Building Materials andConstruction
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Module - 6
Lecture - 6
Strength of Concrete: Non Destructive Evaluation

The last lecture in this series on strength of concrete in that module 6 is non destructive evaluation of strength of concrete.

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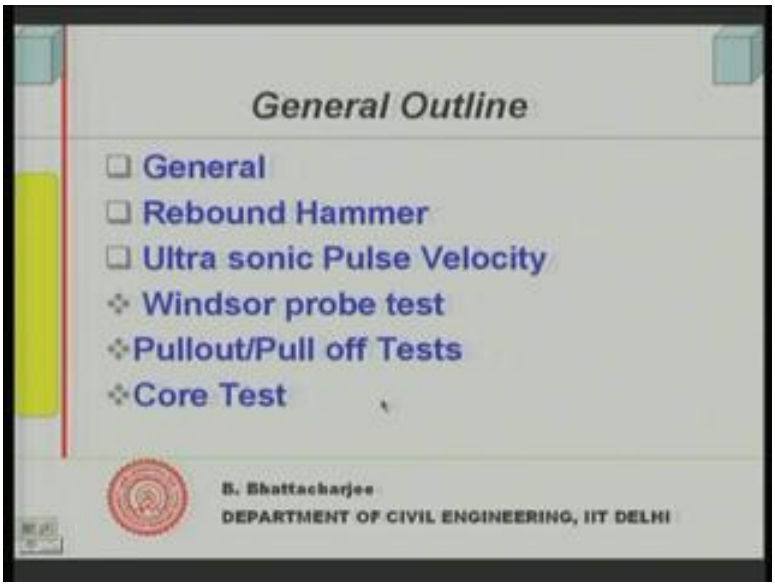

And what we are going to discuss something about general nondestructive evaluation. Then, we will look into Rebound Hammer test, Ultra sonic Pulse Velocity test, Windsor probe test, Pullout pull off tests and Core test. So, this is these are the tests that we look into in the case of nondestructive evaluation. Now, let us just think of why do we need nondestructive testing?

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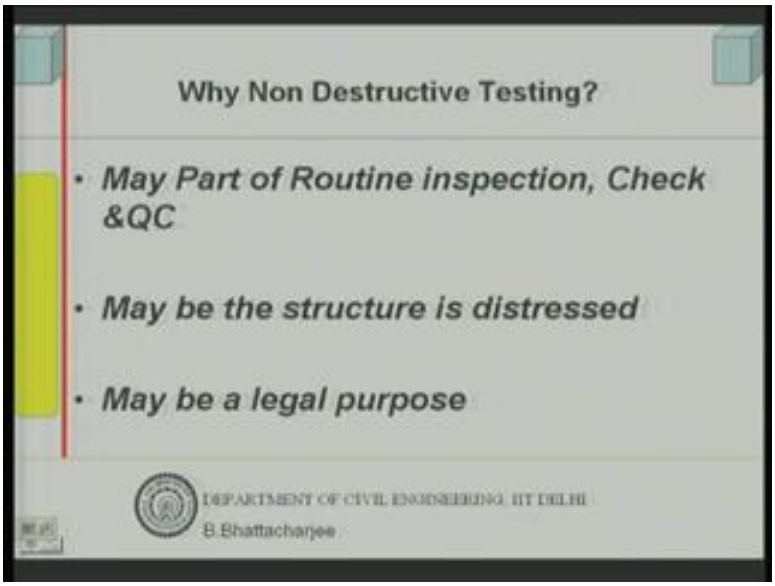

You see in fact, I rather like to put it as In situ testing.It's only nondestructive is not necessary, because some of them are semi destructive testing, but In situ testing.We have seen that we test concrete cubes, mainly to find out the potential of the mix; strength potential of the mix and also for quality control purposes and strength in the structure is different than that of the cube.

So, if I want to know what is the strength of the concrete in structures then I should do actually nondestructive testing. It can be part of a quality control job also you know some sort of routine inspection, because 1 have to monitor the condition of the structure from time. Depending upon the situation very important structures 1 may have to monitor more of them are not.

And it is not only strength there are several other, parameters we look into conditions of way of structures.May be their durability issues which we have not discussed sofar may be their performances against various environment and so on so forth. And you can have even continuous monitor of the structural performance by instrumenting the structure themselves, but anyway at the moment we are not looking into such bigger issues.

We are only looking into in situ testing mainly in nondestructive and semi destructive testing of concrete for strength. So, it could be part of routine inspection check or quality control part purpose as well.In pre cast concrete it can be used many of this test can be

used for quality control purposes. Some time may be there may be structure might have actually been under distress it might be under distress.

Therefore, 1 may have to evaluate the structure in situ, may check its stability and some time legal purpose you want to buy a structure building. Then, you like to know what is this condition and therefore, you would like to know whether it is stable or not.So, in such situation 1 has to know the strength, because if you know the strength take the strength from the structure as determined, as you know as evaluated.

So, nondestructive In situ testing method you find out, what is the exactly strength that exist in the structure at the moment. Concrete structures we are talking of and then you do the regular analysis and design and see whether it can sustain the load; expected load that it is supposed to encounter during its service.

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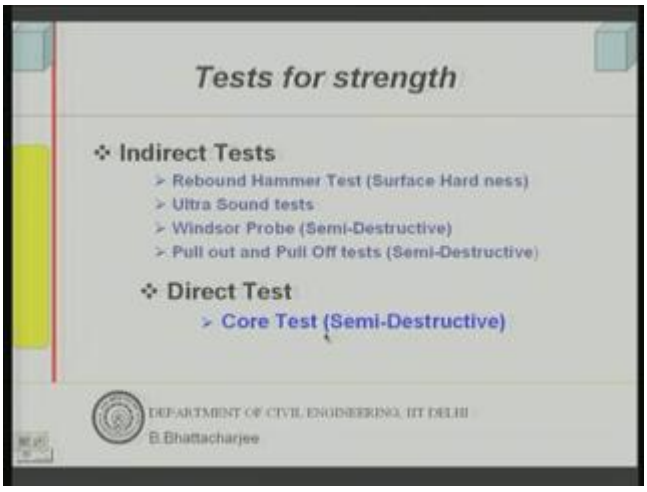

So, these are the purpose of non destructive testing or testingin situ.Now, when we like to know the strength in structures I cannot of course, smash the structure or destroy the structure in order to find out its strength. So, what we do you know strength measurements in laboratory you have seen it is all destructive you crush the cube, you crush the cylinder to find out what is the strength.

So, you cannot really do that in the structures although some load test etcetera therefore, integrity measurement. But destructive tests are mostly not done, exceptional cases may be there when you are not going to use, but therefore, non destructive testing and this

non destructive testing many of them would be indirect measures; that means, you measure something and that can be related to the strength or related in some manner.

For example surface hardness of concrete is a measure of thestrength of the concrete even inside concrete. Because, you measure the surface hardness; hardness of the surface if the surface is hard it is quite lightly that inside itself is also strong, it is hard and strong. So, you can relate surface hardness to the strength. So, it is a indirect way of measuring the surface hardness and then measuring the correlating the strength or estimating and getting some idea about this strength from there.

1 test that is called Rebound Hammer test is, a kind of measure of that kind.Then I have ultra sound test, you know ultra sound test is a other test which is like I have already mentioned in the in 1 of the earlier lectures that, acoustic you know or ultra sound beyond the frequency range of audible range of frequency. You know 20 to 20 kilo Hertz is what we can what is our audible range that we can hear.

So, if you have higher frequencies you do not hear and that you call as ultra sound.Ultra sound frequencies, so when you pass sound at or acoustic waves at those frequencies that is what we call as ultra soundwaves. And this velocity of this ultra sound waves in concrete, again is a measure of the soundness of the concrete.

The concrete sound then it will have higher ultra sound velocitywe have seen that, when we were talking in context of the cracking of concrete, modulus of elasticity etcetera. We said that, micro cracking takes place and therefore, you measure the ultra sound pulse velocity it becomes lower. And that is again, the measure of the soundness of the concrete.So, this is a measure of the soundness of the concrete right then you know about something called Windsor probe.

Then, we have got something called Windsor probe which is semi destructive.So, we have we actually penetrate there is a probe which penetrates into the concrete and lesser it penetrates better the concrete is.Then, we have something pull out and pull off teststhese are all indirect measures you can insert them in the beginning and try to pull it offset. There are other kind of tests which are called pull off test, so which are again semi destructive and this are again indirect methods.

All you do at the surface and try to estimate this over the strength of the concrete indirectly.Right and then we have direct test of course, there is a almost close you can come to the strength of concrete, by direct measurementthe only test that is called core test. So, what you do when you try to find out how good or how bad something is a structure is take out a sample from this structure or several samples from the structure and test them.

Cores are nothing, but the core or the samples you take cylindrical core samples, because that is what can be drilled most easily.So, you have cylindrical drilled core samples and this samples, core term samples you can take out test them like you test cylinders. And in the same manner, as you test the cylinders and then can give you an indication of the strength; of course we know various factors which will affect this strength.

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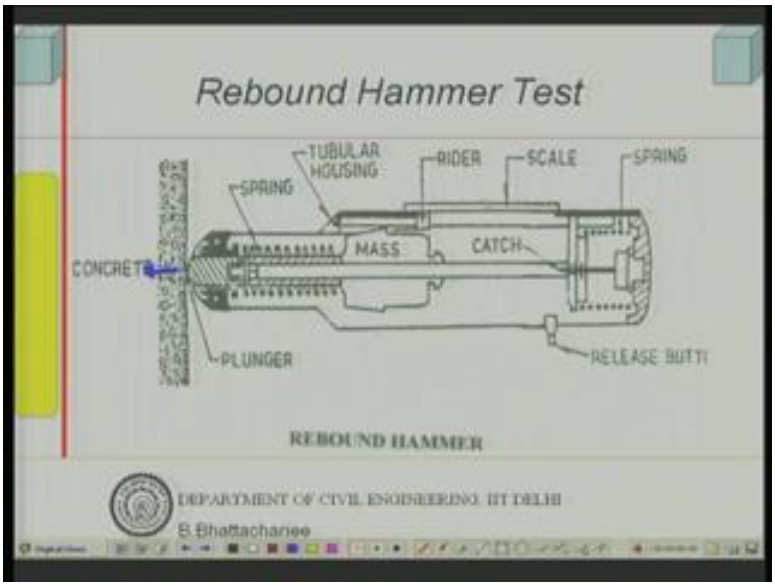

So, let us see what is Rebound Hammer Test give a quick introduction to be, idea is very simple it is actually developed in Switzerland, German part of Switzerland by 1 German called Smith and you know this is a hammer; this is a normal hammer as it is called. There are different types of hammer this is called a normal hammer and as you can see it has got a mass, hammer mass the spring and this mass can be released and it can hit, it can transmit, a kind of impact to the surface through this you know plunger through this plunger.

So, through this plunger it actually imparts an impact, when it impartsan impact here what will happen, the concrete this since this is this mass is supported on the spring and it can it will recoil back it will be rebounding back. And this rebounding back would depend upon, how much energy has been lost elastic energy lost.In a perfectly elastic collision, if you remember from your schooldays physics coefficient of restitution is 1.

So, it will come back completely back, but if there is some energy loss, because these are all porous concrete surface is not hard enough then it will not recoil back fully. Now, this recoil of this 1 is measured through a rider or nowadays there is a scale it can be visually seen, it can be connected to a digital system and you can read it out.

There is a reader device in which you can measure the recoil or relative recoil.This relative recoil is given a name called rebound number index. Such an relatively called you know relative recoil how much it comes back, how much rebound it takes place and that is what is you have a relative index here. So, this relative index is a measure how much it has come back, how much energy you know if the energy loss is less then it will come back more.

So, this rebound number it is given in number scale I have literally devised by the gentleman or the people who have devised this instrument and the rebound number is a measure of surface hardness. Higher the rebound number, higher is the surface hardness.Right there are details of this instrument.There are different types of this instrument namely this is called N type meant for normal concrete, there is something called M-type meant for mass concrete.

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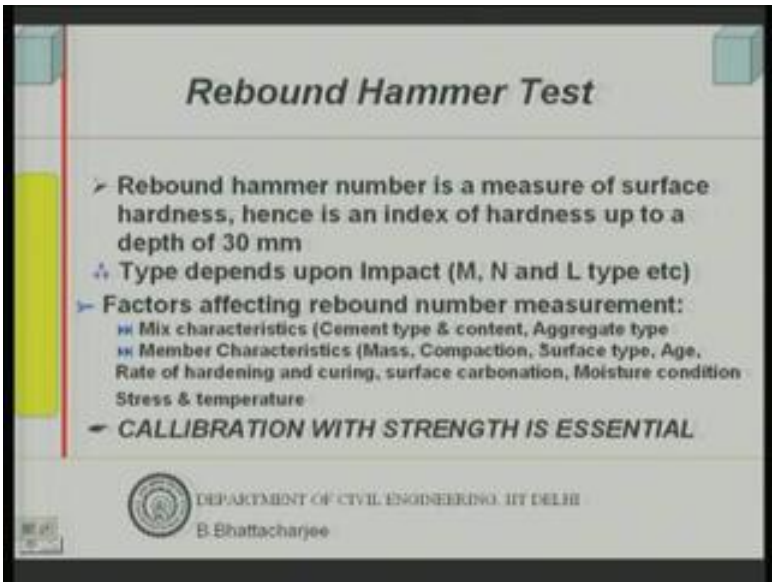

There is something L type, pendulum type which is measured formachinery or light weight structures.Now therefore, what we understand is rebound hammer is a measure of surface hardness is an index hardness up to a depth 30 millimeter, since we are imparting an impact this impact will not go penetrate too much into the concrete it just hardly goes up to a depth of about 30 millimeter.

So, what we are measuring is the surface hardness up to 30 millimeter and since the concretes surface concrete is related to the core concrete. If the core concrete is bad is unlikely that surface concrete would be good.In fact, it will be there is a correlation existing between the 2 in normal case of vibration etcetera etcetera. Unless there are some large internal honeycombing or cracks that has developed usually that is not the case.

So therefore, surface hardness from the surface hardness we can get idea about the strength of the concrete over the strength of the concrete and I mentioned there are 3 types.

Now, what are the factors on which this rebound number depend mix characteristics cement type, cement content, type of cement you see first of all you can see aggregate type then members mass, compaction, surface type, age, rate of hardening and curing, surface carbonation. Now, this carbonation term is coming again if you remember we

talked about carbonation in the context of shrinkage and this carbonation is nothing, but formation of calcium carbonate at the surface.

Since you measure rebound number through the surface only.A carbonated surface or when calcium carbonate is present on the surface this, it makes the surface hard and you get higher rebound number.So, surface carbonation affects the rebound number moisture condition of course, affects the rebound number stress and temperature also affects the rebound number.

Details of this variation we will not look into, but I can just tell you up to about up to certain level of stress rebound number changes. But beyond about 7 MPa or, so roughly there is hardly any effect on the stress, but up to certain level it affects. So, that is how we can find out the surface roughness surface hardness of concrete by rebound number, because higher the rebound number it means the surface is harder.

Right. So, relative hardness of the surface you can measure by this means.Now, if you want to correlate this to the strength then you must have a calibration with the strength and remember this calibration is concrete specific as you can see, because there are several mix parameters which governs the rebound number.They will also govern the strength, but they do not govern the strength and rebound number in the same manner.So therefore, calibration has to be there for your specific concrete.

So, you know manufacturers always provide a calibration, but those calibrations are not reliable in a given case1 has to for example, aggregate. If a calibration has to be done using granite aggregate, this may not be applicable to a concrete which has been made with quartzite aggregate.So, some part of the country we have granite some part of the country we have quartzite some other part something else.

So, 1 partcalibration made in 1 part of a large country like India may not be applicable to other part, 1 has to develop his own calibration. Best way is to have a calibration specific calibration for the specific concrete, because age etcetera also affects.So, this is important if I have calibration then I can actually obtain the strength from such calibration.Strength would be related to the surface hardnessthat is the idea.

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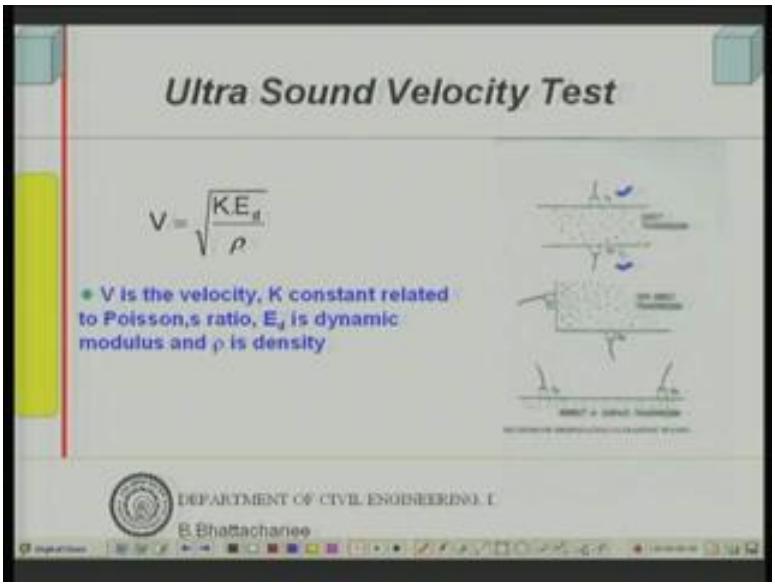

The second test that is thereis ultra sound velocity test ultra sound pulse velocity test. Now you remember we talked about, the velocity being related to dynamic modulus K and bulk modulus and rho. So, V is the velocity, K is a constant related to Poisson, s ratio, Ed is the dynamic modulus and rho is density. So, 1 can actually you know obtain velocities related to the modulus of elasticity and in turn we know that modulus of elasticity is function of strength.

So, 2 things becomes very clear if you have high modulus of velocity will be higher and therefore, velocity can be related to strength. Because, modulus of elasticity this modulus can also be related to strength. There has to be some sort of correlation I mean, it is not simple relationship just mathematical relationship you can derive out, but it will be empirical relationship. Several varieties of relationship 1 can develop, exponential, logarithmic, etcetera, but relationships are not really important for us.

We understand that there is a correlation between velocity and strength of concrete; more importantly possibly velocity and soundness of concrete. If the concrete is dense sound even the core concrete, because the velocity is measured as we shall see by passing directly the acoustic wave or ultra sonic wave through the section itself this direct, this semi direct, this indirect.

So, what you do you have a transducer, you have a receiver, you have actually a oscillator which would generate the frequency you want convert into electrical pulse and

which finally, convert into acoustic waves pulses through the transducer. And this transducer the acoustic waves that is transmitted is received here; we have a time measuring circuit which will tell us what is the time.

In modern instruments all these are combined together, if you just feed in the data of what is the length and the digital system would tell you what is the velocity.If it is a direct length then it will ask you what is the length, this length is known then its fed into the instrument it will tell what you what is the velocity.If it is an indirect measurement then this length has to be fed or you know this 2 lengths are fed then it would tell you what is the velocity.

Semi direct this is called semi direct, where the velocity will travel along you know I mean the acoustic wave will travel along this direction.So, this distance has to be fed into the computer or fed into the instrument to find out the velocity. Because, time of travel through this distance would be measured. In indirect measurement of course, you place the transducer here, receiver here and you can find out the velocity.

But this is highly inaccurate this only gives you, velocity of the surface way all details are not necessary for us, but this is the reliable method of determination of the ultra sonic pulse velocity. And higher the velocity sound is the concrete, in the sense that there will be voids in the system, because we can also understand the velocity of sound, velocity of acoustic wave, mechanical waves, in air is much lower than the solid.

So, you have lot of air voids it would show you lower velocity right, so that is the idea.In fact, if youhave steel in concrete reinforcement concrete then steel will increase the velocity air voids reduces it.So, soundness of the concrete, overall voids in the concrete, how what is the quality of concrete that can be easily judged through this and this can also be used, in indirectly predicting the strength together with the rebound hammer.

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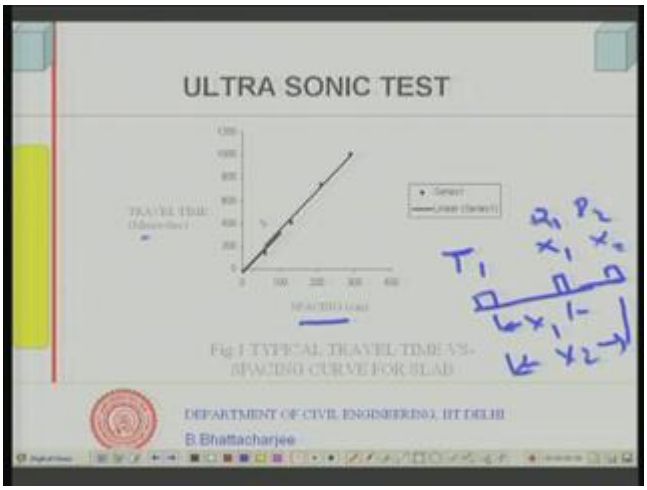

Right when you have indirect measurements actually what you do is, you have the transducer point here T then several x points you can have x1 x2.These are the receiver points receiver you know receiver point 1 receiver point 2. Over the surface you put the transducer here; receiver this place, receiver at different place and go on measuring the time of travel.

Then, you can plot the spacing of this you know this is the spacing x1, this is the spacing x2 and corresponding to spacingyou can plot the travel time and if you you know you will get a linear line, the 1 over the slope this will give you the velocity.This is usually measured in micro seconds in old instruments. In new instruments of course, you can feed in thisdata of spacing and it will straightaway calculate and digitally read it out for you.

So, velocity can be calculated from indirect measurements also, this is from a typical travel time versus spacing curve for a slab 1 dimensional measurement. But remember this gives you, favorably lowvelocity values you know not at all reliable manufacturers quite often tells that you can increase the velocity by 5 percent.

But this is not reliable should be used, should not be used for strength predictioncan be used for comparison purpose of 2 concrete that’s all. Because, these values are very very low and does not give you the proper indication of the overall concrete, because it does not go through the total core of the concrete.

Total internal you know it does not go inside the concrete whereas, direct measurement the acoustic wave passes through and through, so you get full information information about the full section.So, this is not very reliable, but this is how you can measure you know in case you have to do then you can do itfor comparison purposes.

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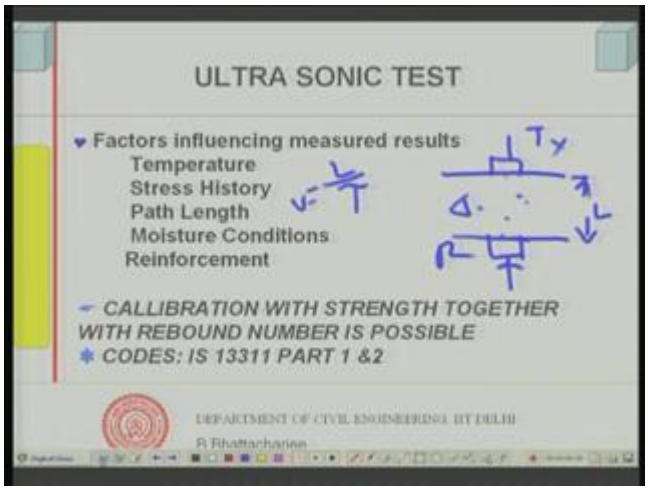

What are the factors which influence the ultra sonic pulse velocity result?Temperature, stress history, path length, moisture condition, reinforcement and calibration with strength together with rebound number is possible; you can have a multiple correlation.You know you can have strength as a function of ultrasonic pulse velocity and the rebound number. And from such correlation you can predict the strength reliably.

Reliably for a given concrete, because various factors affect both ultrasonic pulse velocity as well as rebound number.The Indian standard codes are mentioned hereinIS 13311 part 1 and 2. These are the Indian standard code meant for ultra sonic pulse velocity and rebound hammer test right, just for how do you measure just to reintroduce this ultra sonic pulse velocity measurement here.

You have the transducer here T x and this is the concrete section, this is the here the receiver that is the direct measurement and this is the length. So, if T tau T is the micro tau is the micro seconds you know time of travel through this L by T is simply the velocity and of course, most of the instruments these days modern instrument calculates and gives these values. So, that is what ultra sonic pulse velocity is and it can be used for measuring soundness of the concrete we will see some issues related to interpretation.

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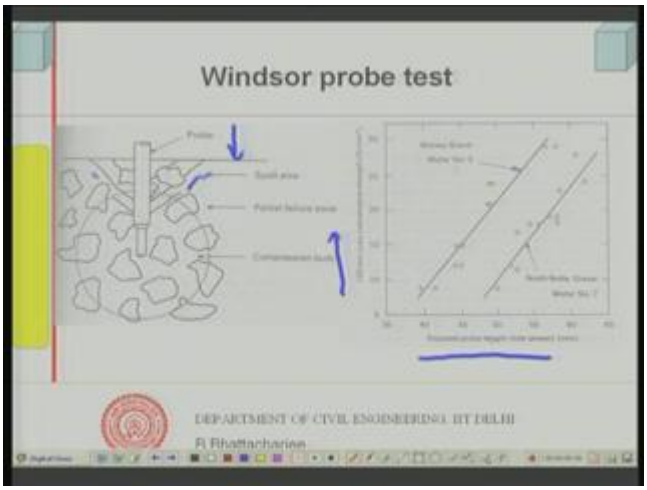

A third type of test is called Windsor probe test. Now, here we have a gun actually. It simply looks a gun and it has got probe the bullet is nothing, but the probe. So, this probe this Windsor probe you know the gun is actually just fixed to the just brought close to the surface of the concrete and is fired. What happens? The probe penetrates into the concrete like this.

Because, fired with some energy and it penetrates into it, probe penetrates into the concrete and causes actually partial failure zone will be there compression etcetera etcetera. It causes compression there will be some spoil area breakage of the concrete, because it will penetrate through the concrete. Now, if the concrete is good it will penetrate less, if a concrete is relatively not sogood the surface concrete we are talking about, it is again the surface concrete only.

So, penetration resistance of the surface concrete is what we are measuring. First you know rebound hammer we measure the surface hardness of the concrete, ultra sound sonic pulse velocity when you are measuring thesoundness of the full section of the concrete. It is a kind of voids or solid you know, solidness of the concrete of the full section and this is again penetration resistance of the surface concrete we are measuring.

So, the unpenetrated length of the core is a measure of the strength of the concrete.For example, exposed problem can be plotted againstthe strength and you know calibrated against 100 millimeter cube compressive strength. And that is what is kind ofcalibration 1 gets like, some kind of aggregate and some other kind of aggregates etcetera, etcetera.

So, you can have calibration curves again available for here.So, unpenetrated length or exposed probe length is a measure of the strength of the concrete or you knowcan be correlated to the strength of the concrete. This is 1 measurement, but this is semi destructive because itactually spoils the concrete a little bit of surface concrete.

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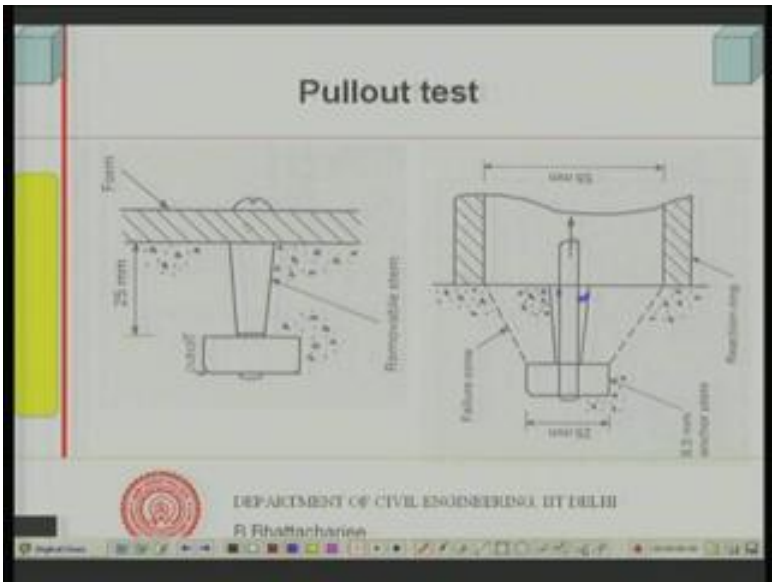

Then, there are test called pull out test. Now, here what you do is you put the inserts right in the beginning like inserts like this are put in right in the beginning you know. So, we have a this portion you have to actually insert them in the beginning itself and this time of course, can be removable this is the forms.

So, put them right in the beginning they are there in the beginning and you can remove them and later on what you do, you this same 1 which is about 25 millimeter 25 millimeter you know just to show you the order 25 millimeter. Diameter sort of and this is now can be fitted and it is this space has been left, you see this has been this is inside right in the beginning.

So, we have kept ityou remove the form, now put this 1 inside which can be tightened up together with this and you pull it using some sort of reaction ringyou apply a reaction here; you pull it through. So when you pull it through it will actually, this will apply some sort of compression, this will apply some sort of compression and this would be. So, this this concrete in this zone is left likely to be in compression and there is a failure zone.

Finally, it will pull through this and this is about 55 millimeter through which the reactions are applied and is pulled through. And this pull out force is again can be related to strength of the concrete; this can be related to the strength of the concrete.

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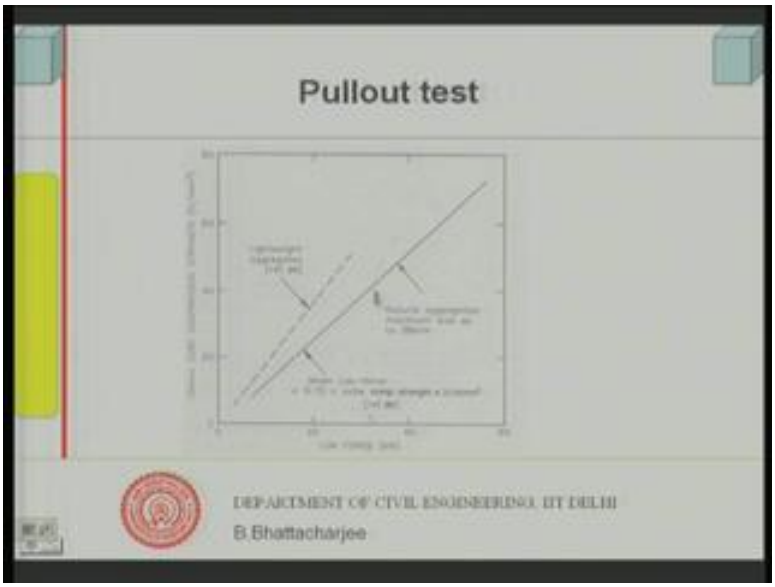

Right so this is called this is some sort of lock test is 1 of the test that is similar pullout test. There are other versions of the similar kind and you can again the force that is required to pull it out, is function of the compressive strength of the concrete. So, you can correlate the force that is required to pull it out the force you can correlate this with the strength of the concrete and this for different aggregate.

For example, this is natural aggregate up to ms of 38 millimeter right, which is about you know 2 and a half inch 1 and quarter 1 in 3 quarter of the inch that is what it is.Because, 38 millimeter that makes it actually 1 and a half inch and this is for light weight aggregate. So, you can see the lock force can be related to compressive strength of concrete right. So, that is what this pull out test is all about.

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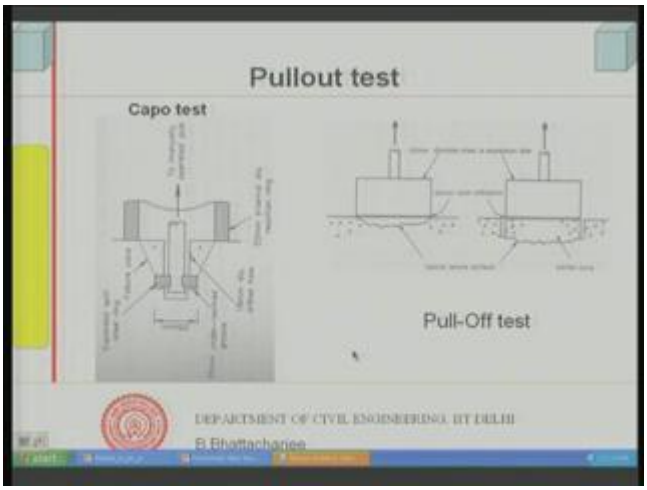

There are other variation of this test for example, capo test is one and these tests are actually now getting popular. The Windsor probe test and this test were not so popular being semi destructive, but capo test and this test are now getting popular.This sound tests are now getting popular, because some of this test has been shown that it is possible the calibration may be universal.

Calibration may be calibration with compressive strength may be universal, but however; this are to be still you know research was still needed.Now, capo test is a modification of the pull out that lock test that I mentioned earlier.What is done in this case is in the previous 1 you have to have an insert kept in the beginningright during the time of construction.So, the strength you should be planning for the strength test you can use that for strength development test, how the strength is developing with time.

So, you can use it for that purposes or if you know, that becomes a useful way to use that particular test or at any time you want to find out the strength. But in a distress structure or structures, where you want to just now see already built up structure and you have not put in any insert there how you are going to do, how you are going to do, use this testthis test Capo test provides such a solution to such a problem.

So, in that sketch what is done you drill a hole through it and there are means, by which you can actually widen this hole here and then you have to still ring fit it here you know. So, then you can widen this ring and this ring cane pulled now through this you know through this jack operated rod and you have rings reaction rings.

So, in an actual structure you can do this, actual structure later on in situ you can do this test sizes you can see 25 millimeter this is about 40 millimeter so right. So, it is not small portion where you drill a small hole and then you can use this 1.

So, this can be done in structures which have been which have been already built slightly different varieties variation of this 1 is, what you do is you have again a device through which you know you can 50 millimeter diameter jack pulling pull out road actually. This is the device whichcan be glued here.

So, you have a strongepoxy resin strong epoxy resin bond here this you put and bond this 1, bond this plate or disc here and this can be pulled out. So, when you pull it out the failure will be something like this.In a way that it is actually there can be a tension failure. There could be a tension failure here and it will give you some idea with the tensile strength of concrete.

Slight other variation of this 1 could be that drill a partial core here; partial core here do not remove it and glue this with epoxy here and then pull it.So, then this failure would be taking place somewhere here.So, this is called Pull-off test, pull out test and pull-off test some variations of this 1s and 1 can relate the strength to this sort of you know indirect measures.

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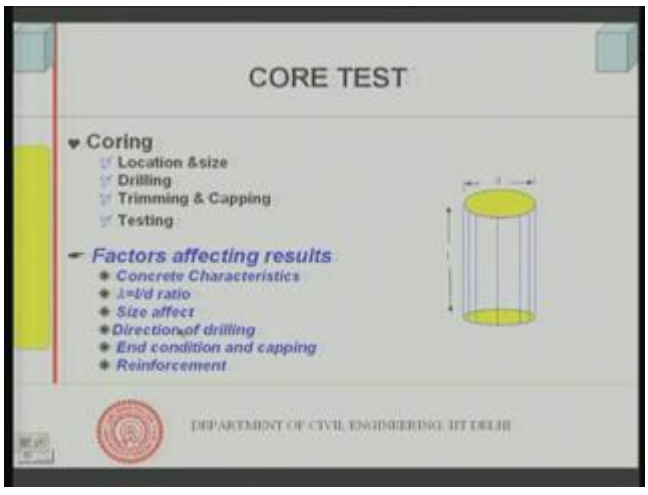

Now, these are so far you have discussed about the indirect test.1 direct test is the core test this is the most reliable, but unfortunately there are 2 problems this is damaging to the structure you cannot do this very large number. It is difficult to do this 1 in very large number this basically, because this is semi destructive definitely will create weak points in the structure.

But at the same time this gives you the most reliable results. So, anyway let us see and how you utilize this together with the indirect system, indirect methods that will be more useful for us.

So, when you do core how do we drill? We actually drill the core through rotary drills usually with a coolant. So, we have a simple drilling machine with rotary drillbits, which will penetrate into the concrete and you can just take out the core it will cut the core and you can take out the core.So, important issues related to such corings are: location and size of coring location of the core, size of the core, the drilling process then you do trimming and capping then testing.

Right we will see the factor affecting this result a little bit later on.Let us say, this is how a core concrete core will look like you know it will have a diameter d and length l after of course,after it has been polished, after it has been actually trimmed as it is called trimming and capping trimming is done.Sol and d, d is the diameter, lis the length what are important location is important, location should be such selected selected in such a manner number 1.

So there must be useful that must be useful for my test, but it should be at such location where, if I create a damage it should not weaken the structure too much.Although you will fill it up in with expansive cement or similar other kind of formulation non shrinking formulations you know, expansive cement which expands the structure too much. Because, you form a core this core has to be filled in and this has to be filled with such material which actually will not shrink and get sort of detach from the original structure.

So, it has to be actually shrinkage compensating of formulation, but should be taken from such position that it does not create much damage to the structure that is number 1 issue.

Number 2issue of course, is it must be according to the general principle of location selection of the non destructive testing what I mean to say is, we shall see later on that strength of the concrete varies depending upon the location of the structure for bottom or top or middle. So, 1 has to take care of that sort of situation strengths are not same and accordingly you must take it at random manner, if you are interested overall behavior and accordingly 1 must select the location.

Size of the core should be minimum 3 times more than, the you know diameter this d least dimension should be more than 3 times. The maximum aggregate size to have it to representative other ways you can do it, but you have to do large number of cores.For example, if you take 50 millimeter and you have 20 millimeter aggregate then you may have to do test 9 cores instead of testing 3 cores to have representative results.

Size of the core is important minimum size should be minimum dimension of the core should be more than 3 times the maximum size of the aggregate in the concrete, so that is how we select the size. For example, 40 millimeter aggregate size you cannot use three inch core 75 millimeter you cannot use.You have to use atleast 150 millimeter core and. soon.

Drilling is usually done through rotary machine as I told you.So, this rotary machine drills the concrete and cuts out this sort of shape although it will be undulated at the bottom and undulated at top. You know, you will get some sort of surface of course, the surface you will get like this, bottom you might get something like this.

Once you have obtained the core from the surface because essentially from the surface you will get.Some time in slabs you top finish surface. So, you will get some what undulated bottom you will get definitely some sort of undulated.Then, you would trim it off cut it off by concrete cutting machine, diamond cutting machine this drill bits are also diamond drill bits usually and then trimming is done with this.

Now, while drilling you usually use can use water cooling or air cooling or oil cooling where, water can contaminate the concrete for chemical test. Then, 1 have to be 1 has to be careful regarding the coolingmaterial cooling fluid that is already that is used.Right now, trimming you do and you get polished surface like this.It should be plane parallel as we have discussed earlier for strength of concrete, compressive strength of the concrete.

So, however and l by d ratio are most of the core specifies this minimum l should be l by d ratio should be 1 and maximum to 2. And you we have understood, why l by d ratio you know how strength varies with l by d ratio.So, minimum specified is 1 now, supposing you are not getting 1 or you know some or other you are not able to trim it then you can do capping, but capping must be done with the standard material specified in the core.

For example, if it is specified high alumina cement it should be high alumina, if it is specified sulphur cement it has to be according to that. So, high alumina cement you have seen is the strongest capping whereas, sulphur is somewhat lower. So, specific capping should be used it should be used uniformly and strength should be correlated accordingly.

Because, strength would vary depending upon if you have done capping with some other material then testing is done in standard manner. Now, let us see what are the factors which affect this test result obviously, concrete characteristicswill be affecting the strength lambda which is l by d ratio. We have understood now l by d ratio, because there will be platen effects which we have mentioned earlier in connection with strength and we have curves and relationships which tells us how the strength would be, how the correction factor for l by d ratio.

Normally we standard cylinder is l by d ratio equals to 2. So, we have correction factors for the near the l by d ratio and you should not test the cube core which has got l by d ratio less than 1.

So, this affects the strength size affect large size of course, could have smaller you know higher strengths, large size will have smaller strength, small size will have higher strength we have seen such variation. And direction of drilling has got some effect, if you direction are parallel to the casting, drilling is done parallel to the casting that is horizontal drilling or it is done vertically then strength differs as much as by 8 percent.

Some relationship we will seeso, this direction of drilling has got a role to play in core. And condition and capping we have mentioned strongly affects the strength of apparent strength of concrete and if there is reinforcement, then this will also change the strength.

In fact, it will lower down the strength by introducing some sort of discontinuity at the interface and all this factors affect the core strength. So, there has to be correction or brought in and then 1 would like to find out what is the equivalent cube strength.

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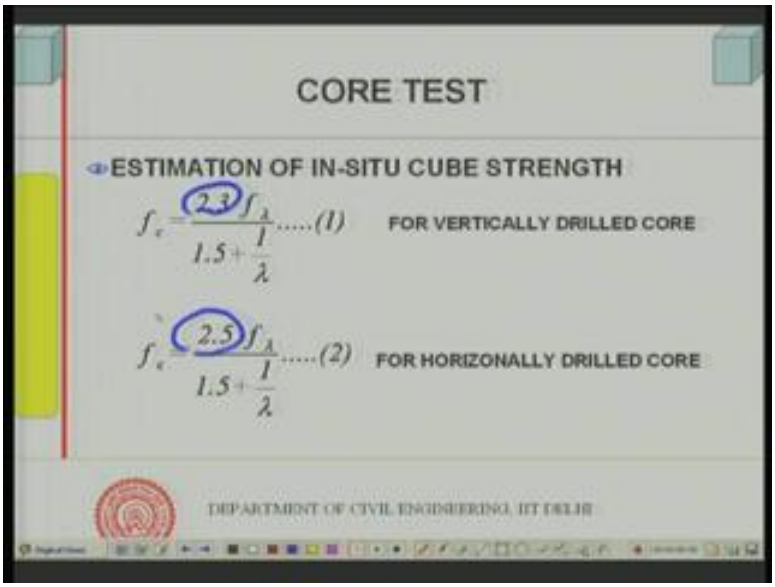

This is the formula given in British code the In-Situ cube strength you know we distinguish something called In situ cube strength from standard cube strength.We have mentioned that, strength in structure is different than strength in the standard strength in standard cube.So, standard cube strength is much higher usually higher and in design this is taken account of

So, estimation of In situ cube strength. So, this formula gives us In situ strength for vertically drilled core for horizontally drilled core this is something like this. You can see that the correction this factor here; rest of the things remain same this value is lower here this value is higher here 2 5 and this is 2 3.

So, that is the apparent strength you are getting here for vertically drilled core is higher, apparent strength you are getting here for vertically drilled core is about 8 percent higher than horizontally drilled core. This is because the layer effect because casting you know moisture would come up and the cement goes down.

So, apparently vertically drilled core gives you better results higher strength results, that is why you multiply by a smaller factor and this is multiplied by a bigger factor. Lambda

is a l by d ratio, so f lambda is a measured strength lambda is the l by d ratio. So, you can see if l by d ratio in this case l by d ratio equals to let us say 2 these values equals to 0 5

So, 1 5 plus 0 5 makes it 2. So, 2 5 divided by 2 is 1 252 5 divided by 1 5 plus 0 52 is 1 25. So, the strength for lambda equals to 2 strength is increased by 25 apparent strength would be increased by 25 percent. When lambda equals to 1 this value equals to 1.Lambda equals to 2 you know like this is equals to 1.

So, this f c equals to f lambda straight away.When lambda equals to 1 this value equals to 1, so 1 5 plus 1 equals to 2 5, so f equals to simply f lambda.So, anyway this is what we find out in In situ test. This is given in British code of course, IS code does it in a slightly different manner I will just tell you.

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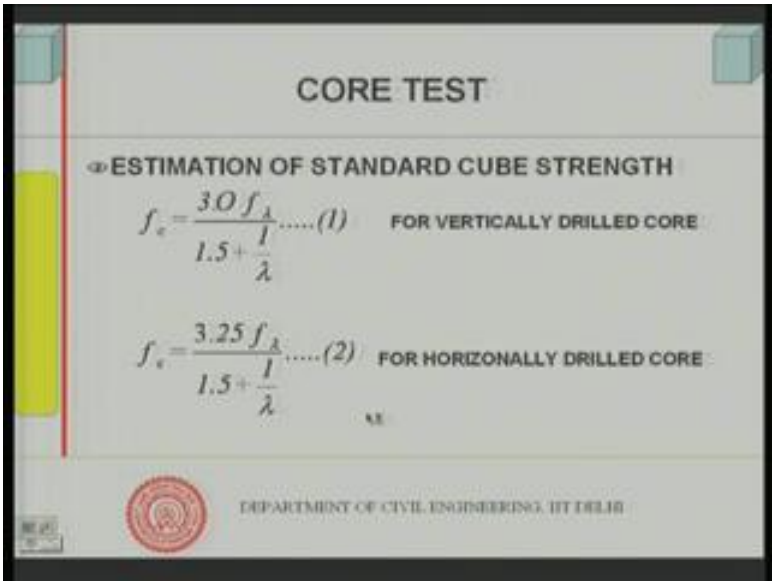

Right now, supposing I want to find out the standard cube strength then I must increase the strength and it is suggested that roughly you can increase the strength by 30 percent. So, if you increase the stress strength by 30 percent 2 3 becomes 3 and 2 5 becomes 3 25. So, this is what is the standard cube strength, so we can predict the strength at cube strength.

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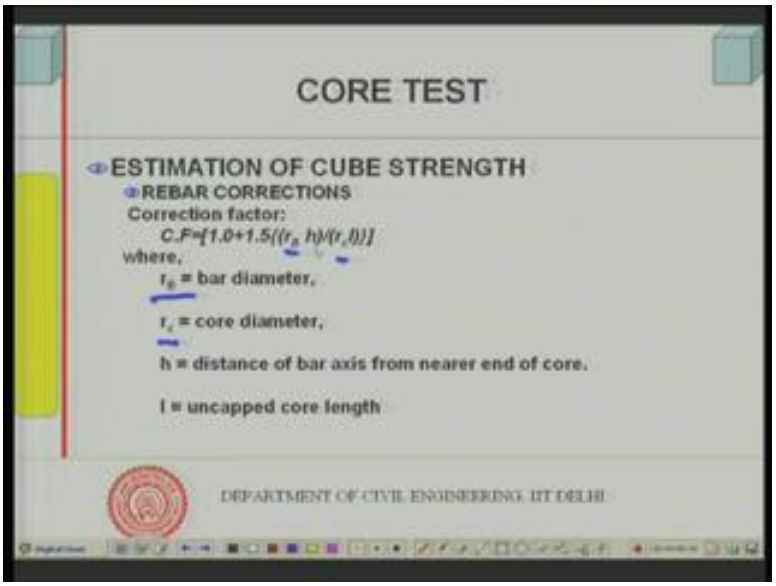

If there is a reinforcement correction suggested in the British code is something like this correction factor is really is more than 1. Because, reinforcement lowers down the strength and if you go through this equation this is the bar diameter this is the bar diameter divided by r c is a core diameter. So, ratio of r b by r c and h is the distance of the bar axis from nearer end of the core.

For example, if this is my core and this is the bar, so this distance is the distance from anearer end of the core h and l is a total uncapped length. So, h by l this ratio, so it is 1 5 times this multiplied by this is the correction factor 1 0 plus 1 5 times multiplied by this factor.So, this correction factor will be generally correction factor will be more than 1. Now, if you have number of bars then you should sum up all this sum up all of them and the correction will be obtained for all them together.

Usually if more than 1 bar is very unusual, so if there is a reinforcement bar correction factor can be. But it is better to avoid reinforcement in core, it actually spoils the drilling machine and of course, also introduces an additional correction factor.So, it is better to avoid and 1 can do it if 1 does what is called find out using a bar locator or cover meter to find out the bar and then do it.

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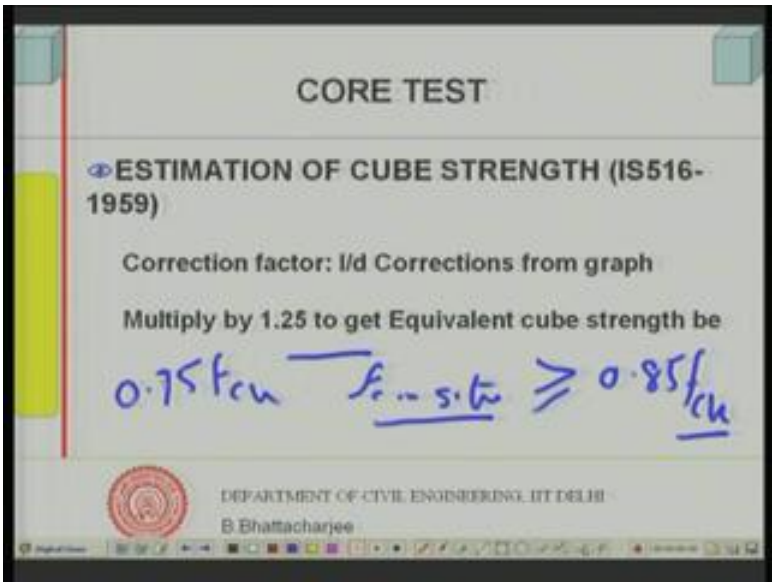

Right as far as IS: 516 is concerned you remember we have given the correction factor for l by d correction from graphs. There was a curve graph l by d divided by correction factor. You know the graph was there. If you remember and we discussed earlier in 1 of those discussion. So, what you do you use this correction factor given in the code through from chart and for the bring the strength to correct the strength for l by d equals to 2 your l by d ratio could be say 1 5.

Then, using the correction factor you get the strength or l by d equals to 2 multiplied by 1.25 to get an equivalent In situ cube strengthand code is very specific.This strength should be mean of this strength for a particular location should be 0 85 times should not you know this strength should be this strength, that you get equivalent strength that you get should be greater than.

So, f c In situ if I call it In situ strength should be greater than 0 85 fck for concrete to be accepted for a given rate. And no individual result should be less than 0 75 fck.Mean of result mean of result should be greater than 0 85 fck and no individual result should be less than 0 75 fck. For example, if I tested three cores mean of this three cores for a given slab.

Let us say, should be more than 0 85 into grade of the concrete in that slab let us say it is M twenty grade concrete. So, 20 into 0 170 85 into 20 would make it 17.So, mean

strength of the cores should come after your corrected first l by d correction multiplied by 1 25 should be more than point.

So, you know 0 17 into you know to actually be accepted as M 20 grade of concrete. And none of this core strength should be less than 0 75 fck that is 20 into 0 7516 which means, nothing should be less than 16 and mean should be more than this to be accepted as M 20 grade of concrete. Accordingly we can accept any other you know grade of concrete and so on soforth right. So, these are the how we do measurements? Now, let us see how overall planning and interpretation we do.

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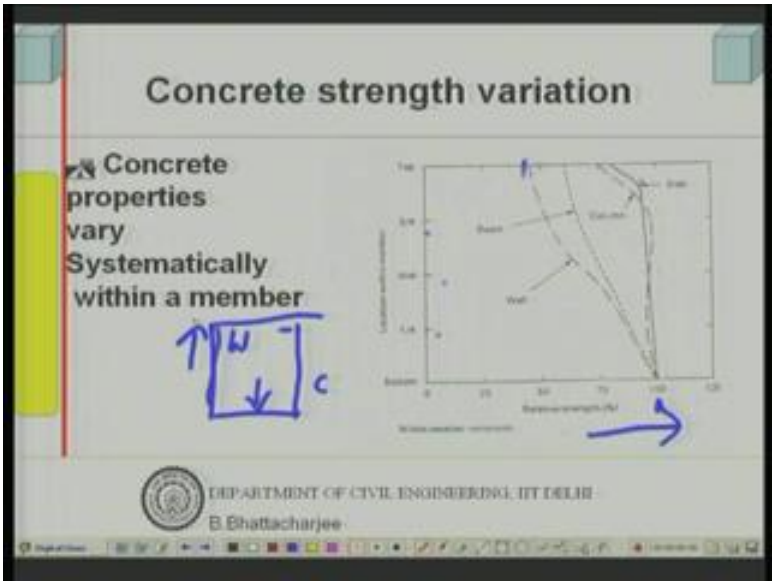

We must understand few facts while doingnon destructive testing, you see concrete properties vary systematically within a member.This is what is been observed relative variation of strength in a member you know. So, now this is what has been observedrelative strength supposing at the bottom of the member it is 1, then top three - fourth of the height meet height, one-fourth height etcetera, etcetera.

For slab you have seen that by an large strength is more or less same, but the top strength would reduce for column it something like this, vertical it is something like this.At the top there will be less strength and for beam it is something like this and for wall you may have even nearly less than 50 percent of the strength at the top. So, if you have 1 at the bottom top it could be as 50 percent.

Why is it so? Because, inherently concrete consists of cement, water etcetera.So, cement will have a tendency c will have a tendency to come down, w will have a tendency to come up.So, water cement ratio here is the maximumwe have seen that we discussed that earlier some time.Maximum water cement ratio at the top side concrete is also not as good, but this is the worst concrete you will have bleed water will be accumulating at the top.

So, you have highest water cement ratio in this zone possibly least somewhere here.So, this is highest water cement ratio in this zone strength would be least up there maximum strength we will see at the bottom. And that is why you find there is a relative strength in variation takes place and it systematically varies within a member. Now, this must be remembered while selecting the location that is what I was mentioning.

Supposing just you go on selecting everything from the top then you are likely to find lower strength. If you select everything from the bottom then you are trying to find out higher strength.But one has to randomize appropriately to take appropriate number from all places, for coarse or any other rebound or any other measurement you are doing you must do it keep this in mind.

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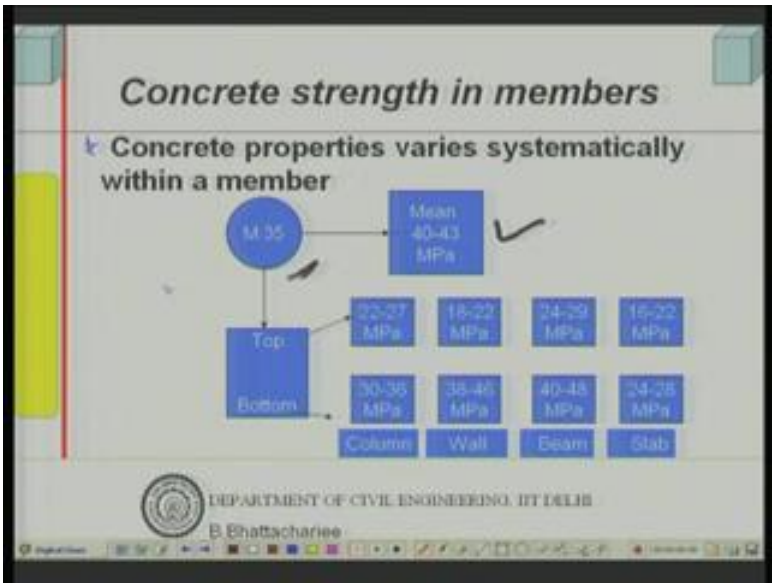

Concrete strength variation in mind right concrete properties varies systematically within a member and this has been recognized and you can see this again comes from British code. You know they are finding this from British code that, if you have a 35 grade of

concrete, mean cube strength will be 40 to 43 MPaM 35 grade of concrete target mean strength is higher. We know because of there will be you know this is 95 percent characteristic strength as we call it. If you remember when we define the grade of concrete we said 95 percent of this time the cube strength should be exceeded. That strength should be exceeded.

So, for M 35 grade of concrete cube strength should be exceeded 95 percent of the time it should exceed 35; only 5 percent of the time spent can be lower than 35. Sothe mean strength is much higher, because mean strength corresponds to that strength which will be exceeded 50 percent of that time. So, 40 to 43 MPa would be mean cube strength.

Now, you see the top and bottom of various members column would be something like this, wall would be something like this, beam would be something like this and slab would be something like this.In fact, what we saw in the earlier diagram was relative strength between bottom and the top, but bottom strength itself is much lower than the grade of concrete.

So for example, in case of slab of M 35 grade you might find the bottom strength itself is 24 to 28 and top would be much lower as we go up it would be constant throughout, but at the top it will be somewhat lower. And in case wall we have seen, here the bottom is of course more or less it will be slightly higher than the grade of concrete you know somewhere close to this, but this is nearly halfthat you know 38.

So, half is about 19or, so nearly half and beam in similar 40 to 48 you get bottom quite high, but the top somewhat less and column it is something like this.So, this is how the strength variation takes place within the member. And this 1 must keep in mind, while selecting location and after doing the test during the interpretation time as well.

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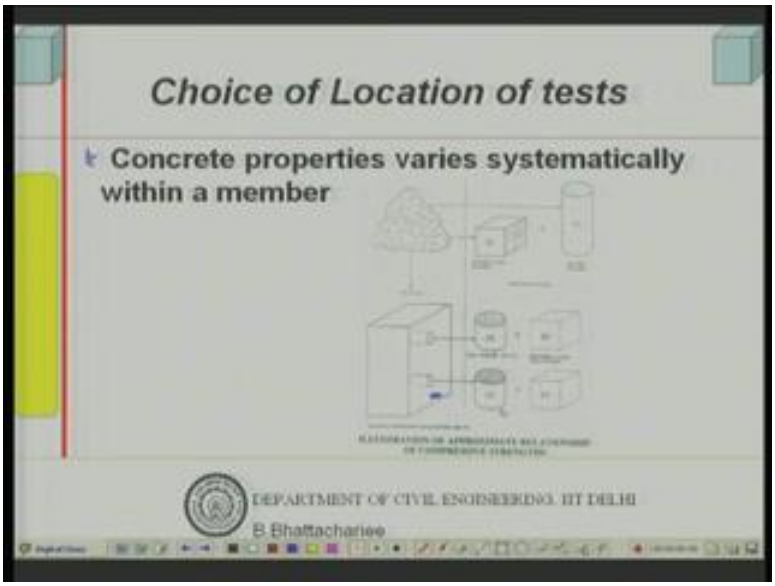

So, location of the test you must keep in mind, so the you know concrete properties varies systematically. This is been shown through another diagram also. For example, you know it is something like this the bottom I mean bottom would show somewhat higher strength in cylinder and concrete cylinder and concrete you know it is showing that core to equivalent cube.

So, we find out core to equivalent cube, we find out 1 is to 1 core and this is the bulk concrete; concrete in cylinder and cube strength. This is what is the same what we have seen earlier it is shown in a slightly different manner same thing. So, this is been understandable that concrete strength varies systematically within the member right.

We will come to interpretation number of test although I am not really included the number of test the statistics behind number of test in this discussion. But I would like to mention here the number of test you want to do in a structure, depends upon how accurately you want to determine, how reliable you want to determine.More the number of samples you take you will be your accuracy will improve. Error of estimation will be less you will be close to the true value, but it will increase the cost also some cases damage also.

So, the number of test will be done is a function of damage, cost and the accuracyyou know it is a compromise of all this. So, you know this is a compromise of all this.So, you know this is a compromise of all this.

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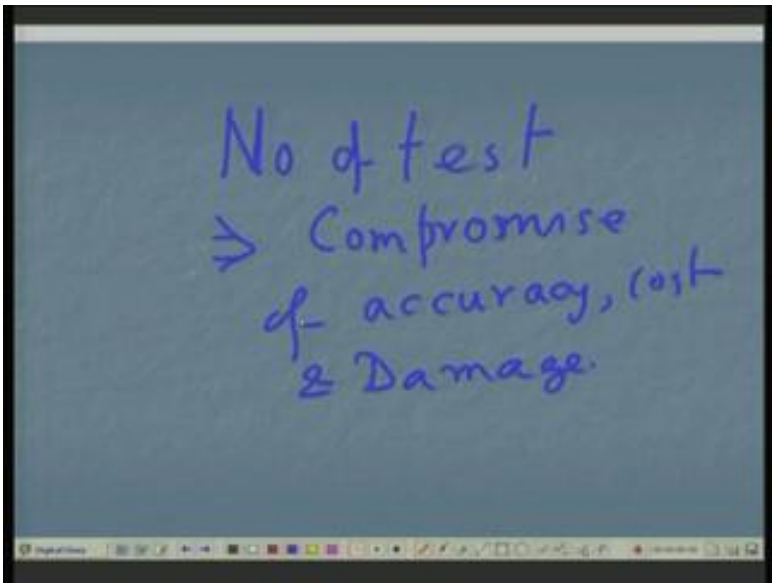

So, number of test we do is a compromise of compromise between all this; you know number of test actually is dependent on is a compromise of accuracy, cost and damage. And there is a whole set of statistics behind this how we choose this. But at the moment we are notlooking into at the moment we are are not looking into this, but you know locations we have discussed not in details, but some idea number of tests are selected in this manner.

If the problem is the person if the agency, whichis trying to do the test would like to do as many test as many number as possible. Whereas, the owner of the client would like to as least as possible. Because, the cost is important.So, it has to be a compromise between the 2 and also the damage to this. Now, interpretation of the test results will finally, depends upon the objectives.

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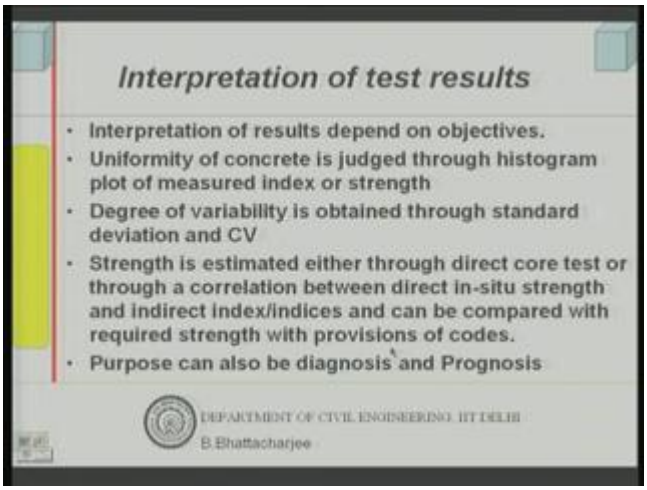

Uniformity of the concrete can be judged through histogram plot of measured index or strength.Supposing I just want to find out how uniform the concrete is, is the source of concrete is 1.It is a uniform concrete I can plot the histogram plot and I can find out whether concrete is uniform or not.

If I want to find out the strength then of course, I have a correlation, but if I am just interested in the degree of variability then standard deviation and coefficient of of variation I can find out some statistical measure.At the moment we are not doing this exercise, but we know this how we have to do for our purpose in this discussion, we must know that we can do all these interpretation.

When it comes to strength estimation this is important, you see either through direct core test or through correlation between direct and In situ strength and indirect indices. So, I must have a correlation available and can be compared with required strength and provisions of the codes etcetera.Now, this is done either I must have a established correlation or I must develop this.

Sometime in not very old concrete if cubes are available, I can test this cube got from the indirect non destructive means and crush them under standard you know in standard manner. And establish a correlation between cube strength and the concrete that is to be tested you know In situ.If that cannot be done and limited number of core can always be taken.

A limited number of core can always be taken from the side. Limited number because core tests are costly they are damaging.So, you would like to do as minimal as possible you can do a limited number of core and establish a correlation with the indirect index or indices. And using this correlation find out the strength, estimate the strength all over the structure by doing large number of indirect test.

Because, indirect tests are not damaging particularlyrebound hammer ultrasonic pulse velocity test.They are not damaging and you can do this test and if you have a correlation available, using this correlation you can predict the strength.Remember this strength correlationI mean the strength prediction will not be very very accurate plus minus 20 percent is acceptable.

But you will get you can predict the strength by doing less number of core test and using those core tests results for calibration purpose. Then, do large number of indirect test and estimate the strength from the indirect strength result, using that correlation. But that correlation has to be concrete specific right. So, this is how strength can be actually estimated in In situ infrastructures and then check it with the provisions that is available in the code like I mentioned 0 85 time f ck the mean strength should be.

No individual results should be less than 0 75 etcetera.Or some other code gives you elaborate way of doing it. Some cases of course, diagnosis and projection of the future damage can also be our purpose, but then we are not looking into in this discussion, we are lookingonly to prediction of strength.

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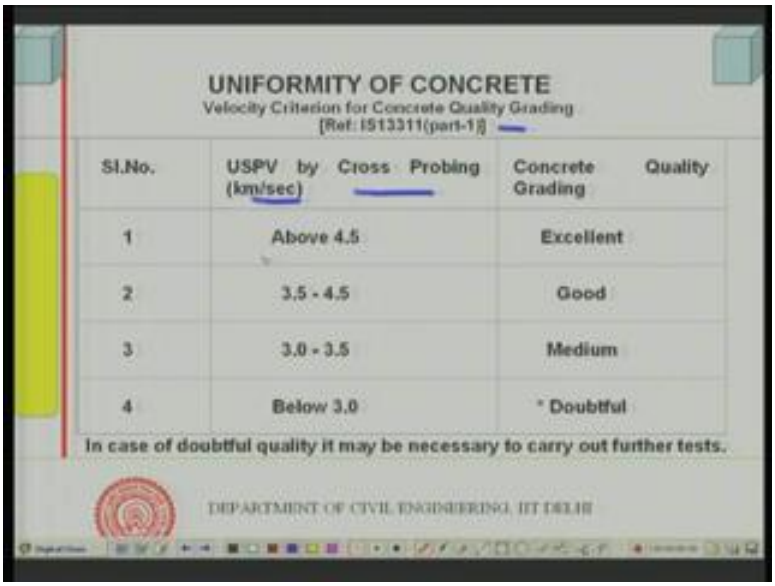

Uniformity can be judged from ultra sonic pulse velocity it can be judged from ultra sonic pulse velocity test like this you see as per this code or many other codes, if you have direct measurement ultra sonic pulse velocity by cross probing that is direct measurement. Measured in kilometer per seconds, if this value is more than four point five kilometer you can say concrete is excellent which means, that it is compact it is solid sound no pores; no compaction pores you know the you say it is a solid concrete.

It is a solid concrete honeycombing nothing it is a real sound concrete and quality etcetera.If the velocity is between this then you can call it good, if the velocity is between this 3to 3 5 it is medium and below three is doubtful.It is doubtful it is not rejected at as yet it is doubtful. If you want to reject it, you may do some more test and then reject it you do some more test and reject it.

So, this is 1 thing 1 can do as per our ultra sonic pulse velocity test is concerned and determine the ultra sonic pulse velocity test is concerned and determine the quality of concrete.So, first thing you can find out quality of concrete how much quantity of concrete you know, how much area the concrete is of excellent quantity and if there are 1 or 2 doubtful quantities or you know doubtful qualities are not.

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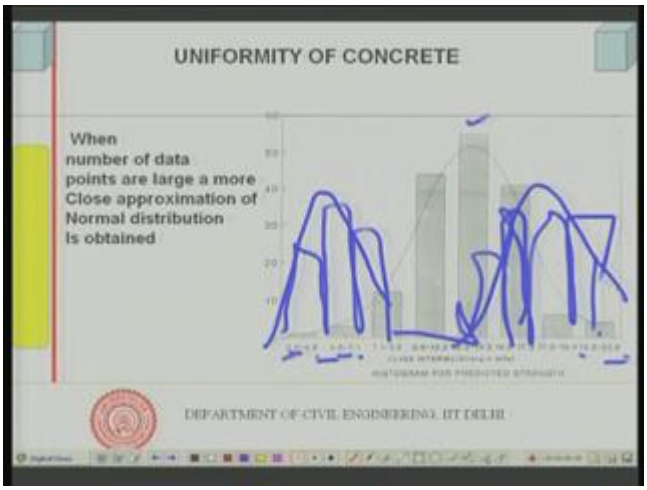

If it is doubtful do further test then you can use histogram plot I mentioned. Find out you know whether the concrete is uniform or not. Now, a uniform concrete would show normal distribution behavior you plot histogram for example, here it is drawn for strength here it is shown for strength.

Strength range from 2 to 4 6 to 7 1 and similarly something like 19 9 to 20 2.It is actually and actually a structural concrete where measurements were done. And you can actually this class intervals number of class intervals, you can determine from statistics using right kind of formula which I am not discussing here.

But once you have done this classified total data range from 22 5 to about 2 has been divided into number of classes class interval as we call it in statistics. And in each class intervals how many samples are there that you can plot which, we cal as frequency histogram and you knowing the frequency histogram.

If this is showing one pick that is a normally distributed you know. So, uniform distribution uniformly 1 can pick normally distributed pick. So, I say it is a uniform concrete comes from one source, because nothing you know it will have some variation about its mean. But supposing I would have got instead of this I would have got something like this, something like this and there are nothing here and then something like this, something like this, sort of something like this sort of curve.

It means, if there are 2 distinguished picks that would have told us, that concrete has come from 2 different sources and if it is all unsymmetrical also it sort of thing that would tell me that concrete is totally non uniform.So, uniformity of the concrete uniform means it has come from 1 source nothing about strength quality, sound or not that I can find out from ultra sonic pulse velocity and by plotting histogram making histogram plot for, either ultrasonic pulse velocity or rebound hammer or evenstrength I can find out whether the concrete was uniform or not you know.

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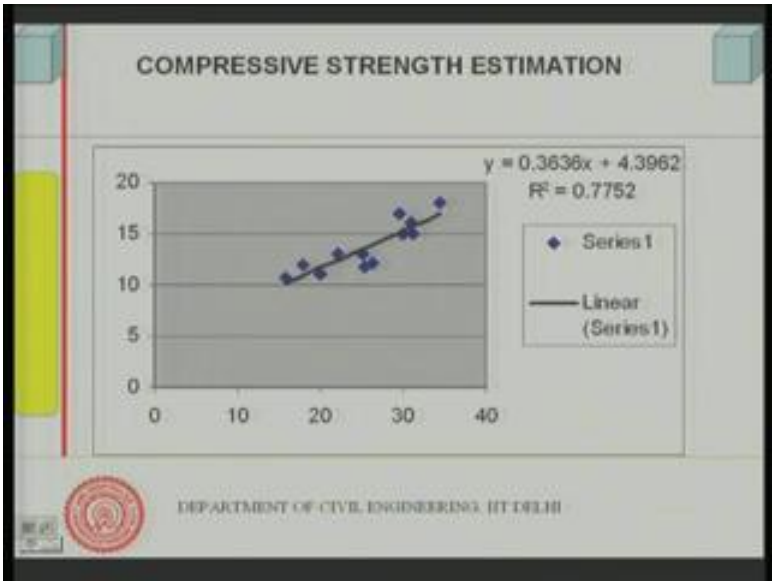

So, it must show normal distribution behavior compressive strength estimation while compressive strength estimation if I have correlation available. And if I have just a rebound hammer correlation this is not a very good correlation as you can see R square you can just get it in Microsoft excel.

So, x axis is this is the strength versus rebound number x axis is actually rebound number y axis is strength a correlation has been obtained. And this correlation is a 1 dimensional correlation, 1 can obtain this correlation from some data and for example, if this is your rebound hammer this is your rebound hammer. For example, if this is your rebound hammer, this value is the rebound hammer then strength can be found.

So, correlation has been established once established correlation is available you can use this correlation to find out a rebound number is known I can predict the strength. Now, when you have combined correlation available for rebound hammer and ultra sonic pulse velocity you know combined correlation available for rebound hammer and ultrasonic pulse velocity.

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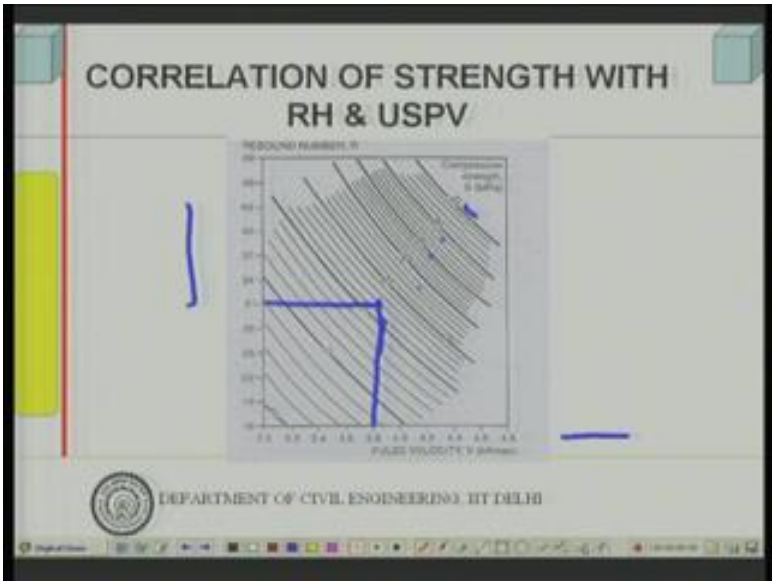

Then, you can find out the strength from this sort of a combined correlation. Say this side is rebound hammer number this side is ultra sonic pulse velocity; compressive strength line this is forty line 35 you know 30 etcetera etcetera.For example, if I have value of 3 5 kilometer per second and 31 is a ultra sonic rebound number from this correlation I can find out this strength is this line which is actually 211987.

So, I can actually predict the strength when such a correlation is established right.So, that is what it is and then that is how we can determine the strength of concrete. So, that is how we can strength estimation we can find out we generally determine the structure through non destructive testing and then predict the strength. And the strength predicted should be f ck divided by you know about 80 percent according to British code this is about 80 percent.

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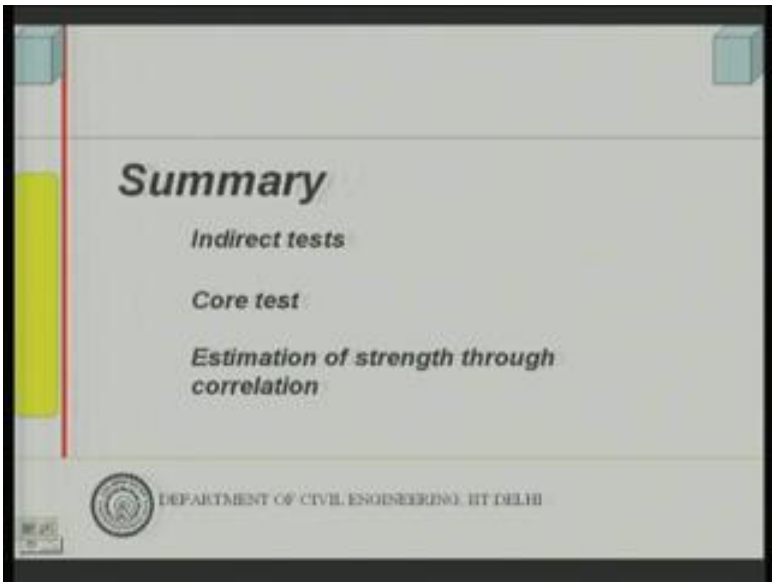

So, what we have now discussed is we have found out what are the indirect test the core test and we have how do we estimate the strength through correlation that is what we have looked into. So, I think with that actually nondestructive testing, we conclude nondestructive testing.

Thank you very much for being with us.