Concrete Engineering and Technology
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Lecture - 20
Roller Compacted Concrete

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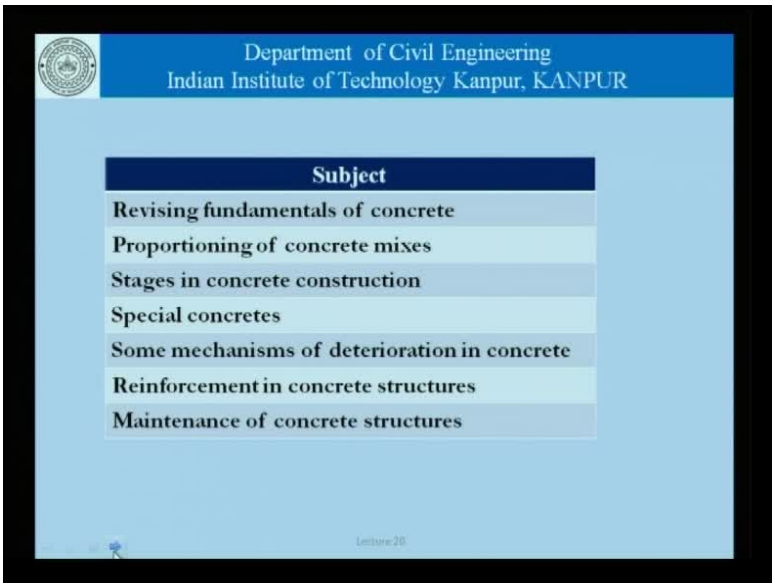

Welcome to another lecture in this course on Concrete Engineering and Technology. We are talking about revising the fundamentals of concrete, proportioning of mixes, stages in concrete, constructions, special concretes, mechanisms of deterioration concrete, structures in reinforcement, and also issues relate into maintenance of concrete structures.

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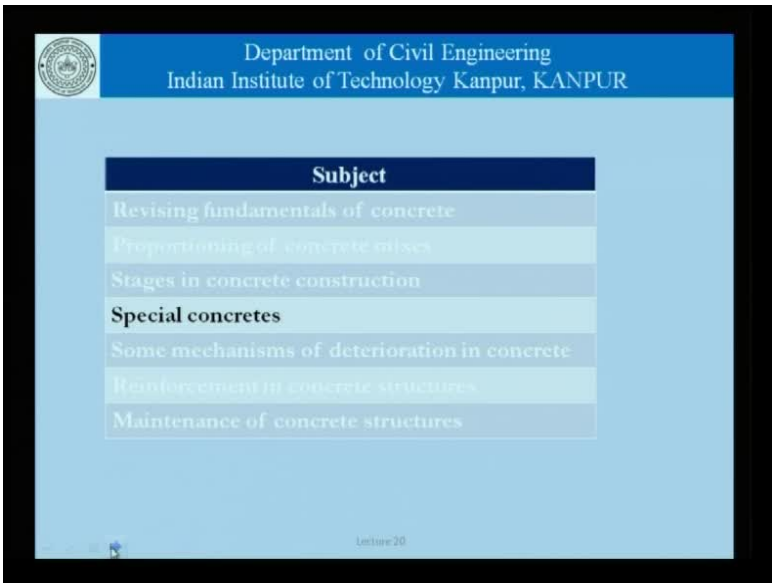

We will continue our discussion today with the special concretes.

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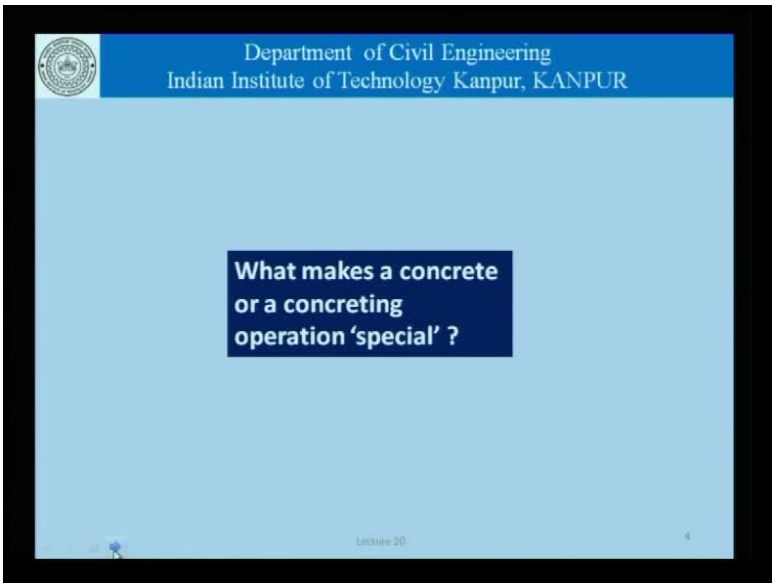

And to reiterate what makes a concrete or a concrete operation special.

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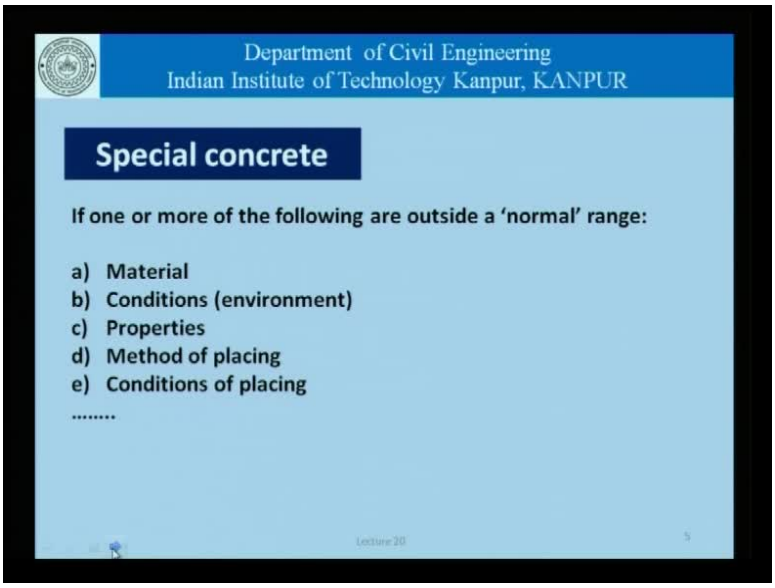

Is the fact that one or more of the following are outside a predefined normal range, it could be in terms the material used, the conditions or the environment in which concrete is been placed. It could be in terms of the property of the concrete that we are casting, the method of placing or the conditions in which the concrete is being placed.

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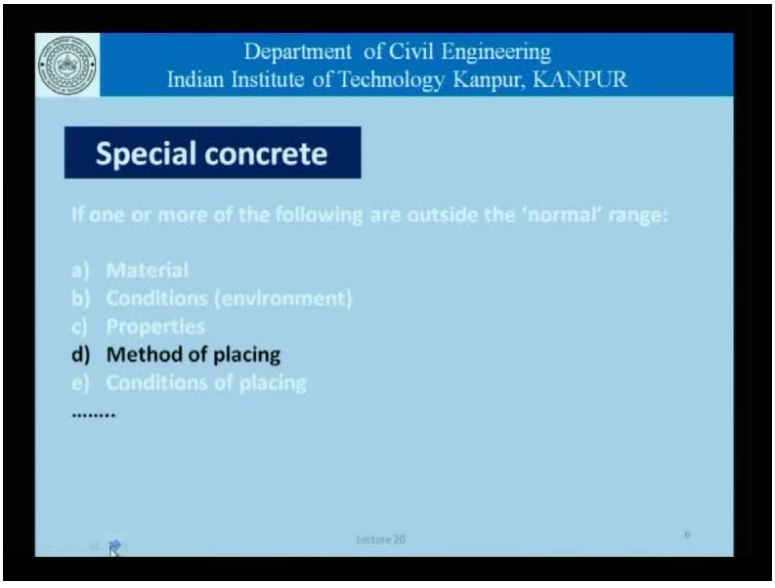

So, today's discussion will focus on a special method of placing the concrete, and we will be talking about roller compacted concrete.

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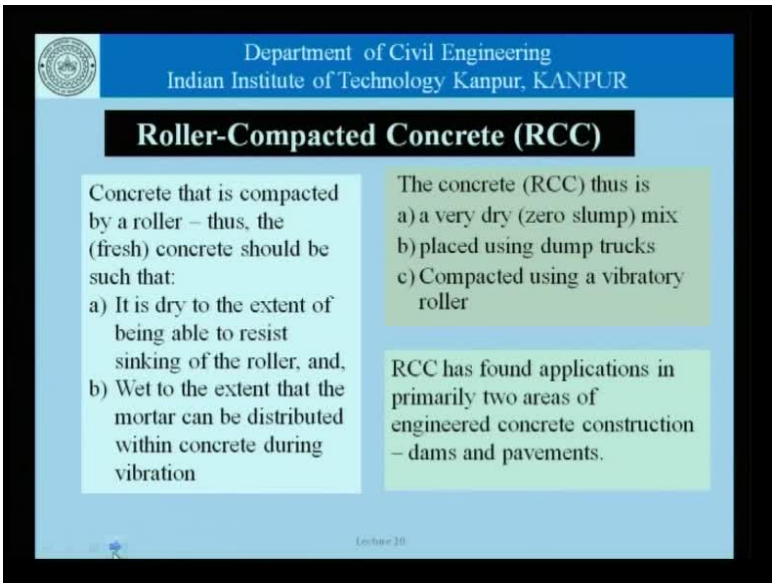

Now, what is roller compacted concrete? It is a concrete there is compacted by a roller, that is the fresh concrete that we have should be such that, it is dry to the extent of being able to resist the sinking of a roller. And it should be wet to the extent that the mortar can be distributed within the concrete, through this vibration. It is not vibrator or compacted, using internal vibrators or nil vibrators listed there is a vibrated roller, which is moved on the surface of concrete, in order to compact this concrete.

And therefore, given the fact this roller could be quite heavy, the concrete has to be such that, it is dry to the extent that the roller does not sink. And it should be wet to the extent that, mortar can still be moved around within the words of the aggregates. The concrete can thus be defined as or looked upon as of very dry a zero slump mix, which is placed using damp trucks and compacted using a vibratory roller. Now, this has found applications in primarily to areas of engineered concrete construction, damps and payments, and we will see the moment the reason for that.

Let us take a look at a large block of concrete such as, what we would expect in a gravity damp or long rote which is being made with concrete, we are talking of rigid payment constructions. So, in these two cases we can have block construction that is we brake this large block down into smaller blocks, let us say block 1, block 2 and block 3.

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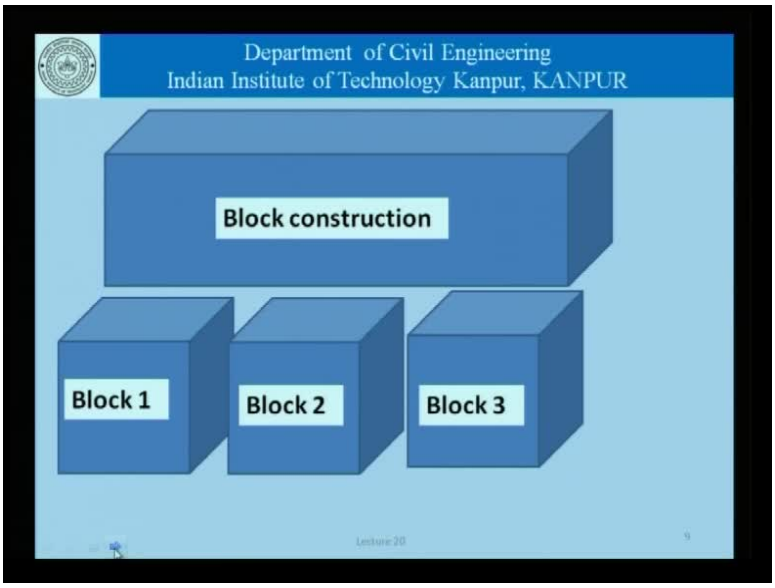

And these three blocks are caused one after another with the suitable gap and so on, and so forth; that is one way of casting this large concrete block. Another possibility could be that instead of blocks, we talk in terms of a laid construction, in which case we divide this block not as blocks like we did last time that is this way, we do not do that.

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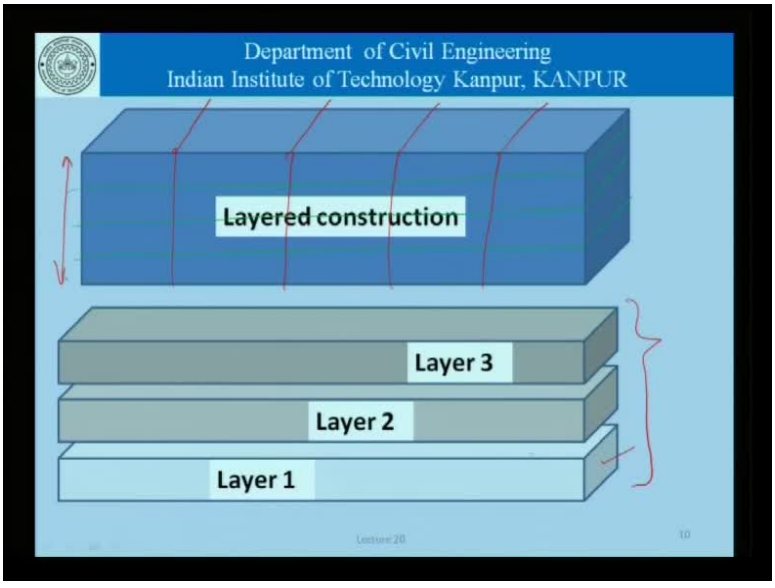

Instead we divided the block in layers, and caused this as layer 1 followed by layer 2 and finally, followed by layer 3, so this a fundamental difference between casting this large block with blocks, which is like this or in terms of layers which is like this. Now, what

are some of the differences between block construction and layered construction, block construction needs form work to be erected and the concrete to be placed in relatively; and concrete to be placed in relatively large heights.

As a result of that, it becomes more difficult for the heat that is generated on a account of hydration of cements, to escape to the surface. Whereas, in the laid construction, the surface area is large and the thicknesses relatively small, thickness being relatively small facilitates movement of heat into the atmosphere; and helps prevent develop any thermal gradients within the concrete. So, given a certain set of conditions, the chance of thermal cracking happening in laid construction is much smaller compared to block construction.

And that is one of the reasons why roller compacted concrete or this kind of laid construction is preferred, basically roller compacted concrete refers to this kind of laid construction, where each layer of concrete is caused. And then compacted by moving rollers on this surface; so to that extent it is similar to compaction of soil, when we do any kind of rote construction or we want consolidates soil we move rollers, layer by layer to compact to soil. And that is exactly what we do when we are compacting the concrete, so that is what is the very fundamental, a very preliminary understanding of roller compacted concrete.

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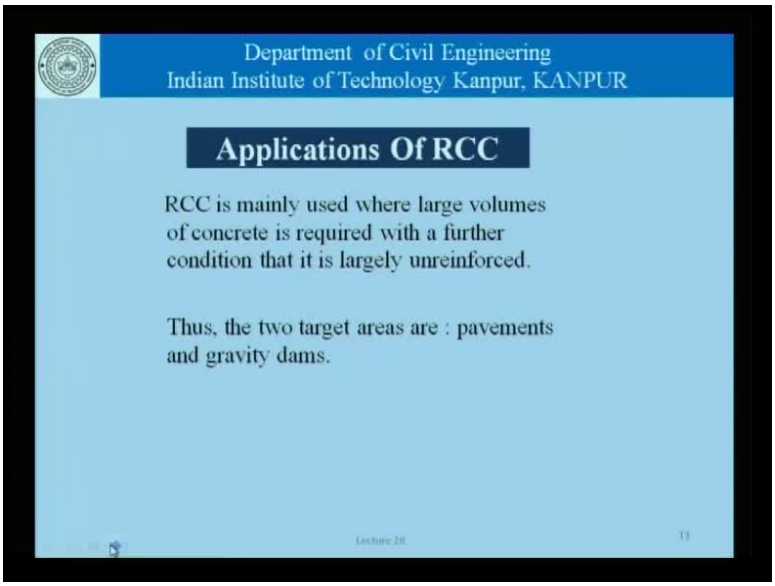

Now, continuing with the applications, it is mainly used where large volumes of concrete are required with the further condition, that the concrete is largely on reinforced. The

presence of reinforcement makes the placement of concrete difficult, and adds a very different dimension to the casting. And therefore, as for as roller compacted concrete is concerned, attention is generally confined top plain concrete.

And as I mentioned the conditions which are met for these and the two areas, where these conditions are met are pavements, and gravity dams. So, these are the prime structures, rich are cast or can be made using this technology of roller compacted concrete. So, in this case the specialty or the non-normal nature lies in the method of compaction that we are adopted, instead of using normal internal vibration; we are using a very special kind of compaction method.

And this necessitates that we take proper care in all other steps, material selection, proportioning, determination of properties and so on, and so forth; as we shall seen our discussion.

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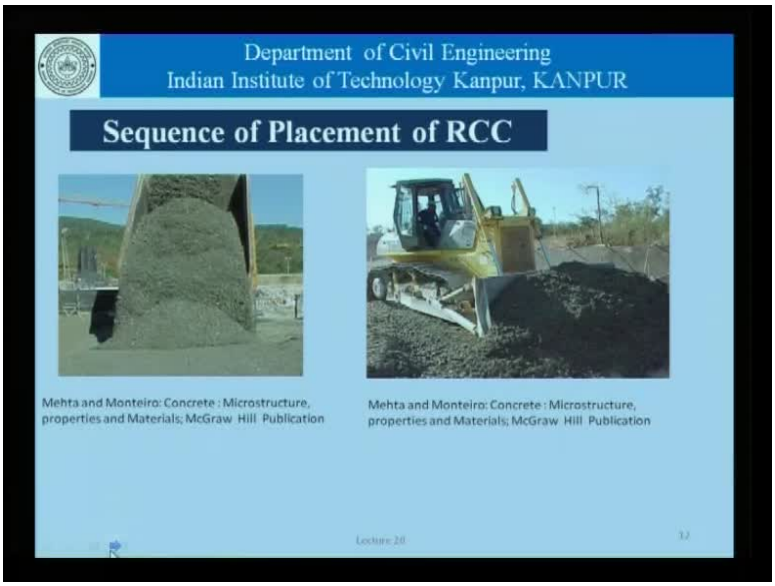

There is the set of pictures which will tell us or give us an idea as to what roller compacted concrete is all about, so here we see concrete bring dumped at a site using a tipper. So, if we can make out that this concrete is nothing but, more or less moist gravel or it is very stiff zero slump concrete. It is very different from the kind of concrete that we have normally seen, which has a slump of let say 10 centimeters or 8 centimeters of may be sometime a little more, this concrete looks very different.

As for as moving such blocks of concrete or moving such fresh concrete is concerned, it is very common to move it with bulldozers, so the dozer basically spreads this concrete around in the area in which it is required.

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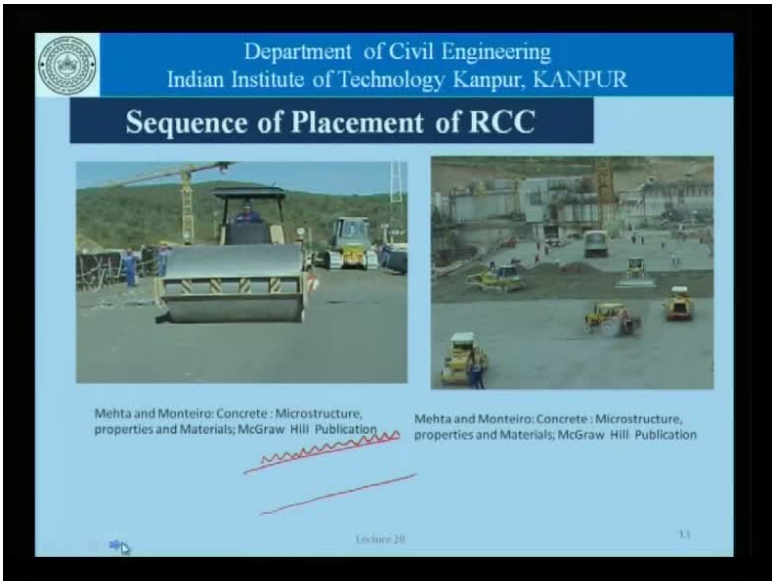

Followed by this spreading we have this kind of a vibrate re-roller, that is moved on the concrete to compact this layer. So, we have this layer of concrete which is now being compacted by moving a vibrate re-roller on the surface. And this picture here is a over view of a construction side, where roller compacted concrete is being used, so there are tippers, there are dousers and there are rollers, so it is a, so it is an example of highly mechanized construction.

And these pictures I hope help you understand, why we need large free areas of concrete placing, why we do not want reinforcement to pre-present in the concrete, as for as the interference with the concreting process is concerned. So, this is a bird's eye view or a rough understanding of roller compacted concrete. Now, once we go back to the, let us get back to the description of this concrete once again, it is relatively stiff mixture of aggregate, cementitious materials and water that is compacted by vibratory rollers, and hardened into concrete. And depending on the requirements the strength of RCC which is roller compacted concrete, may be specified to be in the range of 25 to 30 MPa. So, now this is strength is not outside the normal, we very often deal with 25 to 30 MPa kind

of concrete, except that this concrete is placed very differently compacted very differently.

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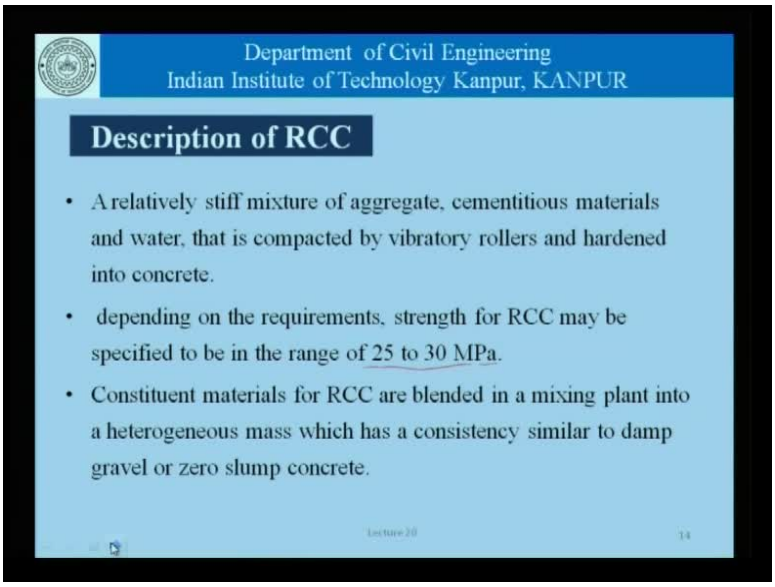

And due to that reason, in the fresh stage it looks very different, the constituents materials for RCC are blooded in a mixing plant into heterogeneous mass, which has the consistency, similar to damp gravel or zero slump concrete. So, the basic principle or of concrete engineering is not violated, we still have the same materials that is aggregate cementitious material, that is cement and the fly hash and water.

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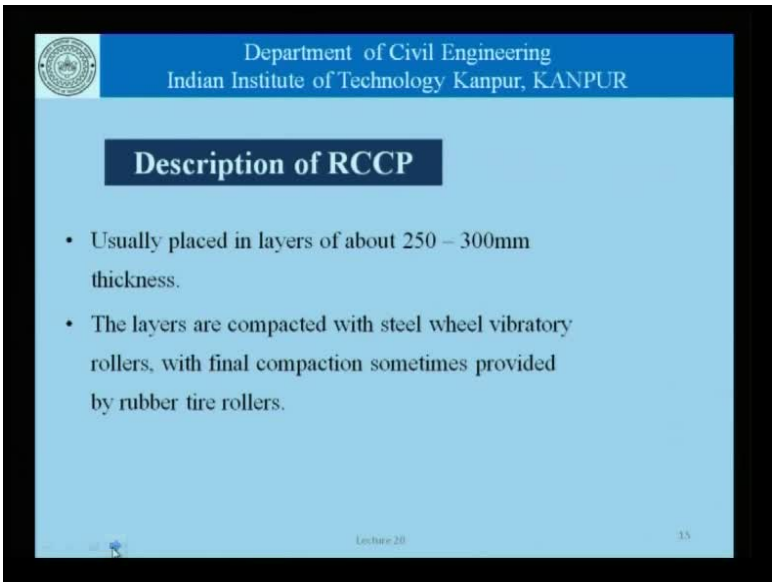

Except that, we are now compacting it using rollers and finally the product is of course hardening into concrete. As far as the late thickness is concerned, we will discuss it a little more later on, usually the number at adopted is about 250 to 300 mm in one layer. Now, this layer thickness is related to several parameters or factors, including the size of the aggregate. Including the compatibility of the concrete that depends on the type of roller being used, the effectiveness of the roller in terms of it is ability to compact the concrete and so on.

The layers are compacted with steel vibratory rollers with final compaction, sometime being provided by rubber tire rollers; so this is a matter of pure engineering and working at sites.

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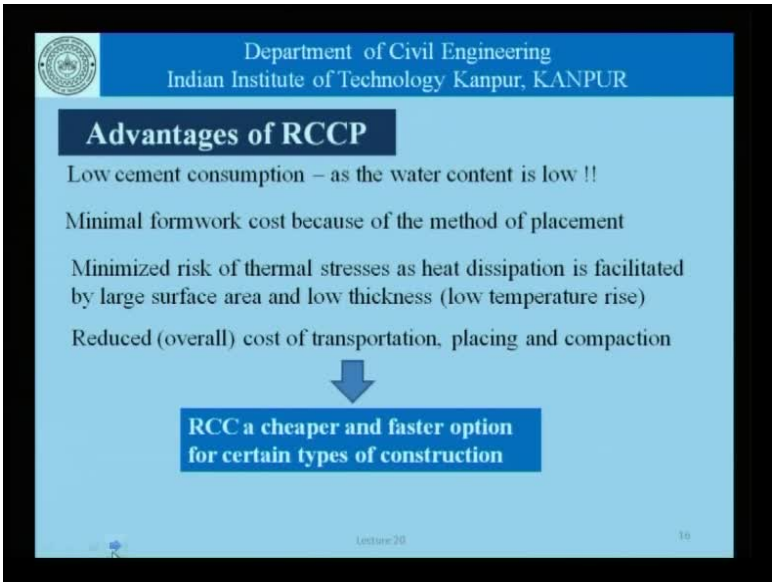

And as far as the advantages concerned, we have low cement consumption, because the water contented self is very low, we have minimal formwork cost, because the method of placement as we good see, that there is hardening form work required, except at the (( )). There is a minimized risk of thermal stresses as heat dissipation, is facilitated by the large surface area and smaller thickness which means, there is low temperature rise and virtually low thermal ingredients.

We have a reduced over all caused in terms transportation, placing and compaction and finally, therefore, roller compacted concrete gives us a cheaper and faster option for

certain types of construction. It cannot obviously be used for normal construction in terms of buildings or pressures and so on.

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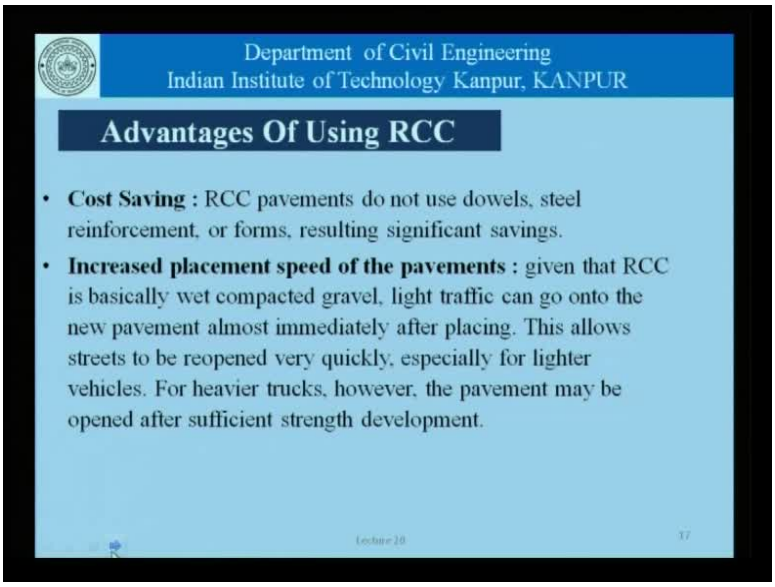

As far as the cost saving is concerned, the RCC payments, if we are may be if we are making pavements or rods using a roller compacted concrete, we do not use doubles and still reinforcement of forms, and this results in significance savings. As far as the increased placement speed is concerned that helps us a lot, this couple with the fact that RCC or roller compacted concrete can be looked upon as basically wet compacted gravel.

It is time to reason that light traffic can be allowed to go all these pavement, more or less immediately after the concrete has been placed. Of course, heavy traffic cannot be allowed and lesser amount of is strength development has taken place, so this helps as a lot as far as using roller compacted concretes, in pavement construction is concerned.

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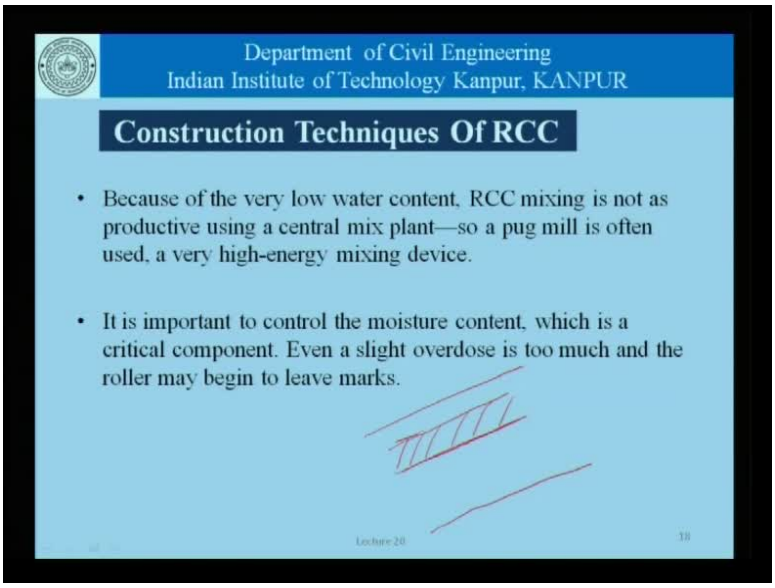

Now, because of the very low water content, the mixing of roller compacted concretes is not often very productive, if we use a central mixing plant, so we often use a pug mill is often which is a high energy mixing device. And we have to be very clear careful as far as the moisture content of the RCC's concerned. Even a small increase or an over dos of water or an under dos of water could make the concrete very different, and if there is more water the roller may begin to leave marks, and that something which we do not want.

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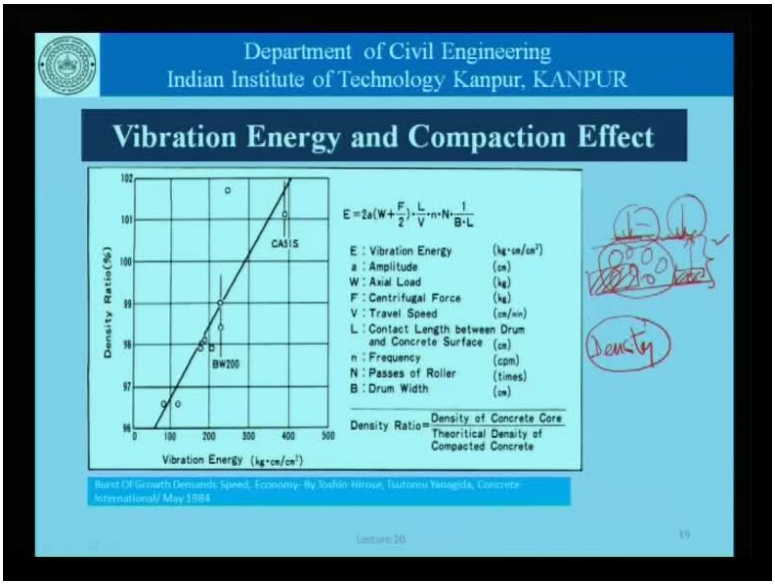

We do not want a pavement where the roller is moving over this width, let say to leave marks along the edges which brings us to the theoretically studies on vibration energy, and compaction effects. See what we are looking at is trying to place or concrete having a certain thickness, and this has some amount of aggregates, and the rest of it is mortar. Now, if we are trying to apply a vibratory load at the surface and what we want to happen here is compaction, that is we want the mortar to move into the voids, if there are any voids within the aggregate system; and we want to get read of any air that will be trapped inside.

Now, the effectiveness of whether or not, this concrete here at the bottom would get compacted. Because, of this kind of vibratory loads being applied the surface, would depend on the thickness; the characteristics that we have here of the vibration in terms of the amplitude. And the frequency, the mass of the roller setting there and also the properties of the intermediate concrete.

So, with all these factors put together, we can define densities of this concrete as a variable, or as a parameter which can be used for quality control of roller compacted concretes, it is very important that concretes are compacted. Now, in the case of roller compacted concrete, it would depend on the kind of energy that is being impact, on the kind of energy that is imported to the concrete, which is related to the like I said; the frequency the amplitude of vibration, and also the number of passes, how many times thus the roller pass over a given section.

Now, one way of writing as specification as far as roller compacted concretes or quality roller compacted concretes is a concerned, is to say that such and such roller would make 3 passes or 6 passes or something like that. Or it can be said that it will be a certain number of passes, or a certain amount of density that is obtained in the concrete, because that is really the performance parameter. So, we are talking in terms of defining density of the roller compacted concrete as an important parameter, in defining the quality of the roller compacted concrete as placed.

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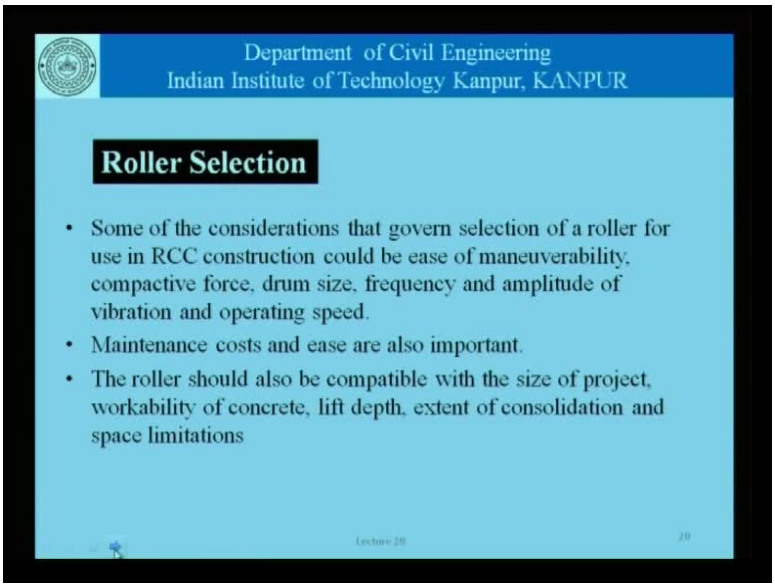

(( )) to say now, the roller selection is in important part now of the construction using roller compacted concretes. And some of the concentrations that governs the selection of roller, for use in RCC construction could be the is of maneuverability, compacted force, the dram size, frequency an amplitude of vibration, and the operating speed. Besides maintenance cost and the ease of operation, we should also remember that the roller should also be compactable with the size of the project; workability of the concrete, lift depth, extent of consolidation and space limitations.

So, all these things put together would help us choose the right roller to be used at a particular site, needless to say that if you do not choose the right roller will not get the right density. If you do not get the right density we do not get quality construction similarly, the project might be delayed or it may take more time, then if we choose the roller a preoperatively. So, we must choose the equipment that we have or that we use in a particular site, very, very carefully considering the variables involved.

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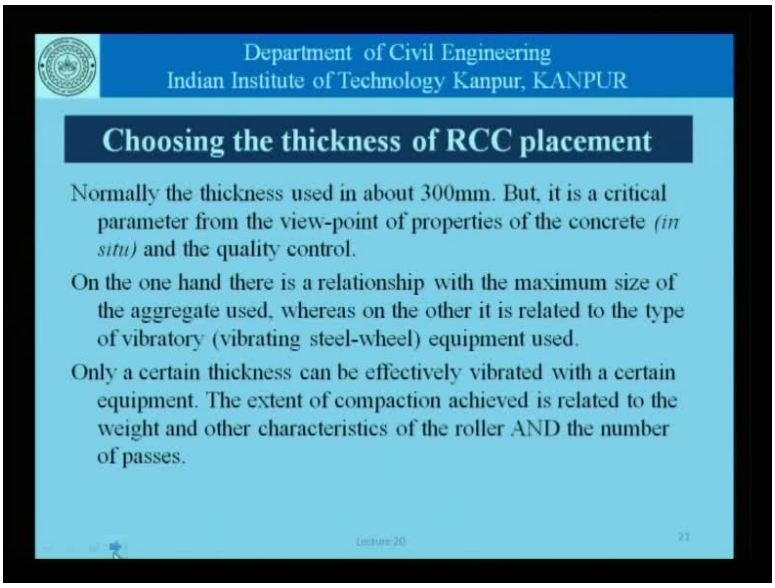

Getting back to the discussion on thickness which I said was about 250 to 300 mm, and it is critical from the point of view of properties of concrete in situ and the quality control. On the one hand there is a relationship between the maximum size of the aggregate used whereas, on the others related to the type of vibrate equipment used. And only a certain thickness can be effectively vibrated with the certain equipment, the extent of compaction achieved is related to the weight and other characteristics of the roller, and the number of passes.

So, all these things put in together and engineering must choose the thickness of the roller compacted concrete to be used in a particular project. So, if we are having a pavement which requires us to have let us say 600 thick concrete, 600 mm thick concrete, it is up to the engineer to decide, whether it he will do 2 layers of 300 or 3 layers of 200, and so on. And chooses equipment accordingly, often times depending on the equipment available the kind of concrete and the thickness can be chosen.

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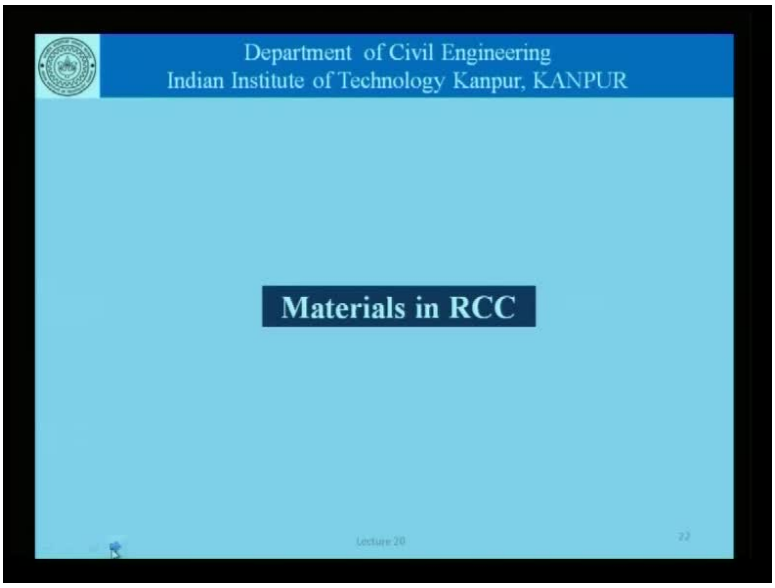

Let us now talk about materials in RCC, that is the ingredients.

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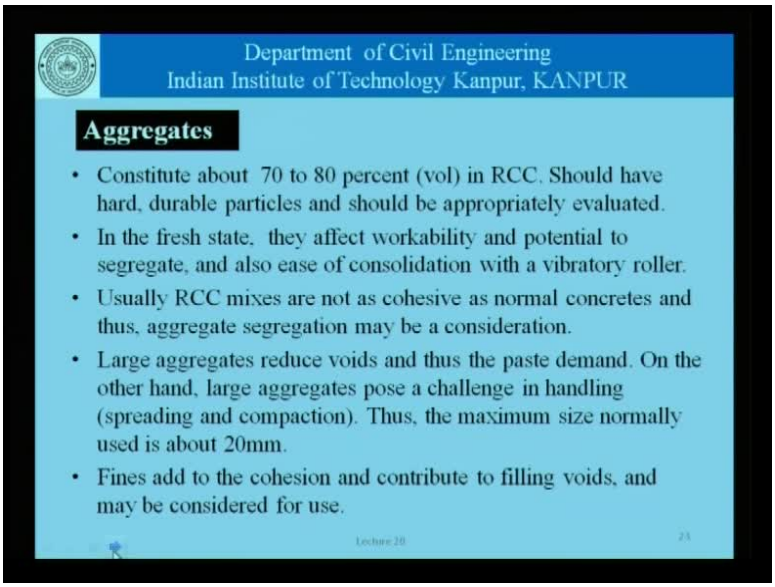

Now, the ingredients are not different from normal concretes, accept that in the case of RCC, the aggregate constitute about 70 to 80 percent by volume, and naturally they should be hard durable particles, and should be appropriately evaluated. Appropriately evaluated means, we already have that test to carry out evolution of aggregates, in terms of the physical properties. And those tests are no different simply because they aggregate

is being used in RCC, so we need to carry out the same tests we may have different is specifications.

Another thing to remember is that the volume of aggregate is higher here and therefore, that has implications in terms of the entire properties, and so on. And therefore, its very important that the aggregates of properly chosen, in the fresh state they aggregates effect the workability, and the potential to segregate, and also the ease of consolidation with the vibratory roller. It is not only the ease of vibration, but it is also the is of movement that is being post around, the wave is saw using a dozer.

So, if you use very large particles, it may become difficult to move them around using dozers, and ensure that they are uniformly distributed throughout the concrete mass. And that is something which we cannot a fort at the end of it throughout the structure, whether we do it by blocks or we do it with layers. The assumption that the concrete at different places as far as the structure is concerned is the same cannot be violated, so we must ensure that the concrete is a homogeneous mass throughout the structure.

And that could compromise, if we use very large particle as for as course aggregates are concerned, because of the tendency it promotes segregation, the difficulties involved in moving them around, and so on. We must also remember that RCC mixes are not as cohesive as normal concrete and therefore, aggregate segregation may also be consideration, and larger aggregate reduce voice, and thus the paste demand.

So, if we increase the size of the course aggregate the surface area reduces and the paste required as far as concrete is concerned goes down, that was our understanding, and it still is our understanding as far as concrete engineering is concerned. On the other hand, we must remember that large aggregates pose a challenge in handling, is spreading in compaction, as we have discussed just now. And therefore, as compromise the maximum size used as far as roll the compacted concrete is concerned, is generally about 20 millimeters.

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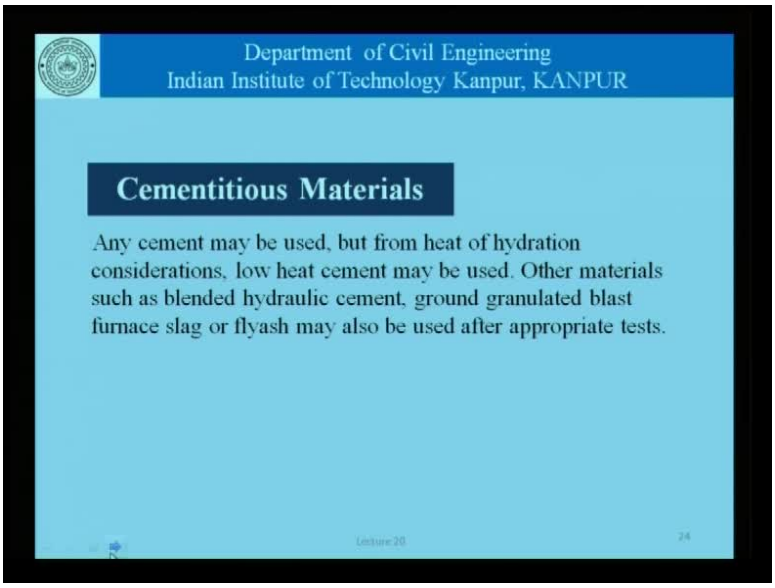

Fines add to the cohesion of the concrete and contribute to filling the voids and therefore, should be considered for use. As far as cement issues materials are concerned any cement can be used, but from the point of view of the heat of hydration use of low heat cements, may be considered. Having said that, we should remember that roller compacted concrete is after all being placed in relatively thin layers, and thermal stresses are not likely to be a major problem.

And therefore, this issue is rather in significant as far as most roller compacted concrete construction is concerned. Other materials such as blended hydraulic cements, grounds slab or flyash may be used after using tests, to ensure that the quality of construction in the quality of concrete, in a particular project is not compromised.

Now, chemical admixtures are weapon that a concrete engineer has now to alter a property of concrete, but now in this case when we are talking of using chemical admixtures in roller compacted concrete kind of a construction. We should re-iterate and recall that the effectiveness of chemical admixtures is related to the cement properties, and also the amount of cement present in the matrix.

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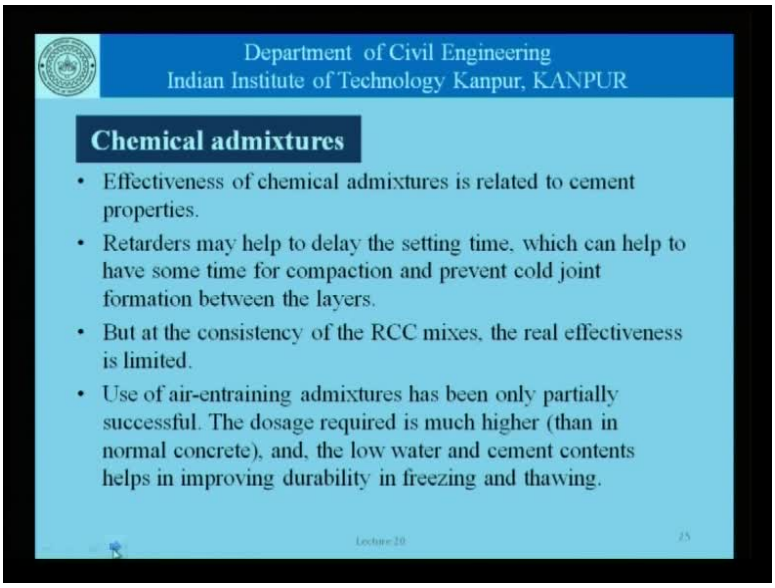

In fact, the chemical admixture added itself is dozed in terms of the cement content, even we say 1 percent chemical admixture by weight of cement, naturally if the cement content in the mix is very low, the total amount of admixture is also low. We may like to use retarders is certain cases, because the help delay the setting time and also give us sometime as far as compaction is concerned, and preventing cold joints between layers.

So, we may like to use a retarder in roller compacted concrete, if we want to have some more time for compacting the concrete. And that would depend on what is the kind of mobilization we have, whether we have the right kind of dozers to move the concrete around, and the right kind of vibrators to compact the concrete. If there is a problem there, we may like to have or we may want to have more time, during which the concrete can be compacted.

And that is when retarders come in handy, but given the consistency of the RCC mixes that is in terms of slump and workability, the real effectiveness of chemical admixtures is rather limited. In fact, as far as air and air-entraining is concerned it has been found that it is difficult to control the air content in RCC construction, heartily because of the small cement content; and the method of compaction and so on. Not only the dosage of the air-entraining each in required is much higher than in normal concrete, but also they effectiveness in increasing the durability of the concrete against freezing and thawing, has been found to be suspect.

Having said that the durability of RCC construction as far as cyclic, freezing and thawing is concerned is suspect, I would also like to add that there is literature with suggest that. If roller compacted concrete pavements are covered with as fault for a certain thickness, the durability of the RCC is no longer problem, continuing our discussion, let us talk about proportioning and RCC mix.

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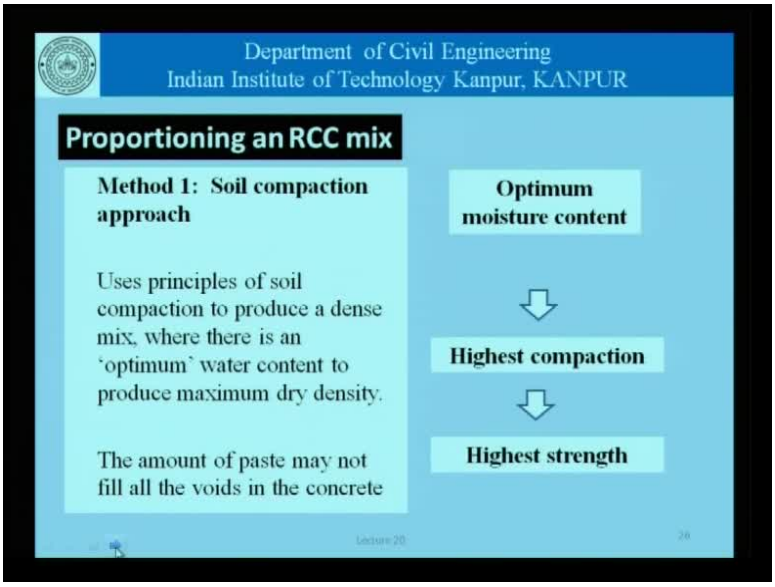

Now, here given the very special method of compaction, sometimes we use the soil compaction approach to proportion of RCC mix, which is different from our traditional method of proportioning concrete mixes which we have practice so far. In this case what we do is use principles of soil mechanics, and soil compaction to produce a dense mix, where there is optimum water content to produce maximum dry to density.

We know that inside mechanics or in soil, or in geotechnical engineering we have the concept where if we continue to add water little by little to a soil mass, the density increases a plus certain point in time and then reduces. So, this moisture content at which the density is higher or the highest is call the optimum moisture content, or the OMC and that concept is what used in proportioning and RCC mix in this approach. We must remember that in this case, the amount of paste may not fill all the voids in the concrete.

We look at concrete in this kind of an approach, as the material made up of different particle may made up of particles of different sizes and gradation. So, we know the gradation of the aggregate particles being used, we know the gradation of the cement

being used, and what we try to do is to find the optimum moisture content which would give the maximum density. Naturally in this approach, the concept of water cement ratio is not so relevant, so to iterate we have optimum moisture content, and that gives us the highest compaction, and that gives us highest strength.

So, the strength is not really being talked about now, in terms of the water cement ratio of the concrete mix, but it is being talked about as related to the moisture content in the roller compacted concrete mix.

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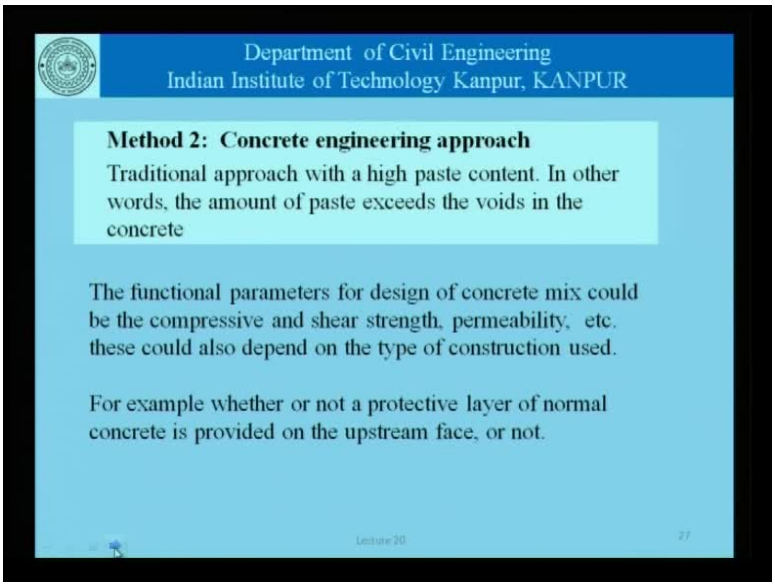

Now, as against this we of course, have the concrete engineering approach where the paste content is high, high paste content means the amount of paste exceeds the voids in a concrete. And that is the traditional approach that we are already know that we have the water content, that we have the cement content, we make sure that the paste content is hard then the void content, and proportion the mixing so on.

The functional parameters for the design of concrete mix could be compressive and shear strength, permeability etcetera, and these could also depend on the type of construction. So, in the case of roller compacted concrete as we saw, concrete is placed in layers and therefore, the shear strength and the bond strength between layers is a very important parameter, in addition to the compressive strength or the concrete per say. Also given the fact that a roller compacted concrete is used very often in dam construction, permeability is an important consideration.

And thus specifications for dam concrete very often, laid down maximum acceptable permeability of water determine by a certain method. Now, in the case of roller compacted concrete the issues is more critical, because concrete is being placed in layers, and these layers, if they do not bond properly, if they do not bond in a manner that the concrete becomes smaller thick, the chances of permeability through the joints is very high. So, it is not only important that the permeability we control through the concrete, but it is also important that permeability be controlled through the joints.

Whether not we are not specific requirements in terms of having a maximum permeability through the joint and so on; that is concerned it would depend on whether or not a protective layer of normal concrete is provided on the upstream face or not.

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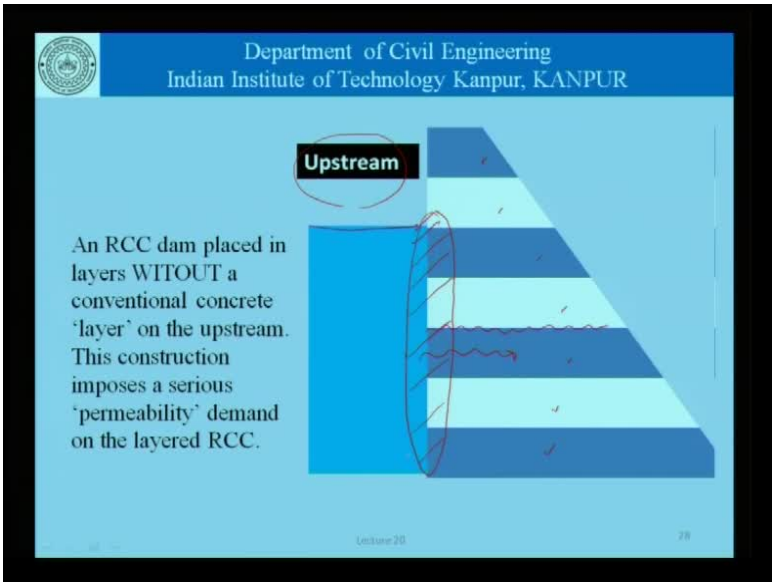

Now, what is this protective layer, let us explain that, let us discuss that, if we have a damped which is shown here and it is caused in layers as shown here, so we have dam where we have constant in layers, using roller compacted concrete kind of a method. If this was the upstream said which had the certain amount of water setting here, we are looking at permeability through the joints, and also through the concrete. Now, this is very important if we do not have any normal concrete at the interface, if this entire concrete was caused in layers. So, in this kind of a situation of course, permeability of the concrete is a very, very major consideration.

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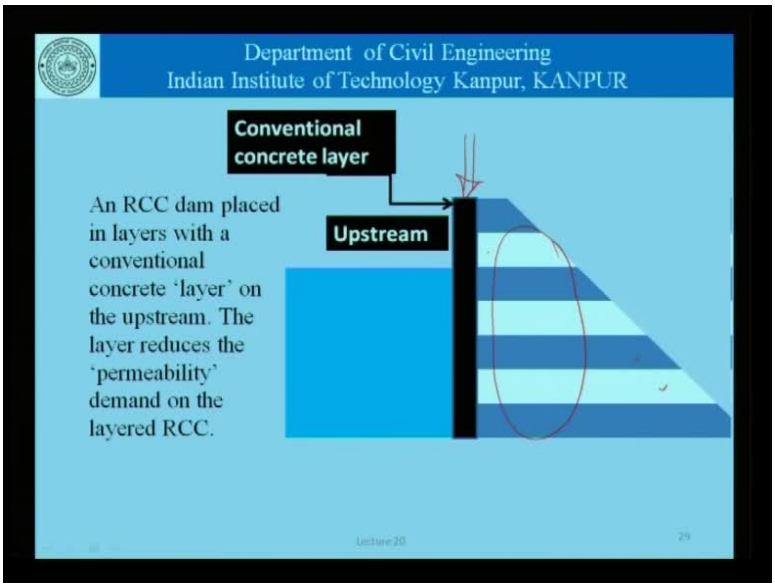

However, if the concrete was caused in a manner that this layer, or this lift of concrete along the height of the dam is caused with conventional concrete. That is it is not caused in layers as shown here, in that case we are not so much bothered about the permeability of the roller compacted concrete.

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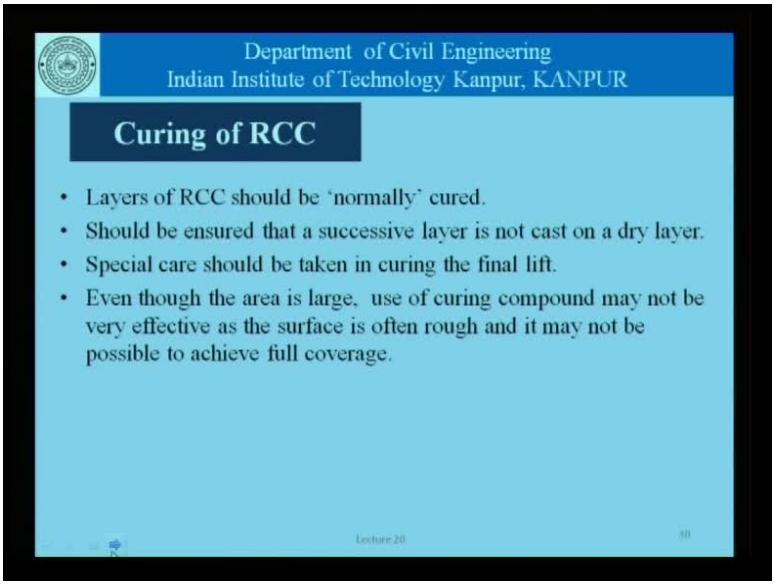

Now, coming to curing of the RCC, the layers of RCC should be normally cured that is there is no reason to believe that the curing can be done, or needs to be done any different layer. It should be ensured that successful, if layer is not caused on a dry layer

of concrete, because as it is the amount of water present in a concrete is less. And if that water to gets absorbed in previously cast lift it is likely to lead to a poor quality construction.

So, we must mixture that the previous lift is not necessarily wet, but is such that it will not absorbed more water, special cared needs to be taken in curing the final lift, initial lift is alright, because more concrete will get caused on that. But, as far as final lift is concerned we need to control the moisture condition, for much longer period of time and ensure proper hydration of the lifts. Even though the area is large use of curing compounds may not be very effective, in the case of roller compacted concrete construction, as the surface of a rough.

And it may not be possible to provide full coverage of the compound throughout the large surface area. So, even though we may like to do it or it helps us, if we can simply is spread a curing compound on the surface, but unfortunately in roller compacted concrete that is not always possible.

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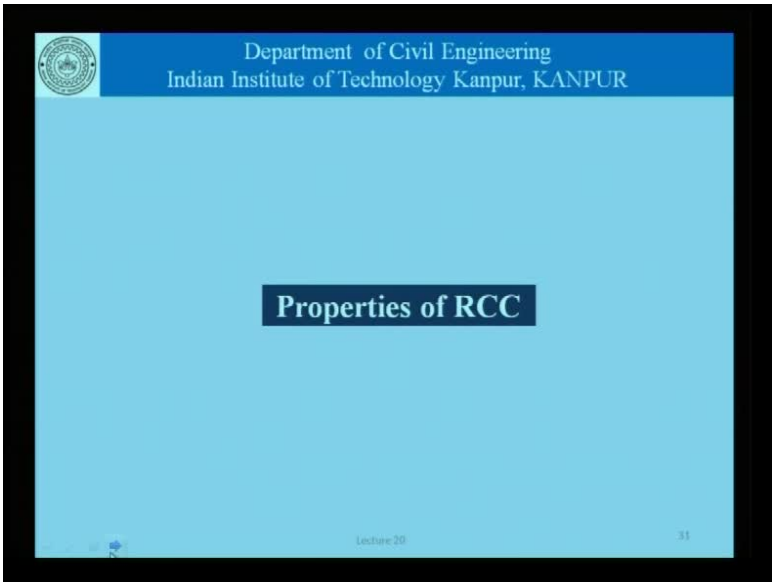

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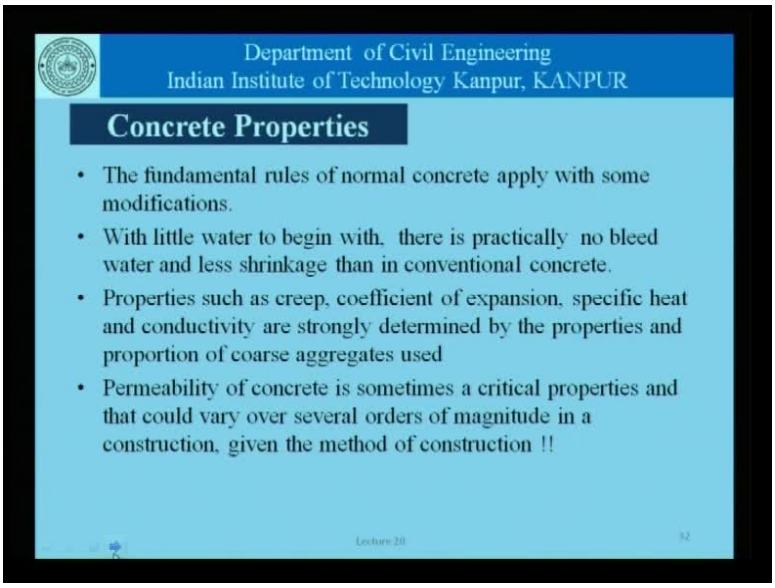

Now, coming to the properties of this specially cast or specially compacted concrete is concerned, the fundamental rules of normal concrete apply which some modifications, with little water begin with there is practically no bleeding or shrinkage in this concrete. Of course, property such as creep coefficients of expansion is specific heat and conductivity, which are important from the point of view of thermal stress generation. These properties are strongly determined by the properties, and the proportion of the course segregate and that is at a much larger volume than normal concrete.

Permeability concrete is sometimes a critical property, and there could be a difference of several orders of magnitude in a construction given the method of construction. So, the method of construction that we have is gross, that is it need not be ensuring that the properties at the micro level or at the level of a very small element, or the same through the concrete. But, we only ensure that by and large, the properties of concrete are the same, if we actually carry out measurements of strength or permeability we will finds that there is, a reasonable mortar of variation as far as these properties are concerned.

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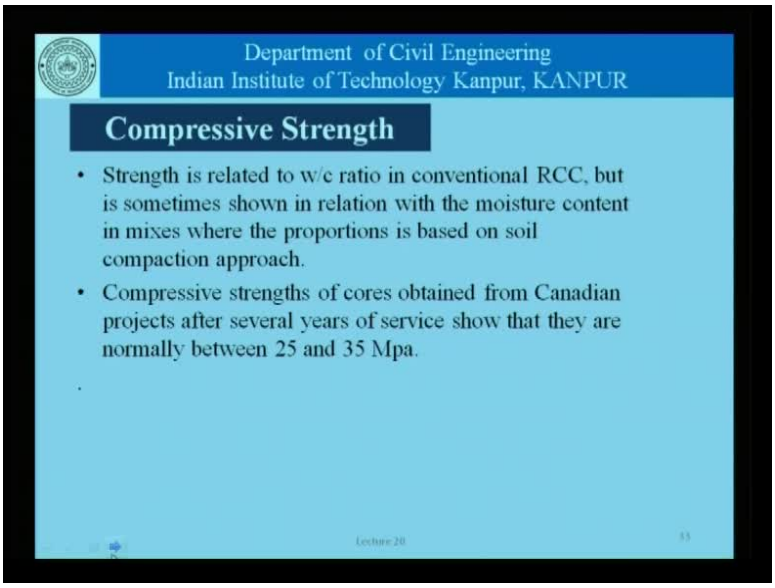

Now of course, compressive strength is related to what is a cement ratio in conventional RCC that is if the proportional have been carried out in a high pate regime that is using the traditional, reinforce concrete of the concrete proportioning approach. But, it is some time shown in relation to the moisture content in the mixture, where the proportioning is based on soil compaction. Some studies where compressive strength are obtained using course from Canadian projects, showed that the strength of concrete varies between 25 and 35 Mpa in these projects.

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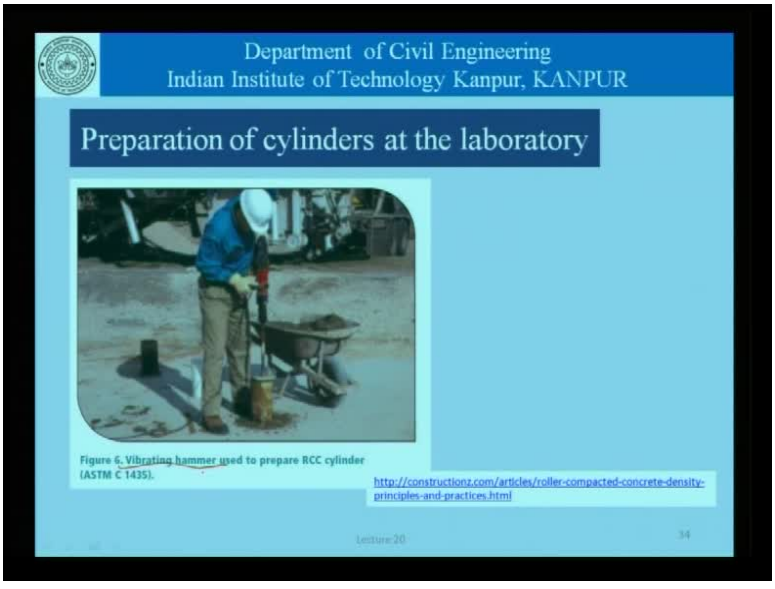

Now, this here shows, how should is specimens be prepared as far as roller compacted concretes are concerned. Now, given that roller compacted concretes are not internally vibrated, it makes no sense to internally vibrate, the cylinders that are used for quality controller roller compacted concretes. So, what we do here is we use a especially designed vibrating hammer to prepare the cylinder, and that is more or less the same effect as a vibrated roller; this vibratory hammer being applied at the surface of the concrete in this cylinder.

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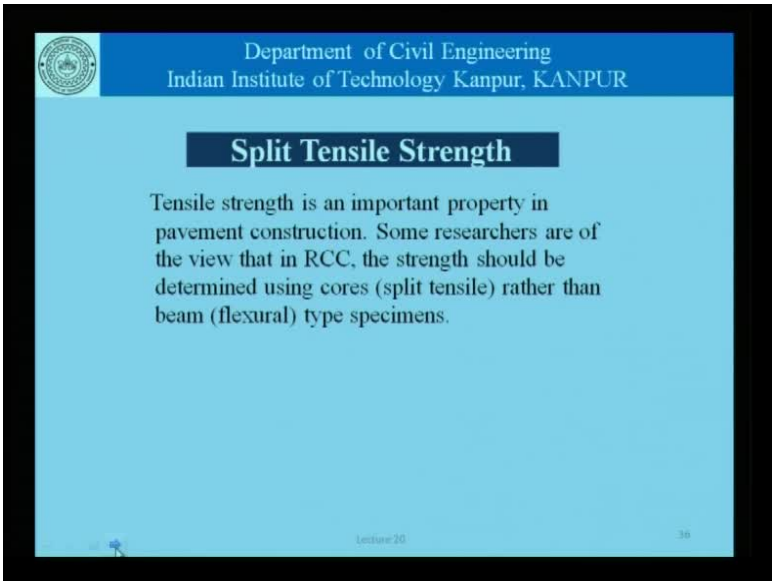

Tensile strength is an important property as far as pavement construction is concerned, and some researchers after view that in RCC, that is when using roller compacted concretes. The strength should be determined using course, where we determine this split tensile cylinder, and not necessarily from the flexural test of beams. Now, the reason for that is something which I would like to leave to you to ponder about.

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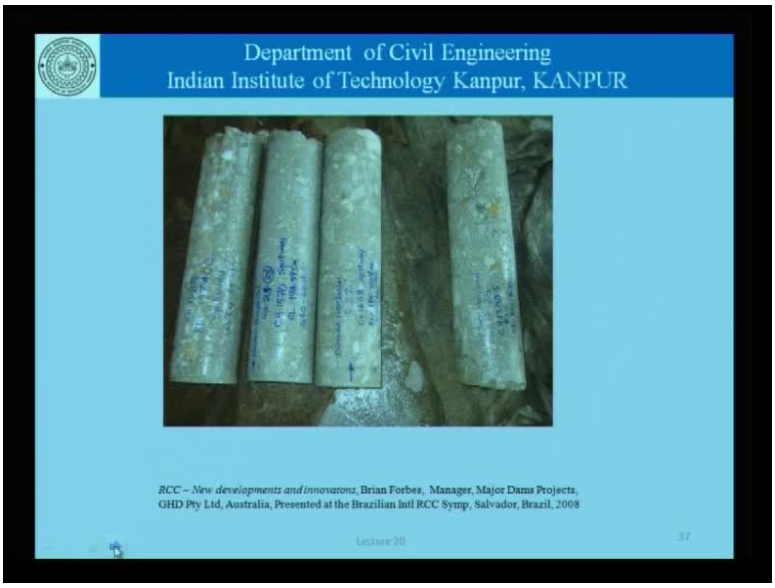

And think this picture here shows the course from the roller compacted concrete construction.

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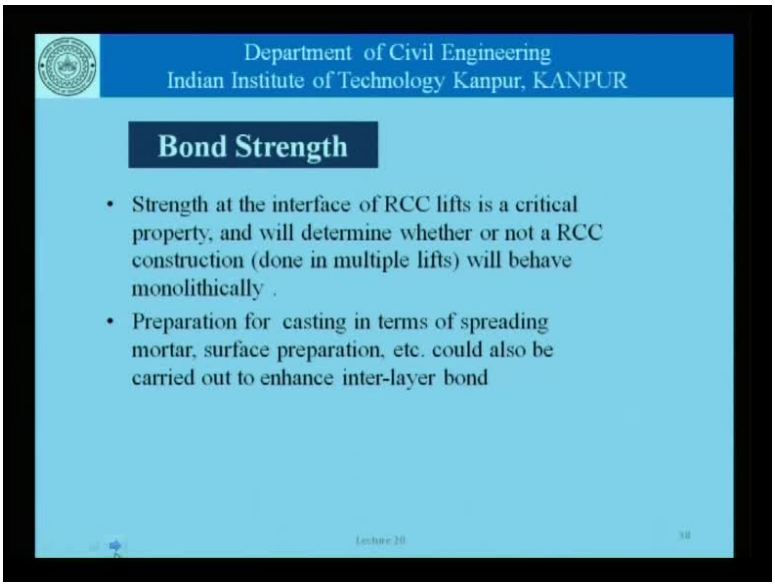

Now, coming to bond strength that is this strength at the interface of the lifts, this could be critical property and will determine whether or not the RCC construction which is done in multiple lifts, behaves as a single unit, or behaves monolithically or not. And in order to ensure good properties across that interface, we could carry out operations such as is spreading some grout or mortar, before the next lift is cost. Or we could carry out

surface preparation exercises on the previous lift, before the fresh lift is caused, so as to ensure that the previous lift and the next lift, the are properly bonded.

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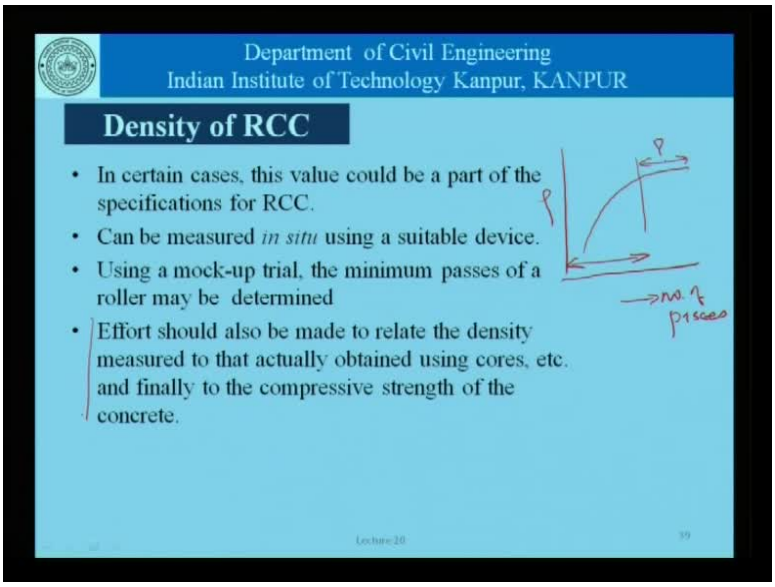

We did talk about density a little bit, and in certain cases this value could be the part of the specifications of the RCC, it can be measured is to using a suitable device, and using a mock up trail the minimum passes of a roller may be determined. So, in a mock up that precedes actual construction, we may determine or estimate that in order to get a certain density of the concrete, what is the number of passes that are required.

So, if we plot the number of passes to the density of the concrete that we obtain, it slightly that we will get a relationship which is something like this. That beyond the certain point having more and more passes is relatively in effective that it is not contributing in to the change, in the density. But, in this regime having more passes is indeed effective as far as achieving higher density is concerned.

And that is the kind of test that we need to carry out in order to determine what should be the minimum number of passes as for as the roller is concerned given, a set of equipment, and a type of concrete and so on. Effort should also be made to relate the density measure to that, actually obtained using course and finally, to the compressive strength of the concrete. If we are able to carry out this exercise, then we have a actually close the loop, as far as quality control in RCC or roller compacted concrete is concerned.

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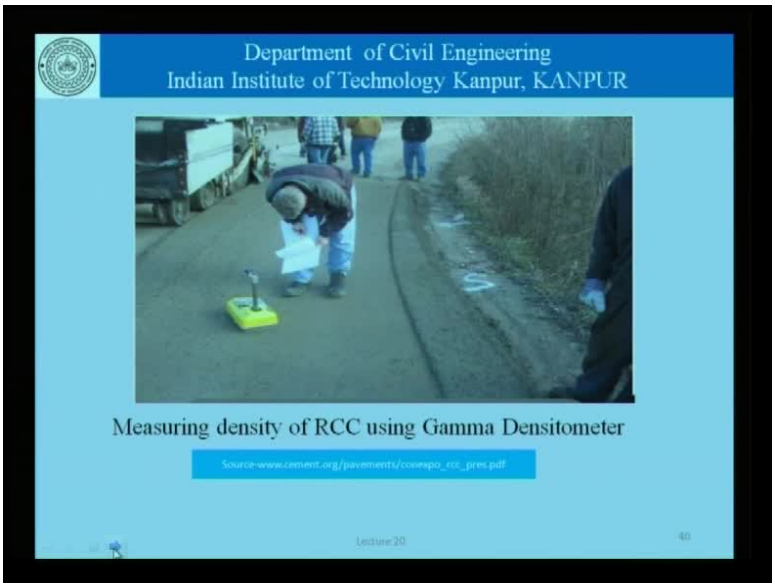

Now, this here is the measurement of density of RCC or the in situ measurement of density using a gamma density of meter.

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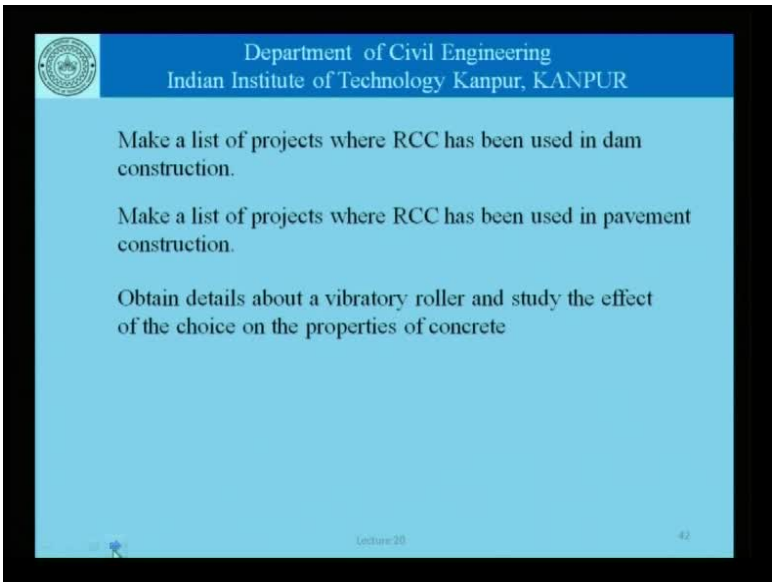

Coming to a close of our discussion today, let us take back some questions, make a list of projects where roller compacted concrete has been used in dam construction. We could make a similar list of project where this concrete has been used in pavements, and obtained details of a vibratory roller. And study the effect of the choice of this roller on

the properties of concrete, there are several other things which we have alluded to an our discussion today; and they can also help us better understand roller compacted concrete.

Thank you.