Concrete Technology
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Lecture - 22
Compaction and Curing Concrete

Welcome to module five, lecture four. So far we have looked into issues of fresh concrete and of course the production process, and in the last lecture of this module we will look at the two important aspect of handling fresh concrete mainly compaction and curing of concrete.

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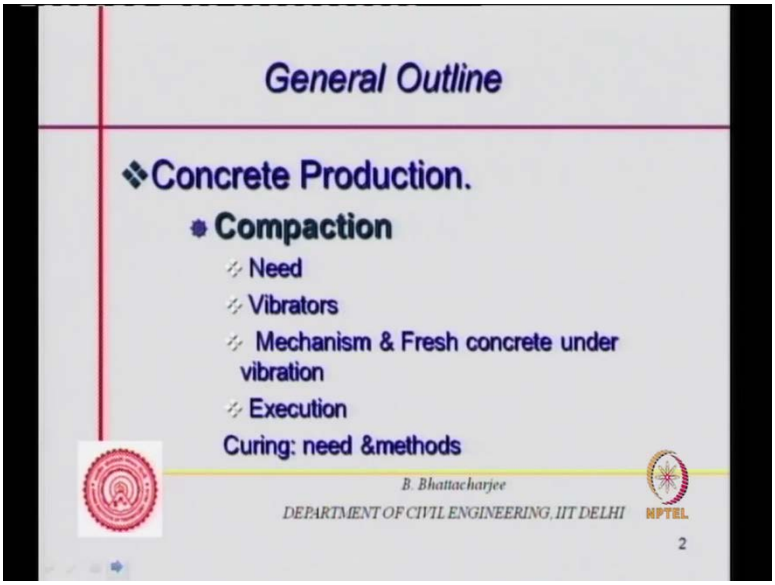

So, first we would talk about compaction, why do you need it all, then generally we use it vibrators, so something about the vibrators themselves, then mechanism and fresh concrete under vibration a little bit, because you have discussed quite a bit of it elsewhere earlier. And then we will talk about execution of vibration again abruptly, and lastly we will talk about curing need and methods.

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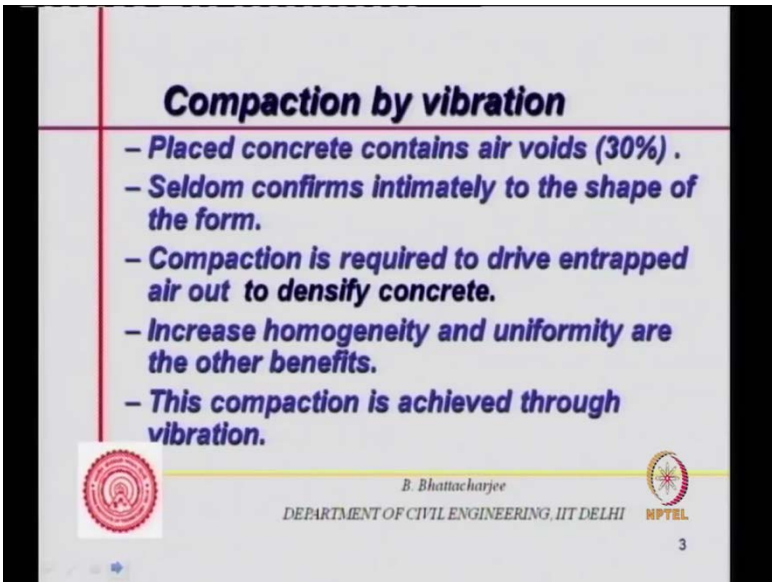

So, let us talk about compaction and that you usually do by vibration. Now I mentioned this earlier that place concrete contains air voids up to 30 percent, you know if it is of course dry concrete. We are not talking about very highly flowing concrete or self-compacting concrete, and also we said that it seldom confirms to the shape of the form. So, therefore compaction is required to drive the entrapped air out to densify the concrete and also to increase homogeneity and uniformity; you know this has the other benefits but largely to entrapped air has to be driven out and concrete must be densified. So, that is why we need vibration. This compaction is achieved of course by vibration that is what to be mentioned earlier.

Now concrete vibration, well energy for compaction is supplied through oscillatory motion of vibration which is nearly simple harmonic motion. We can measure the frequency of such vibration in air but it is difficult to measure within concrete though it is more relevant if we can measure the amplitude of this vibration. So, energy of compaction is supplied through vibration oscillatory motion of vibration, and it is generated by means of rotating extrinsic having a frequency and amplitude of vibration.

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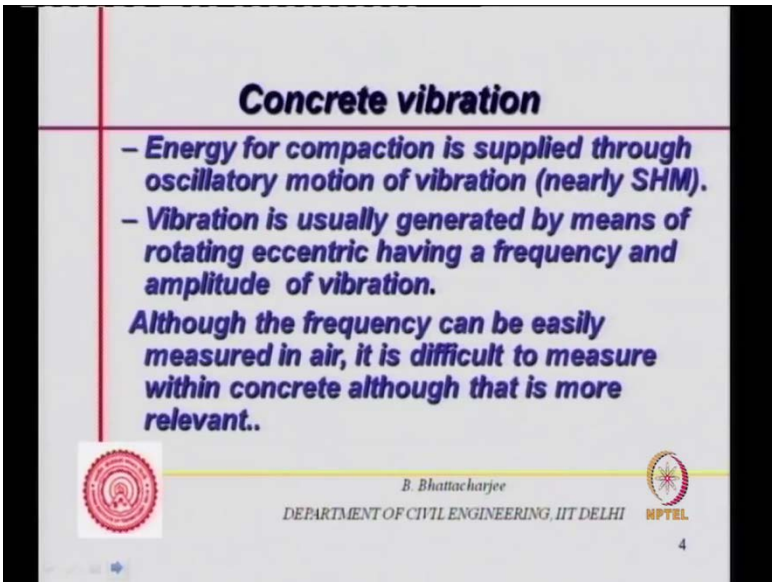

So, it is essentially all types of vibrator actually in some kind you know it is basically moving extrinsic having frequency and amplitude generates the vibration, and this oscillatory motion which is generated which is simple harmonic motion causes air to divot; we will look into the mechanism of course. We can determine the frequency of the vibrating machine or whichever I use the equipment in air but within concrete is difficult because effect of the damping and other things, the interaction of the vibrator you know vibrator component which is you know vibrating component with the concrete is difficult to measure the frequency there.

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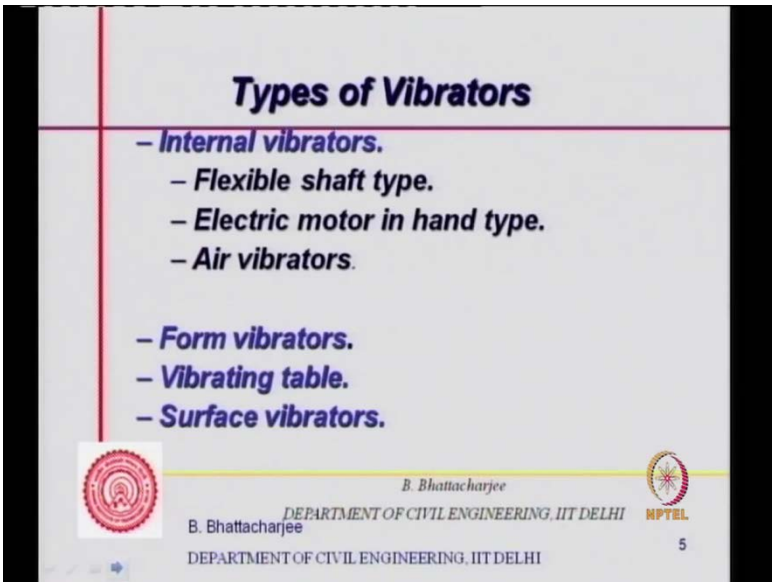

Now we have generally two types of vibrators classification internal vibrator and obviously external vibrator, but internal vibrator themselves are again classified into three types. We will not discuss all of them because it is not on machines but most commonly used one of the internal vibrator is the flexible shaft type, right, flexible shaft type. Other one is of course the vibrating machine but the mortar is handheld and from there power is transmitted straight away to the vibrating component. Then there are air vibrators which can also be internal vibrators, but the most common type is a flexible shaft type.

Once in a while you might see an electric mortar in hand and it is the rotating part or the eccentric which actually provides vibration; it is just connected to the mortar. The external vibrator is form vibrator which vibrates the form and also I can have a vibrating table generally used in laboratory or in p-cast you know for p-cast elements. You have a table which can vibrate and you put your molt and the concrete and therefore the vibration takes place there. Form vibrators are relatively more common but most common of course are the internal vibrator flexible shaft type. So, let us see what they are. There are some surface vibrators used for floors vibrating screeds, etcetera, etcetera which you know floor vibrating for floor or flex surfaces lab etcetera, etcetera.

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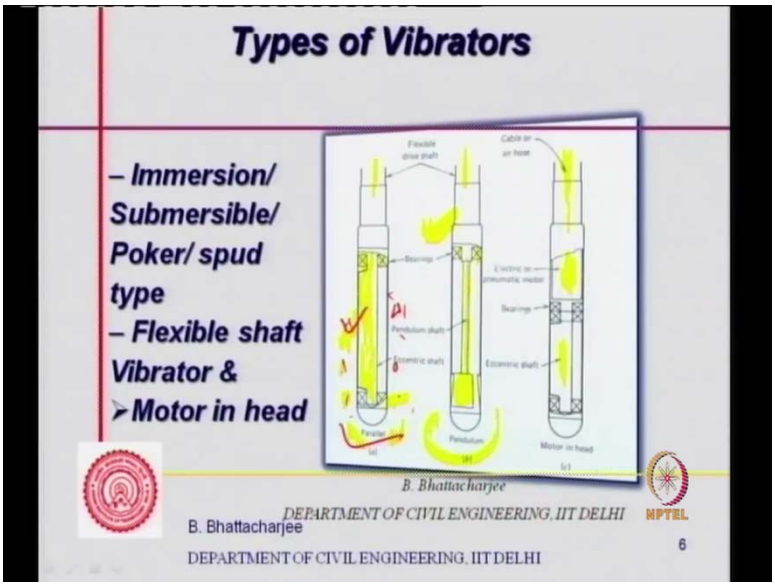

Immersion or most common is the immersion type of vibrators which are called immersion vibrator or submersible poker or spud type. They have flexible shaft and other

one is mortar in head type; let us see quickly how do they look. This is three types which can be there; for example, you can have a bearing hear flexible dry shaft which is normally a spring which can rotate actually. A shaft is itself a spring which will be rotating connected to a mortar and then there are the bearings, and this is the eccentric mass. So, this is the eccentric mass, mass of the eccentric shaft, there is a bearing hem bearing hem, and this rotates eccentrically.

This rotates eccentrically causing oscillatory motion circular oscillatory motion and a concrete in the surrounding will be actually subject to this oscillatory motion of the vibrator which actually pushes the concrete somewhat and then again it is released. So, there is a kind of compression of the concrete, and then there is the kind of rarefaction, because this will be moving in simple harmonic motion. So, this is one type. The second type is pendulum type where the mass is here. The flexible shaft is here which is actually as I said is spring; it is connected to the bearing, but there is a rod. There is again pendulum shaft. Now this pendulum shaft is connected into the mass eccentric mass and this eccentric mass again causes oscillatory motion, you know this rotates and causes oscillatory motion of the vibrating needle that is there. So, these are also called poker vibrator, needle vibrator.

They have all flexible shaft and here the mortar is here, electric or pneumatic mortar is straight away here. So, mortar is here, it is cable or holes simply, it is cable or holes even if it is pneumatic, then there will be air holes. So, air will compress air will come through this and here air will come compress, it will get compressed here, eccentric is also similar. These are not very common, this is very common type, very common is this kind, this type and even this may be quite useful. So, this is how they work. So, this is how they work actually the needle vibrator as we call it.

So, this component of the equipment, this component of the equipment, actually this component of the equipment goes inside the concrete and causes oscillatory motion around in the concrete around which will be compressed and rarified and so on so forth readily going out on longitudinal waves as well as it might be generating other kind of waves also but largely it will be generating longitudinal waves and may be some transverse waves too but causes actually you know kind of oscillatory motion stress around over a circular radius you know for a circular area having a radius of influence.

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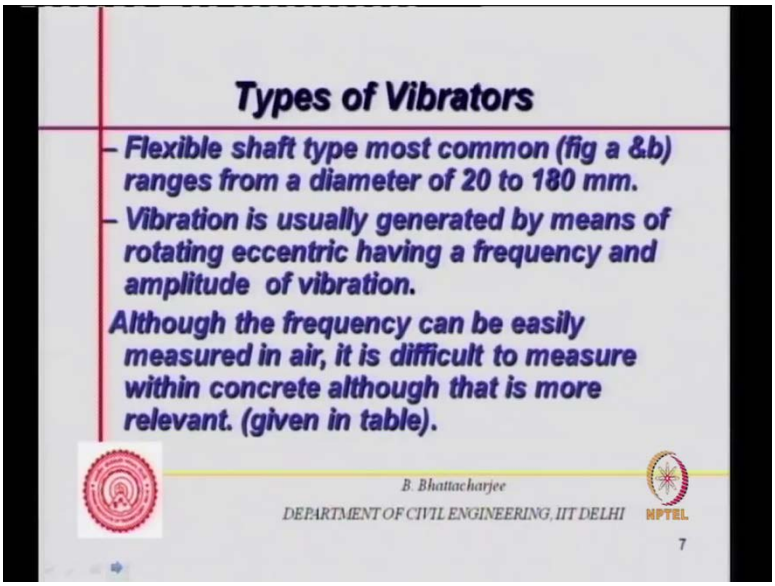

So what do you do? You shift from one place to the other and then you know it goes on vibrating the concrete as there. This is flexible shaft type is the most common, and its diameter can range from 20 millimeter to about 180 millimeter. So, usually vibration is generated by means by rotating eccentric as we said having frequency and amplitude of vibration and basically frequency is etcetera it is available, data is available.

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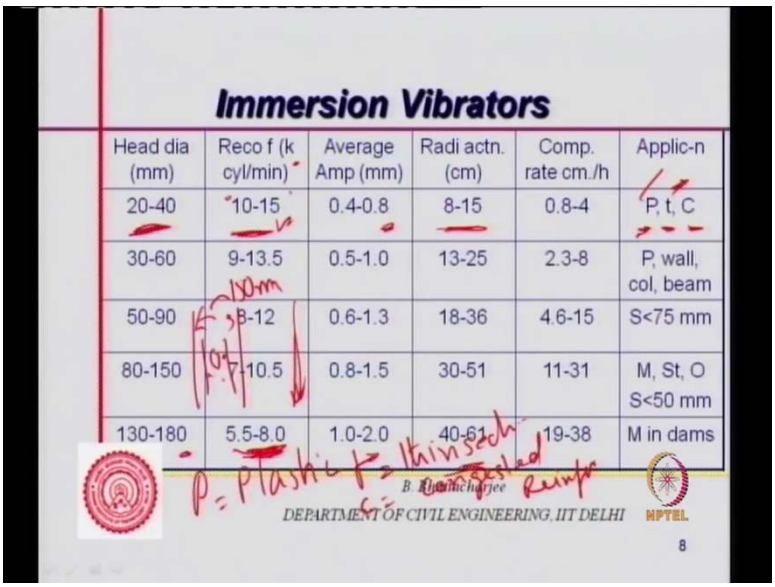

So, dimensions are from 20 to 180. Now you can look at this head dia of this needle 20 to 40 mm where you will be using this plastic concrete thin section, right. This you will

be using in a plastic concrete p stands for plastic, t stands for thin section and congested reinforcement. So, here c stands for, p stands for plastic, t stents for thin section and c stands for congested reinforcement. So, it is thin head dia 20 to 40 mm, 20 mm is used in thin section. For example, let us say web of a box section some web thin box you know thin web about, say, 100 or 150 mm, 100 mm, 100 mm or 150 mm thick web and you have lot of reinforcement here, plastic thin section cable is passing through, so it is a thin section.

Now concrete has to be plastic because if it is a dry concrete you may not be using this. Now recommended frequency of course in kilo cycles is given as 10 to be recommended frequency in kilo cycles per minute it is given in that means ten to fifteen thousand kilo cycles per minute is the recommended frequency and you can see as the diameter increases this diameter increase frequency reduces. So, this has high frequency, this has lower frequency, alright. Average amplitude is low here, average amplitude is higher, so average amplitude is high, frequency will be low, average amplitude is low, frequency is generally higher. So, radius of fraction is 8 to 15 centimeter in this one radius of fraction is much more.

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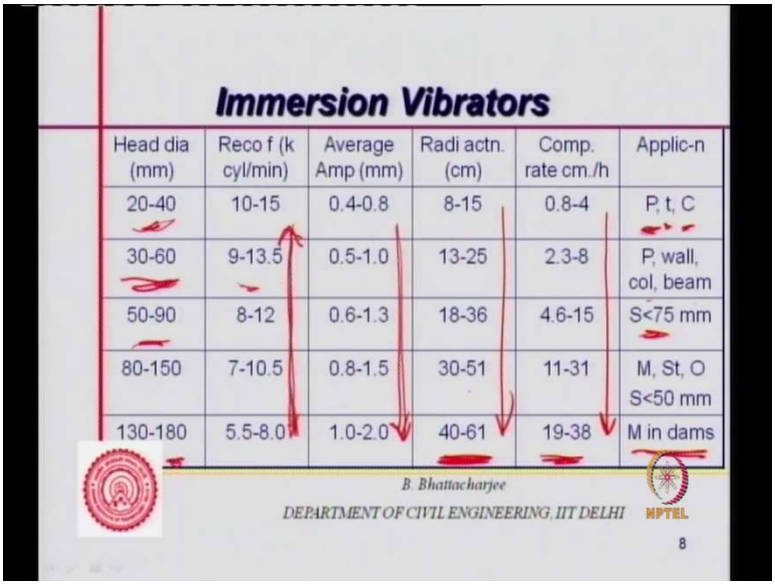

So, where you want to use where you have thin section plastic concrete congested reinforcement you might use this while this might be used in mass concrete. You can see its radius of operation is quite high and compaction rate is also fairly high. So, where you

have large mass concrete of course you want to vibrate it, then you might use massive section you want to use this there, mass m stands for massive concrete. So, mass concrete in dams you will use; in between if you see 30 to 60 very common is about 66 mm somewhere around this; this is very common. Slump less than 75 mm it suitable for that kind of concrete relatively stiff not very stiff, this is absolutely plastic you know may be 100 mm slump or less than it is just below pump able concrete let us say. Pump able concrete is quite flowing but pump able concrete self if you are compacting then it should be you can use this also, but in thin section larger section of course you can use this one.

So, plastic concrete wall column beam you can use 30 to 60 and this range as you see it reduces here 10 to 15, 9 to 13.5 and so on so forth and average amplitude increases along this direction, this becomes lower, this increases along this direction, this increases along this direction, radius of action increases along this direction. So, this increase along this direction and compaction rate also increase along this direction. So, 80 to 150 you will be using actually mass concrete, slump less than 50 mm, slump less than 50 mm and this could be on you know basically relatively dryer concrete one use this. So, that is how one chooses the needle vibrator.

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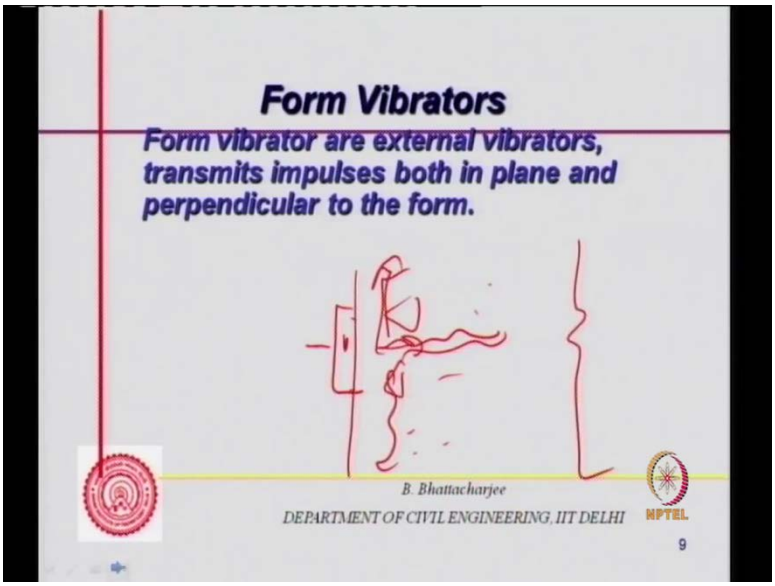

Form vibrator are external vibrator, transmits impulses both in plane and perpendicular to the form. So, what do you do in this case? You have the concrete here, you know this

is the concrete side of it; you put the form vibrator here, right, and it is fixed. So, it is fixed here form vibrator here. So, as it vibrates it transmits vibrator wave both in this direction as well as this direction both in this direction and causes vibration. So, again it will be rotating eccentric. So, it causes from to vibrate, right. So, both, in plane and perpendicular to from it actually transmits the vibration; I deliberately did not want to put in a figure because then I will be going too much into the equipment part of it.

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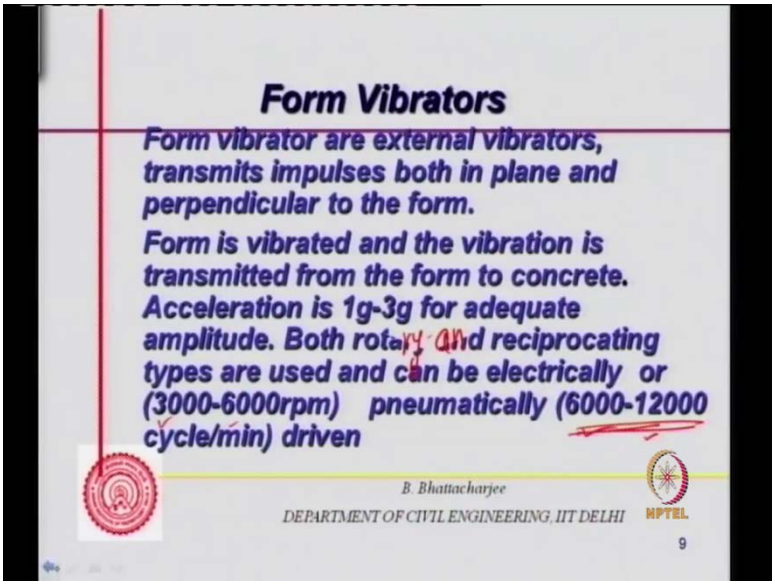

Now form is vibrated and vibration is transmitted from the form to concrete. Its acceleration generally ranges from 1g-3g for adequate amplitude both rotary and reciprocating types are used and can be electrically or pneumatically prepared. So, basically you can have both you know rotary type and reciprocating types and can be electrically or you know pneumatically operated and you can see the rpm. So, this rpm if you can see the rpm kilo cycles per minute it is 6 to 12 kilo cycle there is a 3 to 6 kilo cycles per minute you know. So, if you look at the earlier one earlier cases, so this is relatively large on the higher sit on the larger needles use you know the frequencies can go back to the previous one.

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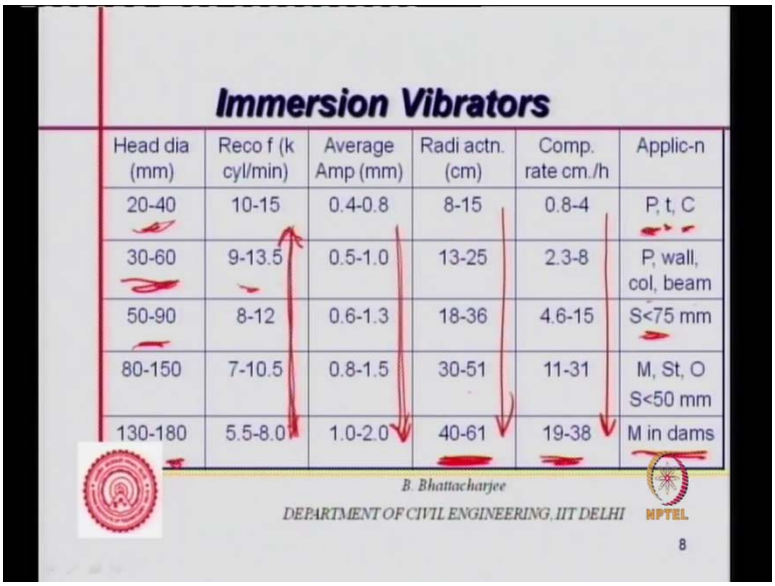

So, you can see that if you remember this is go back to this 10 to 15 the smaller one was using thinner ones were using higher high frequency. So, this is somewhere in between, right. So, that is what it is. So, this is from vibrators.

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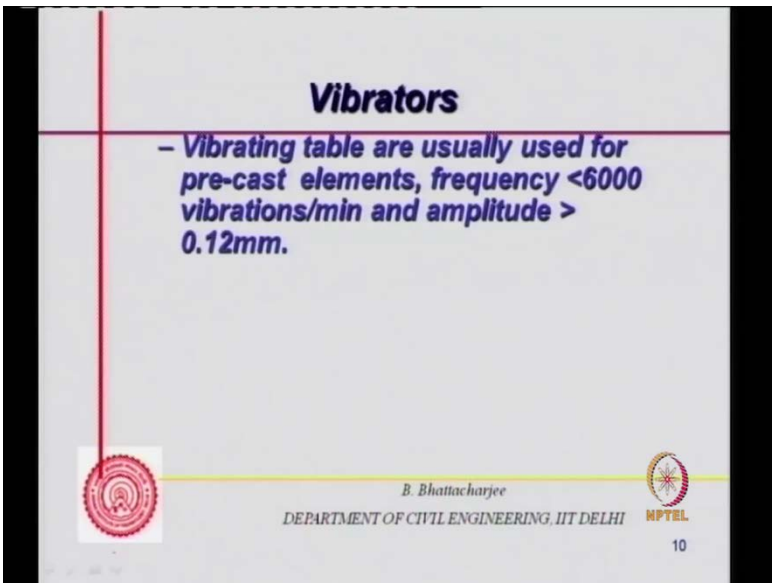

Quite often we use them in thin sections; we use them in thin sections where we cannot use really a poker vibrator or needle vibrator you know the first ones where we cannot use them then we can use this or when we are using them together with this, this is used. So, vibrator form vibrators are used in thin section. It is not the best thing; form vibrators

are definitely not the best of the kind of vibrators because some of the energy will be lost in vibrating the form itself. So, that is not the best one. Needle vibrator obviously does a much better job because it is an internal vibrator and coincides and compact the concrete. Certainly the vibration will be limited up to certain depth form module.

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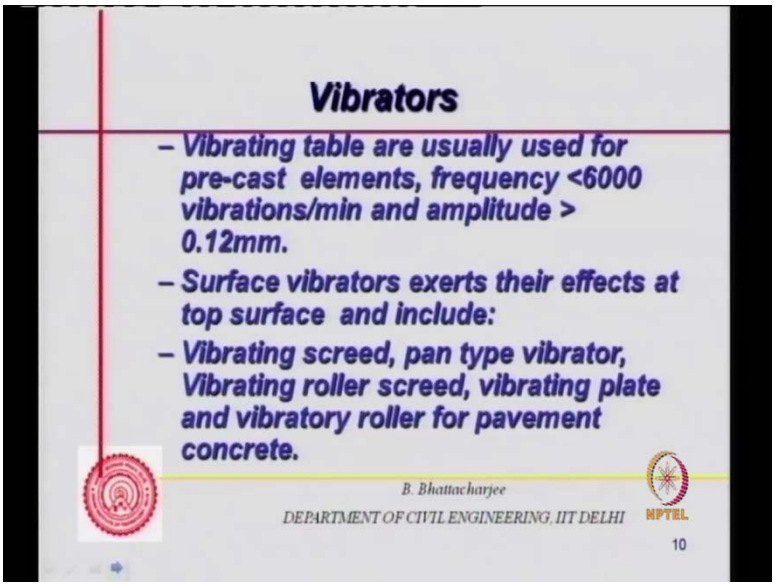

The other kind of vibrator that is table vibrator vibrating table are usually used for pre-cast element or for laboratories frequency is less than 6000 rpm vibrations per minute and amplitude is less than 0.12 millimeter. So, this pre-cast element can be used, for pre-cast elements one can be use this. Surface vibrators exert their effects at top surface and include of course the vibrating screed, pan type vibrator, vibrating roller screed, vibrating plate and vibratory roller for pavement concrete. So, they have their specific use or you know specific use this surface vibrator.

So, they have seen where we select the needle vibrator of one dimension, right. Now we can look into form vibrators, where do we select them? When it is impractical to use internal vibrators or it might be supplementing the internal vibrators. Vibrating screeds are used in thin slabs. High frequency and low amplitude vibration generally results in more efficient compaction. So, that is what is a thin. You know if the thinnest of the needle vibrator actually is most affective but its radius also low, so your effort in moving this could be relatively high. How does fresh concrete behave under vibration? Let us see.

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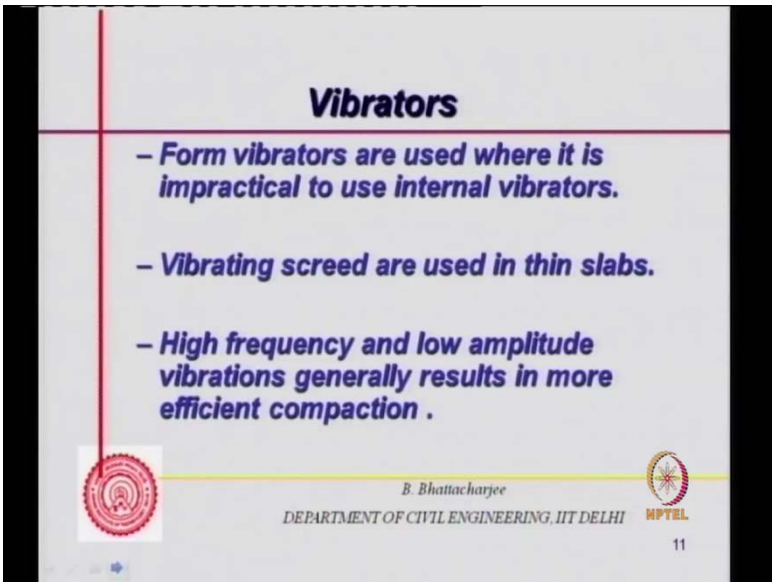

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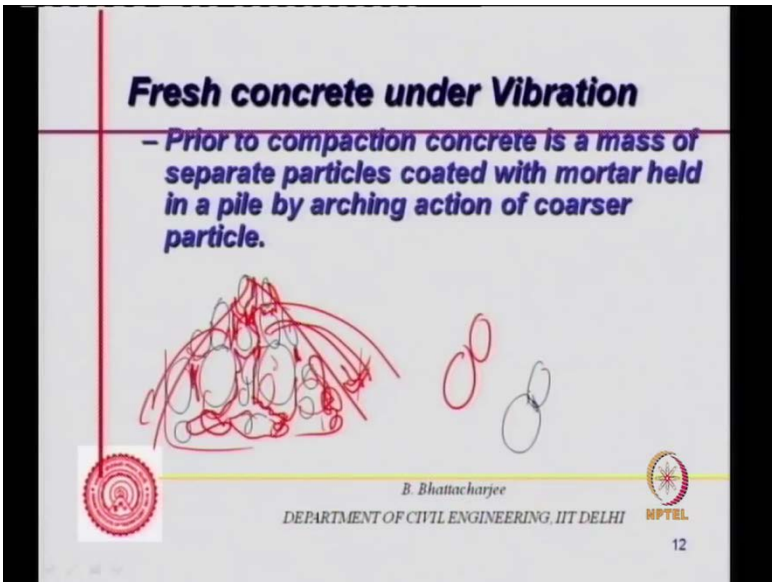

As we said prior to compaction concrete is a mass of separate particles coated with mortar held in a pile by arching action of coarser particles. You know if you can recall it will be something like if you can remember it will be something like particles of different sizes and shape hipped up together and you have actually mortars in between. You have mortar in between, so you have mortar in between. It is like a pile of a material with mortar in between. So, the red is the mortar, black is the aggregates, I have put it as spherical aggregates then it need not be so. So, the mortar should be somewhere there.

So, it remains like if you know it is like a hip, it is like a hip mortar held in a pile by arching action of the coarser particle.

So, then basically will be arching action one supports the other and one particle supports the other. Now as you know this actually should be it should be able to move, get the shape of the mode, so what you have to do? You have to see that these particles moves downward, these particles moves downward you know. So, you have to see that this particle has to downward. This particle has to move and get the shape of the modulation. So, arching action of this one they actually hold the particle because one particle is touching the other. So, by friction one particle is touching the other. So, by the friction they are just in position. So, actually the formed into gravity is restricted or obstructed by the friction between the particles. So, you have to overcome this friction and how do you overcome this friction. So, one has to overcome this friction and let us look at our next statement.

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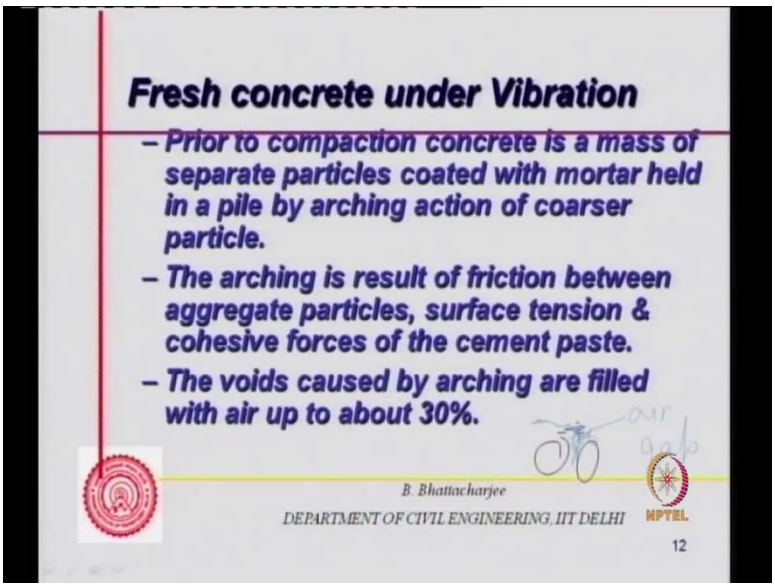

The arching is result of friction between aggregates particles, surface tension and cohesive forces of the cement paste; of course since the paste is in liquid or plastic state and it is in plastic state, therefore there is some surface tension and cohesive forces of the cement paste that will also held in position the particulate system itself in the hip. Now you got to overcome this. So, this arching actually results in a void of air of about 30 percent because you know these particles are something like this, and there is mortar as I

said but there will be air gap in between. So, there will be air gap, in between there will be some amount of an air gap; there will be some amount of air gap in between. So, this air gap is about 30 percent; air gap is about thirty percent. So, you will have air gap somewhere in between this particulate system, and this air gaps are air gap, and they would be about 30 percent, 30 percent air gap will exist and you have got to dry this air off. So, that is the idea; that is the idea of the vibration.

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So, what happens? Vibratory impulses actually liquefy the mortar portion of concrete and thus reduce the internal friction resulting in consolidation by force of gravity. Then once it is vibrated concrete you know vibrated completely the friction is reestablished and cohesion is restored and strength increases. Then how does it occur? So, vibratory impulse essentially causes the water or the water particle in the cementitious system of phase systems which can vibrate more which actually moves more than the solid particles and more they are constricted the max are you know it will exert more pressure, and this presser actually overcomes the friction resulting in a kind of collapse of the system.

So, the velocity of compression waves generated could be of the order of 45 meter per second in the beginning of vibration and increases to 240 meter per second at the end. So, essentially liquefaction of the mortar occurs; that is because the more water within the pole system would vibrate more or move more than the solid particles and cause an

excess presser in the system. And that reduces down the friction or overcomes the friction within the particulate system, and results in mobility or movement of the movement of the particle and also drives out the air.

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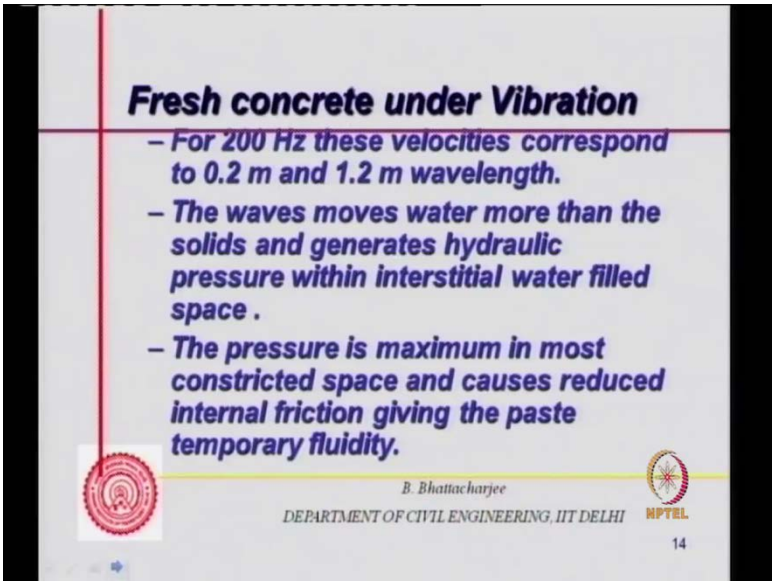

For 200 Hertz the velocity of this corresponds to about so wave length is of the order of around 0.2 meter to about 1.2 meter wavelength. That is of course the wave moves water more than the solids; that is what I was saying and generates hydraulic pressure within the interstitial water filled spaces. And this pressure is maximum in most constricted space and causes reduced internal friction giving the space temporary fluidity; that is what I was just saying. So, this water within the constricted space because of the movement it exerts pressure and that overcomes the friction and that is how the particles moves, right; that is how compound particles moves.

The process of liquefaction is this is we understood through let us say box shear test which is done in which is normally good in soil. Now these kinds of tests were also conducted in concrete long long back, and one would see something of this kind. See one would see something of this kind; for example, you have shear strain along this direction and shear stress along this direction. You have shear strain along this direction and shear stress along this direction.

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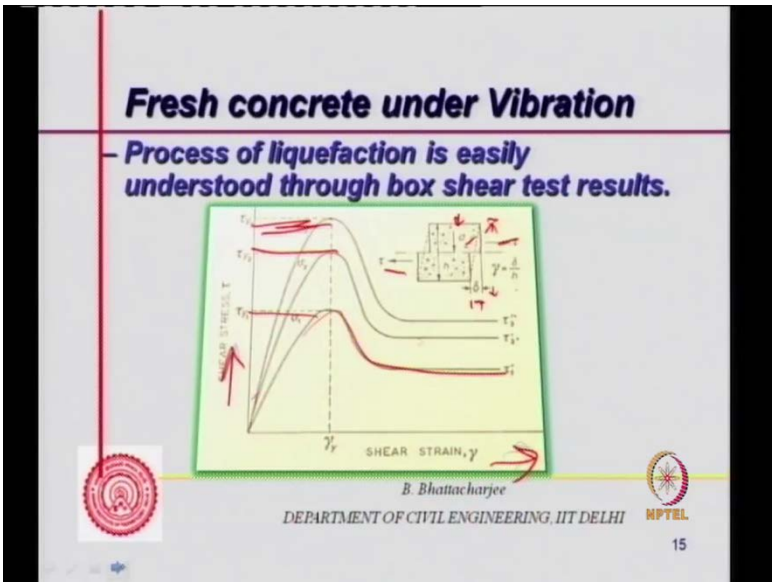

Now you are applying normal pressure sigma n, n tau is applied from this side and strain is measured delta divided by h, this is h and delta is this distance. So, if you measure the stress versus strain you will find this sort of curve and this depends upon sigma 1 sigma 2. So, as we have increased the yield shear stress actually increases. So, higher normal force yield shear stress actually increases higher normal force yield shear stress increases. So, concrete people have done approximate box shear test and this is the kind of behavior which normally one would see.

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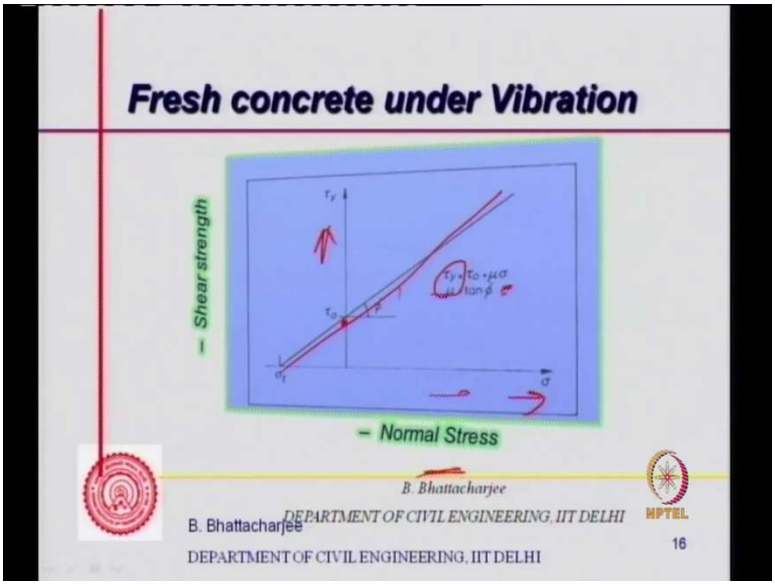

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And then like soil you can actually put shear stress versus normal stress card, and this is your normal stress, this is the sheer stress, and it can be related linearly like this. So therefore, tau yield shear stress is the function of tau zero at this point the intercept plus mu into sigma, since this is a function of mu into sigma. So, you see the yield shear stress is the function of yields, what is yield shear stress? That was this one that was shown here that was shown in the previous diagram.

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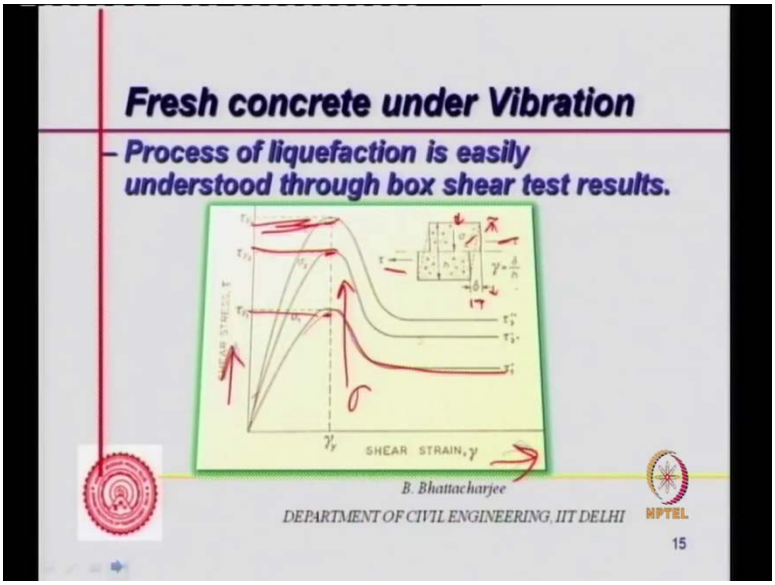

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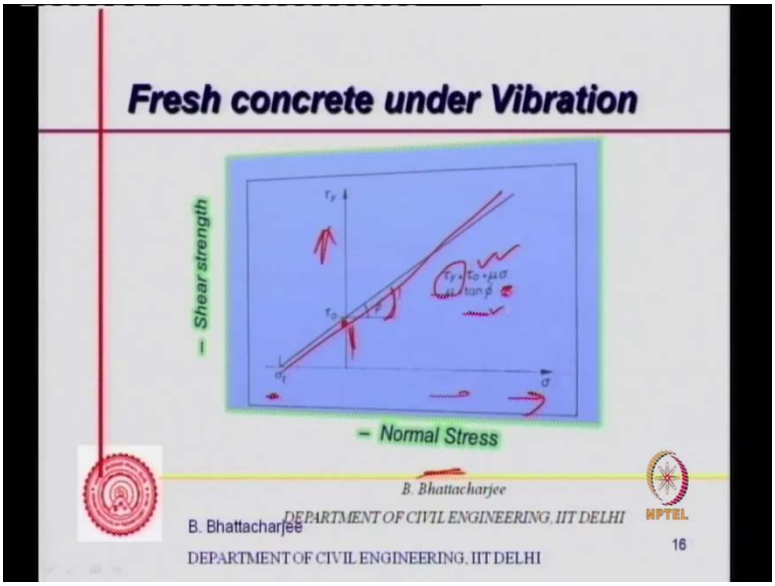

This is the yield shear stress. It increases with sigma. So, as sigma increases yield stress increases and one can linearly relate this simply linearly relate this. And this is tau zero at zero normal stress and of course you know this is the tensile strength of the whole thing normal tensile strength. So, mu is this slope and sigma is the normal stress. Now mu is equal to ten pi, pi is what is angle of reports. So, mu is equal to 10 pi and that is the angle of reports. This we know in soil this is what we see.

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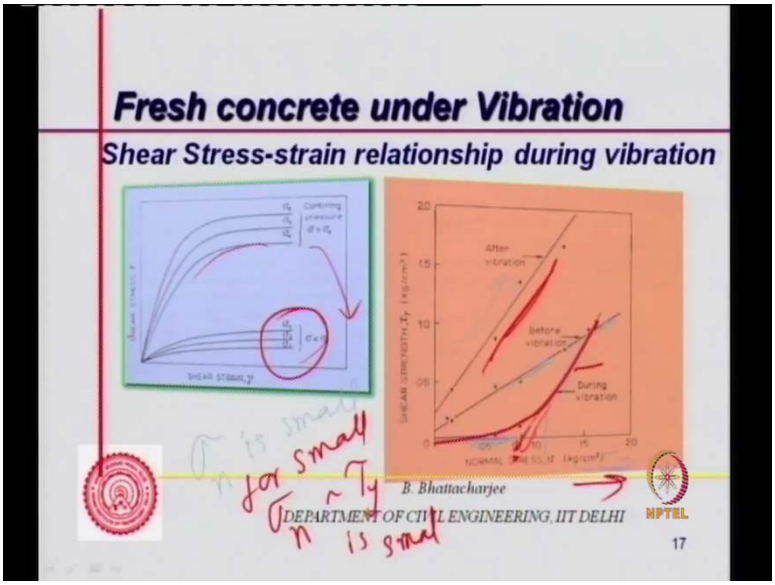

So, concrete drier concrete almost behave like soil and people have studied this and shear stress-strain relationship this was before vibration if one measures. But supposing I measure this during vibration what will happen is if I forget about the grouping portion the strain's opening portion both same sigma 1 sigma 2 sigma 3, stress-strain curve is something like this but when I vibrate stress strain curve goes like this. That is during vibration the stress the yield stress reduces significantly and you know the stress strain curve becomes something like this.

So, if I look it again this was the case prior to this is mu, this is my mu, and this is this is my mu, and this is you know tau y is equal to you know this, sorry this is the tau y is equals to tau zero mu sigma before vibration and during vibration what happens is before vibration; during vibration what happens is actually there is yield shear stress reduces significantly, right, yield shear stress reduces significantly and after certain period of

time you find that you know like yield shear stress actually reduces significantly tau reduces significantly depending upon of course sigma value.

So, my sigma this is my sigma after an increase in the sigma value you find that it behaves almost something not exactly parallel to this but in some value like this. So, when your sigma is applied sigma normal is small; it is small, yield shear stress is for small sigma n sigma n tau y is small during vibration, this is during vibration. So, during vibration it behaves like this, during vibration like this and up to certain sigma value up to certain sigma normal value practically there will be no yield shear stress. Now this is actually this sigma value corresponds to actually equivalent force of vibration.

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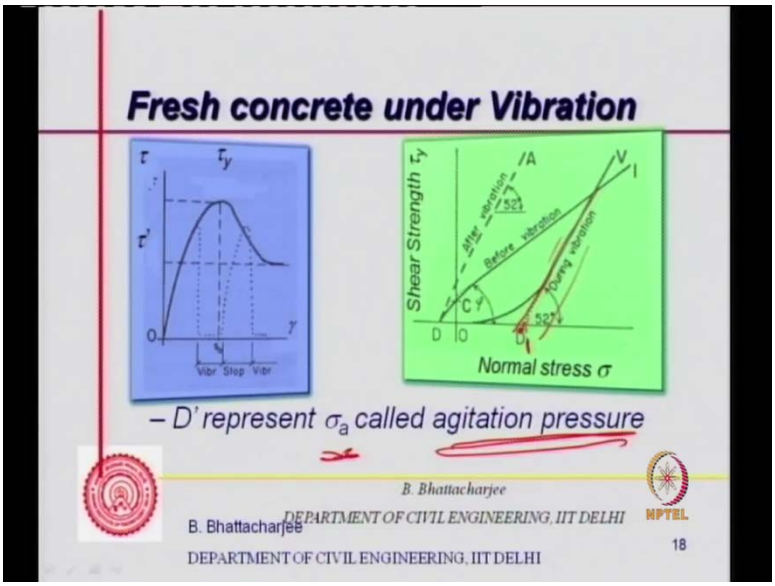

What you call is we call this as you know we define this as agitation pressure. So, the agitation pressure if the normal stress is less than the agitation pressure which is actually the slope if I extend this line this is during vibration. So, if I extend this line this is the normal stress that will correspond to agitation pressure. So, this is agitation pressure. So, during vibration it is like this, and we can go back to this diagram again earlier diagram again. So, this is agitation pressure here. So, if your normal stress is more than the agitation pressure then only you find that yield stress starts increasing. So, the result of vibration yield stress reduces significantly.

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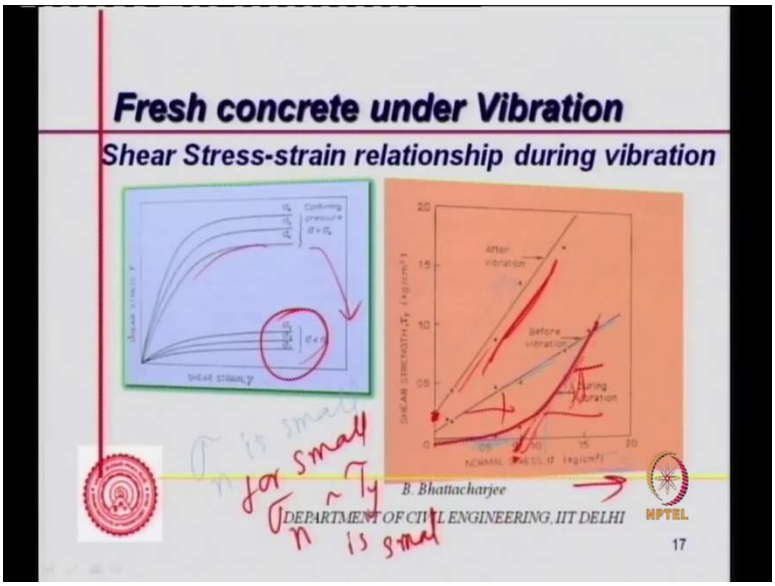

But mu of course the slope of this one, slope of this one is more than the original. What you call is we call this as you know we define this as agitation pressure. So, the agitation pressure if the normal stress is less than the agitation pressure which is actually the slope if I extend this line this is during vibration. So, if I extend this line this is the normal stress that will correspond to agitation pressure. So, this is agitation pressure. So, during vibration it is like this, and we can go back to this diagram again earlier diagram again. So, this is agitation pressure here.

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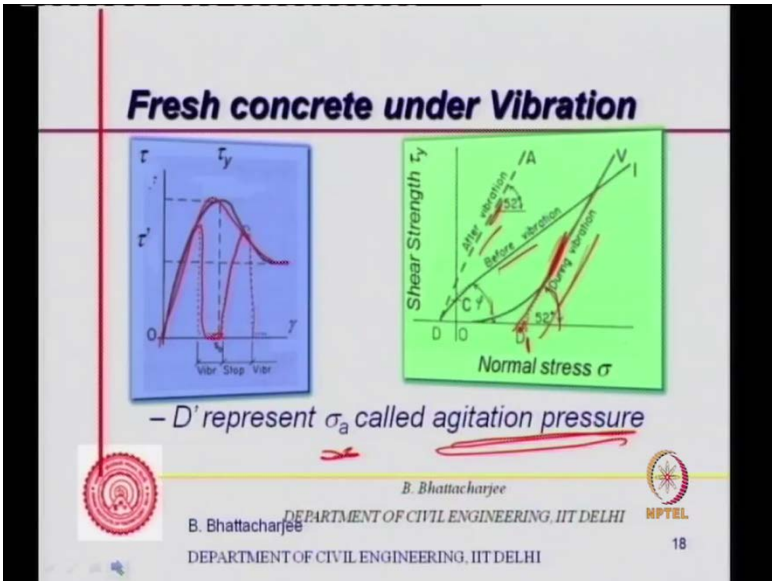

So, if your normal stress is more than the agitation pressure then only you find that yield stress starts increasing. So, the result of vibration yield stress reduces significantly. Same thing is shown here during vibration before vibration and after vibration. So, this angle also increases. This is more or less similar angle, this is more or less similar angle, this angle is similar while this angle is less. So, actually you attempt phi, mu sigma. So, the ten phi actually has increased angle of reinforce is increases; that means it has it can stand on its own more stiffer and stiffer angle.

And this diagram also shows you something like this, this is before vibration. During vibration you start vibrating and initial stress comes down very significantly and then you stop again it reestablishes itself and that is how it is. So, basically when you are vibrating initial stress come down; therefore, particle can move. Particle can move, movement due to the shear force can occur, it can move over each other or slide over each other shear flow would be occurring actually and then due to this the air would be driven out and it can get the right kind of shape, shape of the module.

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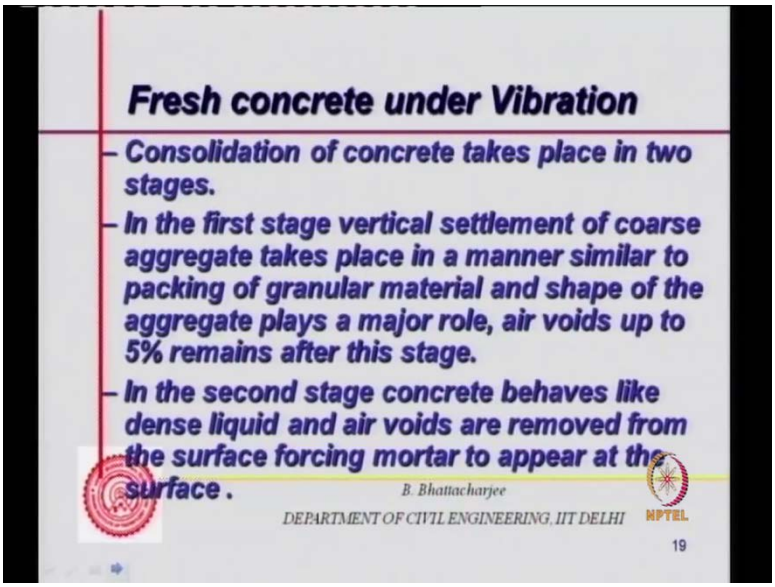

So, that is the mechanism of vibration, that is the mechanism also fresh concrete. Consolidation actually occurs in two phases. In the first stage vertical settlement of coarse aggregate takes place in a manner similar to packing of granular material and shape of the aggregate plays a major role, air voids up to 5 percent remains after this. Spherical particle will actually easily role over and therefore you know in the first stage

itself vertical settlement becomes easier for surrounded aggregate. Then you have at the end of the second stage concrete behaves like dense liquid, because the air voids has been removed quite a bit and finally air voids are removed from the surface forcing mortar to appear at the surface. So, this is important to understand or know that mortar will appear at the surface, you know as the air voids moved out the water will appear at the surface.

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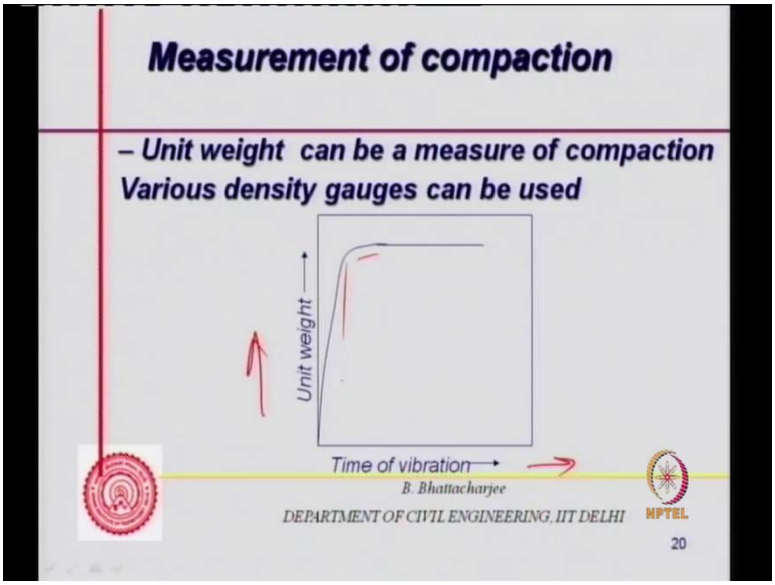

So, you know once your first phase is over second phase actually mortar will come out and that is also a test for whether the vibration is complete or not. We will find that the stabbing or mortar phase is coming out of the top and then you can stop that. One can measure the unit weight by various density gauges and they typically look like this unit weight time of vibration. So, this is your time of vibration and unit weight. So, after certain period of times vibration in complete. In fact somewhere here the mortar would have come out right at the top and after that you need not look into any further the vibration is over.

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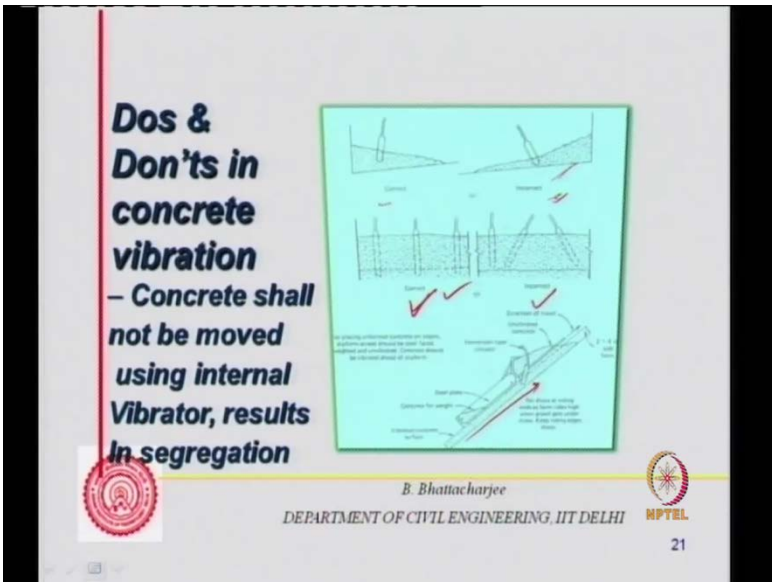

What you should not do with respect to vibration? You see this is the correct type, this is the incorrect. So, needle vibrator should not be penetrated in an angle; this is incorrect, this is correct because you know will be dragging the concrete along this direction. So, by and large it should be vertically put down; it should be vertically put down, and if it is on a slope surface it should be done you know from this the concrete is over. There are air places so you do from the bottom and go upward. So, it is desirable that one does vibrating right vertically downward without inclining without inclination of the nylon. It is not desirable to incline the nylon and one should not push the concrete by vibration like this is being done here. So that is some do's and don'ts with respect to vibration. It should not be moved using internal vibrator and which can result in segregation.

That means penetrate vertically to sufficiently embed in concrete held stationary and remove slowly, say, 7.5 meter per second centimeter per second is a good velocity slow velocity but one may not be measuring them. The idea is that when you are taking out of the vibrator it should be taken out slowly. It should be direct regular spacing to ensure compaction of all portions with adequate overlap; there should be adequate overlap. I mean typically it should be like this. If this is the radius of action which is known for types of needle that we talked about, the second one needle location will be here, so that there is right kind of overlap. So, this is the overlap.

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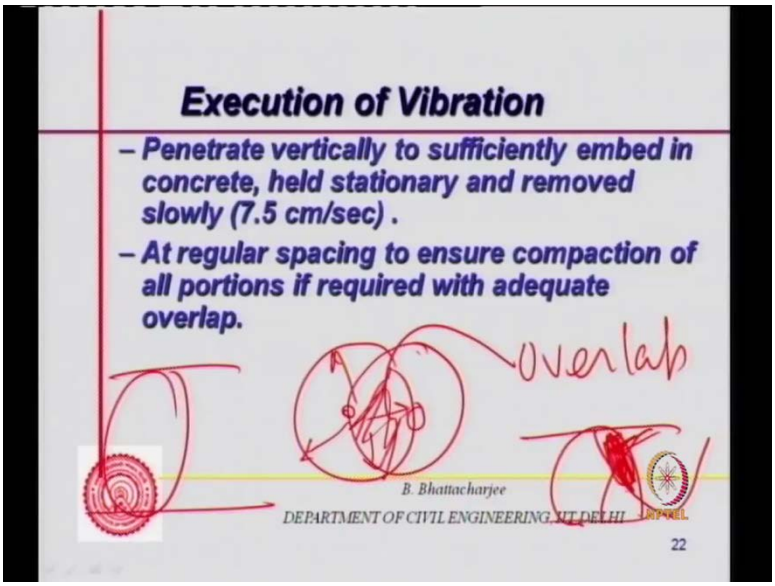

So, overlap should be like this; right kind of overlap should be there. In other words if I have sections like this where I have one circle covers it or thinner section you know it covers may be something like, then next one should be something like this this and so one, so that overlap it is here, overlap is here, next one should be something like this. So, there should be sufficient overlap, sufficient overlap that is the idea. There should be sufficient overlap, right, there should be sufficient overlap. That is the idea. No left portions should be left blank.

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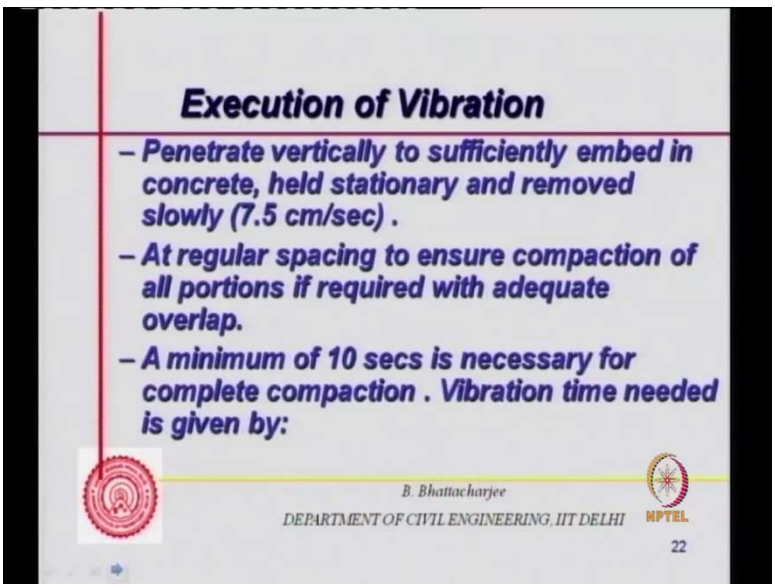

Minimum usually 10 seconds is necessary for complete compression vibration time needed is given by some equation; I think I am not talking about that.

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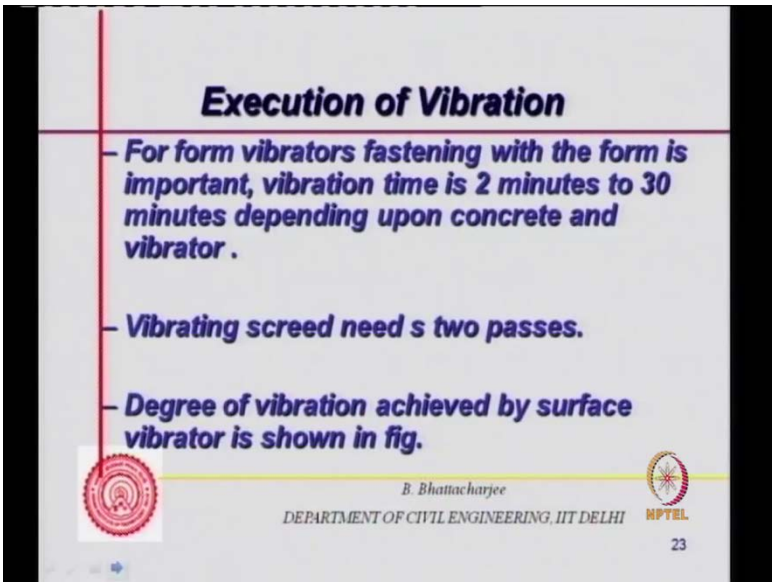

I am not talking about that because equations nobody is going to use it that much but we understand that at least 10 seconds if you keep it and when you see the mortar has come out mortar has come out as and you know mortars has come out you pick it up pick the needle vibrator just lift it up slowly at a very slow velocity and you can see that slightly right at the top. For of course shorter vibrators, which are fastened with the form vibration time is 2 minutes to 30 minutes depending up on concrete and vibrator itself. So, they require longer period of time more energy. Screed needs of course two passes, and degree of vibration achieved by surface vibrator of course one can see from the figure that is there.

Actually it is up to only certain depth vibration is there. So, it is about something like about you know 8, 10 centimeters from the top which means that 80 mm and not really much; after that the density reduces down. So, it is only the top portion maximum can reach you know you can actually vibrate. Similarly shutter vibrator also will not go throughout the section if the section is thick. So, that is what it is, right.

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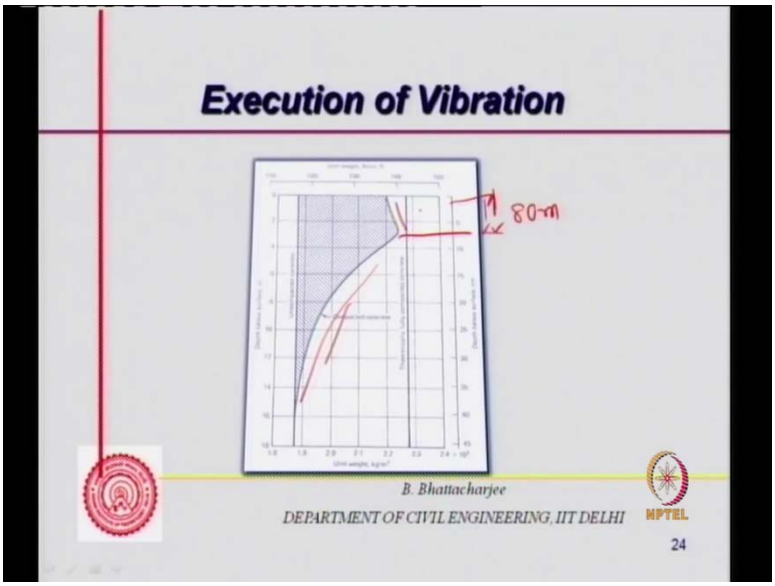

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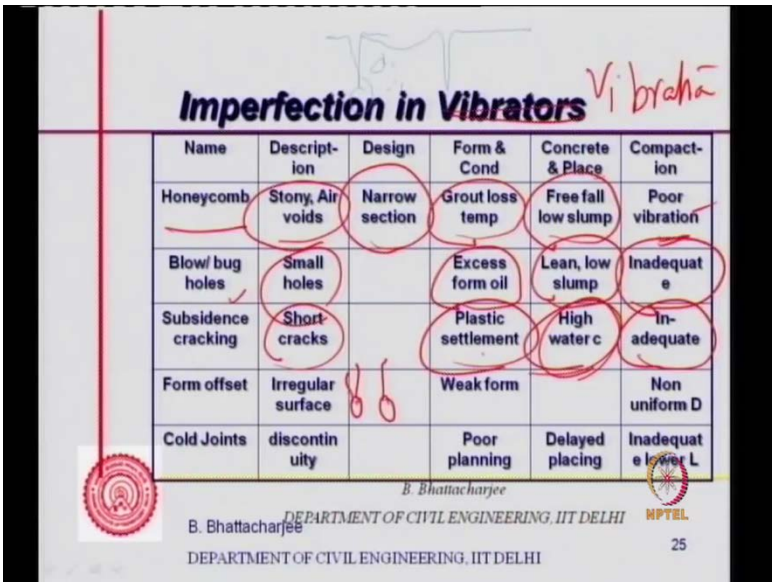

Now in perfection in vibrators honeycombing, actually it should be in vibrations actually in imperfection due to poor vibration essentially. So, in vibrators is not the one in vibration you can say concrete vibration. Honeycombing if you have not done the vibration properly, but it can have you know stony air voids and generally happen in narrow sections and grout loss can also cause this if the forms are not joined properly. Freefall low slump concrete is a concrete type and poor vibration can result in this.

Well blow holes or bug holes which you see normally in concrete small holes esthetically ugly looking. Excess form oil if you are using you can have this kind of thing, lean and low slump concrete you get it and of course inadequate vibration. So, poor vibration can result in honeycombing, inadequate vibration can increase the bug holes permission; bug holes are pretty common. There are not very harmful but they look very ugly not a good finish. Subsidence cracking of course this can happen due to plastic settlement. Now it is a bleeding concrete; this can occur in concrete which is bleeding you know because which is bleeding the water comes up and the solid subsides.

So, this can happen and inadequate vibration can result in this. High water content is usually the concrete cause which can result. So, concrete which has got high water content you might get short cracks. The cracks look like this in fact. Sometime we might be discussing over reinforcement sometime you might see just over you know this is the concrete. In fact it might look something like this. So, the top concrete surface might look like this. There is a crack and then there the subsidence, there is crack and so on so forth. So, you have reinforcement here, this is a concrete surface.

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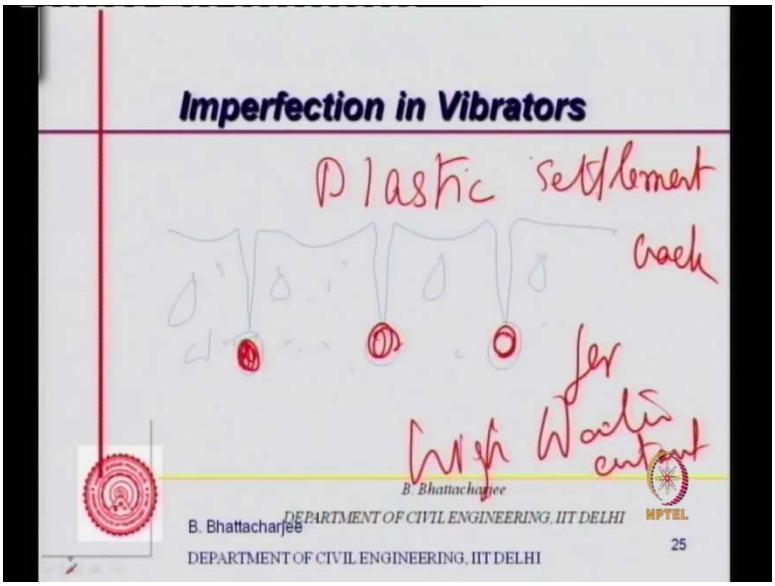

So, in the concrete surface let me draw it just here let me draw just here you know it can look like this, then there is a crack, then there is a crack. It is usually quiet often could be our reinforcement and then several other situations, this is my concrete. So, this is that slab large slab and similar sought of situation. You might see some plastic settlement

cracks just over the lever just over the lever you know just over the lever; you might see them just over the reinforcement bar.

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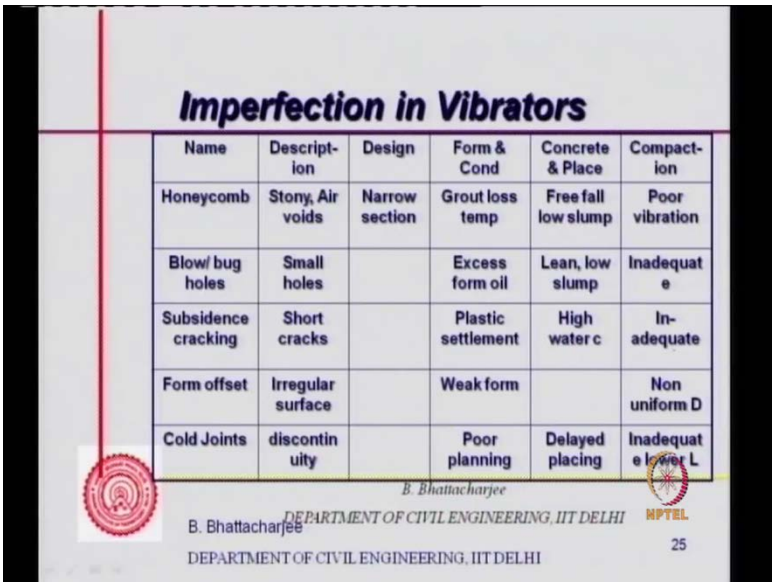

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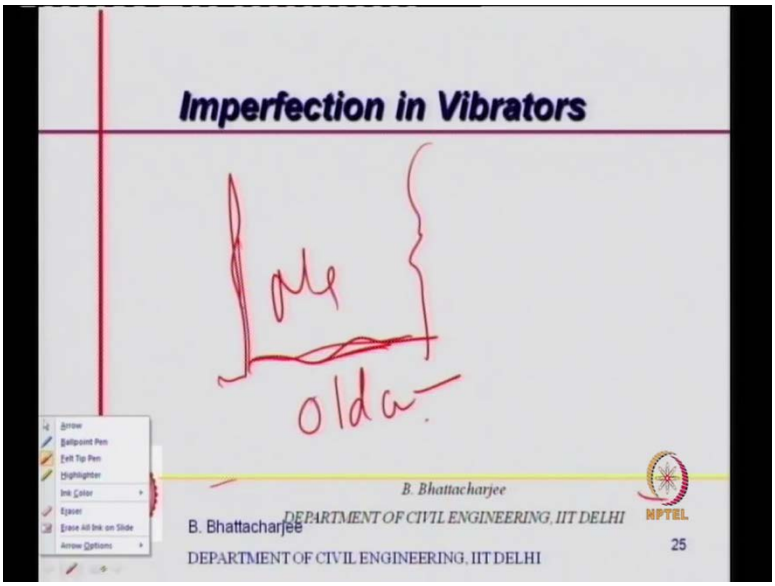

So, this is plastic settlement type. It comes when your water is too high plastic settlement crack, plastic settlement for high water continent and inadequate vibration. So, where you have high water content if you have done inadequate vibration you might still get this steam you might get this; I mean inadequate equation is also a cause not the primary cause but it is also a cause you can see. Form offset of course it has nothing to do with

vibrations. If your form is I have not been bolted properly; this can result in effects. Cold joints formation that is also inadequate vibration of the lower level; you know cold joint occurs when you have one concrete old concrete old concrete and then you have new concrete which is over here new concrete. So, there it can be cold joint formation, and this is inadequately vibration vibrated. You might have cracks coming in or cold week joint forming here if it not vibrated properly. So, that is it; these are the defects which can come from vibrations imperfections that can come from vibrations.

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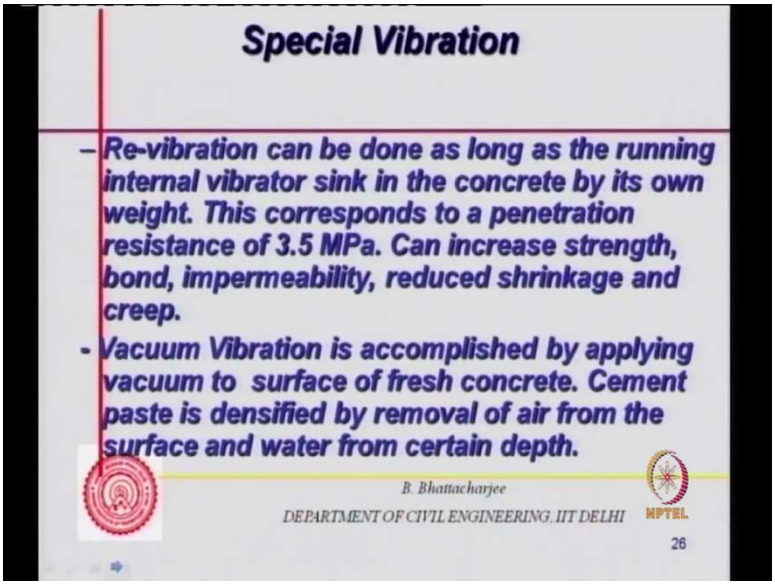

Special vibrations are vacuum vibrations. Re-vibration can be done as long as running internal vibrator sink. So, if your internal vibrator if it sinks in to the concrete and penetration resistance of around 3.5 MPa. Now penetration resistance is a measure of setting, and it should be 3.5 Mpa. If it is more than that then you cannot increase; you can increase strength, bond, impermeability, reduced shrinkage and creep. So re-vibration is not desirable. But you can do if it is to be done you can do it as long as the concrete is not set, and it is measured by penetration resistance. Vacuum vibration is accomplished by a flying vacuum to surface of fresh concrete.

Cement paste is densified by removal of air from the surface and water from certain depth. Now this is applied where you vacuum dewatered concrete, floorings, abrasion resistance high abrasion resistance like warehouse flooring or industrial flooring. So, this is done where you are likely to have lot of abrasion. Basically water is removed; this

water is used for placing the concrete but it is removed. So, water-cement ratio is low and you get relatively strong concrete.

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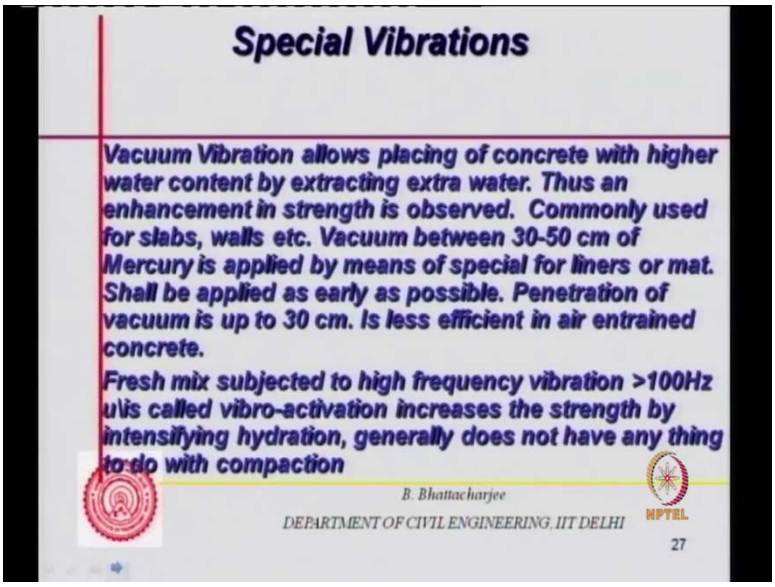

So, placing concrete has higher water content by extracting extra water then you extract the extra water. So, its strength is improved commonly used for slabs, walls, vacuum between 30 to 50 centimeter of mercury applied by means of special. You know liners of material which you allow water to come out but the solid will come. So, you have a mat placed on top of the concrete and then water is evacuated out you know so the water is taken out. It should be applied as early as possible. Penetration of vacuum is up to about 30 centimeter is less sufficient in air and training concrete because then air will come out. Fresh mix subjected to high frequency vibration over 100 Hertz is called vibro-activation increases the strength by intensifying hydration, generally does not have anything to do with compaction. So, if you have used high frequency vibration then hydration processing; it has nothing to do with the compaction, right. So, these are special cases.

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Now let us look into the second part of our discussion that is curing. You know hydration reaction is not instantaneous; it is not like an explosion reaction which is instantaneous. So, it occurs over a long period of time, and therefore water must be available for hydration. Now for hydration to continue you need a relative humidity of 100 percent. Besides there will be loss of water by evaporation, and it shall be prevented, and if you cannot prevent it, it should be replenished. You may not able to prevent it; so, it should be replenished.

Then somewhat water will be consumed by the chemical reaction itself, so what we call it self-desiccation, and this also got to replenish. So, essentially what happens is reaction requires longer period of time and occult set only 100 percent RH. So, you must maintain 100 percent RH, water by loss of evaporation occurs and that has to be replenished to maintain 100 percent RH and self-desiccation also would cause some water loss and that should be also replenished and also sometime maintain conducive temperature .

So, this is the purpose why you need curing you know need for curing. Well, most important is if you do not do this if you have inadequate hydration occurring the capillary pores in the system, which we have discussed earlier if you can recollect we have discussed earlier. Sometime you know between cement hydrates out of product, etcetera, etcetera, and you will have unhydrated cement system, unhydrated cement is somewhere there. Then there will be capillary pores interconnected capillary pores in

between. You know you will have capillary pores. So, this capillary pores which you have discussed earlier they need to be segmented; then only when you sufficient hydration products they will come and touch each other from both the sides and capillary will get segmented. So, minimum curing is required in order to ensure that capillary gets segmented; otherwise, unsegmented capillary will result in poor durability of concretes.

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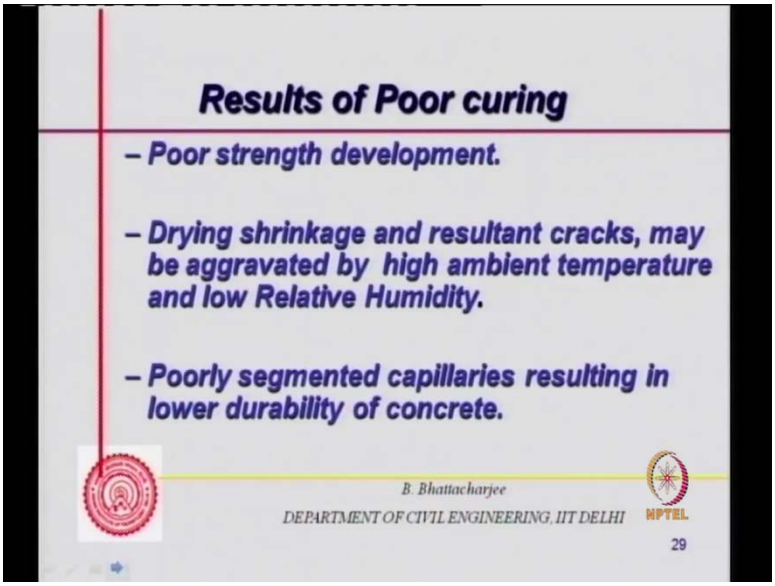

So, if you have not done good curing what will happen? Obviously, strength develop would not be there because hydration was not occurred, lots of spoor space will be remaining and drying shrinkage can result, because the water has gone out. So, it can cause drying shrinkage, and this can result in cracks, may be aggravated by high ambient temperature and low relative humidity; poorly segmented capillaries results in lower durability of concrete. So, this is what is the effect of curing.

Now how do you do curing? We do moist curing. Supposing I have got a water cement ratio of 0.5 concrete and if I cure it continuously submerged, this is continuously submerged; the strength will increase in this one. If 28 are cured strength will increase in this concrete. 14 days cure strength will go like this up to 14 days and then it will flatten out. So, 28 days strength will increase nearly up to or 20 are a little bit then it will flatten out. Continuously moist cured will go like this; continuously in air of course strength development which be much less with time and up to three days they will be increased slightly more than three days.

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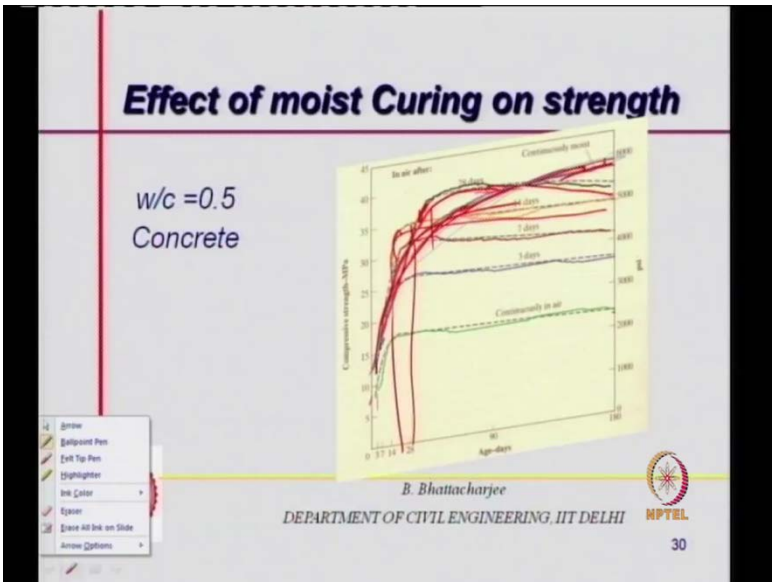

So, what happens is when you have stopped curing after that digestion process for a little while and after that there is no further strength development. So, therefore you know strength development I mean compressive strength is a function of curing in, and if I continuously cure it moist cure it continuously moist cure it then this is what I get. You know it increases significant continuously it will go on increasing. So, that is what it is.

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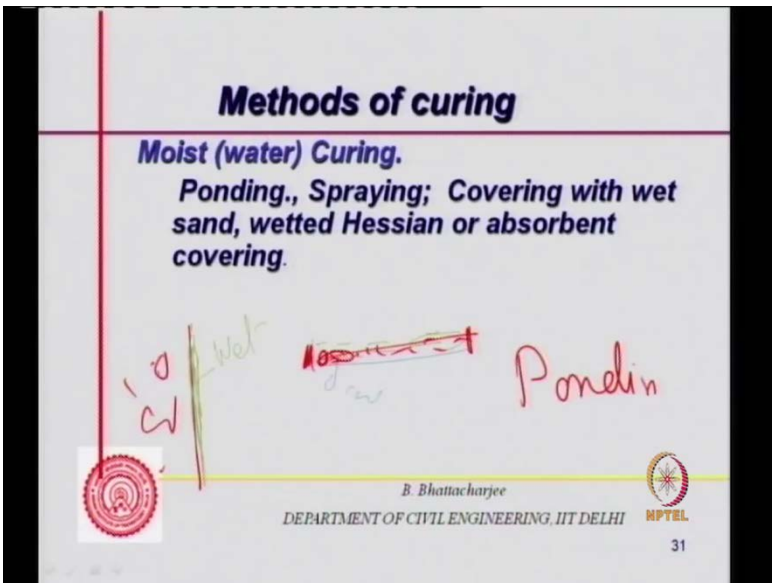

For strength gain I need some amount of minimum curing you know more the moist curing I do concrete will be gaining its strength. Methods of curing obviously water

curing is the number one, ponding, spraying, that is how you do. If it is a slab if it is a slab like this if it is slab you know concrete is here, so you make some sort of a barrier some sort of a barrier here on both the sides and simply do you know ponding, simply do ponding. So, you will have ponding water here. So, this slabs you can actually do ponding. Slabs you can do ponding. Ponding can be done on slabs.

Spraying spray with kind of any kind of pipe and then covering with web sense, so instead of ponding what you can do is you can just put in sand particle here and this is to be maintained well or you put wet Hessian cloth, clothes are absorbent covering. So, this could be for slab or for column also. For example, it is a column you can put actually wet Hessian, you can put wet hessian here, Hessian clothes here which will remain wet all the time. So, you keep it wet with some kinds of absorbents. So, this is you know moist curing is done in this manner.

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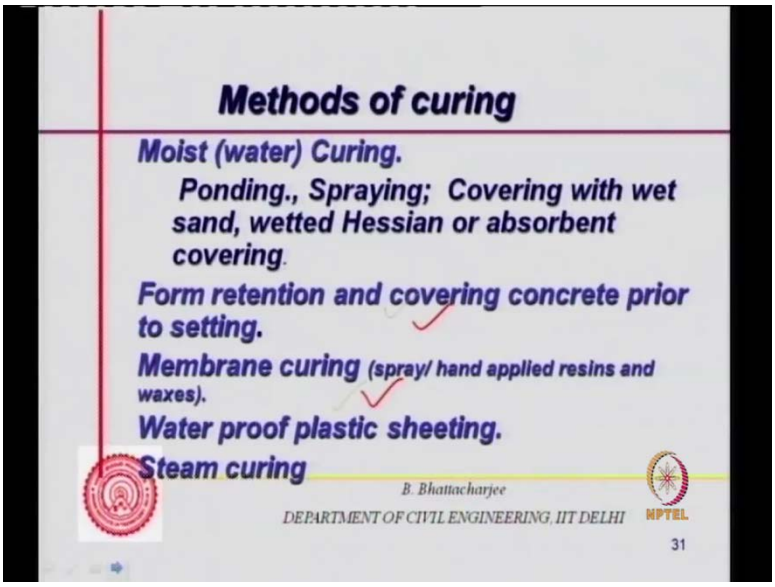

Then you have got form retention and covering concrete prior to setting; of course you can retain the form but that will not be replenishing the water or cover the concrete prior to full setting or even after that. So, water actually will not go away but at the same time water will not go away but at the same time you know it will not replenish. Membrane curing basically we apply resins and waxes on top of the concrete to form a membrane. It can be spread or hand grass applied let us say.

So, that what it does; it will see that no water goes out. Whatever water is inside that is used up, so no evaporation. So, both second and third you know this one and this one they will ensure that there is no loss of water but then there is no loss of water but then they will not replenish the self designation water. So, these are the methods. Then you have stream curing, waterproof plastic sheeting some people have used and steam curing. Steam curing is used where you want to get accelerated strength may be presetting you are doing, so you want to do the presetting quickly, and that is what where you use this.

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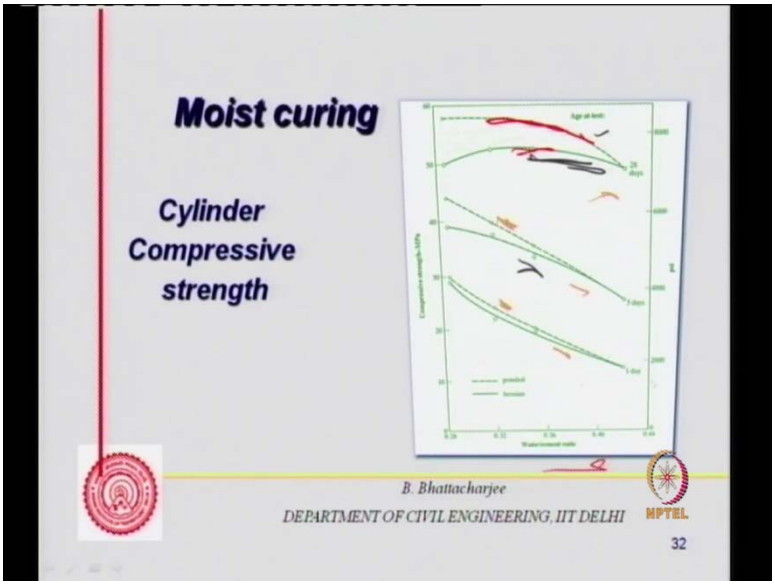

Moist curing if you see compressive strength then compare the compensative strength you see 28 days you know this side is for different water-cement ratio. So, you get the compression is pounded and Hessian. So, this high one is pounded, this is Hessian cloth; Hessian cloth is somewhere here, Hessian cloth is here, pounded is there. So, Hessian pounded. So, pounding does it good job; pounding does a good job actually, pounding does better job. Pounding is here, pounding is here and Hessian is relatively less, Hessian is lower one. So, Hessian is lower one, and this is for 1 day, this is for 3 day, this is for 28 days. So, pounding does a better job than Hessian or you know putting a water absorbing cloth or something colored you know cylinder. So, basically what we want to see is the quality because quantity values do not make much of essential varied from concrete to concrete.

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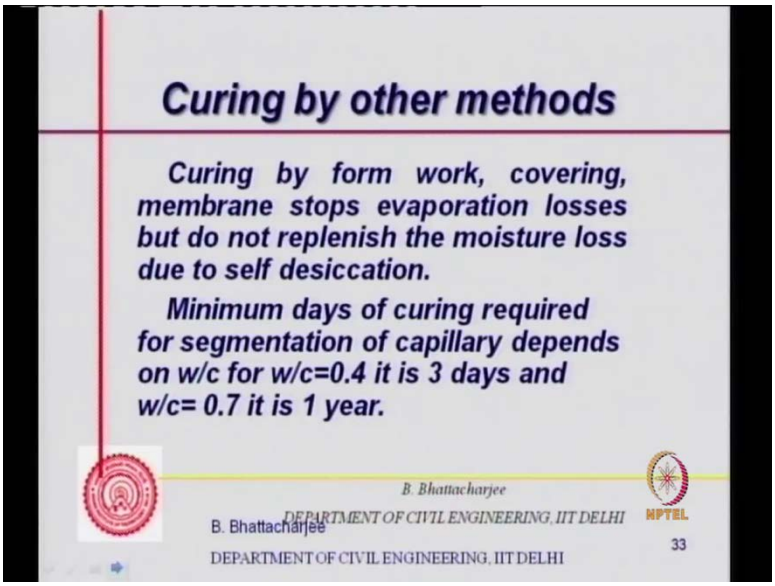

So, pounding is a good thing when you have the facility, and also there is a possibility of doing. For example, you can do pounding on slabs or horizontal members particularly large horizontal members but you cannot do it on column. Curing by form work, covering membrane, of course stops evaporation which I said but do not replenish the moisture loss due to self-desiccation; that is the problem. Now you need a minimum days of curing for segmentation of the capillary, and it depends upon water-cement ratio. For example, water-cement ratio 0.4 it is just three days, and for water-cement ratio 0.7 it may take one year. So, higher the water-cement ratio more these are required to segment the capillary. So, it is understandable because more higher water-cement ratio larger size will be the capillary pores and more will be the capillary, and they will be more connected you know beyond percolation threshold so all of them will be connected.

So, code actually specified minimum curing days based on this. For example, Indian code says that 7 days minimum curing is required for ordinary Portland cement, but if it is Pozzolana blending they you need 10 days in normal weather but correspondingly you will need 10 and 14 days in normal weather and of course a dry weather like dessert areas where you know it is more dry, there you need 14 days when you have Pozzolana blended cement, but pozzolana blended cement they will require more number of curing days for strength developments, because that process is slow.

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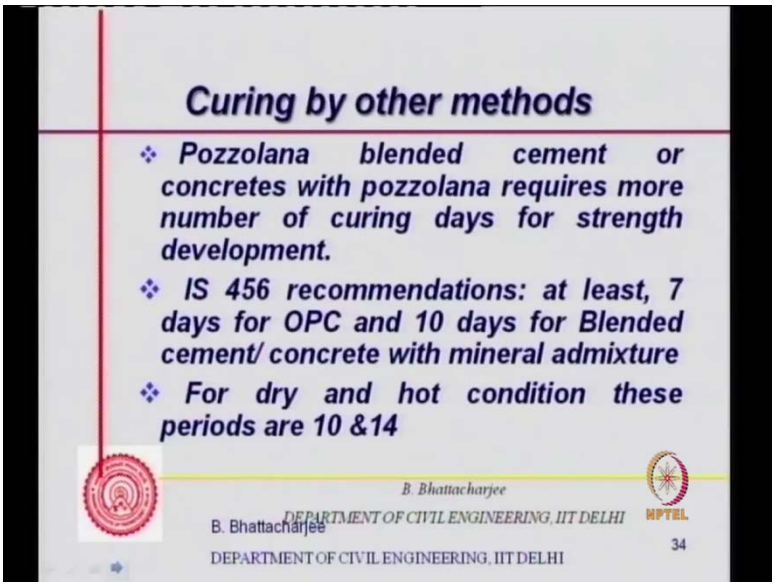

So, that is what I was saying IS 456 recommendation at least 7 days for one PC, 10 days for blended cement concrete with mineral admixtures in normal condition, but for dry and hot condition these periods are 10 and 14. Other codes are actually much more elaborate; I do not have time here to talk about those, they are much more elaborate. Some of them would talk about the curing depending upon water-cement ratio also the kind of evaporation of losses. Possible air velocity you know for example, astral British code was quite elaborated in this method, out code is much more simple and simpler. So, that is what it is.

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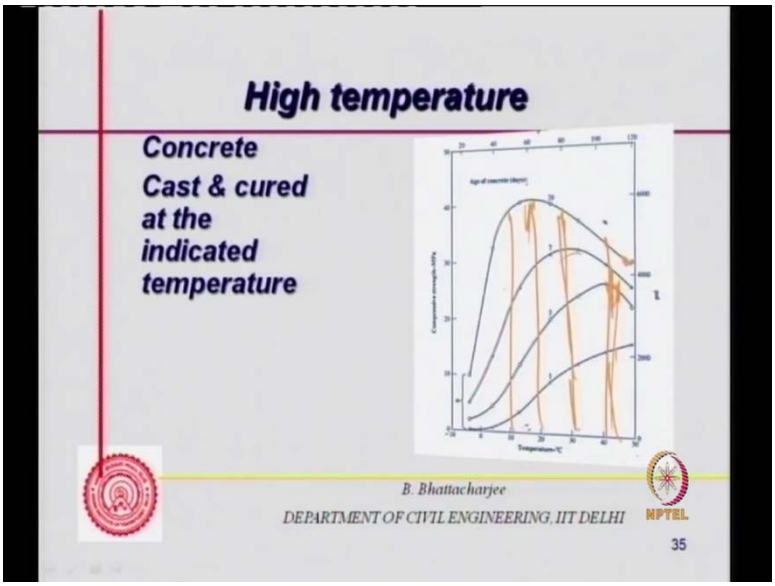

What about temperature? Concrete cast and cured at the indicated temperature let us say this is you know this is basically temperature is 30 degree centigrade one day H. So, H and this is 28 days. So, if you cure it at let us say 10 degree centigrade, strength is here, 20 degree strength is here, 30 degree strength is introduced, 40 degree strength is here. So, if you look at 20 day strength cured it at 40 degree will be less strength than cure it at somewhere around 20, 22, 24 degree; similarly, 3 day strength and so on so forth. So, it actually you know higher temperature early strength gain is high. It is almost close to that. Higher temperature early strength gain is high but later 28 day strength it actually reduces down. So, maximum 28 day strength you are getting at 20 degree centigrade when you are casting and curing at the same temperature, alright.

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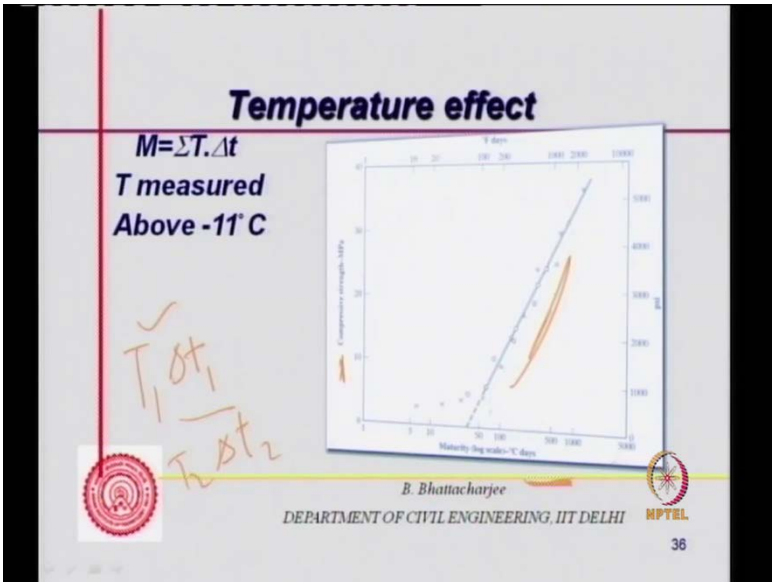

Now we talk in terms of something called maturity temperature effect. What has been seen is that T measured about 11 degree centigrade and if you know for let us say T 1 delta T 1. So, it was maintained at delta T 1 for delta T 1 times, T 2 for delta T 2 time, etcetera, etcetera, and sum this up. This is what is called maturity, and it has been seen then maturity log scale degree centigrade days versus compressive strength can be linearly relative. So, higher temperature lesser time you will get almost same effect when you have lower temperature and longer period. That is the idea and that gives you the idea about steam curing.

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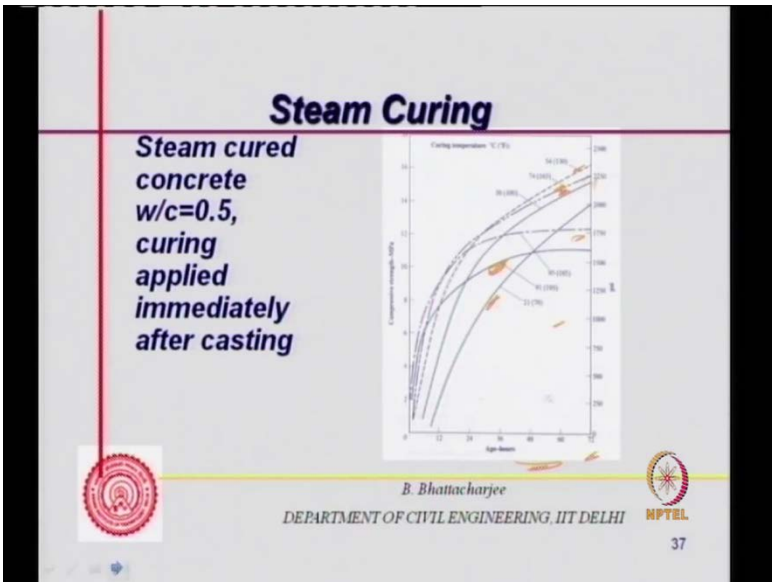

So, we will just look at steam curing. Steam cured concrete if you apply immediately after strength gain is poor but if you maintain it at 74 degree centigrade you are somewhere here in this curve, 54 is somewhere there, 31 is somewhere there, 91 strength and gain you do not get. So, compressive strength at different age it is given hours 72 hours free day strength. So, somewhere around 74 or so degree centigrade you get strength good strength in 3 days if you are looking for. Very high temperature does not give you very high strength.

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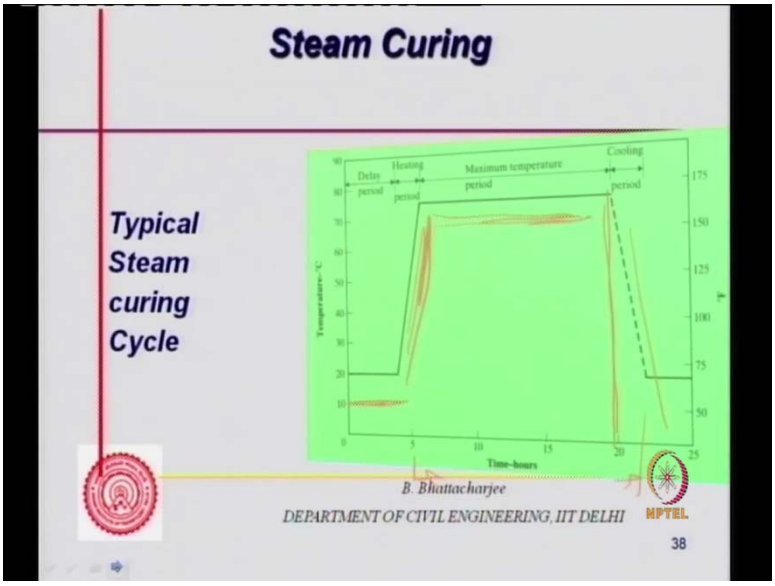

Generally stream curing steam at atmospheric pressure will have a low; you know it will have at about 75, 80 degree centigrade. So, what you do is you do not apply immediately because then strain you do not get. So, there is a delay period. This is the delay period. Then there is a steam heating period, maintain that temperature you know supply the steam and maintain it then cooling. So, basically something like 5 to 20 if you do it for about 15 to 20 you know 15 hours, 13, 14 hours of steam purring, you can develop. This is the kind of practice that we do to get good strength, alright. So, steam curing is something like this, typical steam curing cycle and this is if you are trying to get RD strength.

So, you can summarize now. Basically we have looked into all the methods of compaction and then you know the mechanism how the compaction occurs, and lastly then we looked into curing, the methods of curing, need for curing, importance of curing that is what we have highlighted. One thing the curing is very important from durability purpose which people quite often ignore. It is good for strength development but minimum curing is absolutely essential for durability. We quite often try to ignore it also because of the kind of practices that you have.

If it is a sprinkled one continuous in a precast factory that is a good curing but in-situ curing is done quite often it is ignored, it will be the most unskilled person would be doing it. Now such curing do not have those system, the strength will be lower, durability also might be affected. Another contractual problem seen in Indian scenario curing is always part of concreting. So, obviously it is not a separate item. So, therefore also it is trying to deliver to us. So, that is all as the summery and you know summary of also the module five where we have looked largely into the fresh concrete issues and concrete production process, the curing completes it.

Thank you very much.