Development and Applications of Special Concretes
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Lecture 17
Roller Compacted Concrete

Namaskar and welcome back to another lecture on development and applications of special concretes. The discussion today will focus on roller compacted concretes.

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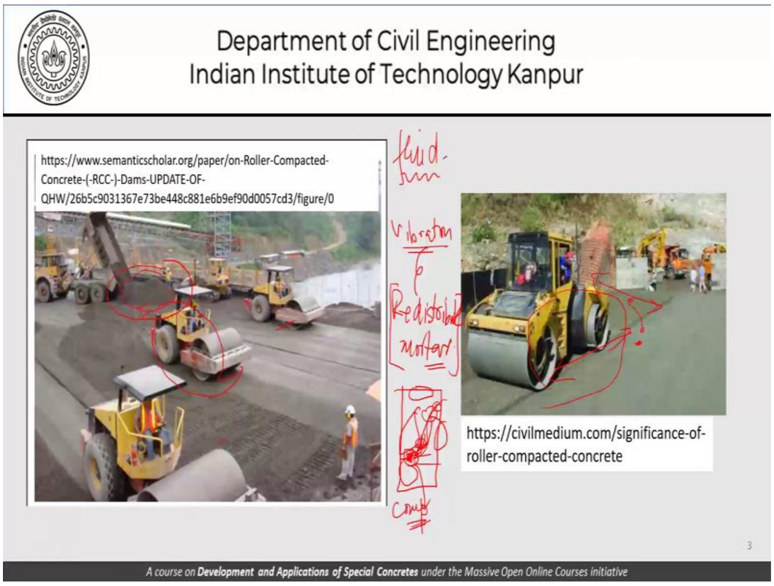

So, this is a bird's eye view of what a site where we are doing roller compacted concrete looks like. So, you can see here that concrete is being dumped using a dumper truck and is being compacted using these rollers. Now if you look at this concrete it is a far cry from what normal concrete which I have been talking about as fluid. What I have said is that in the fresh state we want the concrete to behave like a fluid and in the hardened state like a solid.

Now this concrete here is hardly behaving as a fluid. Now this fluid behaviour or liquid behaviour which is a desirable characteristic that analogy is completely true when it comes to concrete such as self-compacting concrete or pumpable concrete and so on. But this concrete which is roller compacted is not really that. Please understand that now I am trying to modify my definition or my expectation from concrete.

From a real fluid in that sense of the word to a material which fills all the nooks and corners of form work upon vibration. So, vibration and compaction are the tool which helps us redistribute the mortar phase in the concrete and fills all the gaps. So, it is not really the fluid behaviour that we are talking about but the ability of the mortar to be redistributed within the voids of the coarse aggregates.

So that if there is a pocket here which was not having mortar this mortar from somewhere here moves in here some motor from here moves in here. So that it achieves maximum compaction maximum density and that is the root or that is the key to having the right kind of compressive strength. So, these voids here do not have a deleterious effect on the compressive strength of the concrete.

So, moving forward this is just another picture of the roller compacted concrete being placed of course it is a different type of roller you would notice the difference between these types of rollers being used here and the kind of roller being used here. So, we can see that this roller as it moves on this concrete in fact if you see closely will probably see a difference between the levels here and here.

So, what we are achieving through this movement of roller back and forth along this particular width of the concrete which has been placed we are really compacting the concrete possibly to this level. So, this small difference in level that you see here that is what is being removed in order to ensure or as concrete is being redistributed or the material and concrete is being redistributed to complete the voids inside this material which is here.

So, this material here will obviously have certain amount of voids and that voids will need to be compacted and the kind of power that is required that is what is coming from the roller compaction.

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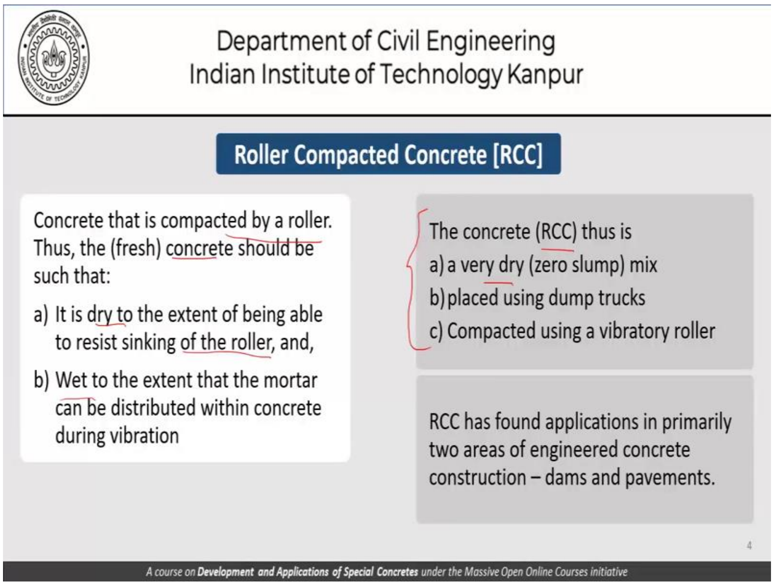

So as far as the material is concerned concrete that is roller compacted or compacted by a roller that is what roller compacted concrete is. And this concrete that is to be compacted by a roller should in the fresh state be such that it is dry to the extent of being able to resist the sinking of the roller and wet to the extent that the mortar can be distributed within the concrete during vibration that is something which I tried to explain to you schematically in the previous slide.

Now concrete which is roller compacted which is roller compacted concrete RCC as we call it here is thus a very dry zero slump mix placed using dump trucks most of the time and compacted using a vibratory roller. Now this is basically the characterization of this mix and has found its applications primarily in two areas of engineered concrete construction dams and pavements as we will see.

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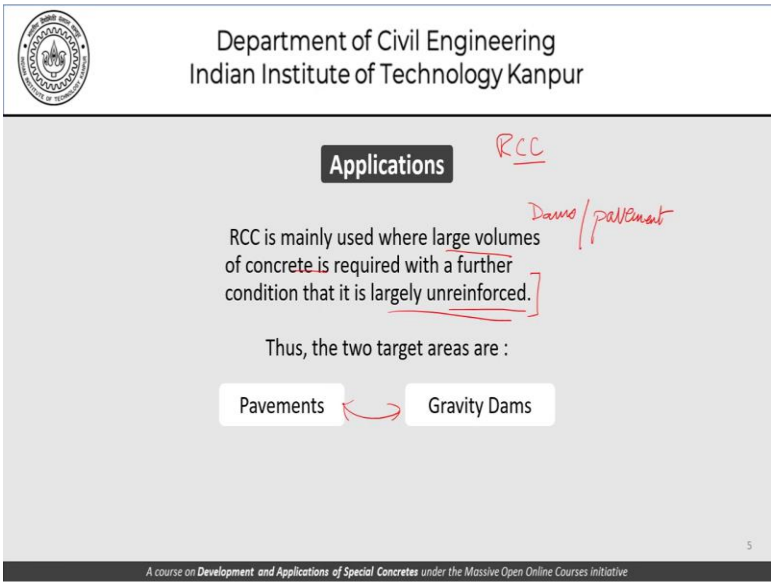

Both these areas that is dams and pavements they are characterized by large volumes of concrete and are largely unreinforced. Why reinforced concrete is a difficult proposition to do with roller compacted concrete that is something which I am leaving to you to think about. RCC in principle roller compacted concrete in principle is used largely for unreinforced structures and there are two targets pavements and gravity dams.

That does not mean that the concrete used in these two conditions has exactly or even remotely the same kind of specifications or same kind of expectations as we shall see a bit of history.

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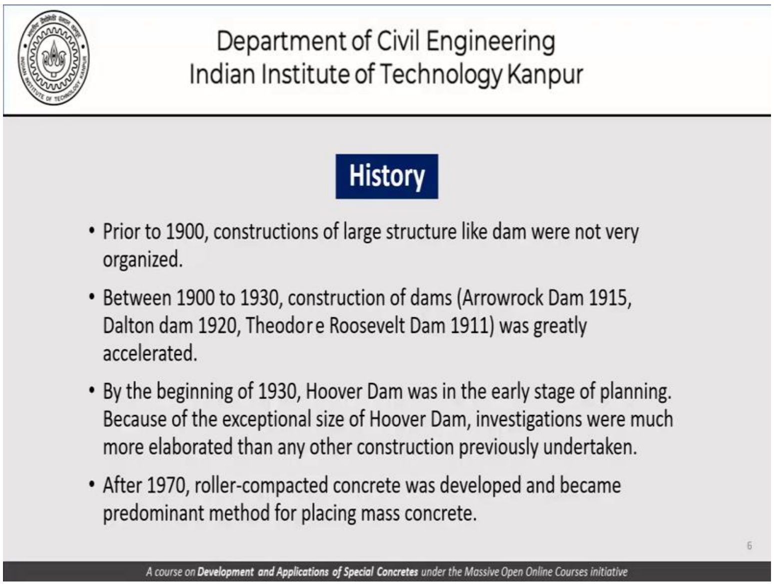

As far as roller compact concrete is concerned prior to 1900 the constructions of large structures like dams were not very organized between 1900 and 1930 construction of dam such as the Arrowrock dam in 1915 the Dalton dam in 1920 and the Theodore Roosevelt dam in 1911 was greatly accelerated. From the beginning of 1930 the Hoover dam was the early stages of planning and because of the exceptional size of this dam investigations were much more elaborate than any other construction which had been undertaken earlier.

Therefore, in a manner of speaking hoover dam in the 1930s was probably a turning point as far as the development of roller compacted concrete in fact development of a lot of mass concrete the thought process therein is involved or is concerned. After 1970 roller compacted concrete was developed basically the idea of compacting concrete through a roller this was developed around 1970s and became the predominant method for placing mass concrete in certain cases.

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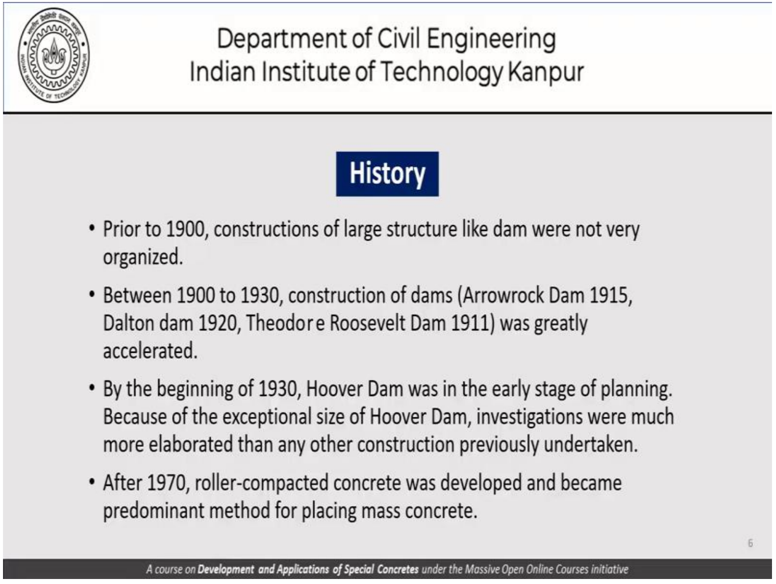

As far as the description of this concrete is concerned, I have already said that it is a relatively stiff mixture of aggregate cementitious materials and water that is compacted by vibratory rollers and it hardens into concrete. So, this hardening into concrete this is a regular process regular process means cement and water they hydrate in much the usual manner to produce hardened concrete.

Except that the method involved in compacting that concrete compacting the materials therein is slightly different. Depending on the requirements the strength of RCC may be specified in the range of 25 to 30 MPa or it could be less or more whatever you want constants for RCC are blended in the mixing plant into a homogeneous mix which has a consistency. Similar to damp gravel or zero slump concrete.

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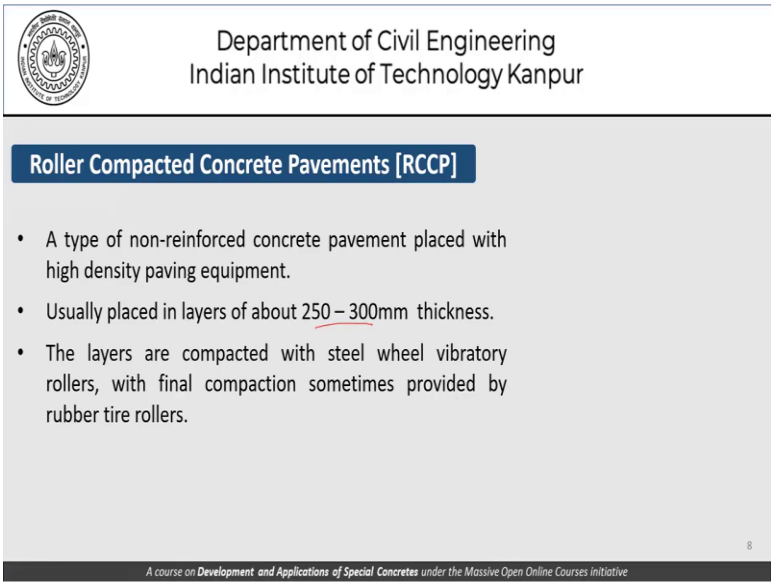

A type of reinforced concrete pavement placed with high density paving equipment that is what is roller compacted pavement concrete is concerned. And is usually placed in layers of 25 centimeters to 30 centimeters thickness and the layers are compacted with steel wheel, vibratory rollers while the final compaction sometimes is provided by rubber tyre rollers.

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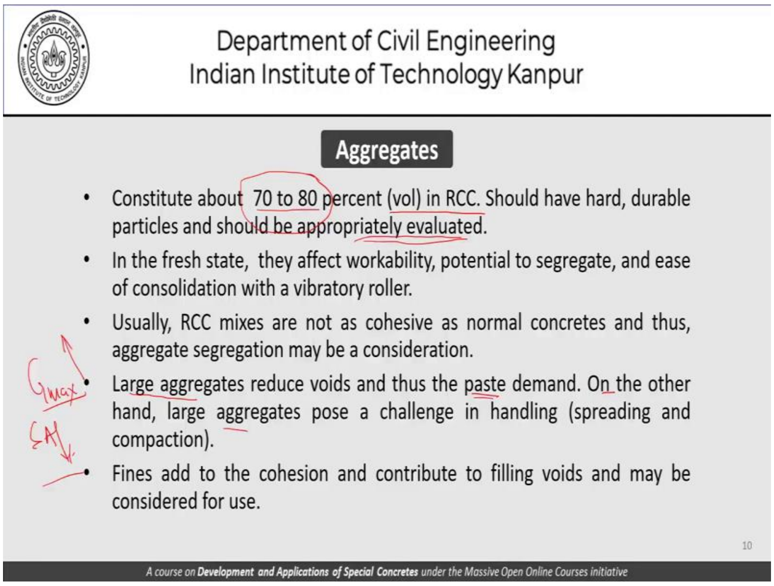

As far as the materials used in this concrete are concerned, we should remember that aggregates constitute 70 to 80% by volume as far as RCC is concerned. Compare this number with the numbers that you have for the normal concrete. You will realize you will find that this number is definitely higher reasonably higher. And therefore, the aggregates have to be hard durable particles and should be properly evaluated.

Now proper evaluation includes not only that for strength but also for gradation. In the fresh state the aggregates they affect the workability potential to segregate and the ease of consolidation with a vibratory roller. Usually RCC mixes are not as cohesive as normal concretes and thus aggregate segregation is surely a consideration that must be borne in mind when designing these mixes.

Large aggregates reduce the voids and thus the paste demands large aggregates means if your g_{max} the maximum size of aggregate maximum nominal size of aggregate. If this increases the surface area goes down and therefore the paste demand goes down. So this is the principle that we use in increasing the size of large aggregates or increasing the maximum size of aggregates used as far as roller compacted concrete is concerned.

On the other hand, larger aggregates pose a challenge in handling that is spreading and compaction of concretes and fines add to the cohesion and contribute to filling the voids and should be considered for use. So obviously the fines are also part of the whole mix design that we do for roller compacted concretes.

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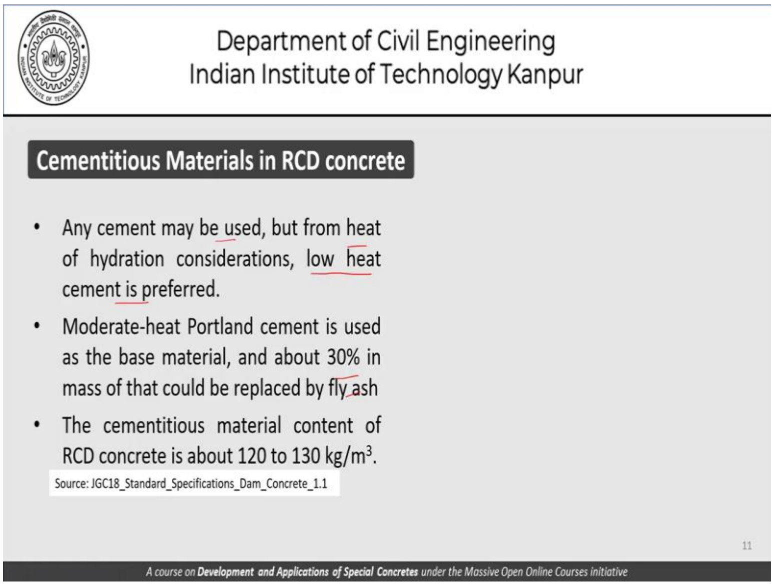

As far as cementitious materials in RCD that is roller compacted dam concrete is concerned, we could use any type of cement that we want but from a heat of hydration consideration we have seen this before. Low heat of hydration cement is preferred. Moderate heat Portland cement is used as the base material and it could be replaced to the extent of about 30% by fly ash. The cementitious material content as far as RCD is concerned is about 120 to 130 kgs a cubic meter.

This number is definitely lower than what we see in most of our reinforced concrete or even unreinforced concrete is concerned.

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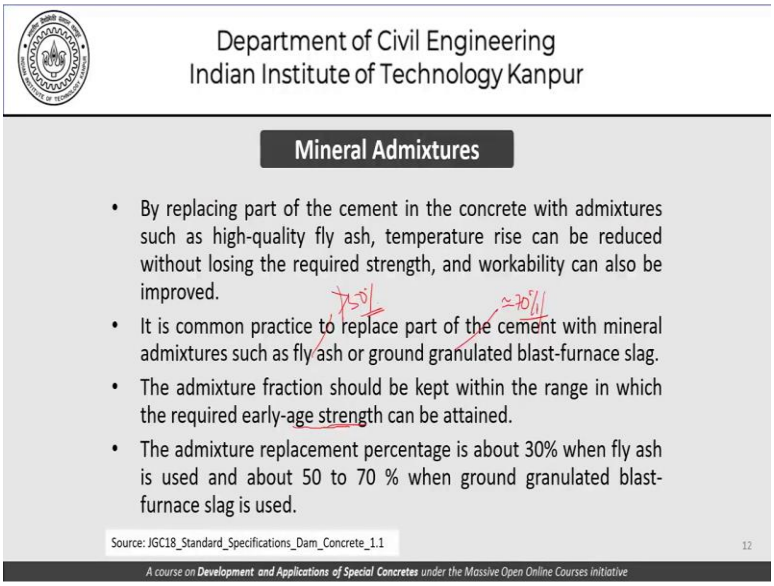

As far as mineral admixtures are concerned by replacing a part of the cement in the concrete with that mixture such as high-quality fly ash. The temperature rise can be reduced without losing the strength and workability can also be improved. It is common practice to replace a part of the cement with mineral admixtures such as fly ash or ground granulated blast furnace slag. The kind of replacement that is possible whether you use one or the other mineral admixture would depend on the kind of admixture being used.

For example, for fly ash normally an addition in excess of 50% is difficult but in the case of ground granulated blast furnace slag you can go up to 70%. Of course, that again should be taken with a pinch of salt because there is enough literature which says that well we can go for higher volumes fly ash and we just need to take the appropriate kind of precautions and ensure that it does not affect the concrete properties adversely.

The admixture fraction should be kept within the range in which the required early age strength can be achieved. If there is a requirement for early age strength there may be problems if we use a lot of mineral admixture so that is something which the engineers have to keep in mind. And the replacement as I have already mentioned as far as mineral aggregates are concerned the percentage could be about 30% it could go up to 50 as I have mentioned here.

As far as fly ash is concerned but 50 to 70% in case of ground gradient blast furnace slag is not so uncommon.

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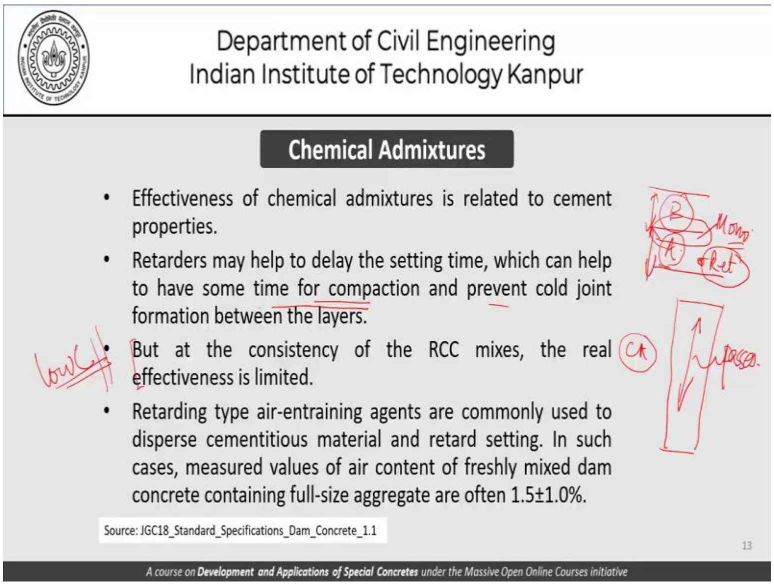

As far as chemical admixtures are concerned the effectiveness of chemical admixtures is related to cement properties and we should make sure that we have made the checks and balances which are required from the point of view of compatibility with cement. Retarders may help to delay the setting time which may be required and in fact it will facilitate our ability to have some time for compaction.

And prevent cold joint formation between layers recall that we have said that RCC that is Roller Compacted Concrete is to be placed in layers. Now before this layer B is placed, we would like to have enough time to be able to compact layer A and since we are talking of a situation where this layer A could be spread over a large area and we need to have time to move the vibratory roller back and forth for a certain number of passes.

And at the same time ensure that this interface between layers A and B behaves monolithically we probably need to have retarders here which will make it easier for us. Give us more time to compact this completely before we are able to place or before we are ready to place the layer B but at the consistency of the RCC mixes that solar compacted concrete mixes the real effectiveness of chemical admixtures is limited.

Why it is limited because one of the reasons is the low cement content. If you have a low cement content the amount of chemical admixture is also low and therefore it will be difficult for us to manipulate or engineer the properties of concrete beyond a certain point. Retarding type air entraining agents are commonly used to disperse cementitious particles and retard setting. In such cases measured values of air content of freshly mixed dam concrete for example containing full-size aggregates are often 1 and a half plus minus 1%. So, you could have air in the range of about 0.5 to 2.5% in the case of dams.

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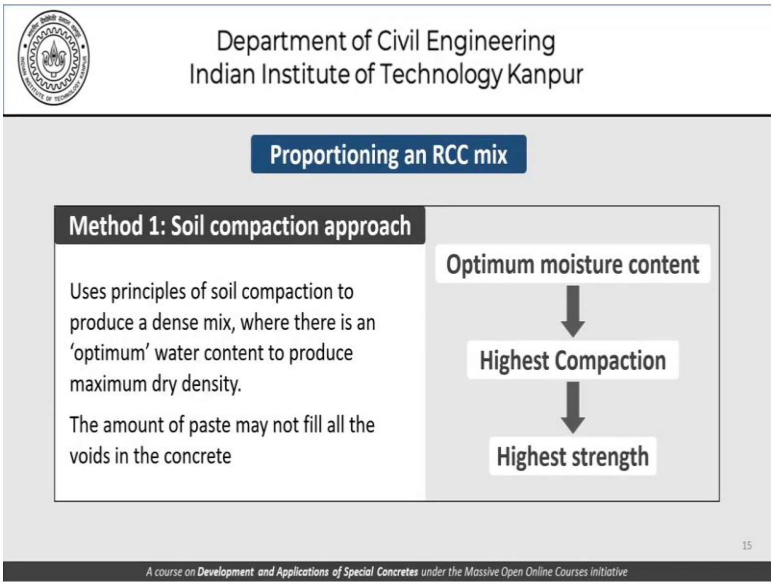

As far as proportioning of Roller Compacted Concrete mixes is concerned. There are basically two approaches one approach is that of soil compaction and the soil compaction approach you know from your soil mechanics a graph like this which has density plotted on this y axis and moisture content on the x axis. So, we have this concept of optimum moisture content which gives us maximum density.

So, this concept from soil mechanics where we are talking of individual particles now compaction of these individual particles with a certain amount of water is what is the domain of soil mechanics. We are trying to use or we do try to use this principle and proportion roller compacted concrete mixes using this principle and try to determine this optimum water content to produce the maximum dry density.

And the amount of paste may not fill all the voids in concrete. Now this is something which is a fallout of this approach at least from a concrete engineer's point of view. The steps involved are determine the optimum moisture content find the highest compaction and that will give you the highest strength. This is the approach that we have as far as the soil mechanics approach is concerned.

If you recall the picture that we have in the beginning in this case when you are talking of RCC then indeed it makes some sense to say that okay we look at coarse aggregate particles much like soil particles. The fact that they are having some kind of coating here of paste around them just contributes to the moisture. Roller compacted concrete can indeed be modelled closer to a soil mass with particles like this surrounded by some kind of moisture containing paste.

And the effort is to find out the moisture content which is optimal in order to facilitate maximum compaction.

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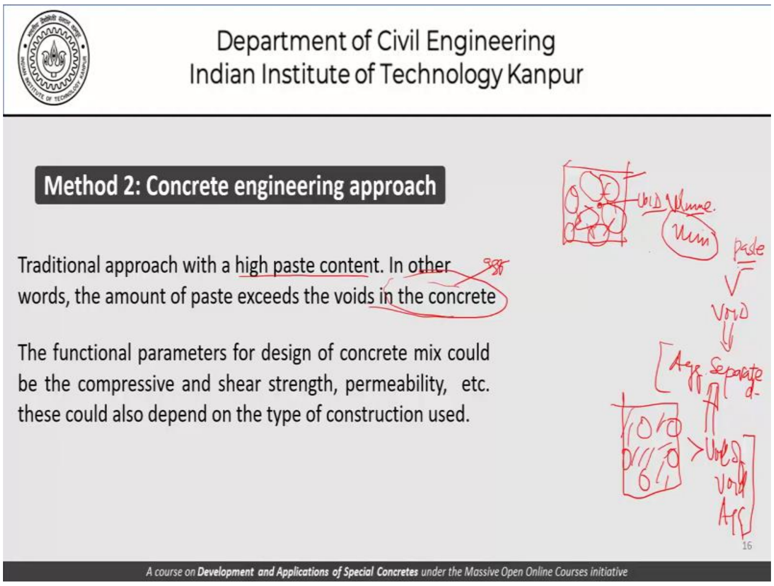

Compared to that we have the concrete engineering approach as far as mix design is concerned where we talk of a reasonably high paste content and in other words the volume of paste exceeds the volume of voids in concrete. And this voids in the concrete refers to the voids in the aggregate. Remember that what we had said in one of our discussions earlier is that if I have a mass of aggregates filled into a box of a certain volume.

Then the void that we have here this void volume is the absolute minimum amount of paste which is required to complete my concrete or to get the concrete. Only if the void volume is lower or the paste volume is higher than the void volume then the aggregates will be separated from each other and not being in contact as shown here is a central point as far as I am concerned and my understanding and imagination or the kind of picture that I have in mind for concrete.

So, to me concrete has aggregates which are suspended in mortar that is they are separated from each other and therefore this volume of paste that I have is obviously greater than the volume of voids in the aggregate system this is something which we have explained and discussed several times. And it comes up again as we discuss the concrete engineering approach to proportioning of roller compacted concretes.

The functional parameters for the design of concrete strength could be compressive or shear strength permeability and so on. And that obviously would depend on the type of construction the kind of target structure and so on.

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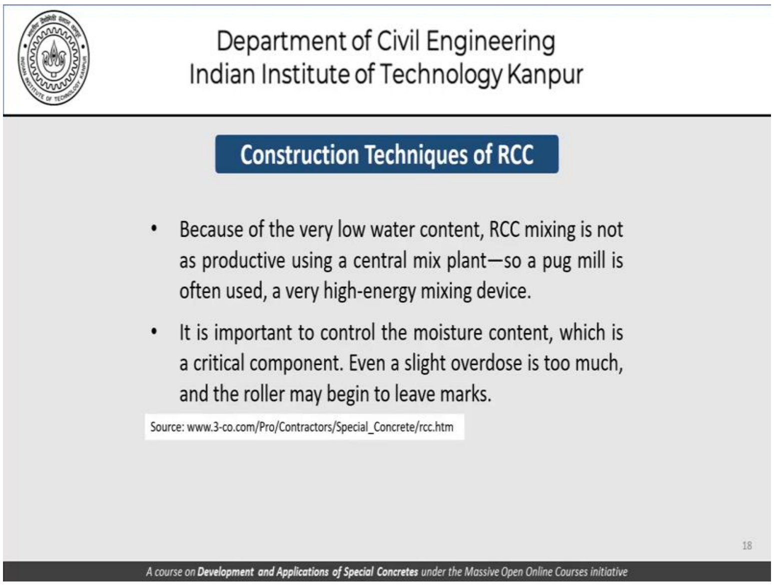

Because of the very low water content RCC mixing is not as productive using a central mix plant. So, a pug mill is often used and that is a very high energy mixing device it is important to control the moisture content which is a critical component even a slight overdose is too much and the roller may begin to leave marks. So, go back to that first picture that we had and you can see that the roller we would not like it to leave marks.

It should be a smooth surface to the extent possible and that is why it is important to have a very good control on the moisture content of the RCC.

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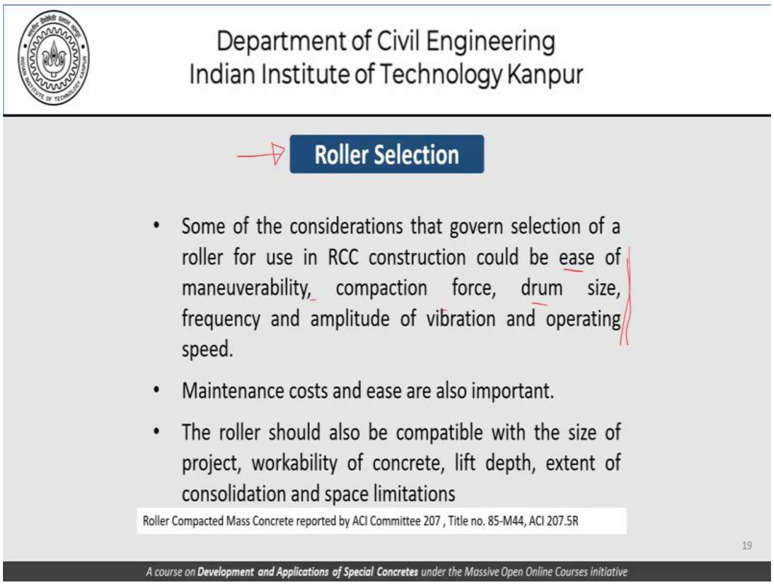

You can imagine that the roller selection is a very key element as far as our ability to successfully use roller compacted concrete at a site is concerned. So, some of the considerations that govern the selection of a roller for use in the RCC construction could be the ease of manoeuvrability of the roller, the compaction force, drum size frequency and amplitude of vibration and the operating speed.

So, these are some of the characteristics that we must keep in mind when we are trying to do a roller selection for a site which plans to use roller compacted concretes. Maintenance cost and ease of course is the other aspect after all rollers are nothing but normal construction equipment and from that point of view like any other equipment the maintenance cost in the ease of their availability in the market is also important.

The roller should also be compatible with the size of the project the workability of concrete being used lift depth, extent of consolidation and space limitations. So, it is important that we choose the roller not only considering the roller characteristics but also the construction characteristics that is what is the lift depth. What is the extent of consolidation that is required and what are the space limitations that we have at site where the roller has to go and vibrate and compact the concrete plate.

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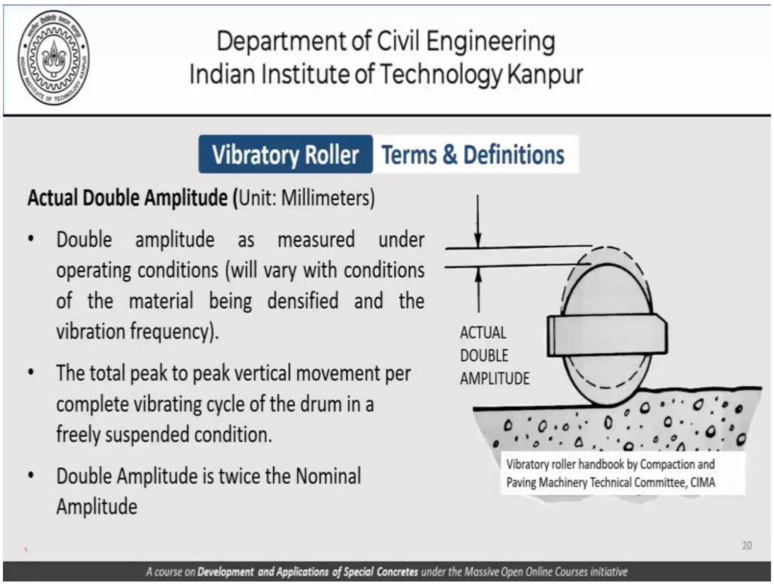

This picture shows a schematic representation of the roller. You can see here that this roller wheel actually oscillates between these two positions here and the bottom is shown here. And as it moves in one pass it is trying to compress or it is trying to cause settlement in the layers ahead. So, if this process is repeated several times, we will have this concrete getting compacted. So as far as the roller is concerned there's something called an actual double amplitude with units in millimeters.

This amplitude as measured under operating conditions will vary with the conditions of the material being densified and the vibration frequency. And the total peak to peak vertical movement per completed vibrating cycle of the drum in a completely free suspended condition. Now this is what defines the actual double amplitude of the roller that we are using. And this double amplitude as we shall see is nothing but twice the nominal amplitude.

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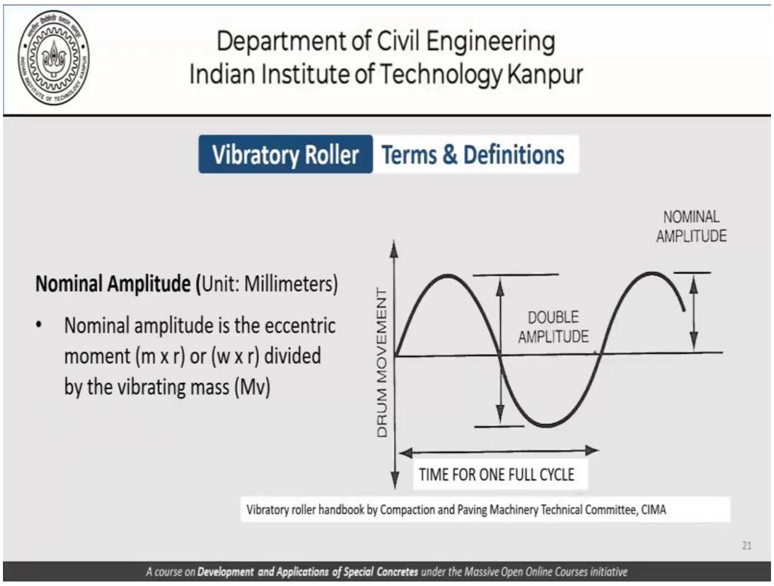

As far as the nominal amplitude is concerned, we can see here the drum movement that is what we saw last time the drum movement could be positive or negative with respect to a certain datum and this is the double amplitude that we are talking about and half of that is the nominal amplitude. Of course, the double amplitude whether it is twice the nominal amplitude or the nominal amplitude is half the double amplitude is a matter of nomenclature.

But yes, the double amplitude is twice the nominal amplitude as we have talked about and the nominal amplitude by definition is the eccentricity moment that is (m x r) or (w x r) divided by the vibrating mass which is (Mv). Now this is something which we are leaving out of the discussion as far as this course is concerned and I am going to cover not only this definition but also several other definitions which are part of characterizing.

And defining the roller that we use for you as part of the something to think about head where those of you are interested to see how the roller compacted concrete actually works from a mechanical engineering perspective from the perspective of trying to characterize the equipment which is used to compact the concrete for that you need to have certain definitions sorted out. Certain other mechanical engineering related issues which we will quickly gloss over and go through very quickly towards the end of the discussion with that let us try to move.

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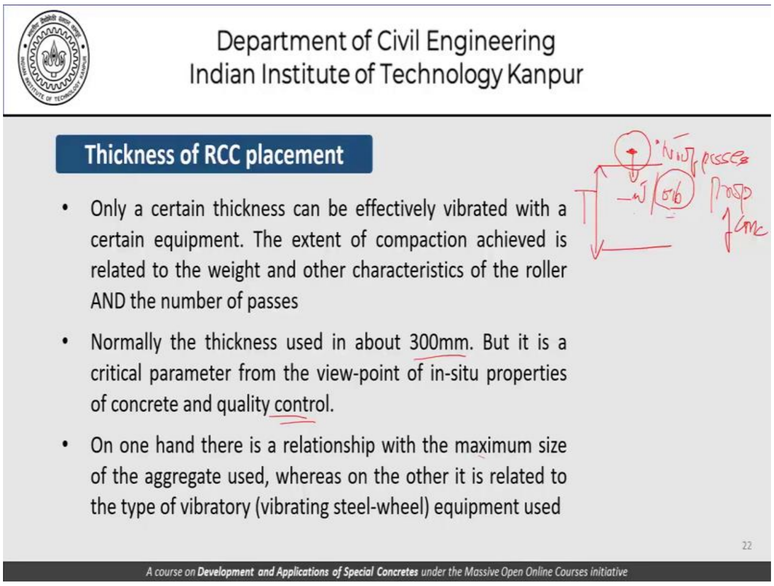

On to the thickness of RCC placement only a certain thickness can be effectively vibrated with a certain equipment the extent of compaction achieved is related to the weight and other characteristics of the roller and the number of passes. Now what is being said here is that suppose this is the thickness T of the concrete which needs to be compacted. Now this thickness T will obviously be a function of the properties of the concrete that we are using and also what roller we are using.

The weight of that roller and the vibratory characteristics and not only of the roller and the vibratory characteristics but also the number of passes. So, for a given weight and vibratory characteristics if we have a number of passes. If we change the weight of the vibratory characteristics obviously, we require a different number of passes to be able to compact the same concrete to the previous level or the level which was achieved with the older weight and vibration characteristics.

Normally the thickness used is about 300 mm but it is a critical parameter from the point of view of in situ properties of concrete and quality control. On the one hand there is a relationship with the maximum size of the aggregate used whereas on the other it is related to the type of vibratory or the vibrating steel wheel equipment which is used.

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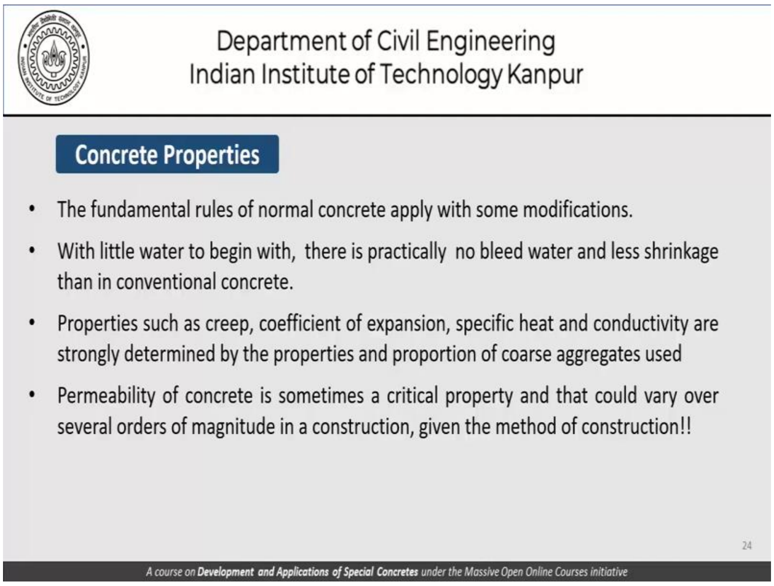

Now coming to the properties of RCC the fundamental rules of normal concrete obviously apply with some modifications always remember that cement and water will hydrate and that hydration process does not really recognize one concrete or the other. So long as there is water and the cement the hydration will happen and that hydration will depend on temperature and so on. But not necessarily on the method by which the cement and water have been brought together and that is what I want to say.

When I say that the fundamental rules of normal concrete will apply but perhaps with some modifications with very little water to begin with there is practically no bleeding water and less shrinkage than conventional concrete. Properties such as creep the coefficient of expansion specific heat and conductivity are strongly determined by the properties and proportions of the coarse aggregate in the case of roller compacted concretes.

Permeability of concrete is sometimes a critical property and that could vary over several orders of magnitude in a construction given this method of construction.

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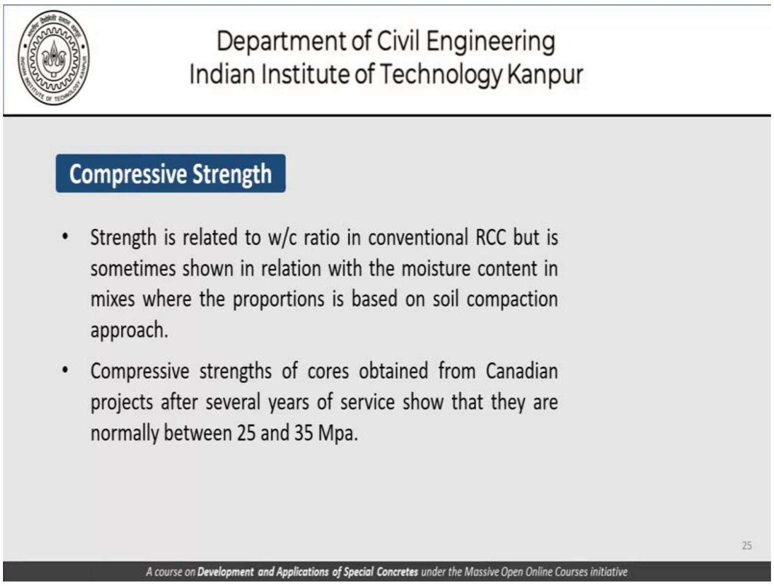

As far as the compressive strength is concerned the strength of course is related to the water cement ratio in conventional concrete. But in some times shown in relation to the moisture content especially in cases where the proportions for RCC have been determined based on the soil compaction approach. Compressive strength of course obtained from Canadian projects after several years of service show that they are normally between 25 to 35 MPa.

But of course, this 25 to 35 MPa is also related to what kind of water cement ratio was used. Having said that let me just mention to you that even though I use this term water cement ratio please remember that cement does not necessarily mean only cement products does not only mean ordinary Portland cement it could also include other cementitious materials. And in all concretes where we are using material like fly ash or slag or silica fume.

Apart from cement it is equally important to be talking in terms of the cementitious material content and talk in terms of the water cement ratio or the water to the cementitious material ratio when we are talking about the importance of this parameter and its relationship with the strength of concrete achieved.

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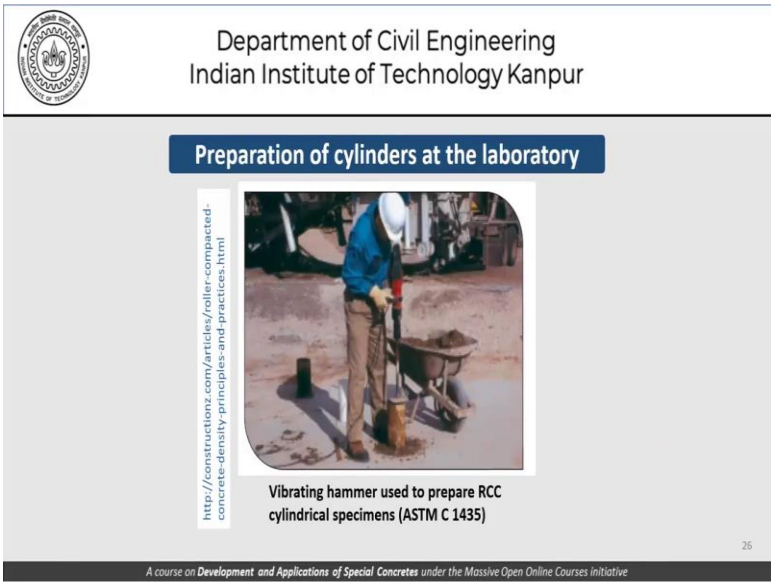

This picture here shows the preparation of cylinders in the lab when we are planning to use roller compacted concrete and you can see that instead of trying to use an internal vibrator what we are trying to use is a vibrating hammer. That is what is used to prepare RCC cylindrical specimens in the laboratory because internal vibrators. Number one there is a problem on how they will work how effectively they will be able to compact the concrete.

But also, they are not going to be used at site and we have already discussed this issue that as far as possible we should try to use equipment in the laboratory which is similar to the kind of equipment that we will use in the field. So even though a compacting hammer or a vibrating hammer is not really the same thing as a vibratory roller it is the best that you can do at least in preliminary studies.

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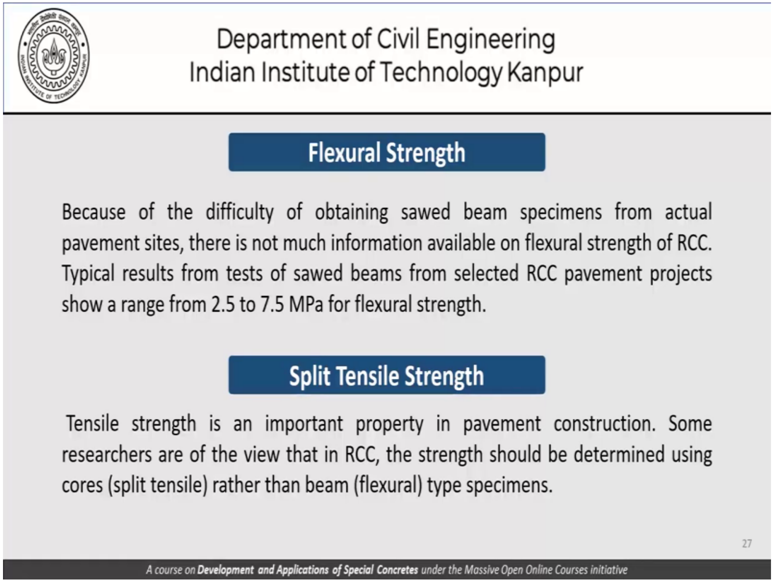

As far as flexural strength is concerned because of the difficulty of obtaining sawed beam specimens from actual pavement sites there is not much information available in literature on the flexible strength of RCC. But typical results from tests of sawed beams from selected pavement projects show a range of 2.5 to about 7.5 MPa for flexural strength and for split tensile strength is another property which is important pavement construction.

There is some research which is advocating the view that the strength should be determined using cores. So that a split tensile test can be performed rather than the beam type of test where we try to do flexural tests.

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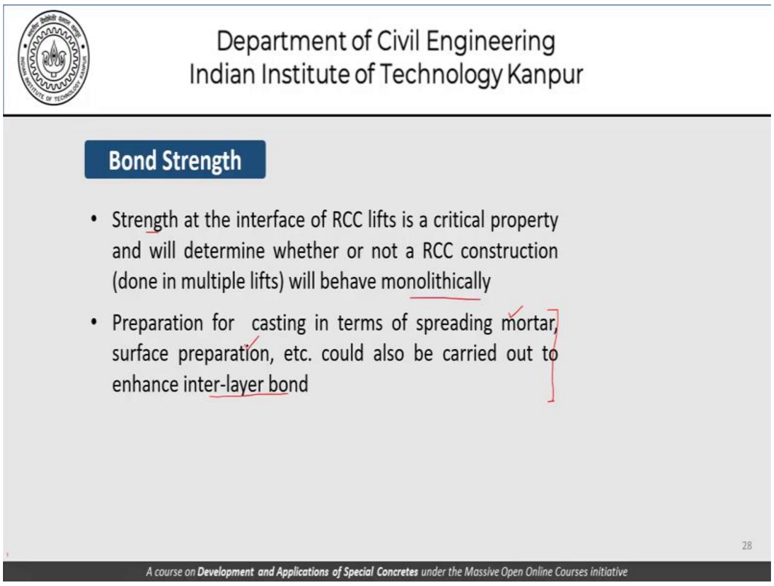

Continuing our discussion with the properties of the RCC. As far as bond strength is concerned, we have talked about it briefly before the strength of the interface of the RCC lift is a critical property and will determine whether or not the RCC construction which is often done multiple lifts will behave monolithically and preparation for casting in terms of spreading mortar surface preparation and so on.

Could also be carried out to enhance the inter layer bond. So, this discussion as far as spreading mortar is concerned or any other surface preparation and removal of latent spreading some kind of an adhesive these discussions are more or less similar to what we do in the case of normal concrete.

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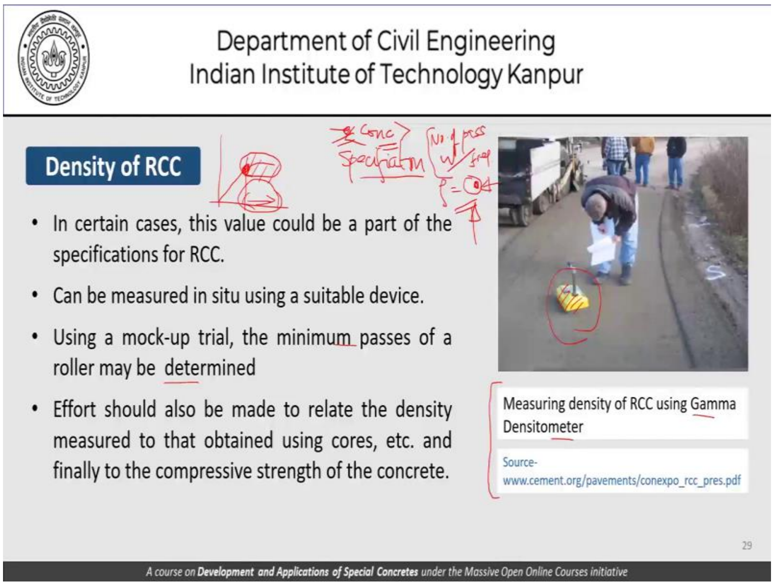

As far as density of concrete is concerned you can see here, we are trying to measure the density using a gamma densitometer. Now I would leave it to you to figure out or think find out for yourself what is the gamma densitometer and how it helps us record the density of the material on which this densitometer is placed. What is the mechanism involved here I am leaving it out completely as far as our discussion is concerned?

But yes, this is the tool that we can use for a specification that we can say that the concrete should be compacted to the extent that it gets a density of such and such which means that we are not necessarily specifying the number of passes or the weight of the roller or the frequency of vibration. We are saying that we want a density here and how it is achieved when it is achieved what kind of properties of concrete that we use here that is also being more or less left out of that specification.

Of course, as far as the properties of concrete are concerned that is something which will be decided somewhere else and will play an important role. But density becomes our performance parameter when it comes to determining the number of passes or the weight of the roller used and so on. We can have both we can have either a density of this or at least so many passes. As is given here this value could be a part of their specifications can be measured in situ using a suitable device.

In a mock-up trial the minimum number of passes or the kind of number of passes which are required to get a certain density or to try to get a curve which tells us the relationship between the number of passes and the density achieved. Because what we would ideally like to do is to say that intuitively if the number of passes increase the density will increase. But beyond that the density will not increase.

So, we would like to get somewhere here where at least we are able to achieve the maximum possible density and not have an unnecessarily large amount; of passes which is not contributing to the densification of the concrete. Effort should also be made to relate the density measured to that obtained using cores and finally the compressive strength of concrete. So, we need to carry out this exercise in one project or another so that data becomes a part of our understanding and experience when we go to use roller compacted concrete in a similar project somewhere else.

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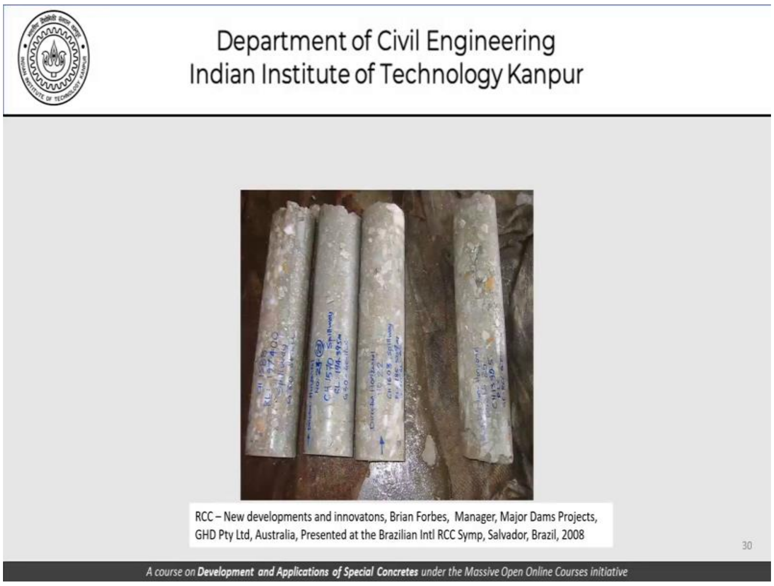

This picture of course shows some cores from a roller compacted concrete project and these cores can be used to study the distribution of aggregates they can be used to obtain pieces which can be tested for compressive strength and so on.

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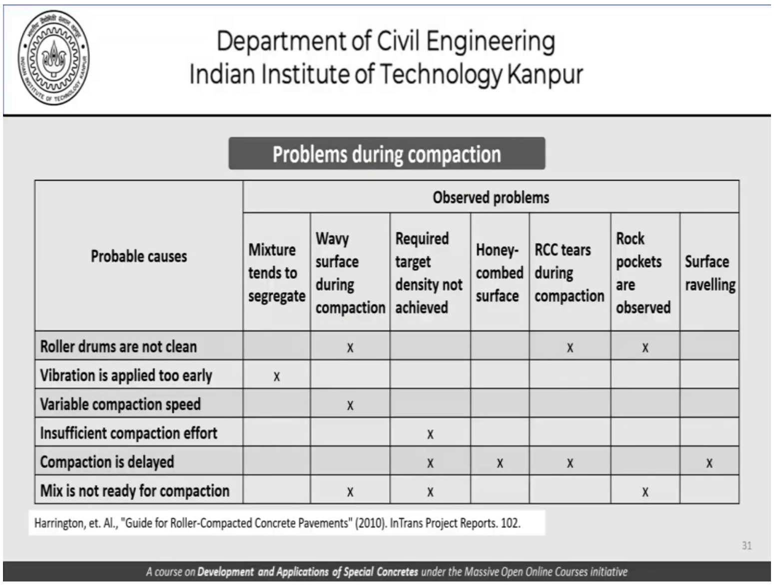

Probable causes	Observed problems						
	Mixture tends to segregate	Wavy surface during compaction	Required target density not achieved	Honey-combed surface	RCC tears during compaction	Rock pockets are observed	Surface ravelling
Roller drums are not clean		x			x	x	
Vibration is applied too early	x						
Variable compaction speed		x					
Insufficient compaction effort			x				
Compaction is delayed			x	x	x		x
Mix is not ready for compaction		x	x			x	

This picture or the table outlines some of the problems that are observed during the roller compacted concrete construction and probable causes the problems could be the mixture tends to segregate wavy surface due to compaction required target density not being achieved honeycombed surface, RCC tears due to compaction, rock pockets are observed surface ravelling and the possible causes could be roller drums not clean, vibration applied too early variable compaction speed used insufficient compaction effort delayed compaction makes not ready for compaction and so on.

So, this is the kind of a chart which tells you that if you have a certain problem what are the problems or what are the areas which you need to look at first. And then move forward and try to do a deeper analysis.

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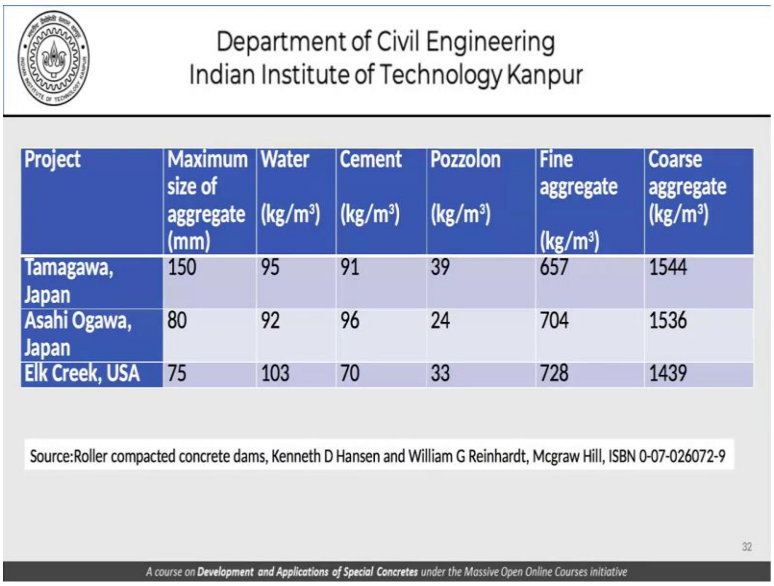

Project	Maximum size of aggregate (mm)	Water (kg/m³)	Cement (kg/m³)	Pozzolon (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)
Tamagawa, Japan	150	95	91	39	657	1544
Asahi Ogawa, Japan	80	92	96	24	704	1536
Elk Creek, USA	75	103	70	33	728	1439

This picture here just gives you some reference mixed proportions used in some of the roller compacted concrete dam projects, roller compacted concrete pavement projects in the world and I am leaving it to you to draw your own conclusions as far as the maximum size of the aggregate used. The total quantum of aggregate and compare those values to the kind of normal concretes that we are used to.

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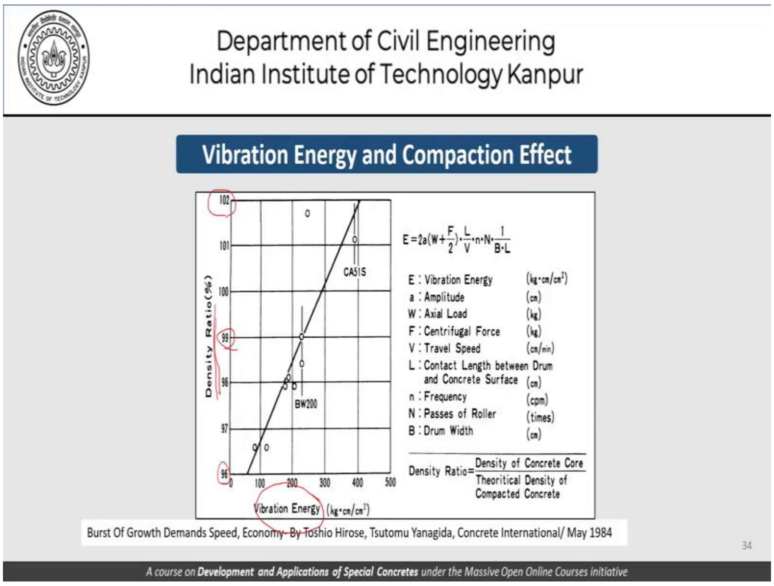

And with that we come to more or less an end of the discussion today except that we still have this something to think about to complete. This picture here instead of including it as a part of the lecture I have brought it into this section which is something to think about and you can see that this picture shows a relationship between the vibration energy and the density. So, there are several ways of looking at it one is that we are looking at a density value which is in the very close bracket of 96 to 99 to 102%.

So, and how is this percentage defined this is the ratio of concrete core to the theoretical density of compacted concrete. So, there is a very small range that we are working with 96 to 102 and what is there on the x-axis is equally interesting. If you see this is the equation that is given and these are the kind of variables that are involved. The vibration energy is related to the amplitude of vibration, axial load, the centrifugal force of the roller.

We will see that slide shortly which gives you; insight into this centrifugal force of the mass, the travel speed contact length between the roller and the concrete surface, frequency, number of passes and the drum width. So, there are all these parameters which come into play when it comes to determining the density of concrete. So, I am leaving this to you to just think about it try to see how many of those parameters you actually can understand.

And reason to yourself that yes it makes sense what are the parameters that are coming in the denominator the way they are what are the kind of parameters which are going in the numerator the way they are and so on.

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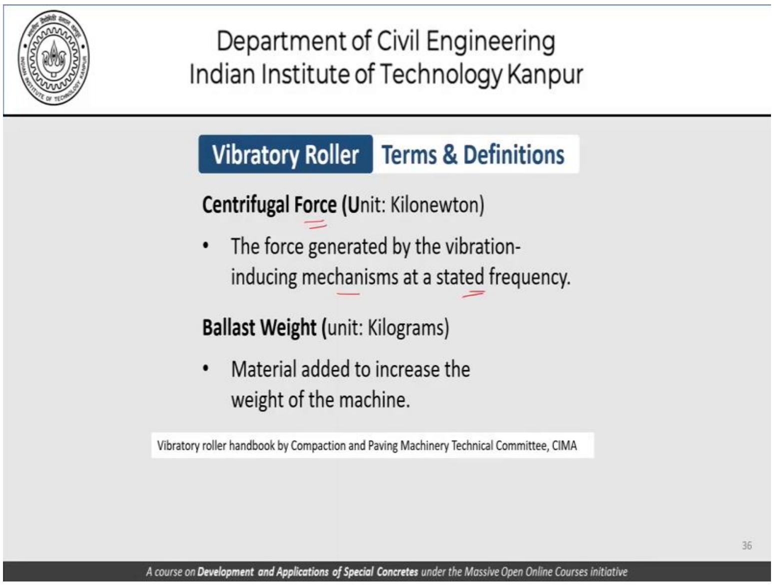

Some more definitions I had said that we will leave it out of the main lecture and leave you with some ideas and request you or have you, think about it a little bit more some of them are. The variable amplitude, the nominal amplitude change accomplished by varying eccentric moments and this part is independent of the frequency. As far as the centrifugal force is concerned which could be measured in kilonewtons this is a force generated by the vibration inducing mechanisms at a stated frequency.

So, the centrifugal force is not independent of the frequency at a given frequency you have a certain centrifugal force. Similarly, the ballast weight that is the material added to increase the weight of the machine.

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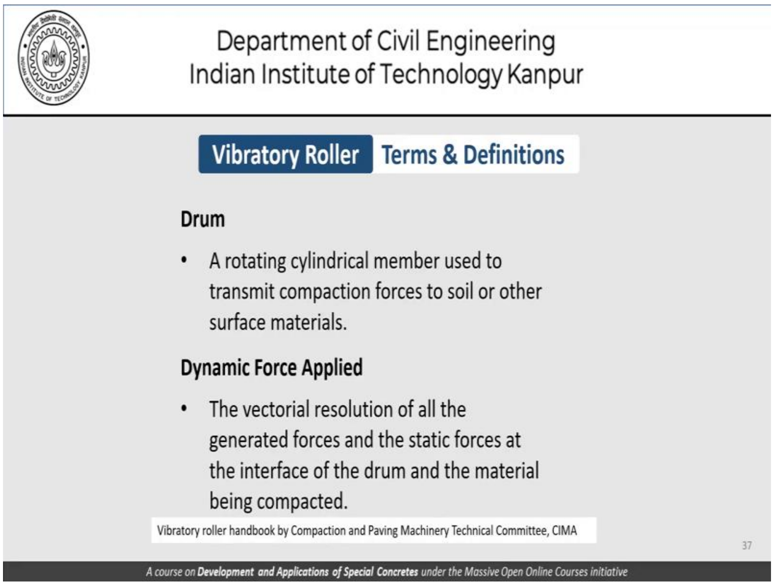

There is the drum which is the rotating member used to transmit compaction forces to the soil or other surface materials. In this case it is not soil we are talking about in this case we are talking about the roller compacted concrete which is in contact with the drum. And the dynamic applied force is the vectorial resolution of all generated forces in the static forces at the interface of the drum and the material being compacted.

So basically, if we have a material here it is under compaction through some kind of a force which is acting at the point of contact. Now whether this force is acting vertically downwards or it is not acting vertically downwards. As far as the dynamic force applied is concerned this is the vectorial resolution of all generated forces and the static forces at the interface of the drum and the material being compacted.

So, if this is a layer of concrete being compacted and this is the roller that is moving on that. So, at the point of contact there is a transmission of forces which governs what is the kind of compaction that will happen here. So, this is what we need to study more closely and that is what our definition is.

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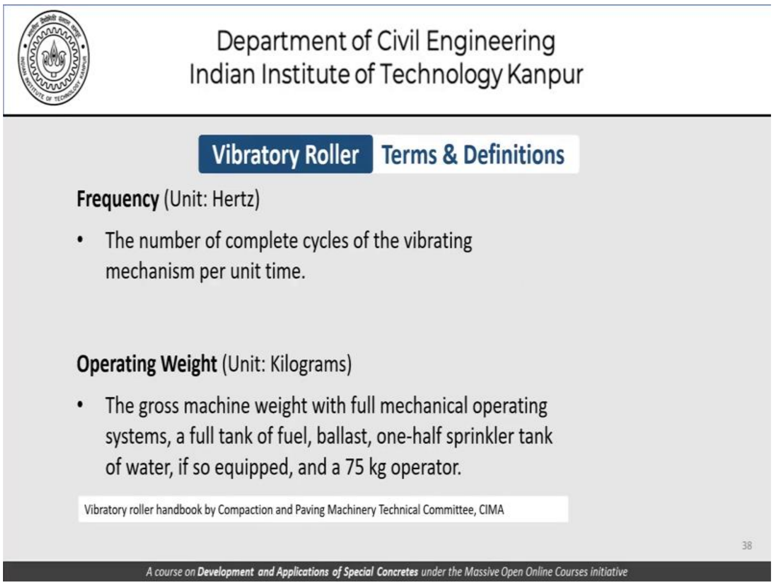

As for the frequency is concerned is the number of complete cycles of vibrating mechanism per unit time, we know that and that is measured in hertz. This operating weight which is the gross machine weight with full mechanical operating systems a full tank of fuel ballast half one half sprinkler tank of water if so equipped and a 75 kg operator. So once we have all this information we know what is the operating weight of the roller that we are talking about.

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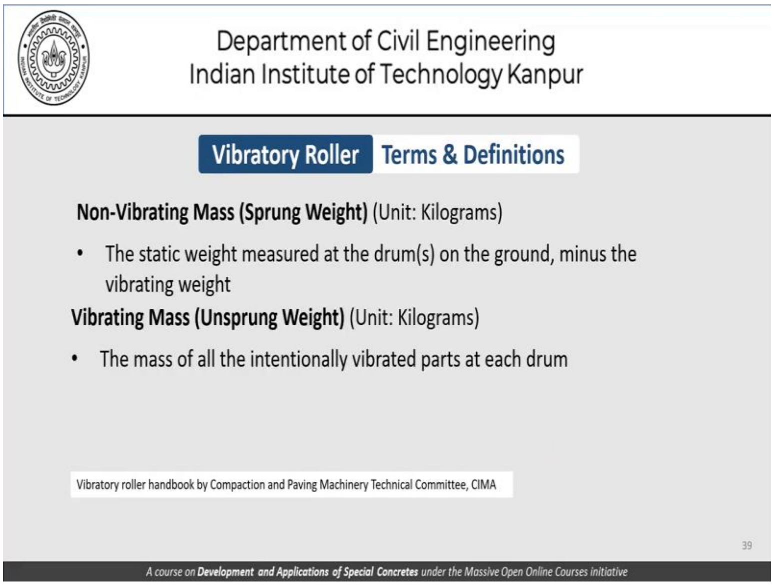

Continuing with our definitions we talk of the non-vibrating mass and the vibrating mass which sometimes also called the sprung weight or the unsprung weight. The non-vibrating mass refers to the static weight measured at the drums on the ground minus the vibrating weight and the vibrating mass the mass of all the intentionally vibrated parts of each drum.

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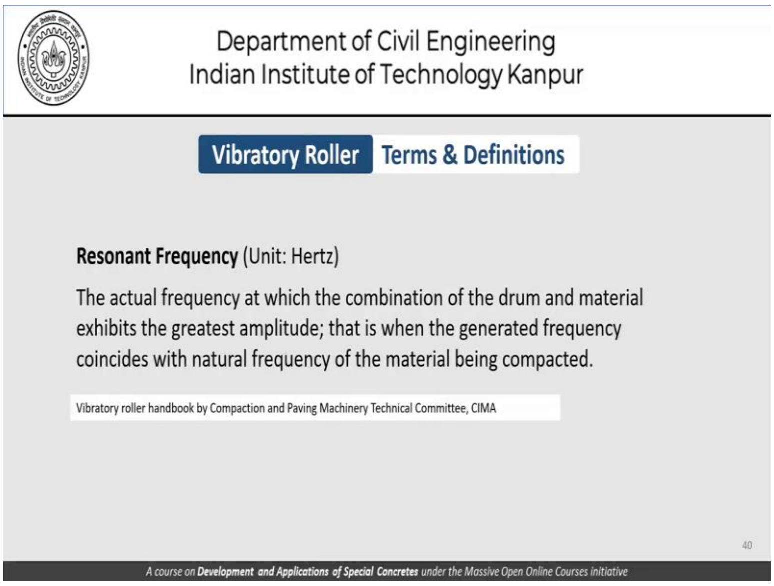

Resonant frequency refers to the actual frequency at which the combination of the drum and the material exhibit the greatest amplitude that is when the generated frequency coincides with the natural frequency of the material being compacted.

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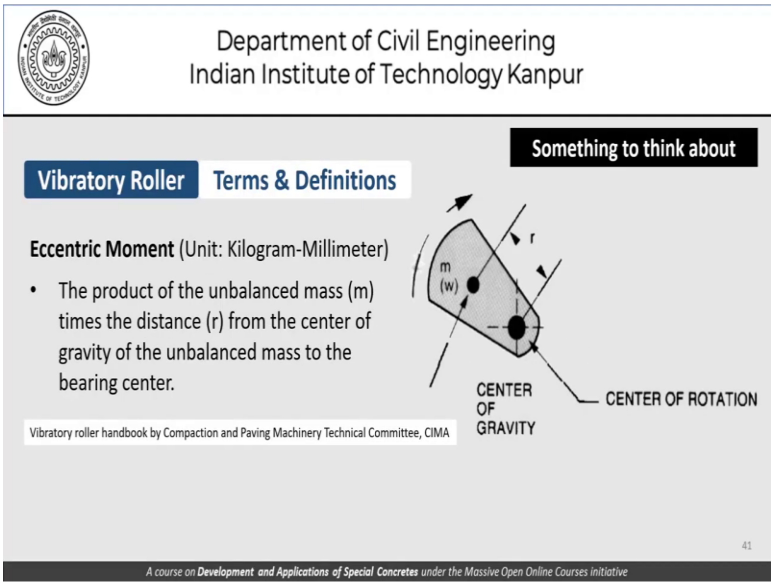

As far as the mechanism is concerned, we have this eccentric movement which is the crux as far as the roller vibrations are concerned and we have the product of an unbalanced mass m which is shown here times the distance r which is the distance of the center of gravity of the unbalanced mass to the bearing center. So here we have the center of rotation and here is the center of gravity and this distance r is what determines the product of m into r.

And that is a critical parameter when it comes to defining or characterizing the vibratory roller is concerned.

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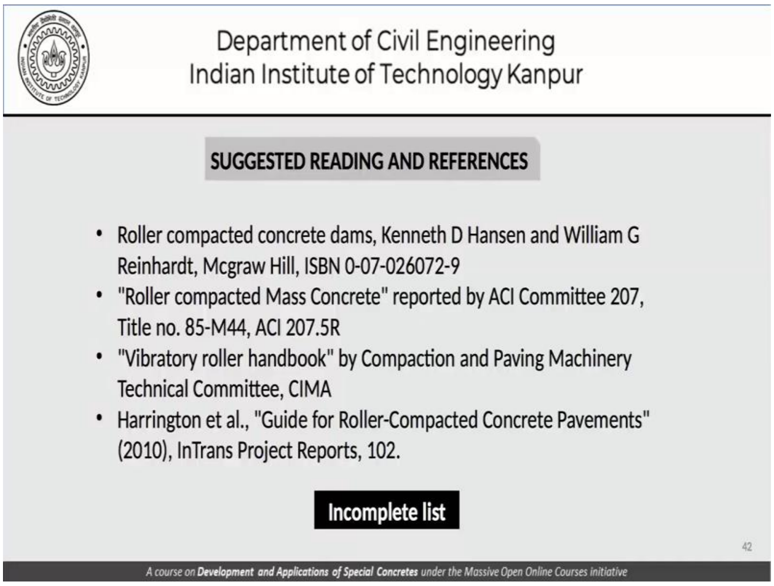

This is a set of some readings that you could do and of course the list is not complete and you are expected to do some reading on your own.

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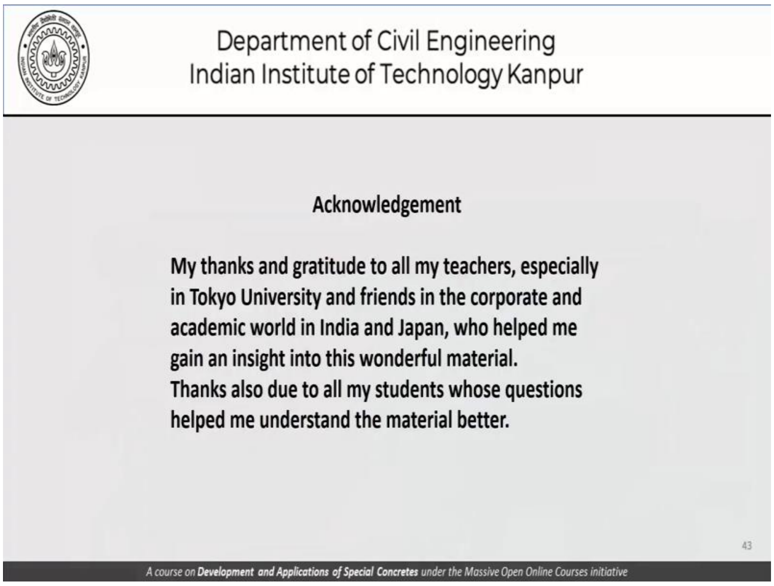

And with this I thank all my teachers my students and my friends who have helped and contributed to my understanding of this material and I hope that I have contributed in a small bit to your understanding. I look forward to seeing you again in the next class where we will start a fresh module that is module 5 as far as the series of lectures on development and applications of special concretes.

Under the massive open online courses' initiative of the Government of India is concerned. So, I look forward to seeing you then thank you once again for all the attention.