Development and Applications of Special Concretes
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Lecture-30
Special Topics
Compaction of Concrete

Hello, once again and we continue our discussion on development and applications of special concretes. And today we will take up another special topic especially relevant from the point of view of special concretes and concrete in general, compaction of concrete.

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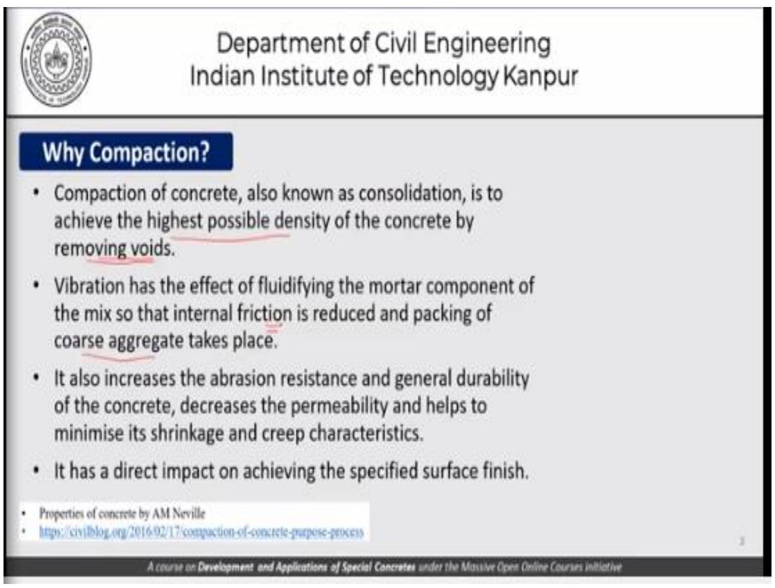

So, the first thing, that comes to our mind is why compaction? The compaction of concrete also known as consolidation is to achieve the highest possible density of the concrete by removing the voids. It is the presence of these voids which causes heterogeneity in the concrete as well as a reduction in the strength and so on. Vibration has the effect of fluidifying the mortar component of the mix, so that the internal friction is reduced and the packing of coarse aggregates takes place.

So, we shall see that, actually the consolidation process takes place in 2 steps. But what is summarized here is that vibration or consolidation has the effect of fluidifying the mortar component of the mix. So, that the internal friction primarily between the aggregates, the coarse aggregates, I should say, is reduced. And the coarse aggregates take the configuration of greater compactness.

It also increases abrasion resistance and general durability of the concrete and decreases the permeability and helps minimize issues or problems relating to shrinkage and creep of concrete. Proper compaction also has a direct impact on achieving the specified surface finish as far as concrete is concerned.

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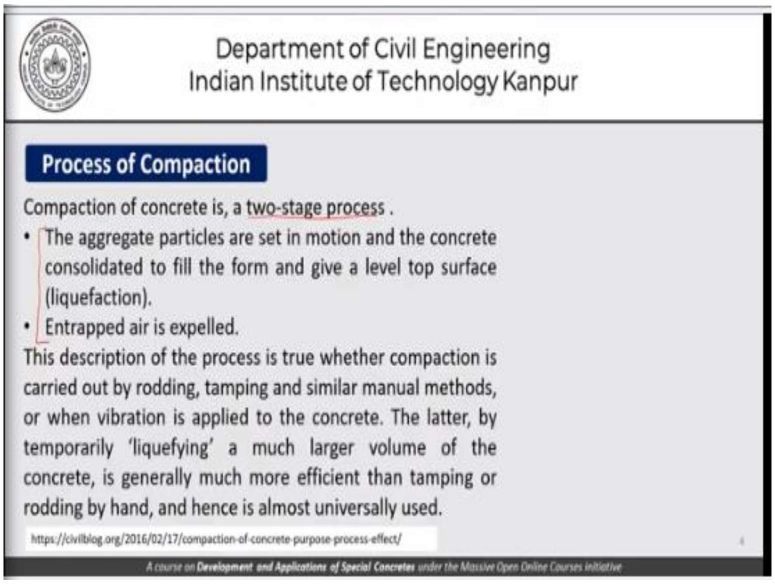

As far as the process of compaction is concerned, I just mentioned that it is a two-stage process. Now what are the 2 stages? In the first stage the aggregate particles are set in motion and the concrete consolidated to fill the form and give a level top surface, this is what has been called as liquefaction. And the second part of it is expelling of the entrapped air or voids within the concrete.

Now it is this two-step process which has to be accomplished during the compaction process of concrete. So, this description of the process is true whether the compaction is carried out by rodding, tamping or similar manual means or when the vibration is carried out using mechanical vibrators. The latter, temporarily liquefying a much larger volume of concrete is generally more efficient than tamping or rodding by hand. And hence is almost uniformly used across the board in major construction projects.

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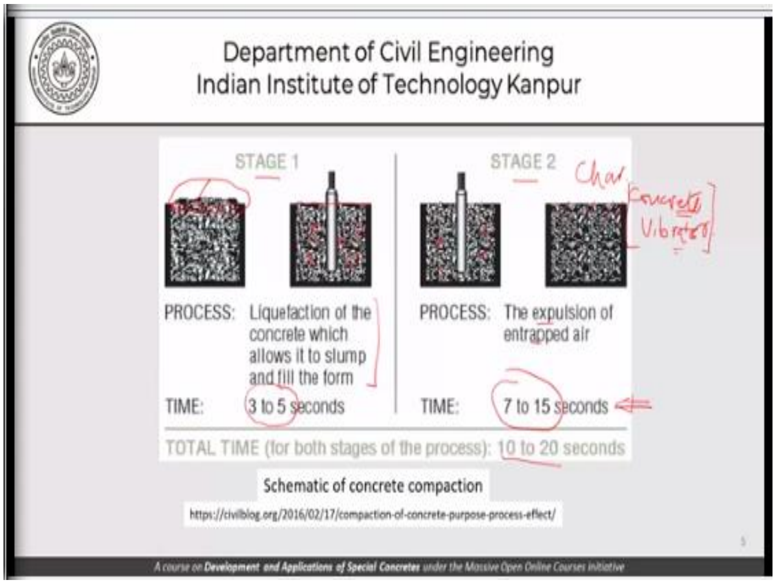

This picture here shows a schematic representation of the stage 1 and the stage 2 of the compaction process. The stage 1 which involves the liquefaction of the concrete, which allows it to slump and fill the form, takes about 3 to 5 seconds, that is what stated here. As far as stage 2 is concerned which involves largely the expulsion of entrapped air from within the concrete here that takes about 7 to 15 seconds.

So, you can see here that in the first stage to begin this concrete is slightly more than the volume required here. But as the consolidation takes place and the concrete or the coarse aggregate particles rearrange themselves within the concrete mass here, the volume is reached, the concrete actually fills the volume here. Now I would also like to point out that though we could simply say that we can add the 2 times here.

And say that the total time for both the stages in the process is between 10 and 20 seconds. We should remember that this is very strongly related to the characteristics of the concrete being used and that of the vibrator. So, whether it will take 3 seconds or 5 seconds or 10 seconds, for this consolidation to happen obviously is related to both these characteristics. If we are dealing with a harsh concrete or we are dealing with a different kind of vibrator as we shall see in the lecture today, these times will be different.

So, the schematic representation or of in principle guidance that, yes, so long as we have air continue to bubble out of the system here, the vibration should be continued. That is something which we can keep in mind, and take the actual measurement or the actual description of time with simply a pinch of salt and move forward.

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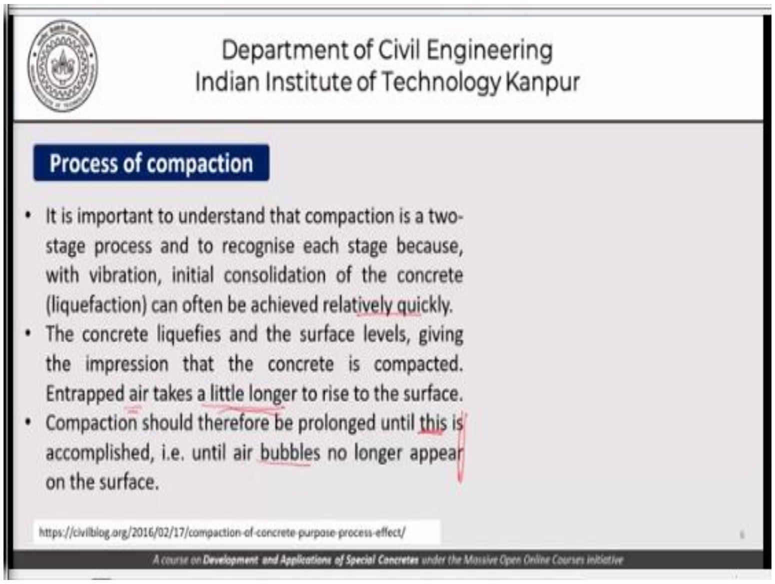

The process of compaction was again to reiterate it is important to understand that compaction is a two-stage process and to recognize each stage. Because with vibration initial consolidation of concrete can be achieved relatively quickly depending upon the type of concrete that we are talking about. And concrete liquefies in the surface levels giving the impression that the concrete is compacted.

But entrapped air takes a much longer time to rise to the surface; this entrapped air is within the concrete. Compaction should therefore be prolonged until this is accomplished, this means release of all the entrapped air from within the concrete. This is accomplished that is until the air bubbles no longer appear on the surface. So, this becomes my criteria for determining the time at which the compaction shall be stopped.

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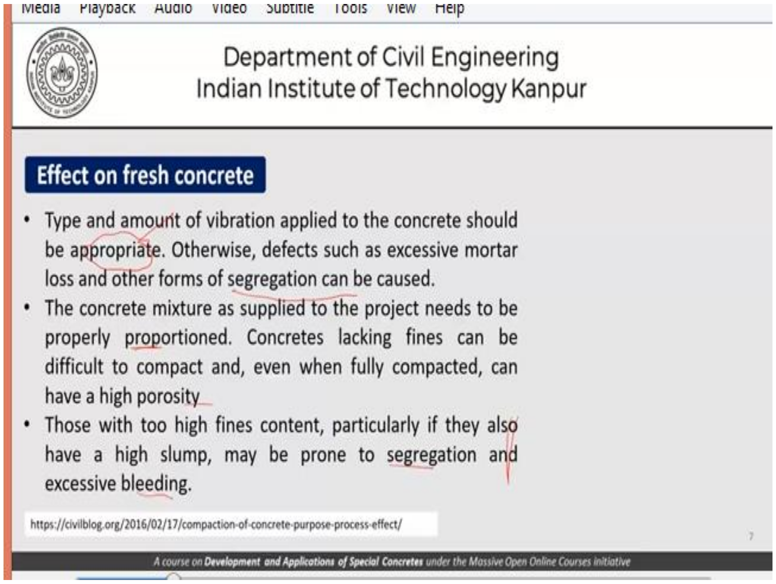

The type and amount of vibration applied to the concrete should be appropriate. So, we are leaving it at a very qualitative world appropriate. Otherwise defects such as excessive mortar loss and other forms of segregation can be seen. Over vibration as we shall see is again as detrimental to the concrete as under vibration. So, we should be careful that we vibrate the concrete only for an appropriate or the adequate amount of time.

The concrete mixture is supplied to the project needs to be properly proportioned, of course the concrete proportioning itself also contributes to the ease of vibration or ease of compaction. Concretes lacking fines can be difficult to compact and even when fully compacted have a higher porosity than concretes which are having a proper amount of fines. Those concretes with a large amount of fine content, however particularly if they have a high slump may be prone to segregation and excessive bleeding.

So, we have to keep these kinds of things in mind and some of these statements you will appreciate are being made with a lot of experience based on literature or sharing of experience from different agencies. For example, this particular discussion if you go back to civilblog.org on 17 September somebody says that, these are the kind of things that we need to keep in mind. So, that is what we are trying to do here, we are trying to put to forward to you issues which are related to the effect of vibration as far as the properties of fresh concrete is concerned.

And a lot of this you can educate yourself through experience, keeping the kind of things that are being mentioned here in mind.

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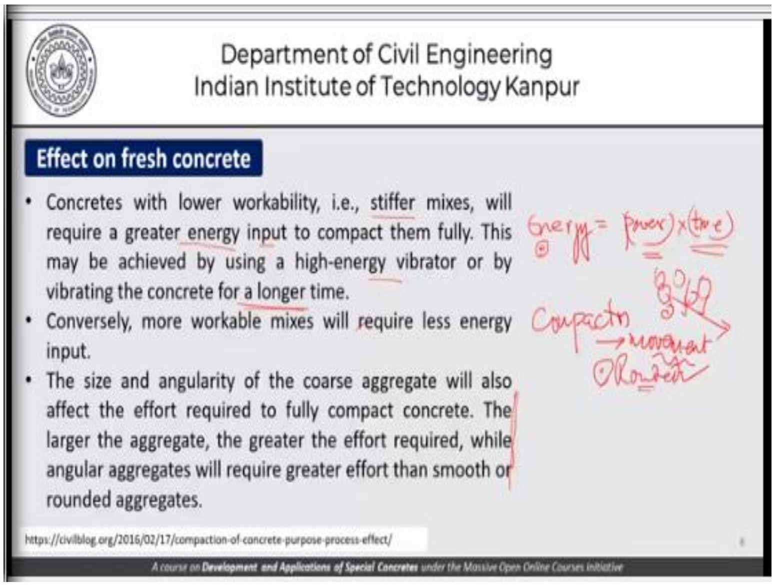

Continue with our discussion on the effect of vibration on the fresh concrete. Concretes with lower workability that is stiffer mixes will require a greater energy input to compact them fully. This may be achieved by using a high energy vibrator or by vibrating the concrete for a longer time. What we are essentially saying is the total amount of energy that is needed for compaction is a function of the power of the vibrator itself and the time that it is used.

Of course, there is a limit on that, because if the power is below a certain threshold level, then no matter how long we vibrate, we will not be able to impart the right kind of energy. In the extreme case if we are trying to do a manual compaction there is a limit to which the power that we can apply to the concrete. And therefore, we can never achieve full compaction as is desirable if we are using extremely feeble means for vibration of concrete.

Conversely, more workable mixes will require less energy input to achieve compaction. The size and angularity of coarse aggregates will also affect the effort required to fully compact the concrete. The larger the aggregate, the greater effort is required while angular aggregates will also require greater effort than smooth or rounded aggregates. Now this part should become obvious given the fact that we just discussed.

That compaction really involves movement of aggregates, in a narrow band that if the aggregate is here, it is not going to move 2 centimeters or 3 centimeters somewhere else. But in the small domain where you have a lot of aggregates, if the aggregates have to move to a more compact kind of a configuration, then it is easier for the aggregates to move if they are rounded.

We talked about the liquefaction of the mortar phase which allows the aggregates to move around a little bit. And that internal friction between coarse aggregates is lower if we are using rounded aggregates compared to our use of angular aggregates. These are some of the things that are obvious from our basic discussion of concrete and concrete materials. As we apply that basic knowledge to compaction and understand the process of consolidation of concrete.

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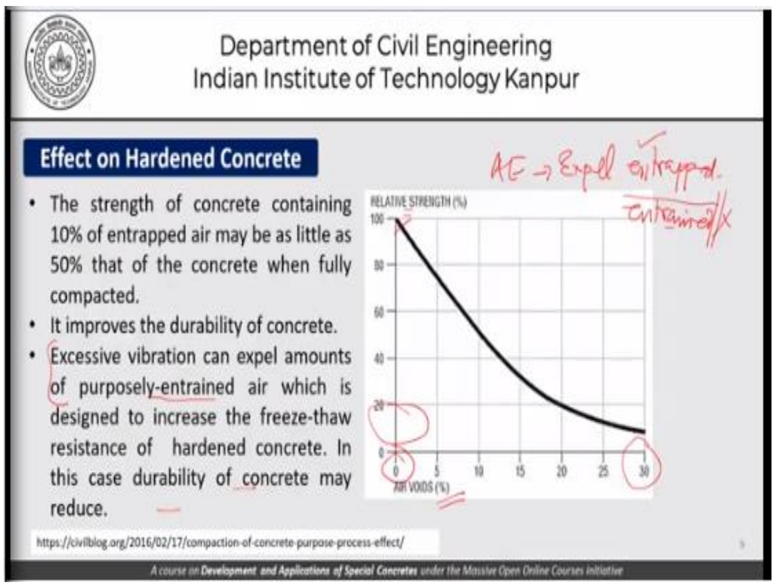

Here we have a representation of the effect on hardened concrete. So, this plots the air voids in concrete versus the relative strength. So, if we have 0 here, of course 0 is an extreme situation, so if we take this to be 100 the strength that we get could be as little as just 10%, if we are not able to expel all the voids. So, of course what we are talking about here is a 30% void system which is a very large void system as far as most concrete is concerned but is included by way of illustration.

So, the strength of concrete containing 10% of entrap air may be as little as 50%, that of concrete when fully compacted obviously consolidation improves the durability of concrete. Excessive vibration of course can expel the amounts of purposely entrained air which is designed to increase the freezing thaw resistance of hardened concrete. And in that case the durability may be reduced.

So, especially when we are dealing with air entrained concrete, we should be careful that we are expelling only the entrapped air. Because if we continue to vibrate beyond that point even the entrained air will try to escape and this is something which we do not really want. So, we should stop the vibration when the entrapped air has been expelled and the entrained air can be allowed to remain within the concrete mass.

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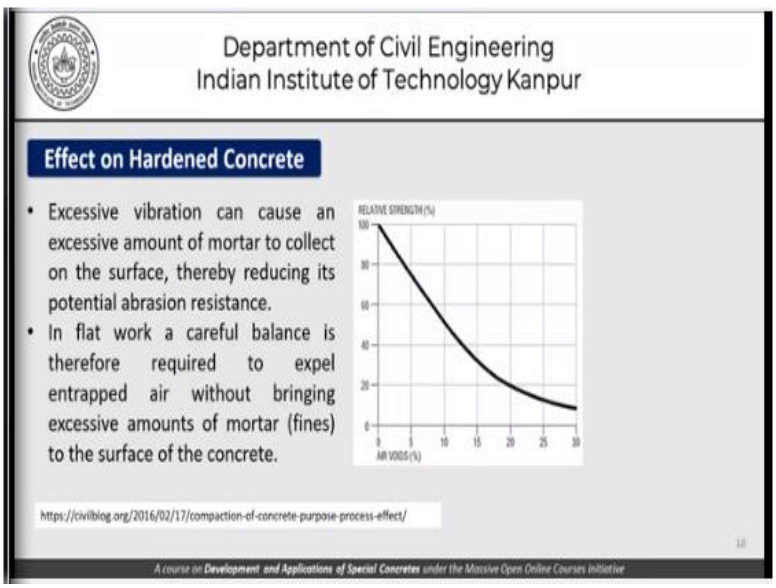

Excessive vibration can cause an excessive amount of mortar to collect on the surface thereby reducing it is potential abrasion resistance and making the concrete not homogeneous. In flat work a careful balance is therefore required to expel entrapped air without bringing excessive amounts of mortar or fines to the surface of concrete.

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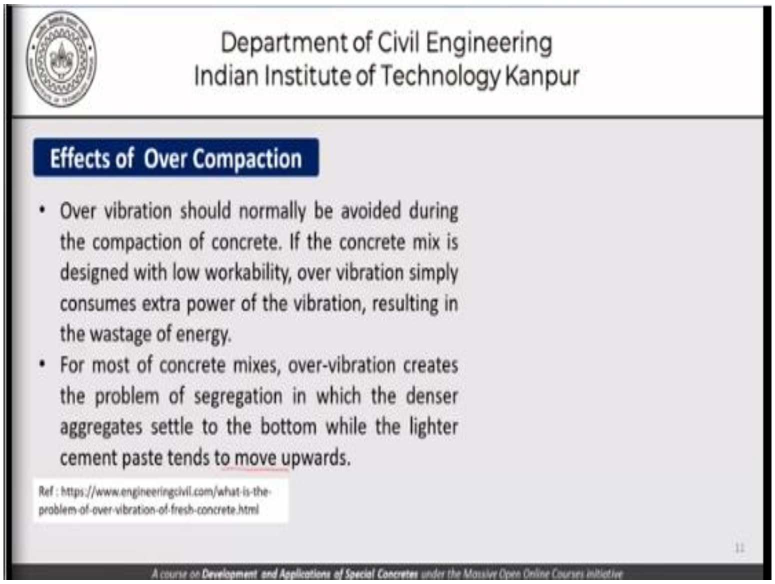

As far as the effects of over vibration is concerned, over vibration that is continuing the vibration beyond the time that is actually required. So, over vibration should normally be avoided during the compaction of concrete. And if the concrete mix is designed with low workability, over vibration simply consumes extra power of vibration resulting in a wastage of energy. For most of the concrete mixes over vibration creates the problem of segregation.

In which the denser aggregates settle to the bottom while the lighter cement paste tends to move upwards. So, it is not a cement paste moving upwards really but the cement paste being lighter facilitates the movement of the coarser aggregates which are heavier in settling those coarse aggregates down. So, the settlement of the heavier coarse aggregate effectively appears as the movement of cement paste upwards.

In any case that leads to segregation and that is what segregation actually is and that could be the result of over vibration of concrete.

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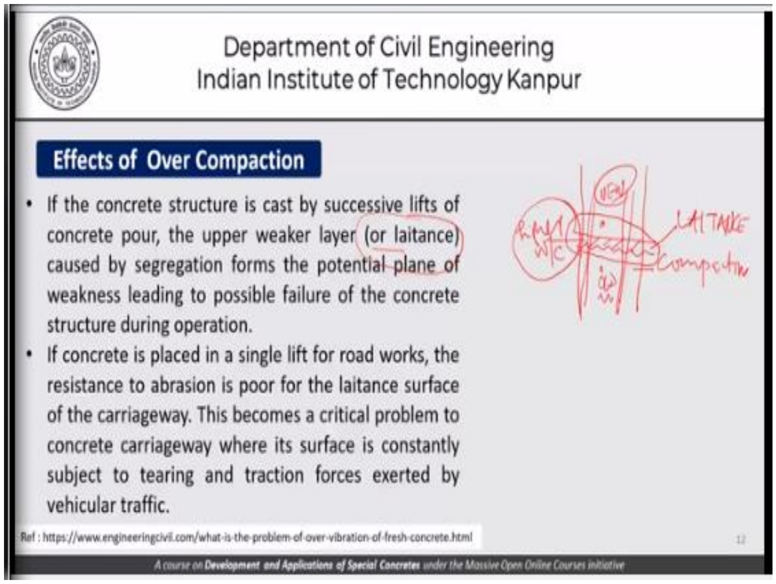

If the concrete structure is cast by successive lifts of concrete pore, the upper or the weaker layer called laitance caused by segregation forms a potential plane of weakness leading to possible failure of the concrete structure during operation. So, what happens is that this laitance needs to be removed before the resumption of construction activities. Like to explain this laitance phenomena once again especially for example if you are dealing with columns or walls.

We cast the concrete up to this level, and we have reinforcement bars which are continuous from this old concrete or the old pore and we want to construct or we want to continue our construction activity with the new pore here. So, what is being suggested here is that this concrete has already been compacted. Now during this compaction at this point here on the top some amount of concrete has collected which is having a higher mortar content or a higher water cement ratio which needs to be removed.

So, this concrete here is what is being called laitance and needs to be removed before we can resume the construction activities in the subsequent pores. So, this is what we are talking about here as far as lifts are concerned. So, when concrete is being constructed using lifts the upper weaker layer or laitance caused by segregation forms the potential plane of weakness leading to possible failure of the concrete structure during operation.

So, this laitance or this layer of concrete needs to be removed, to be replaced by the fresh concrete that we have. Sometimes codes and specifications require that this surface here after the removal of laitance is wetted with cement wash out rich mortar, it also facilitates a proper bond between the old and the new concretes. If concrete is placed in a single lift for road works, the resistance vibration is poor for laitance surfaces of the carriageway.

This becomes a critical problem to the concrete carriageway where it is surface is constantly subject to tearing and traction forces exerted by regular traffic.

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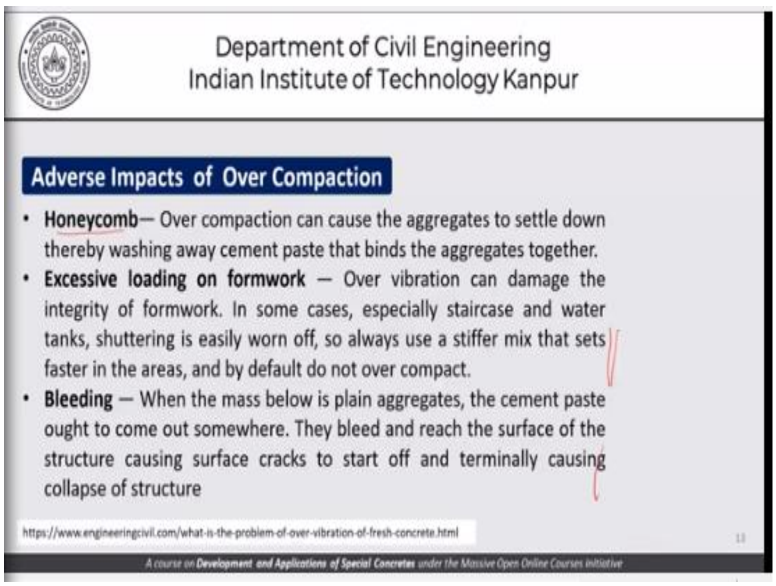

Continuing further discussion on the adverse impacts of over compaction, honeycombing is one of them. Honeycombing which is the result of over compaction can cause the aggregates to settle down thereby washing away cement paste that binds the aggregates together. Excessive loading of the formwork over vibration can damage the integrity of the formwork as well. In some cases, especially staircases and water-tanks shuttering is easily worn off.

So, always use a stiffer mix that sets faster in the areas and by default do not over compact. So, this is the mantra which is being told to a concrete engineer that you can use a slightly stiffer mix that sets faster these areas and do not over compact because compaction or over compaction in fact also place these additional loads on the formworks. Bleeding, when the mass below is plain concrete the cement paste ought to come out somewhere.

They bleed and reach the surface of the structure causing surface cracks to start off and terminally cause the structure to collapse. Of course, bleeding does not so easily lead to a structural collapse but of course that is the ultimate possibility that we have to watch out against.

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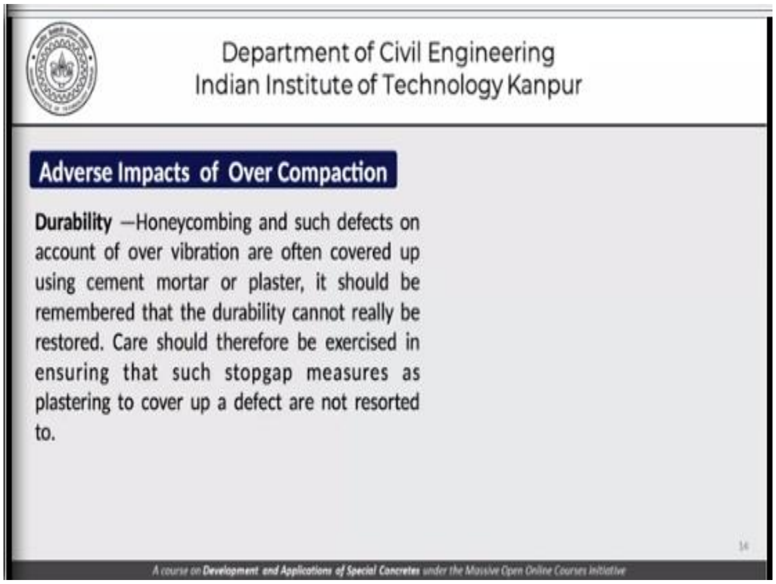

Durability of course is the ultimate impact not all-over compacted structures collapse; some stay strong but the contractor could possibly cover it up with some plastering and cement curing. Whereas the impact such as honeycombing or the leakage of mortar and so on can be apparently rectified at the sites by simply plastering the concrete surface, but that does not restore the durability of concrete.

One should be careful that in order to preserve the durability of the concrete structure it is important that such cover up by way of plastering using cement mortar is not carried out to the extent possible as far as construction is concerned.

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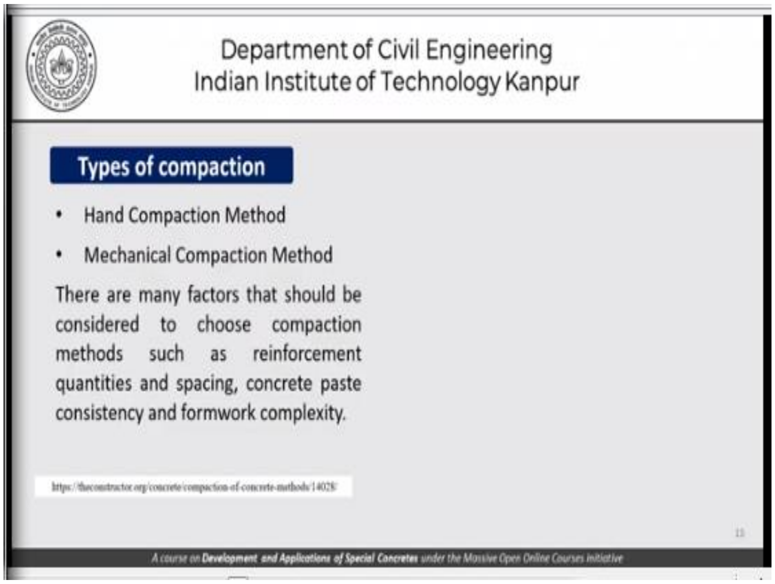

Now coming to the types of methods that we use to compact the concrete; one of course is hand compaction and then we have mechanical compaction. There are many factors that should be considered to choose the compaction method such as reinforcement amount and the spacing involved, concrete paste consistency and the complexity of the formwork.

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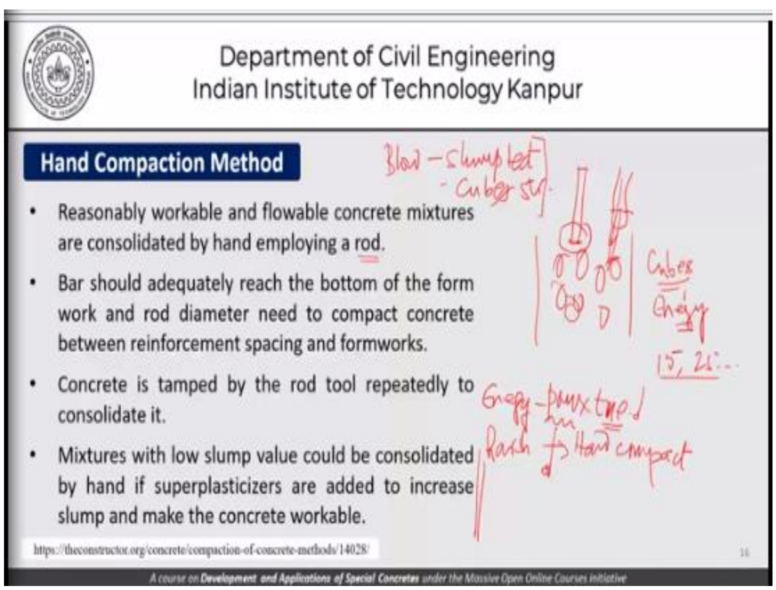

As far as hand compaction is concerned, it requires reasonably workable and flowable concrete mixtures only these can be consolidated by hand employing a poking rod. The bar should adequately reach the bottom of the formwork and the rod diameter we chose as such that the concrete between the reinforcement spacing and the formwork can also be compacted. Of course, if we use a very thin rod things become very difficult to use.

Because the rods then tend to bend on their own, so that is where some kind of skill is required to choose the right kind of poking or rodding kind of methods. The concrete is tamped by the rod tool repeatedly to consolidate it. So, what is being said here is that we put the concrete in the formwork and then we have a certain tamping rod. And what should be the shape of this here at the end whether it should be a flat surface or it should be a semi-sphere.

Or what can be the most effective way of compacting this concrete is something which is given in the literature. The codes which tell you what kind of rods should be used, what should be the diameter? What should be the end shape? And what should be the length? Some of those things are a matter of the codes but at the same time they are also governed by practice and ease of operation.

So, the concrete is tamped whether or tool repeatedly to consolidate it. You will recall that when we are preparing cubes or working in the laboratory, we often use tamping rods for compaction of concrete. And in those cases, in order to standardize the amount of effort or the energy that is being used for compaction the codes specify something like 15 blows or 25 blows or whatever it is for different kinds of tests.

So, I am asking you to look at the codes and figure out what is the number of blows or number of times that this poking rod is expected to be employed in each layer when we are talking of the slump test. Or when we are preparing cubes for strength determination at the end of the concrete construction. So, once you have these numbers, the numbers are there for standardization as I said.

So, that there is a standard amount of effort which has been put in across all cubes and therefore the strength can be actually compared only on the basis of the raw materials. Mixtures with low slump values could be consolidated by hand only if super plasticizers are added to increase the slump and make the concrete workable. So, basically what is being said is that harsh concrete is very difficult to hand compact.

If you want to compact harsh concrete by hand it will be more challenging, I do not say it will not be done or it cannot be done. But it will be extremely challenging to be able to consolidate a harsh concrete by hand compaction alone. This is the kind of situation which I talked about when we said that the total amount of energy in compaction can be taken to be a product of the power times the time.

But if the power is very small then it is virtually impossible to have the kind of time to still get a certain amount of energy. So, these kinds of equations should be taken with a pinch of salt and we should understand by way of qualitative discussion. That in the case of low slump concretes it could be very difficult to achieve proper compaction if we are using hand compaction.

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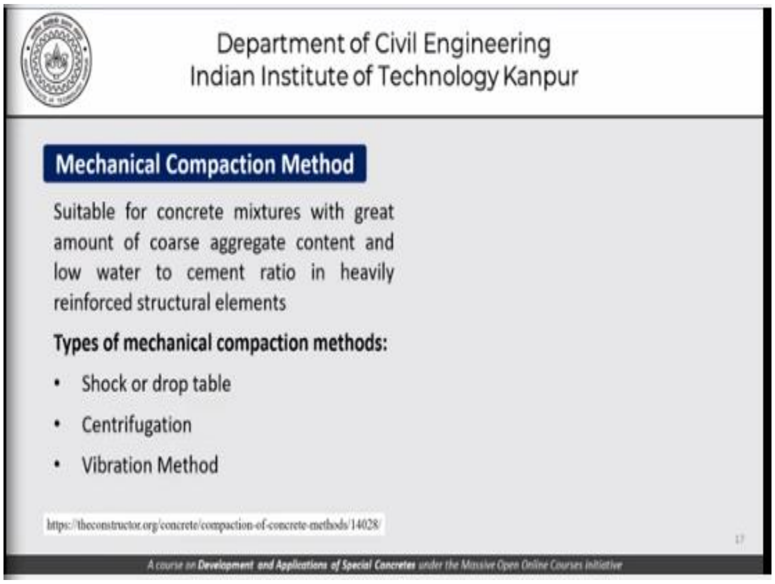

As far as mechanical compaction methods are concerned. They are suitable for concrete mixtures with a higher amount of coarse aggregate and low water cement ratios in heavily reinforced structural elements. The types of mechanical compaction methods that exist for us or available to us include shock or drop table, centrifugation and a vibration method. How the vibration method works is something, what we will discuss as we go along. Moving on to the details of the mechanical vibration systems.

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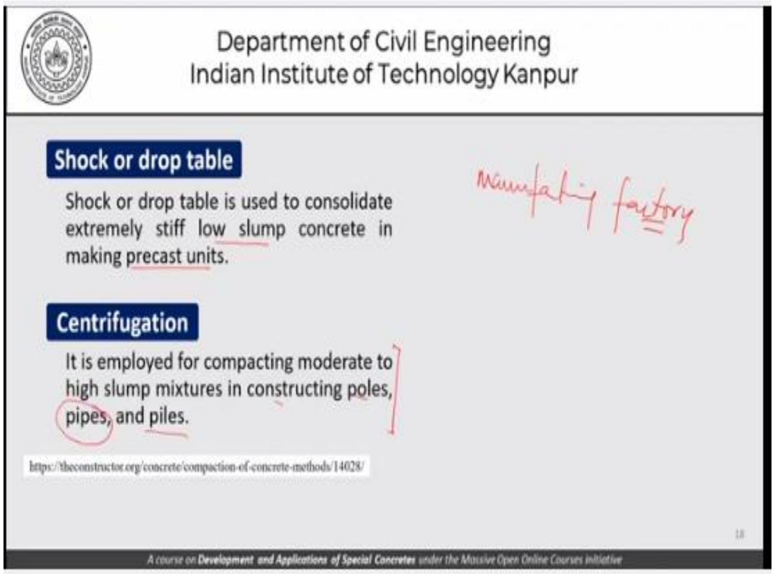

The first is the shock or drop table. So, this is used to consolidate extremely stiff low slump concretes in making precast units. Please remember that when we are talking of precast units, we are talking of manufacturing these units in a factory. Where we can have very heavy equipment installed, that kind of heavy equipment is very difficult to manage when it comes to a construction site.

Of course, at construction sites we have our own construction equipment, but we try to ensure that those equipment at the construction site are lighter to the extent that at least they can be more easily managed. In a factory environment we can manage to have heavier equipment, so when it comes to this kind of equipment such as the shock table, such as the shock or drop table it is better suited for precast units in factories.

Similarly, centrifugation is employed for compacting moderate to high slump mixtures in constructing poles, pipes and piles. This is again something which we use in the factories, I would encourage you to look at how pipes are compacted or consolidated RC pipes how they are consolidated in a factory environment.

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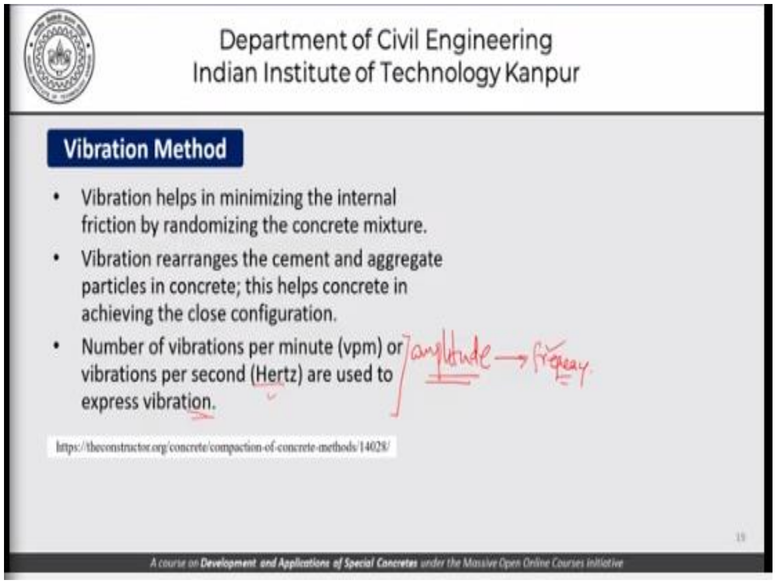

Moving forward we go to the real vibration systems where the vibration of course helps in minimizing the internal friction by randomizing the concrete mixture. Vibration rearranges the cement and aggregate particles in concrete which helps the concrete achieve a close and a compact configuration. So, the number of vibrations that is vibrations per minute or vibrations per second are used to express these vibrations of course.

Apart from the hertz or the frequency of vibration there is also the amplitude which is important. So, any vibration system is characterized by the amplitude of vibration and the frequency. So, we should be careful as to what is the frequency that we are using for the vibrator and what is the amplitude of that vibration?

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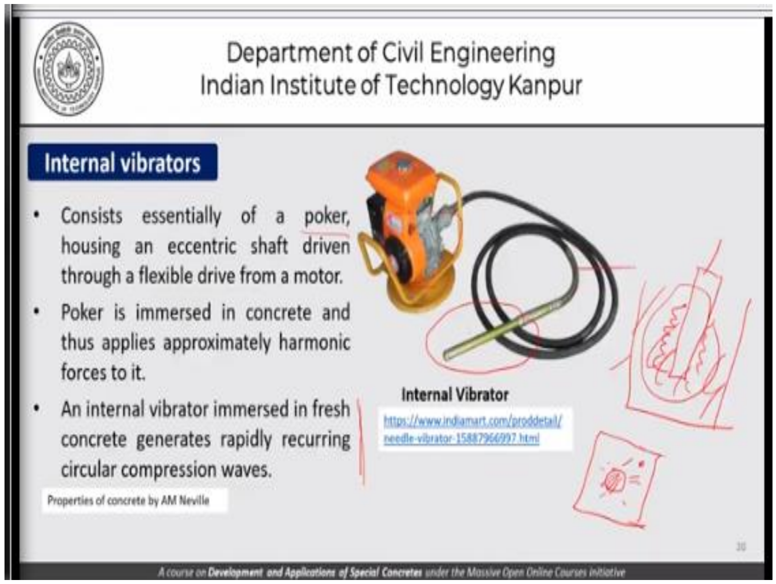

Coming to first of these mechanical systems for vibration of concrete. We are showing here the internal vibrator that is the most common used vibrating equipment at a construction site and consists of a poker. And this is what we are calling the poker here the needle, this poker housing an eccentric shaft driven through a flexible drive from a motor. So, this is the motor there is a flexible drive and there is the poker that is what is used to vibrate the concrete.

So, what we really do is we have a mass of concrete which is poured here and we insert this poker and it vibrates the concrete around it here. So, this is what is the basic mechanism we are familiar with that the poker is immersed in concrete and thus applies approximately harmonic forces to it. And since the concrete is plastic, it deforms and the aggregates there go into configurations which are more closed or more compact.

An internal vibrator immersed in fresh concrete generates rapidly recurring circular compression waves. So, these are things which we should know from the point of view of what happens as we immerse the vibrator. If you look at this picture in plan, what we have is a plan here the top view and we immerse the needle vibrator here, switch it on. So, what we have is some kind of wave generation and propagation through this fresh concrete in a circular manner.

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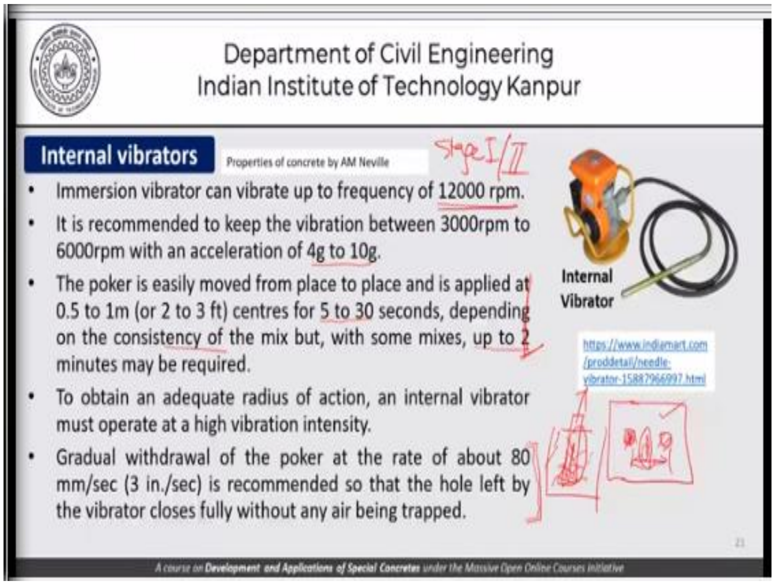

Continuing with our discussion on internal vibrators, the internal vibrators can vibrate with the frequency to 12000 rpm. I would encourage you to go through the literature available on the website for the different internal vibrator or the needle vibrator manufacturers, and find out what is the range at which these internal vibrators are available. 12000 given here is a ballpark number.

It is recommended to keep the vibration between 3000 and 6000 rpm with an acceleration of 4g to 10g. The poker is easily moved from place to place and is applied at 0.5 to 1 meter which could be about 2 feet to 3 feet kind of distance centers for 5 to 30 seconds. Depending on the consistency of the mix but with some mixes up to 2 minutes may be required. Recall what we saw in the initial part of our discussion today, when we talked about the stage 1 and stage 2 of the consolidation process.

Where stage 1 was basically the liquefaction of the mortar phase, facilitating the movement of the coarse aggregate into a compact configuration, and then removal of the voids. So, what we are talking about here is the same range of about 5 to 30 seconds. But at times more than 2 minutes or up to 2 minutes may also be required depending on the consistency of the mix. So, that is something which is obvious something which we must reason to ourselves.

That if we are trying to vibrate this concrete which is very stiff. Then what will be the balance between the distances that we have between 2 places where this insertion using a poker is made versus the characteristics of the poker itself including then the consistency of the concrete mix. Say if somebody was to determine this distance ‘d’ which is the most optimal distance or the most desirable distance between 2 pokes, we have to consider not only the consistency of the mix but also the characteristics of the vibrator.

To obtain an adequate radius of action an internal vibrator must operate at a high vibration intensity. Gradual withdrawal of the poker at a rate of about 80 millimeters per second which is 3 inches per second is recommended. So, that the hole left by the vibrator needle closes fully without any air being trapped. This is something which we need to observe, we need to see that ok, if we immerse the needle vibrator in a mass of concrete and then withdraw it.

We obviously do not want this kind of a hole to be left here, what should happen is that as this needle is being gradually withdrawn the concrete from the neighbourhood should fall back into this hole and compact this concrete. And this tendency again would depend on the kind of consistency of the concrete and the rate at which the poker is being withdrawn.

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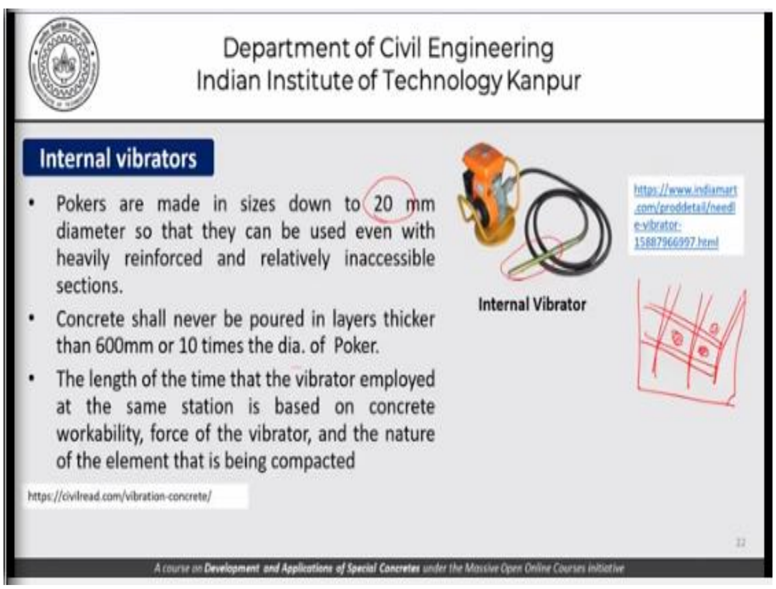

Pokers are made in sizes down to 20 mm diameter, so that they can be used even with heavily reinforced and relatively inaccessible sections. So, obviously this poker needle is expected to go between the reinforcing parts. So, if you have a reinforced concrete section with a lot of reinforcement all over the place. Then we would expect that this poker needle is able to be placed through these gaps between the reinforcement.

And that is why we cannot have a very large diameter for these poker needles. I am leaving it to you to just do some homework and see what are the kinds of diameter needles that are available. 20 millimeters is not necessarily the only diameter, there are other diameters available and pokers with different diameter needles are useful in different types of construction. One of the things that I can discuss with you is that if the concrete is such that it is sparsely reinforced.

That is there is hardly reinforcement then we can use larger diameter needles. Larger diameter needles will have a different configuration and a different paradigm as far as the power involved is concerned. When it comes to smaller needles there is a different paradigm when it comes to the power, the rpm and the effectiveness is concerned. Concrete shall never be poured in layers thicker than 600 mm or 10 times the damage of the poker.

The length of time that the vibrator is employed at the same station is based on the concrete workability, the force or power of the vibrator and the nature of element that is being compacted. So, these are some of the things which are fairly obvious and are being stated just to draw your attention. And put it on record that yes, these are the kind of things that one must keep in mind when determining or deciding about the type of vibrator, the nature of the vibrator or it is characteristics and finally of course the time of vibration.

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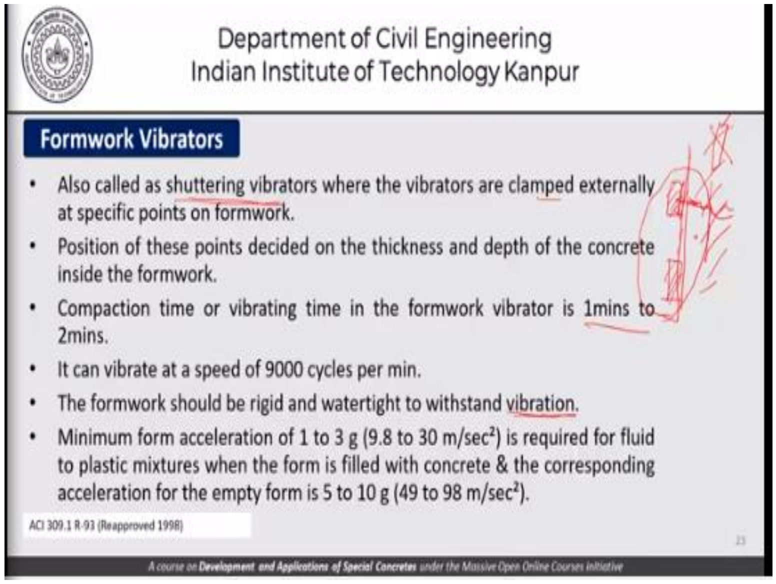

When it comes to form vibrators which is the slightly different form of vibrators. These are shuttering vibrators, that is we do not vibrate the concrete directly but rather vibrate the shuttering. So, what we are basically saying is that if this is my shuttering plate which we have put concrete is there on one side. So, instead of putting a poker vibrator or an internal vibrator here, we will not do that.

Instead, we will stick or we will apply or fix a vibrator on the shuttering plate and vibrate this. And this vibration here transmitted into the concrete will result in consolidation of this concrete. Of course, it is not only one vibrator here that needs to be fixed, we need to fix a series of these shuttering vibrators or plate vibrators or formwork vibrators as we can call them. So, these shuttering vibrators or formwork vibrators are clamped externally at specific points on the formwork to carry out the consolidation process of the concrete within.

The position of these points is decided based on the thickness and depth of concrete inside the formwork apart from of course the characteristics of that concrete in terms of consistency of workability. Compaction time or vibrating time in the formwork vibrator is 1 minute, 2 minutes, again this has to be taken with a pinch of salt, that it is not etched in stone that this should be the time for which the form vibrator should be switched on.

This can vibrate at speeds up to about 9000 cycles per minute. The formwork of course needs to be rigid and watertight to withstand the vibration. One of the things that we must specifically keep in mind is that when we are using form vibrators, the form or the shuttering work needs to be a lot stronger. Then we sometimes may have the kind of materials that we use in the shuttering plates should be such that they should not give way when forced when subjected to form vibrators.

The minimum form acceleration is 1 to 3g and that is required for fluid to plastic mixtures when the form is filled with concrete. And the corresponding acceleration for the empty form is 5 to 10g obviously the kind of forces of the kind of deformations, accelerations that this form will experience will depend on whether it is full or empty, whether there is concrete on this side or not. So, depending on what the kind of condition is the kind of acceleration that is generated in using form vibrators could vary for anything between 1 to 10g?

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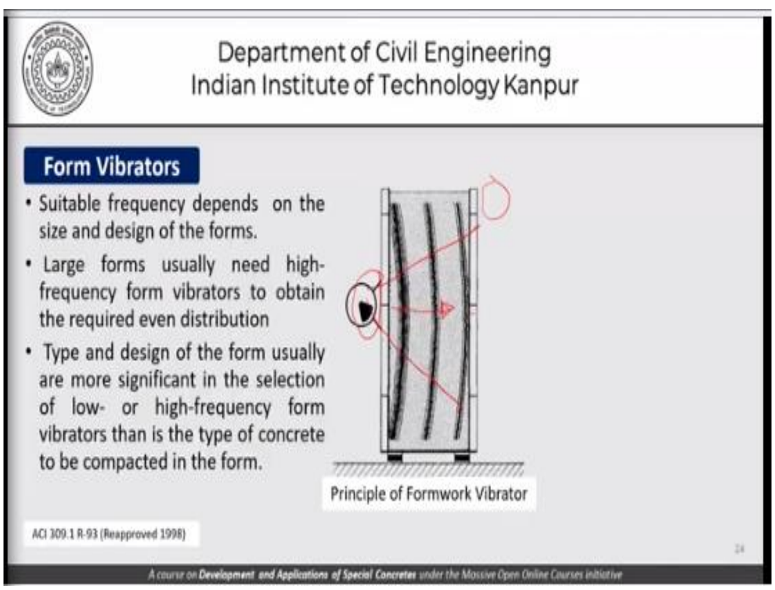

This here shows you a little bit of a principle of how the form vibrators work. Suitable frequency depends on the size and design of the formwork. So, this vibrator here causes these kinds of waves to be generated and progress through the concrete. Of course, what is shown here is the form vibrator being applied only on one end, but if this was a large system there would be form vibrators on both ends.

Appropriately spaced, they do not necessarily have to be facing each other they can be applied at a configuration like this. And the concrete could be vibrated from all over the place to make it finally a homogeneous mass. Large forms usually need high frequency form vibrators to obtain the required even distribution. The type and design of form usually are more significant in the selection of low or high frequency form vibrators than is the type of concrete to be compacted in the form.

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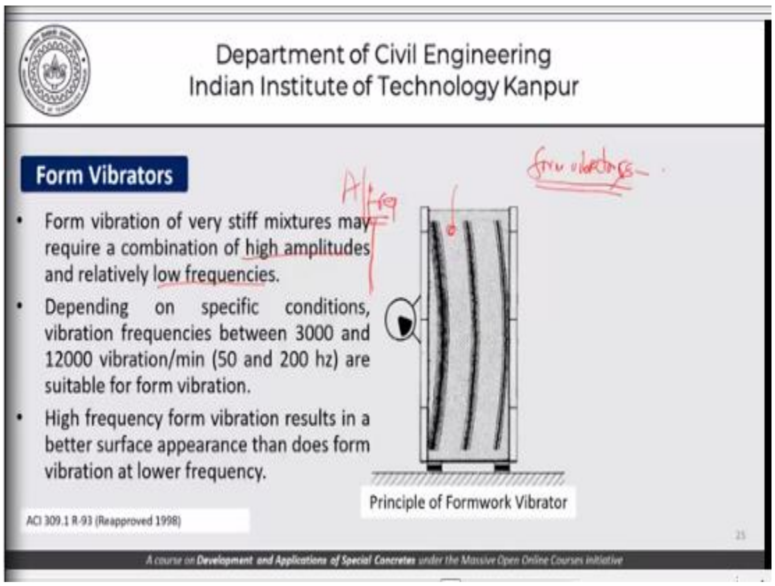

Form vibration of very stiff mixtures may require a combination of high amplitude and relatively low frequencies. So, this is what we were talking about that finally vibration is characterized by the amplitude and the frequency. And depending upon what kind of mixture here is being compacted or is to be compacted, we need to have the right kind of combinations of amplitude and frequency.

I would like you to search for literature and determine for yourself whether the form vibrators that are available in the market have a fixed amplitude and frequency or the amplitude and frequency can be varied by simply changing a switch on the vibrator. Depending on specific conditions vibration frequencies between 3000 and 12000 vibrations per minute which is about 50 to 200 hertz are suitable for form vibration. High frequency form vibration results in a better surface appearance than low frequency vibrations.

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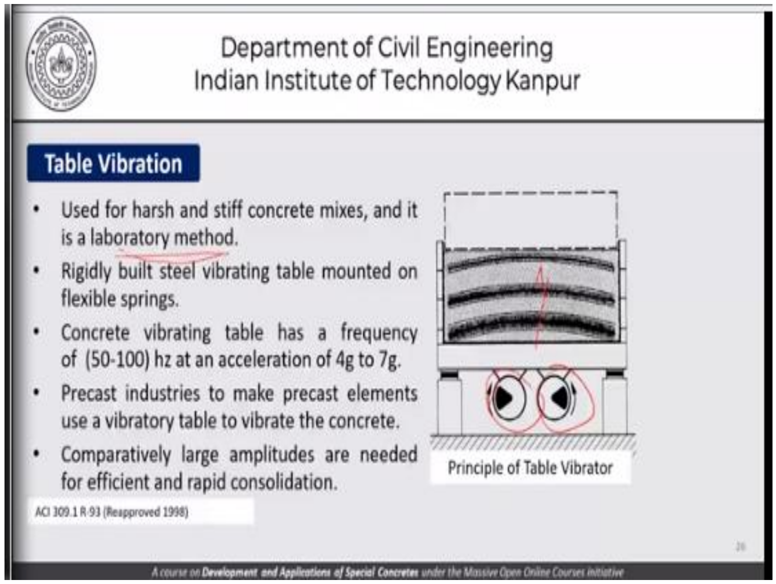

Then we come to table vibrations. Now these table vibrations are used for harsh and very stiff mixes again in the laboratories. Those of us who have worked in the laboratories would know that mortar cubes, concrete cubes at times are all placed on a vibrating table and consolidated by switching the table on for a certain amount of time. So, this picture here illustrates the principle of a table vibrator, we have the motors here operating in opposite directions.

Transmitting to the concrete certain amount of waves propagating through it, resulting in a consolidation of the mix. Rigidly built steel vibrating tables mounted on flexible springs, so that is basically what a table vibrator is. And concrete vibrating table has a frequency of about 10 to 100 hertz and an acceleration of about 4 to 7g. Precast industries to make precast elements use vibratory tables to vibrate the concrete.

And comparatively large amplitudes are needed for efficient and rapid consolidation. So, these are the kind of characteristics that one must keep in mind when talking about table vibration.

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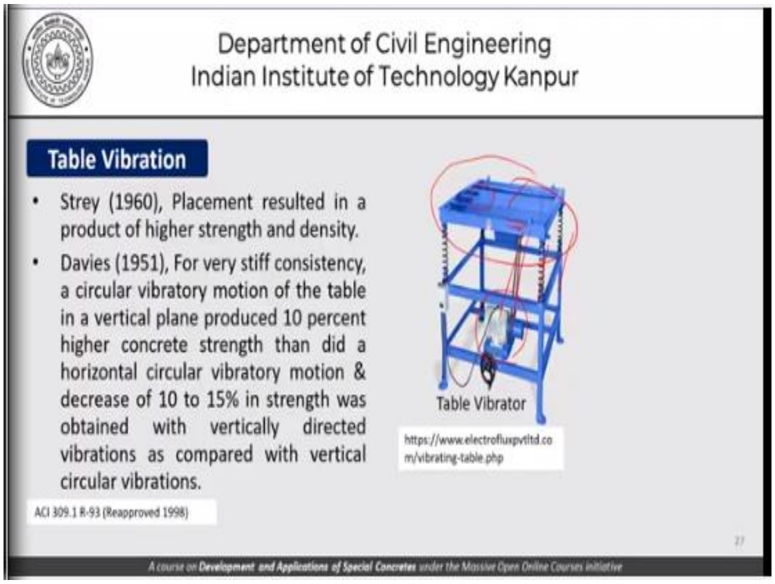

This picture here is more by way of history that in 1951 and 1960 when basically a lot of work was being done as far as the laboratories are concerned to determine the right kind of combination that is required for a table vibrator. It was found that for very stiff consistency, a circular vibratory motion of the table in a vertical plane produced 10% higher strength of concrete than did a horizontal circular vibratory motion. And decrease of 10 to 15% strength was observed with vertically directed vibrations as compared to vertical circular vibrations.

So, you can imagine that what we are talking about here is a table here with springs here, and we are trying to vibrate this table using a motor, the weight is fixed to the table. We can try to have the motor in different configurations, have different stiffnesses here and finally come up with the design which will help us optimally vibrate and consolidate the concrete samples placed on the table. It can be one sample; it could be a set of samples whatever we have. Then we come to surface vibrators.

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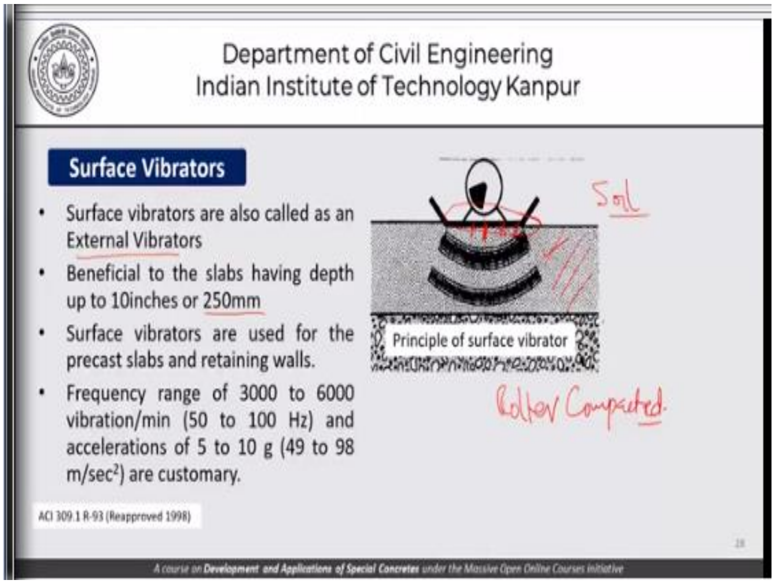

Surface vibrators are also some kinds of external vibrators. And the principle of the surface vibrator is that we have a flat surface here on top of this material to be consolidated, and we vibrate this, leading to a consolidation of this mass. Beneficial for slabs having a depth of up to about 250 mm, surface vibrators are also used for precast slabs and retaining walls. Frequencies range from 3000 to 6000 vibrations per minute which is about say 50 to 100 hertz and accelerations of 5 to 10g.

We often use these kind of surface vibrators in our studies of soil compaction. But of course, nothing stops us and in fact there are applications of this surface vibration in the domain of concrete engineering as well. In fact, roller compacted concrete is an illustration of surface vibrator concretes where the concrete surface is vibrated using a vibratory roller.

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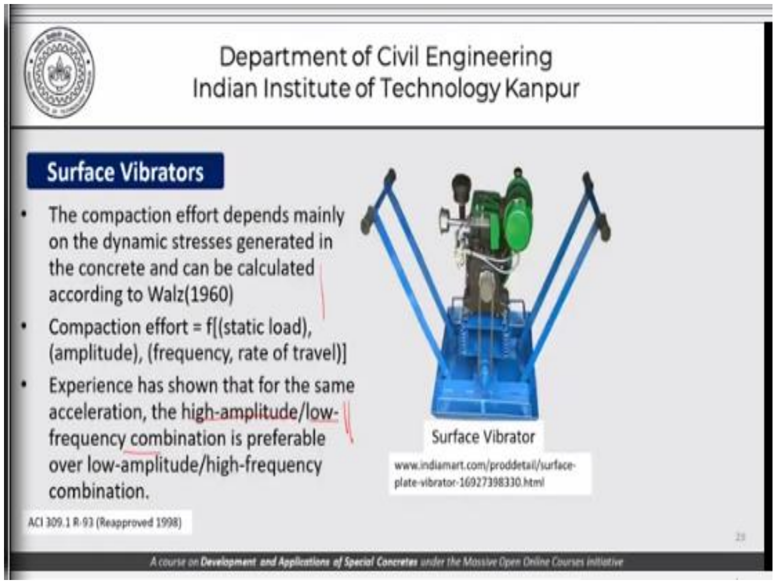

Continuing with our discussion with surface vibrators, the compaction effort depends mainly on the dynamic stresses generated in the concrete. And the calculation can be carried out by procedures which have been determined or figured out about 50, 60 years ago. And the compaction effort is a function of the static load, the amplitude, the frequency and the rate of travel.

So, these are some of the factors that determine the compaction effort that is required. Experience has shown that for the same acceleration, the high amplitude low frequency combination is preferred to a low amplitude high frequency combination. So, what we would like to have is a high amplitude and low frequency combination that is the general choice over a low amplitude high frequency combination for generating the same amount of compaction effort.

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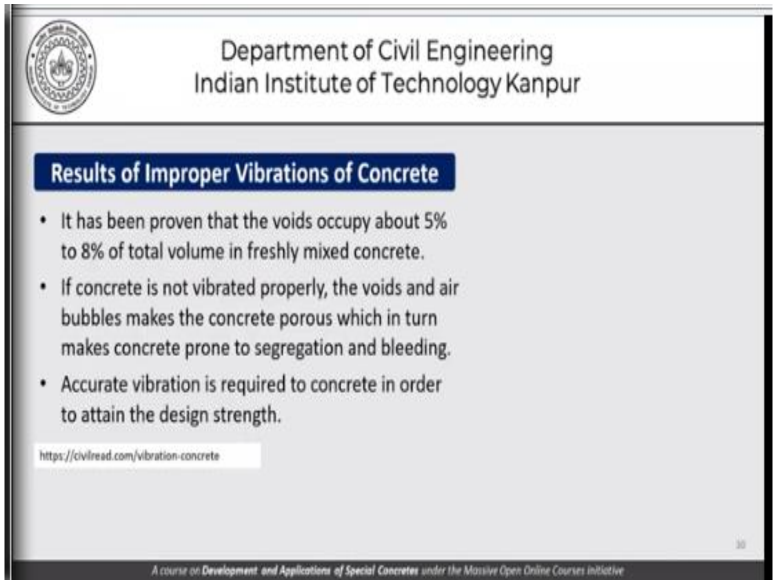

Now before we close, we should discuss a little bit about the results of improper vibrations in concrete, it has been proven. That the voids occupy about 5 to 8% of the total volume in freshly mixed concrete. If concrete is not vibrated properly the voids and air bubbles make the concrete porous which in turn makes the concrete prone to segregation and bleeding. And of course, has a detrimental effect finally on the durability itself. Accurate vibration is required for the concrete to in order to achieve the design strength.

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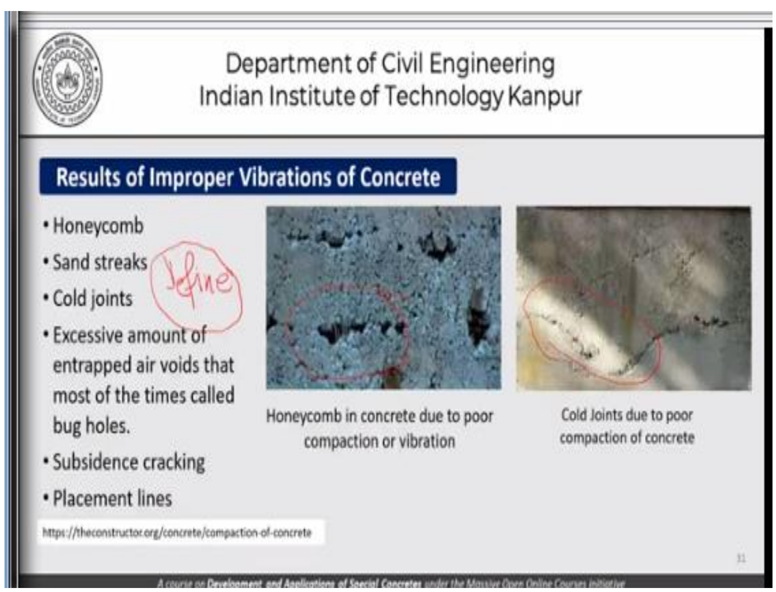

And here are pictures of honeycombing, a cold joint due to poor compaction of concrete. So, we do not want this kind of a picture to emerge after the formwork is removed. Or for that matter this kind of a picture where the cold joints are very clearly seen. We could have honeycombs, if we do not have proper vibrations, we could have sand streaks, cold joints, excessive amount of entrapped air voids that are mostly called bug holes, subsidence cracking and placement lines.

So, these are some of the technical terms which are used and I am leaving it to you to read the literature or search the internet. And educate yourself about the actual definition of some of these technical terms in the context of vibration and improper vibration and the quality of surface concrete that we are talking about. With this we come to an end of our discussion today, where we covered the physics of the vibration process and we talked about the different methods that are available to us.

Primarily we concentrated on the methods that are used in the laboratories or in the field with needle vibrators, form vibrators and surface vibrators.

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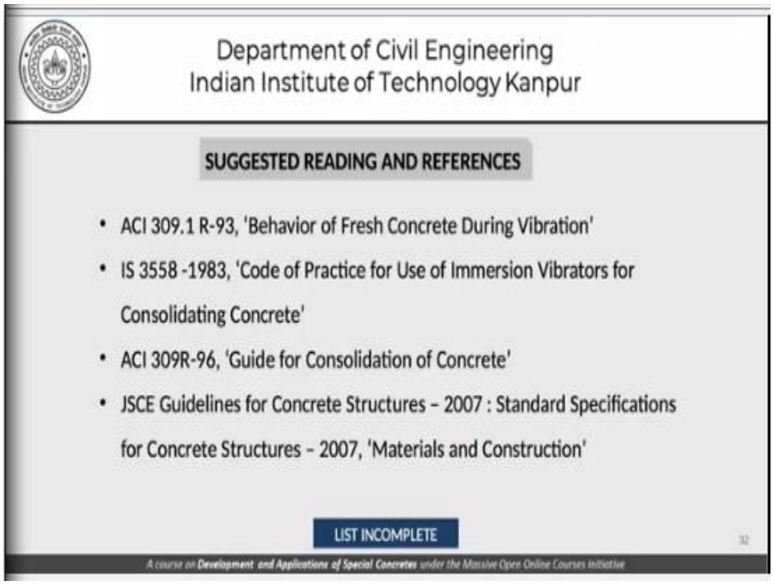

So, the list of suggested reading and references is of course incomplete, and you are expected to learn as much as you can from different sources. In order that you understand this whole idea of compaction of concrete mixes or consolidation of concrete mixes better.

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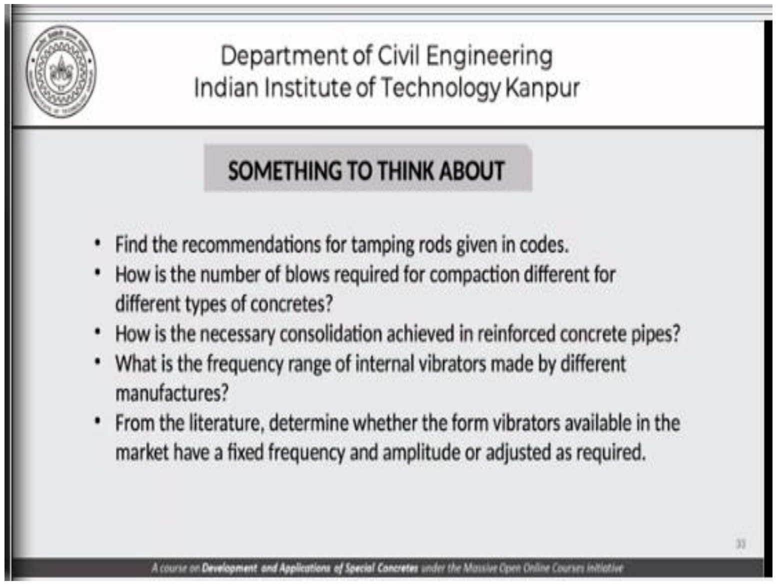

These are some of the things that you need to think about which will probably guide you in the right direction as far as searching the literature is concerned. And with this once again I would like to thank you for your kind attention in this discussion. And we will continue in the next class on some of the other issues that we must finish before we close the course as such, thank you once again.