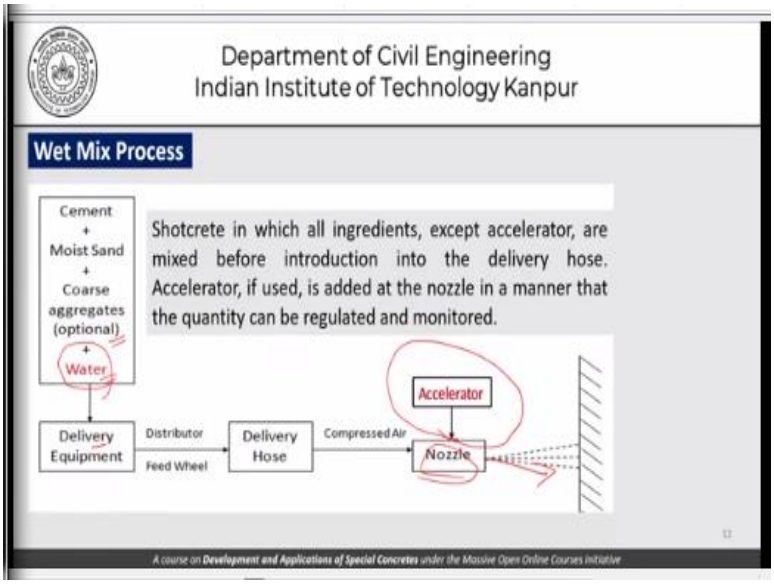

As against this in the wet mix process the cement, sand and coarse aggregate which is optional as I said before and water all of the concrete ingredients are added to the delivery equipment and the concrete is shot into the placing surface straightaway. So, what the difference is that here the entire delivery is for a wet concrete, wet to the extent that water has been pre-added to the mix much like any normal concrete.

So, in other words shotcrete in which all ingredients except the accelerator are mixed before the introduction into the delivery hose is wet mixed concrete. Accelerator if used is added at the nozzle in a manner that the quantity can be regulated and monitored. So, it is only the accelerator which is added at this point here into the nozzle just before the shotcrete is fired onto the placing surface.

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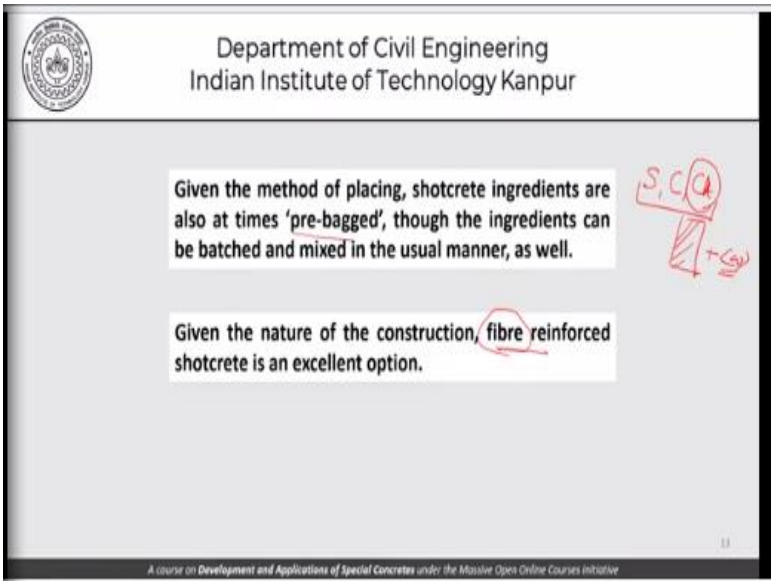

Moving forward given the method of placing, shotcrete ingredients are also at times pre-banged though the ingredients can be batched and mixed in the usual manner as well. Pre-bagging means we have a bag of pre-mixed shotcrete material, that is sand, cement and whatever coarse aggregate is required. That can all be put together in a certain proportion and sold in a pre-mixed bag.

With the prescription that for each bag you use a certain amount of water either with the concrete at the time of mixing and then doing the shotcrete or adding that amount of water at the nozzle

through an appropriate arrangement for the dry mix process. And given the nature of the construction fibre reinforced shotcrete is an excellent option because fibres can very easily be included in this pre-mixed bag. And delivered to the site where it can be mixed with water, water being added to the nozzle if it is required and going ahead with the shotcrete operations.

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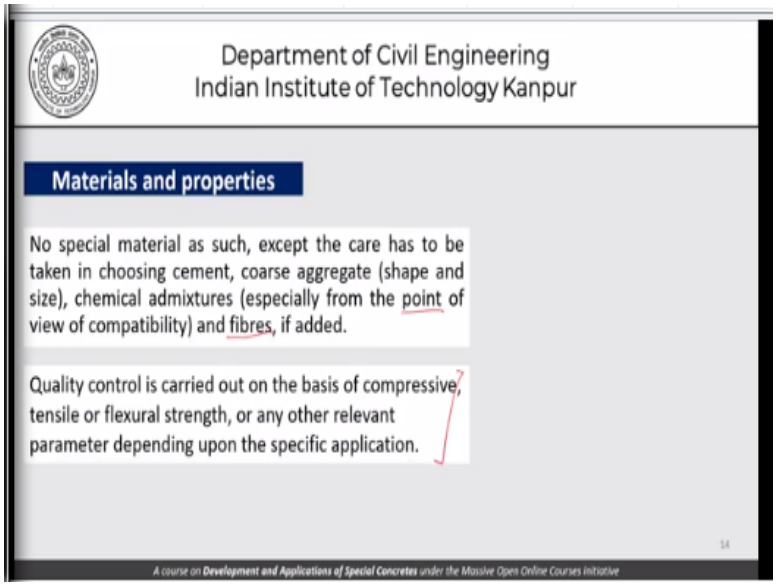

As far as the materials and properties are concerned for the shotcrete, no special material as such is required except care has to be taken in choosing the cement coarse aggregates in terms of shape and size. Chemical admixtures from the point of view of compatibility and also what we expect the chemical admixtures to do whether we are talking in terms of water reduction, whether we are talking in terms of acceleration and of course if we want to add fibres.

So, we have to have a special care in choosing our materials but apart from that it is the good old cement coarse aggregates and sand which is being used in the shotcrete. Quality control is carried out on the base of compressive, tensile and flexural strength or any other relevant parameter depending upon the specific application. So, this is not very critical except for the fact that how we make the specimens for compressive or tensile reflection strength is important.

We cannot use normal methods like using a vibrator, depositing it against, formworks, using smaller samples that we use. And that is what we have talked about extensively or at least in

some form, in some detail when we are talking about the need to have special methods for even taking the samples, we will touch upon this question once again a little later.

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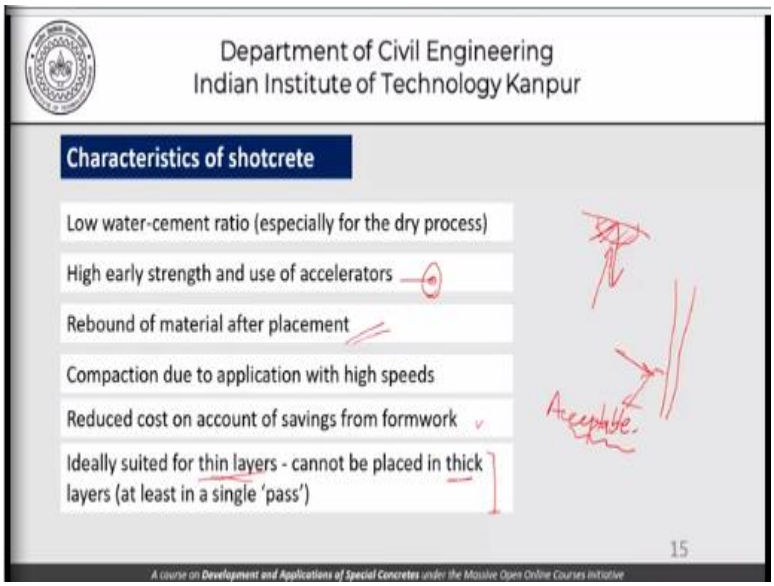

So, as far as the characteristics of shotcrete is concerned, low water cement ratio especially for the dry mix, high early strength and use of accelerators. This is something which is very important because the more time the concrete takes to set, the more is the real danger for the concrete falling off or moving away from where it is supposed to be or moving away from the state of placement.

Rebound of the material after placement is something which we are forced to live with, when concrete is deposited on a surface when concrete is deposited on a surface which could be let us say vertical. And we are trying to deposit the concrete here; it is obvious that some of the concrete will fall off. This is so much more so if we are trying to deposit the concrete in a overhead position.

So, there is no reason to believe that all the concrete that comes to the surface will get deposited here, some of it will surely rebound. Now how much is that rebound is something which I am leaving it to you to think and look up your books, and find out what is an acceptable level of rebound? And what are the measures that are taken to reduce the amount of rebound in the case of shotcrete constructions?

Reduced cost on account of savings in formwork, yes, we reduce the cost in terms of formwork. But then the question is do we pay additional cost in terms of chemical admixtures or in terms of choosing the materials or for that matter in choosing more skilled workmen and so on. So, it is not necessary that if we save the cost in one operation, the entire operation becomes economical. So, one has to be very careful in making a choice.

Ideally suited for thin layers, it cannot be placed in thick layers at least in a single pass. Now this is something which we had talked about very briefly when we are looking at the method of construction of shotcrete. That the method in principle is suited for thin layers of construction and the moment the layers become thick, one has to be very careful in recommending or using a shotcreting as a method.

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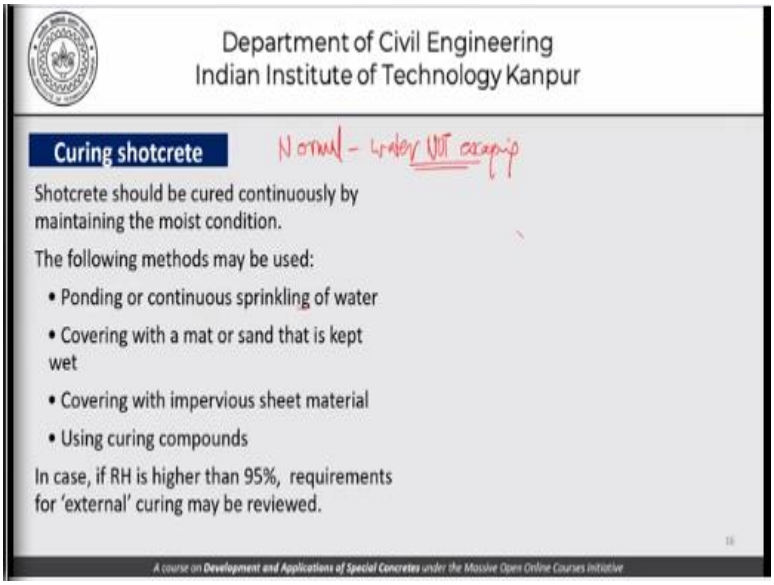

As far as curing of concrete is concerned, like any other concrete it needs to be cured, charcoal should be cured continuously by maintaining the moist condition. The following methods may be used, ponding or continuous sprinkling of water if possible, covering with a mat or sand that is kept wet, covering with an impervious sheet material using curing compounds. And in case the relative humidity is higher than 95% requirements for external curing may be reviewed.

So, the basic point is that much as in normal concrete we need to have water not escaping from the surface. Now if water does not have to escape from the surface, we need to cure the concrete. The fact that the shotcreted has nothing to do with the curing process, the concrete has to be cured depending on the geometry of the shotcrete that we have placing, we may have to develop specific methods for curing.

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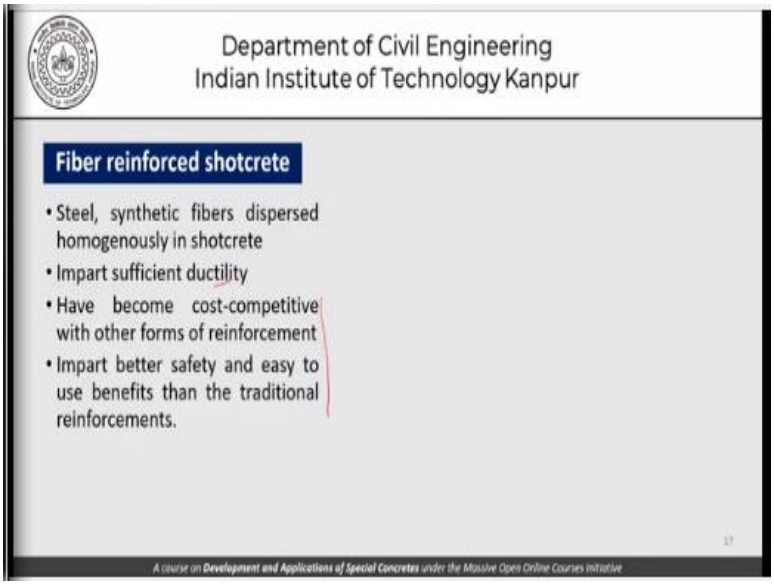

As far as fibre reinforced shotcrete is concerned, yes, the steel synthetic fibres dispersed homogeneously in shotcrete. We have talked about different types of fibres when we are talking about fibre reinforced concrete. And this is one application where fibre reinforced concrete can be used in repair works for example. Impart sufficient ductility that is the normal expectation from fibre reinforced concrete.

Have become more cost competitive with other forms of reinforcement, impart better safety and easy to use benefits than traditional reinforcements of course. There are benefits of using fibre reinforced concrete systems and in the case of shotcrete, we do have the ability of using the potential of steel fibres or any synthetic fibre we choose to use to a fuller potential.

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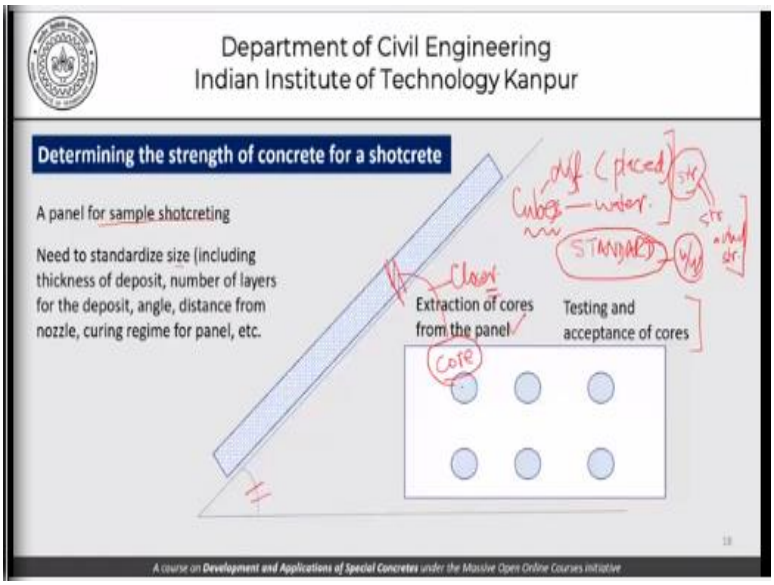

This slide is something which we have seen before. As far as determination of the strength of concrete under the shotcrete operation is concerned. There could be a mechanism by which we have a panel which is used to create the sample, which can then be used to extract coarse and we have testing and acceptance standards which are determined or which are laid out for accepting the shotcrete on the basis of strength.

Of course, we need to standardize things like the size of the panel, including the thickness of the deposit number of layers of the deposit. This angle that we are talking about here the distance from the nozzle, curing regime for the panel and so on. What has to be understood here is that this concrete what I would like you to think about is that we have cubes as the basis for our quality control as far as normal concrete is concerned.

Now these cubes are cured in water and they are prepared differently than the placed concrete. So, there is no one who will argue that the cubes represent the actual method of placement as far as normal concrete is concerned. And therefore, when we interpret the strength of these cubes and try to compare it with the strength of concrete in the actual structure. The kind of considerations that will apply in this discussion are they the same when we are talking about the strength from the core.

That we get here which is extracted from this panel which has been prepared. To my mind and that is something which I am leaving to you to make a final judgment. This method gives me a closer representation of what has happened in a shotcreting operation whether it was a tunnel lining or it was a slope stabilization application or whatever went on. So, in a situation like that if the nozzleman is carrying out the operation for slope stabilization.

And as part of that process, he is also casting a panel which is later used to extract cores which are tested in strength to determine the strength of the concrete in the slope stabilization. That operation is closer to reality than cubes being taken from the concrete, and they have been tested for strength and are trying to make an assessment of the strength of the concrete in the actual structure.

Because these panels can then be cured under identical conditions as the actual structure, that is not something which we do with the cubes as far as standard practice is concerned. As far as the standard practice is concerned these cubes are cured under water. So, that is what has been the essence of our discussion all the while, that when we are talking of special concretes, we need to have a specific and maybe different standards which we need to evolve or write down for specific concretes, specific projects.

Some of those standards obviously exist and I have been giving you reading assignments, I have been asking you all the time to read those standards, find out about those standards. In order to be able to better utilize special concretes in actual projects.

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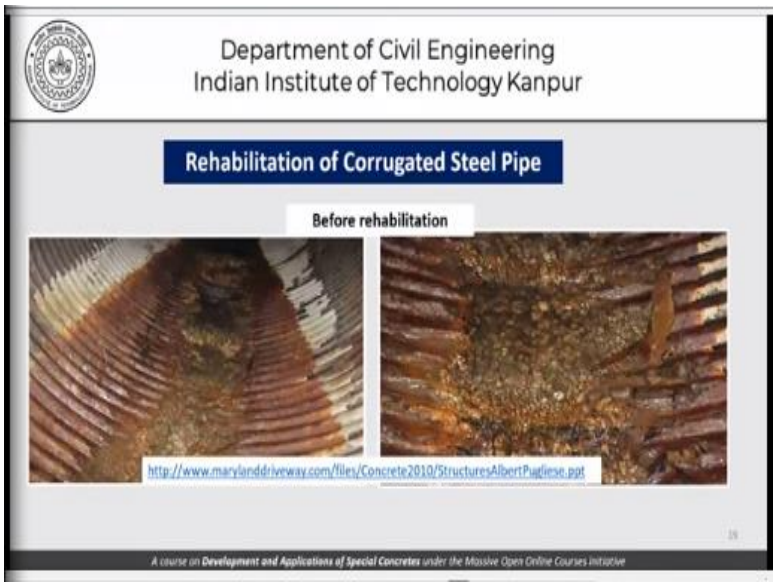

Now let me show you some examples of shotcreting being used for rehabilitation works in particular before we close our discussion for today. This is the rehabilitation of a corrugated steel pipe, so you can see that there is heavy corrosion as far as the steel pipe is concerned.

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And this picture here shows the pipe after rehabilitation using shotcretes. So, what has happened of course is that the corrugated steel pipe has now got a lining of the concrete inside. We have lost some diameter but we have saved or we have recreated the pipe in a different form.

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This picture here is rehabilitation of a brick sewer lining. So, you can see the deteriorated brick sewer here, rehabilitated into a sewer line which is something like this. Again, loss of cross section, yes, but a renewed sewer line, rehabilitated sewer line.

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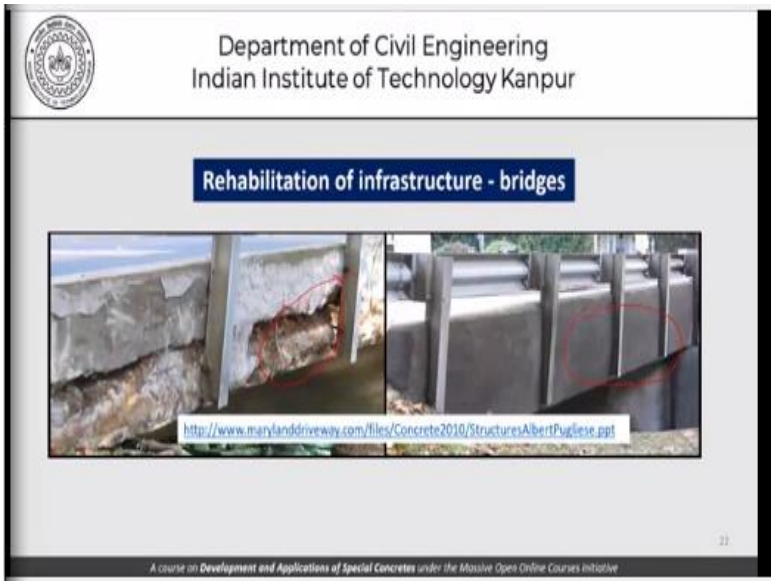

And then of course we have the rehabilitation of infrastructure may be bridges, where we can see this kind of deterioration. And this is the picture which we have after a deposit of shotcreting, not necessarily on this surface alone. But after the loose concrete and everything has been removed from here maybe additional reinforcement has been placed in position and then carrying out the shotcreting operation.

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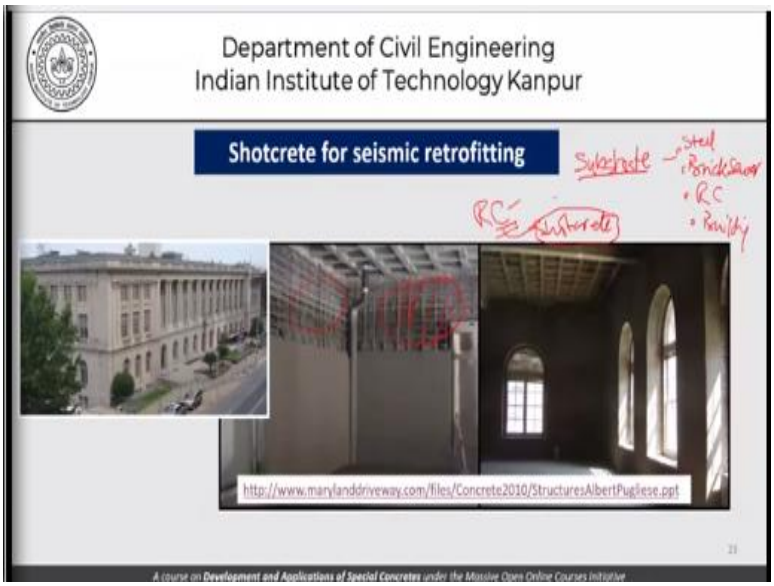

This picture here is for shotcreting operations for seismic retrofitting. And you can see reinforcement panels in the walls and we have a renewed structure which is more compliant with the different standards that we may have for seismic performance of structures compared to those standards that were prevailing when the original structure was built. So, one advantage of using shotcrete in the repair works especially is that it works with any of the substrate materials.

We have seen examples where we had a steel pipe, we saw an example where it was a brick sewer lining, we have normal reinforced concrete kind of bridge structures. And we have a building kind of a structure where these panels could be again made of either brickwork or any other material that is locally available and has been used. But we can use reinforced concrete but we can deposit or create additional thickness using reinforced concrete except that the concrete that we use is shotcrete.

So, the reinforced concrete is the same except that the concrete is shotcrete that is it is a concrete which is deposited using concrete placed under pressure. It is not normal placement; it is just the difference in the placement method. They are slightly different from this discussion can be viewed in a more or less similar fashion as we talked about fibre reinforced concrete. So, fibre reinforced concrete can still be used here as part of this reinforced concrete.

And we can also have this reinforcement which is certainly not fibres this is normal reinforcement being used in the normal sense and the concrete being placed using the shotcreting method.

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So, this again is of a retaining wall where we have this retaining wall, we have reiterated it into this form. And this again shows the versatile nature of the shotcreting operation, and it is applications primarily for repairs.

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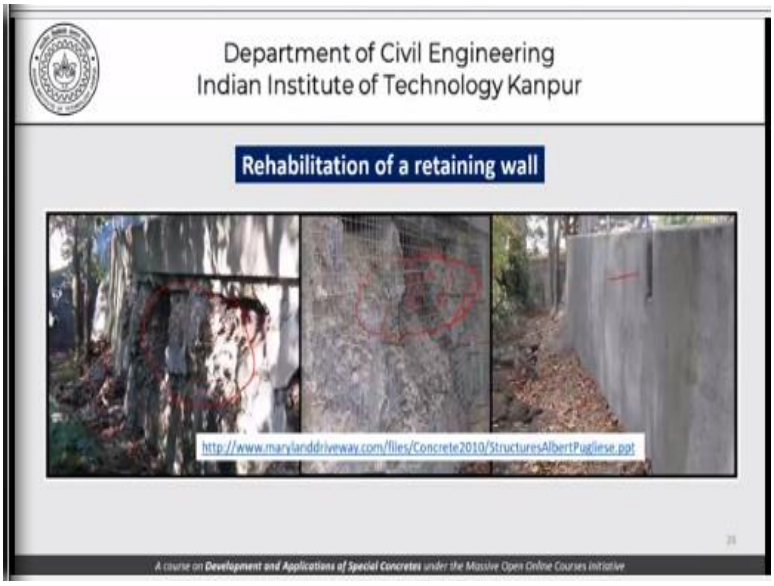

This is rehabilitation for retaining wall; again, we can see the rehabilitation including some kind of a mesh being placed first in position and then the concrete being deposited to strengthen the retaining wall which was possibly deteriorated to begin with.

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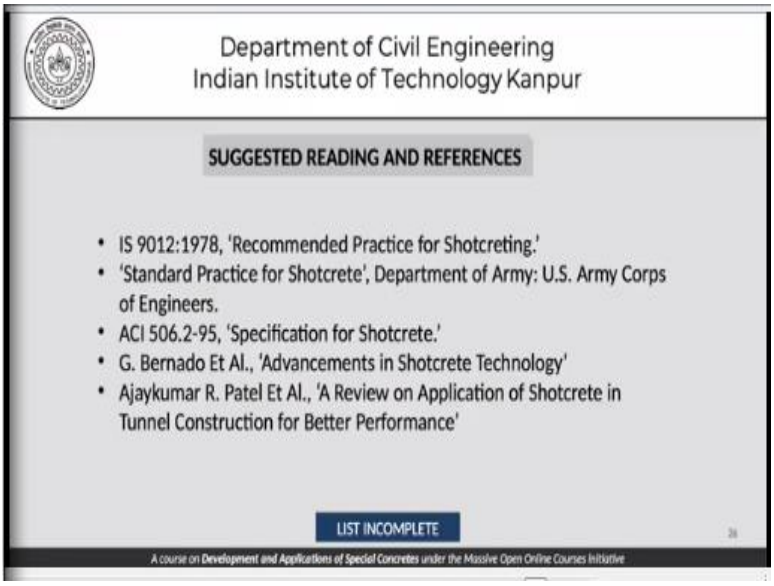

With this we come to a close of our brief discussion on shotcreting. And here are some papers and articles, books which you could refer to, to understand this method better. And perhaps be better prepared to use this method as far as an option is concerned especially for rehabilitation works.

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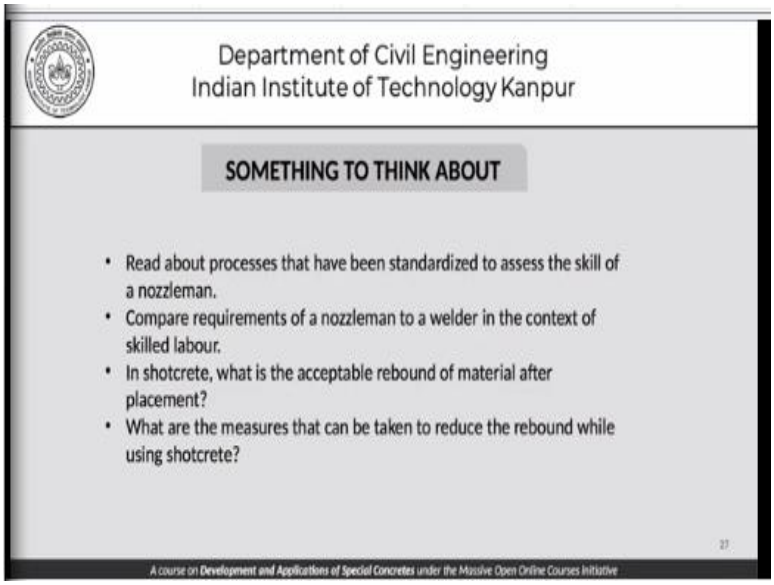

These are some of the questions that you can think about and look for answers while you are doing a search on the internet.

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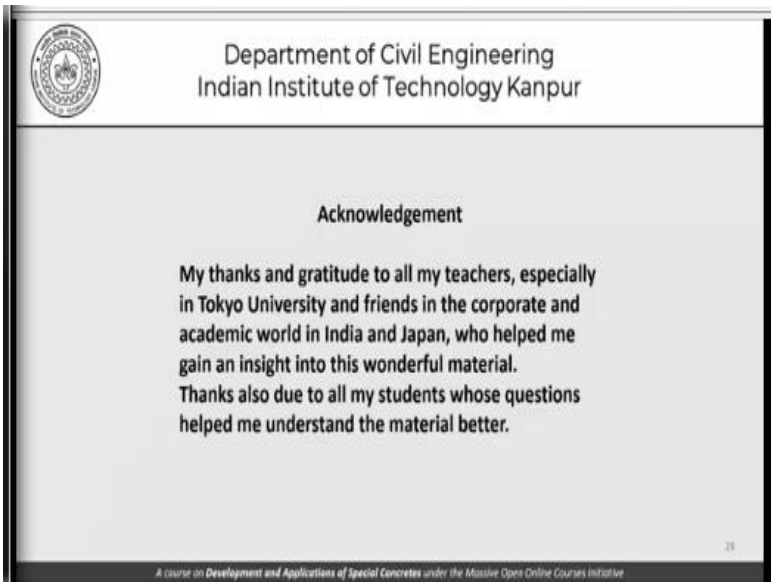

My thanks again, my teachers, friends and students who have helped me understand not only shotcrete but also the concrete in principle better. Thank you once again and I look forward to seeing you in another class when we will be talking about something like high strength concrete perhaps or other topics.