Fire Protection, Services and Maintenance Management of Building
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Lecture – 50
Non Destructive Testing- 2

So, continuing from where we stopped, you know velocity of mechanical wave is a function of elastic modulus and density.

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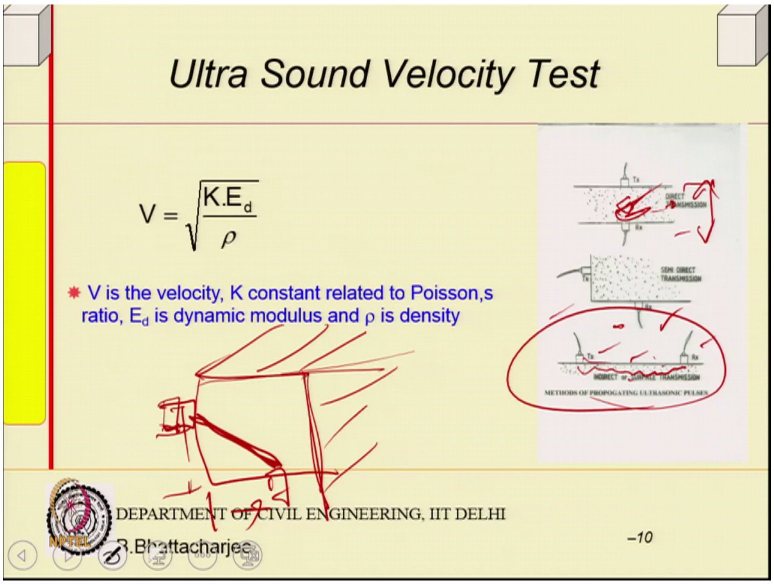

Therefore, it can give you some idea about the soundness of the concrete. Now, how do you measure them? You can actually have what is called a direct measurement like this is your section, you usually you will have a transducer and a receiver right.

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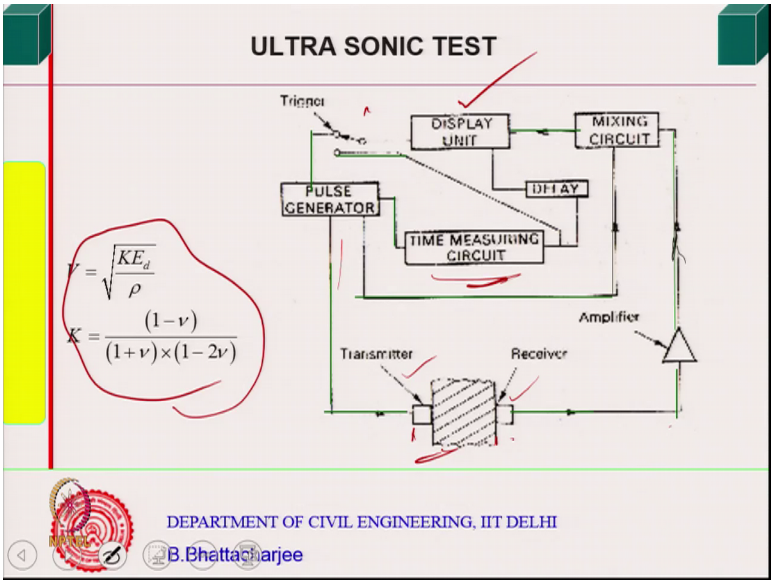

I suppose, I have a diagram. Yes, it will looks something like this. I will come back to that slide later on. So, you have a transducer and a receiver. Now, this transducer is connected to a pulse generator which will generate the ultrasonic pulses, you know some sort of oscillator and then converts this electrical energy into mechanical waves right.

So, this pulse generator and this is a receiver. Then, obviously, this receiver again converts this electrical transducer converts electrical pulse into mechanical pulses and this receive the mechanical pulses and convert them into electrical signal again is amplified. Then, they it actually you are trying to measure that time of travel, you actually measure the time of travel time. So, there is a time measuring circuit right.

So, basically this is received one and this is the input one. So, what is the time delay between these 2 that is what you find out and then there must be some sort of display unit. So, basically you know you switch it on and therefore, pulse is generated and there is a transducer. So, this is your section. So, this kind of a measurement is simply the direct measurement you put the transducer on one side and the receiver just exactly opposite to the other side in this specimen. So, that is called a direct measurement right.

So, direct measurements it actually measures time, but today modern instruments will have a digital display. So, it would ask for an input of the thickness of the section there will this dimension. So, if this dimension you input, it will straight away calculate the velocity and give it in good old days one, you know this will give in micro second. It will give you time of travel through this path in micro seconds and you know the length. So, you calculate out the velocity yourself.

Now, this is direct measurement you can have a indirect measurement because all the places you may not get both the sides of the section right, both the sides of a section. For example, some column I have a column and let us say, I have wall on this side wall on the side both the sides have wall, you know walls on this side. It is not available for whatever reason then, I want to find out what is a ultrasound pulse velocity in this.

So, I can put transducer here, receiver there, you know transducer here, receiver there. Now, this will be the path length then. So, your input path length will be given by since you know this dimension this dimension. Therefore, you can find out the path length. So, this is called semi direct measurement something like this semi direct measurements. Semi direct measurement you can use it in corner, but you can also do for example, a you know basement wall or something only one side is available.

Then, you can do what is called indirect measurement. So, put the transducer and receiver in the same. But then, remember only a small you know what you call S wave surface wave will reach here and it is usually the percentage is very little, it is a around 3 percent of the total energy that goes like this and usually velocity of this wave is less. Then, the velocity of P wave or the you know direct this wave. So, this you cannot you know you cannot compare this measurement result with this measurement result because this rule be measuring only the surface wave right.

Whereas, this is direct measurement and the velocity is less. So, therefore, they cannot be compared, but you want to compare this with another place where you have done this measurement that is possible, but this will not also not give you information about the complete section this will give you information about the complete section this will give you the information about the complete section. For example, if there are voids here bad concrete in the core, you will get in more information for this while this will give you information about the surface concrete, all right.

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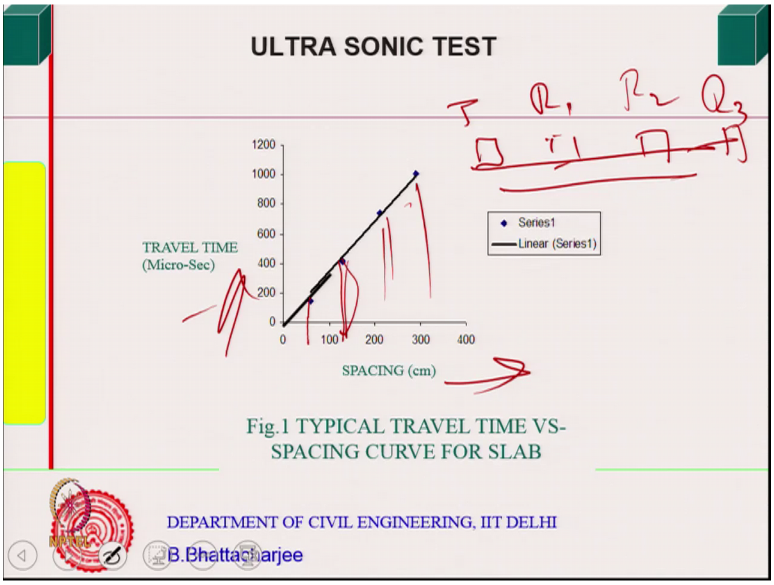

So, what you do is in such situation, in such situation what you do is you know, ok. So, this formula anyway I just mentioned already. So, what we do is in such situation? We place it indirect measurement right in a slab. So, what you do? We measure that fixed spacing say 75. So, you have transducer placed here T receiver 1 R 1 and place again. Shift the receiver R 2, then shift the receiver to R 3 positions something like this right. Then, travel time if you plot travel time will increase when you are making measurement, indirect measurement travel time will increase and is expected to increase linearly if the you know velocity is constant.

So, therefore, you can find out the slope of this one and what 1 over that slope will give the velocity because this side is the spacing this side is a travel time spacing versus travel time. So, distance between distance divided by time will give you the velocity. So, you can actually make measurements at different places this will be more relatively more reliable than taking single point measurement. So, this is how you can measure actually you know indirect measurement, but this can all be used for comparison.

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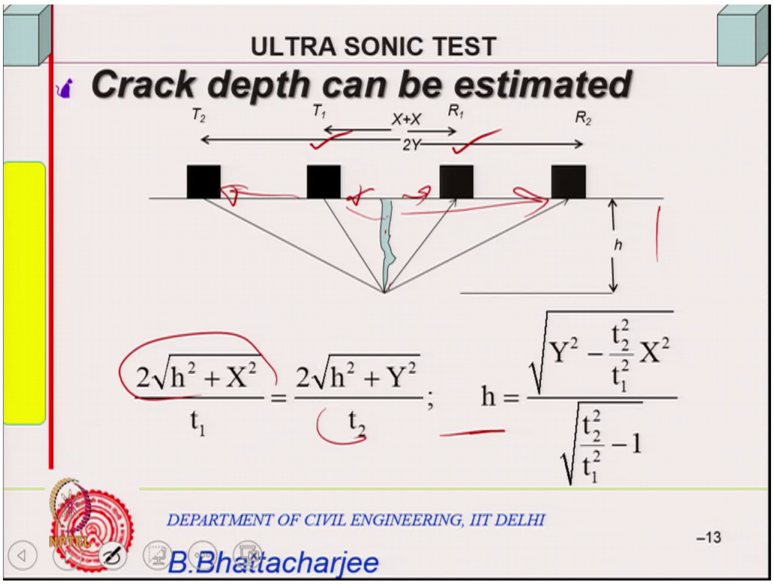

You can also estimate crack depth how simply measure, this is your crack and this is what we actually used in one of the cases of the segment we talked about. So, one could find out or at many places, what you do? First, you place your transducer at this position and receiver at this position at some equal distance. Then, shift it to some distance here Y and this also shift to the same distance from the geometry of this is the height of the crack from the geometry simply you know time of travel in both the cases are known.

So, in this case since is void the receiver will measure the time the earliest time receiver will measure the short you know time required to travel to the shortest distance.

Because, through this air gap is there the velocity will become very less and the this wave will reach much later. So, it will first recognise this one this you know the quickly. So, the path is simply h square plus X square divided by you know. So, to if you see, since the velocity same in both the cases, then this 2 should be same in this case path is Y square plus h square under root right, Y square plus h square under root then twice of this divided by t 2; that is the velocity distance travelled and in this case first case distance travelled is this much.

And therefore, one can obtain value of h 1 can obtain the value of h. So, crack depth you can measure using this kind of technique; particularly, on flat surfaces if is vertical surface same technique you can use and you can find it out. So, crack depth can also be measured or estimated rather using this method right. You can also do it by some other means. What you do in this case?

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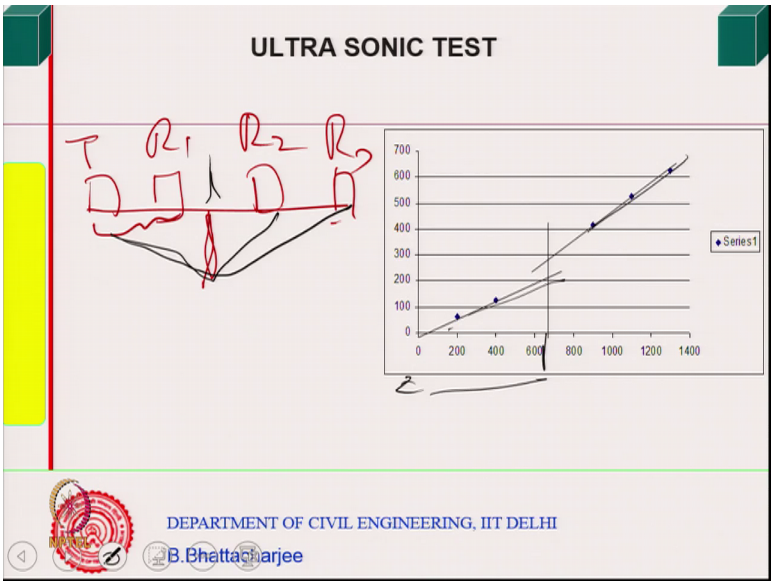

In another case, what you do is you take you know like same principle here is your crack. So, I have a transducer here receiver point R 1, then receiver point R 2 receiver point R 3 etcetera. So, up to this I will have surface wave like this. Beyond this, actually beyond this what will happen? Beyond this, it will travel in this manner right, beyond this because through that crack it will take longer time.

So, it will not register that and then if you find you find that on this side the result measurements taken on the left hand side or one side of the crack at equal spacing, it gives you a line like this. And after some point, the slope simply changes and this is your crack distance from your transducer point, this is the crack distance from the transducer point which you have measured where the space you able to see. So, there is the change like from this difference you can again find out the crack using geometry. The formula is given here using geometry you can derive it.

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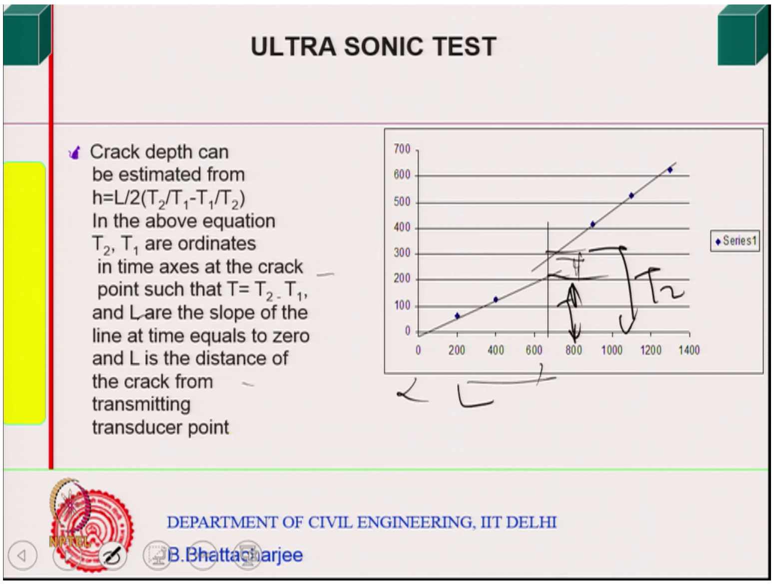

It is not a very difficult one h L divided by T. So, L is this distance and T 2 by T 1 you know measurement time minus T etcetera. So, ordinates at the origin is this T 1 T 2. These are the in T 2 when T 1 are the ordinates in time axis at the crack point such that T is equals to T 1 minus T 2 T 2 minus and L are the slopes here L are the slopes. So, the line at time equals to 0 and L is at sorry this not. So, L is distance from this is L this is L and 2 T 2 minus T 1 is T and this value I am calling as T 2, this value as T 1.

So, from this one can actually find out the cracks depth as well. So, this is how we can actually measure the crack, but I think the previous one was simpler much simpler, much simpler to understand much simpler to understand right.

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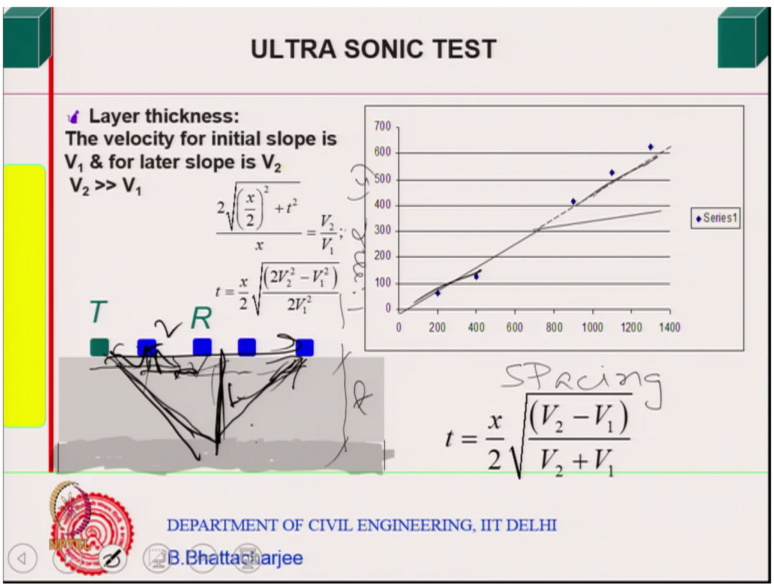

So, you also you can find out layer thickness for example, in pavement supposing you have put a lean concrete, supposing you have put a lean concrete and then you have got or some other or just the concrete thickness rigid pavement thickness, you want to find out below is another layer, then you can use this concept. Again, using ultrasonic pulse velocity you can find it out, ultrasonic pulse velocity we can find it out you know you can find it out how this is your layer thickness, let us say these are layer thickness.

So, put your transducer here, then the receiver points several receiver point's measure. What will happen is this is your you know this is this a transducer receiver points. Now, surface wave will travel like this and as further it goes before this wave can reach it might reach back after reflection through the solid concrete. So, in that case you can find out the layer thickness as well. Suddenly you will find that there is a change in the slope.

Initially, the slope was something like this. Then, there is a change in the slope and thickness of the layer is given by you know this sort of formula t is equals to x by 2 V 2 minus V 1 x is x is the distance spacing equal spacing equal spacing you know for example, V 2 by V 1, this is a slope this is other slope the slopes are different because suddenly there will be change in slope. Now, now V 2 velocity you know this velocity divided by this velocity.

This ratio is being found out from the slope now spacing is if space is x right spacing is x. So, this case it will be x by T x square x square by T and this is divided by in this case, it will be simply x by simply x travelled distance is x in this case x square plus T square under root in this case you know half x square. So, this spacing where you are finding there is a change in slope. So, half of half x by 2 this distance is x by half x by 2 you know and x is the relative spacing when you are travelling like this. So, depending upon this, velocity ratio can be found out in this manner.

So, T could be found out from V 2 minus V 1 divided by C 2 plus V 1 etcetera. So, one can get the layer thickness layer thickness based on this concept assuming as V 2 is much larger than V 1 you know is larger than V 1. So, one can actually use the geometry to find out um, just a minute the something else I want to tell something else I want to tell related to this, all right. This I have already explained I have already explained this. So, spacing also you can determine you can determine also spacing.

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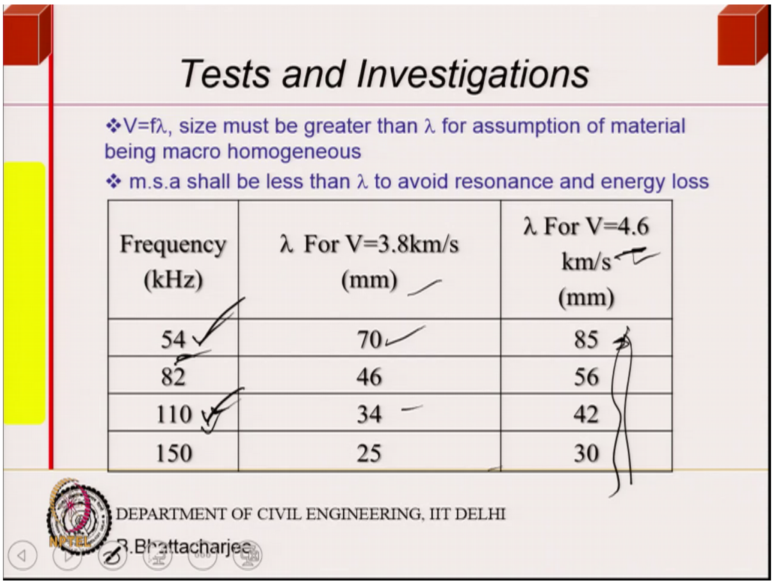

Now, V is equals to f into lambda velocity into frequency. So, size must be greater than lambda that is what I said for assumption of material be macro homogenous right. It should be homogeneous because I am assuming concrete to be homogeneous and m s a shall be less than lambda to avoid resonance and energy loss.

So, if 54 kilohertz supposing my velocity is 3.8 kilometres per seconds my frequency will be 70 mm 100 and 10 hertz this and etcetera and if the velocity is 4.6 kilometres per seconds for higher better concrete these values. So, you can see that you know these are the kind of frequency is normally people using ultrasonic pulse velocity measurement of concrete.

So, machines will have either 100 and 10 kilohertz or 54 kilohertz frequency machine and these are the dimensions millimetre dimensions specimen dimensions. So, there is a restriction on specimen dimensions which you can measure. Now, you can measure in thin sections provided you know higher frequencies as well. So, that is the idea simply calculated based on this assuming this 4.6 divided by 54 kilohertz.

So, 4.6 kilometre per seconds will give you 4.6 divided by you know 54 corresponds to I mean 4.6 kilometre. So, 4 points 4600 divided by 54000. And then, convert the distance that you get in millimetre. This is how you get it.

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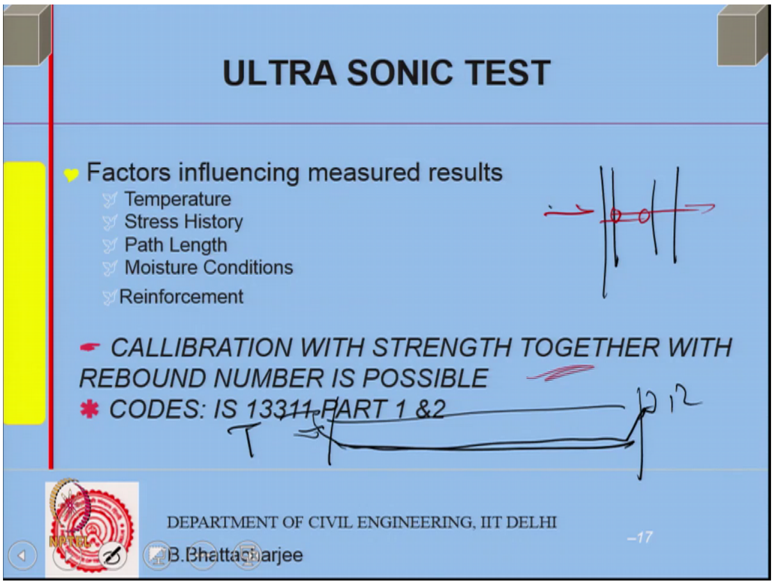

So, that is what it is. So, what are the factors which influence the results temperature some stress you see sometime path length. Obviously, you know, but important is moisture condition. If there is moisture you will get different results. If the reinforcement present, it will modify your result right because velocity in velocity in steel is much higher. So, if you have longitudinal if you have longitudinal rebar and your placing your transducer here T 1 T and receiver here.

In fact, it will not before it travels through this, it will travels through this and you will get much less travel time. So, corrections are needed if you have reinforcement, but normally you do not measure. You measure like this; you measure like know this you know. So, bar would be either like this. So, you usually measure like this along this direction.

So, bar will be something like this or there may be a stir up or there may be a stir up, but normally you can avoid the stir up places bar would be something like this. If the bar diameter less than 20, you do not need to bother about them because this too small compared to the section.

But, if the bar diameter is sufficiently large you have to apply some corrections. So, you can get idea about that soundness of the concrete elastic modulus and density how solid it is, how porous it is, long velocity means porous; higher velocity means solid and sound concrete. But, you want to get the strength then strength there is a little bit of problem.

Because, it is not you know relation relationship between the velocity of mechanical waves or ultrasonic pulses ultrasonic pulse velocity and strength this is not this is usually not linears non-linear and extrapolation because very difficult because you can understand from this from the fact.

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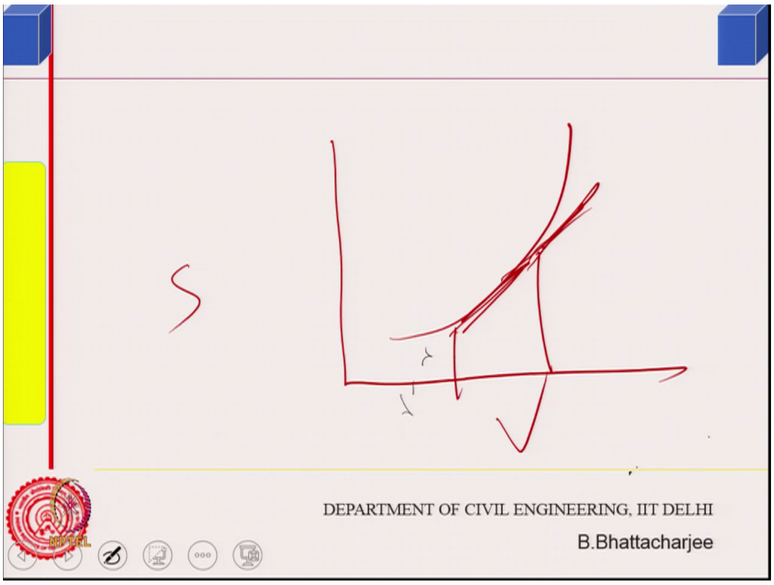

Supposing, I have velocity and strength on this side and some curve linear something like this and I have been able to measure only in this range. The predicting, my prediction can go anywhere wrong future. I try to predict on this basis, I will not be correct.

So, therefore, it is never you know is not really used alone for strength, but together with rebound number, then it you can do it Indian code. For example, 1 3 1 1 part 1 and gives both this test actually. So, part 1 and 2. So, you can what you can do is, but this test is needed in order to a calculation of rebound number also because rebound number gives you only indication of the surface concrete surface hardness while this can give you indication of concrete inside the section.

So, first you test and do it ultrasonic pulse velocity test and if you find the concrete is sufficiently sound in the core, then you can use a develop a rebound able correlation to predict strength. So, that is the idea that is the idea right.

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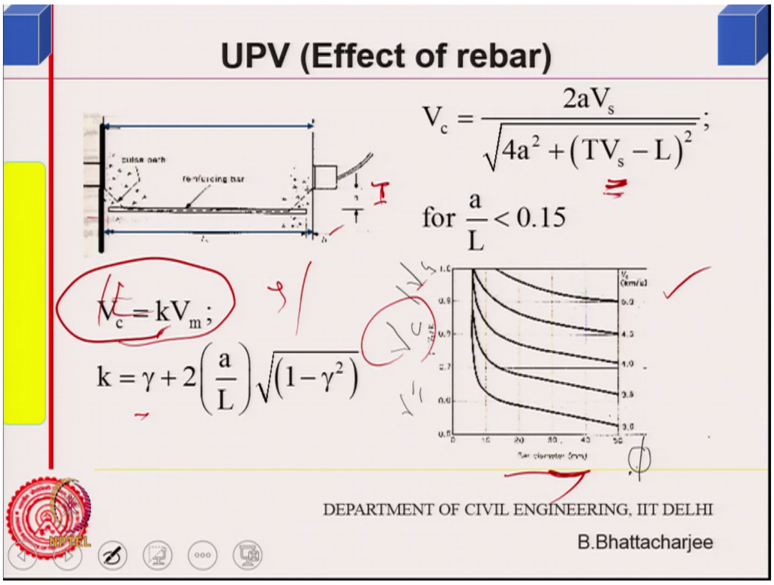

So, rebar effect is important effect of rebar if it is along the direction then you need some corrections which would actually because it will travel through this. So, velocity in steel then becomes important. So, if you know because it will travel through this path. So, correction is needed velocity has to be corrected using this kind of a formula where a you know this is this a length this length is a.

So, that travel distance is a plus the distance of the you know a plus the length of the steel bar right. So, velocity in of steel which you know is around 5.6 kilometre per second. So, velocity in concrete one has to find out the a is this distance L is this length based on this you can find out right; so, for a by L less than 1.15. So, otherwise measured velocity must be multiplied by a factor k where k is given as gamma plus twice a y L 1 minus gamma square. So, this sort of curves are available.

. You know from for example, this a path diameter versus velocity which is velocity of concrete divided by ratio of velocity of concrete divided by velocity in steel. So, this sort of curves are available for various diameters for measured values. So, one can use this kind of curves to estimate the correction, but normally, we do not place here unless in picas units in a beam picas beam or something like that otherwise you do not place it like this. So, the other correction is this is important.

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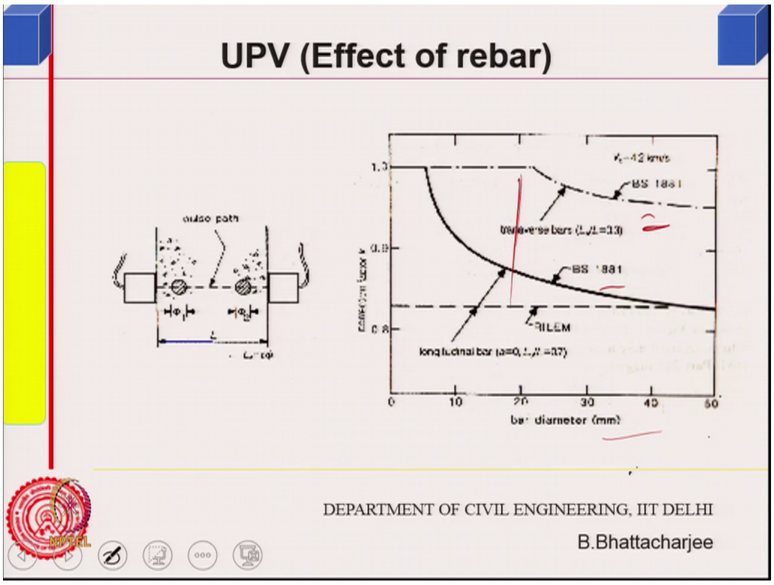

You know, you might find this sort of thing right. This is where this is common and in such case, it is actually British code gives you some ideas, up to about 20 mm ut they are practically do not need much. Some other codes gives you random gives you some correction like this 0.9 or 0.85 or something and in some other you know depending upon the diameter some other cases, they give you the correction factors up to 20 mm or may be about you know some 8 mm 20 mm. You know, will not need actually much of the correction.

But, there will be some correction needed best is to avoid the rebar location if you can. So, you measure change your place and see the velocity is coming lower that value be take rather than where it is coming I.

So, that is about ultrasonic ultrasound, you know ultrasonic pulse velocity test you can not only measure the get idea about the soundness of the concrete and interpretation code gives you some interpretation. The velocity you know, if it is more than 3 kilometre per second, the concrete is acceptable. If it is less than 3 kilometre per second, it says doubtful concrete and anything about 4 point is an excellent concrete. So, I will have a table later on when I talk about of interpretation. So, this is what ultrasonic pulse velocity test and what it can do.

. The next test, let us look at is pull out test right now this is becoming you know this is becoming quite popular although is there for quite some time, but the instruments developed and their calibration. For example, in U S they have been in north America there have been using quite a bit Europe, there has been development and now there in you know it is there are there are varieties of instruments available. Obviously, developed abroad in India and many other places may be. So, a pull out test is something like this.

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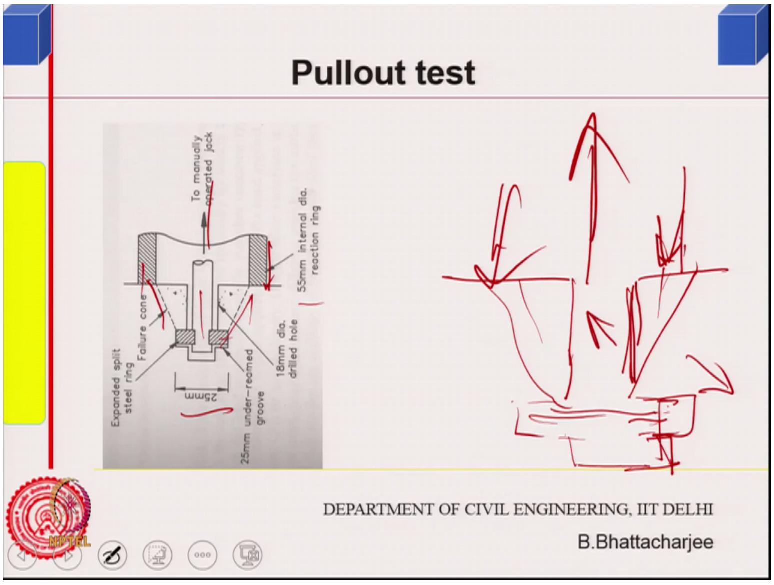

What it does it? You drill a small hole into the concrete right. So, this your concrete surface you drill a small hole and the instrument is there which can actually cut a group likes thing. It can cut a group cut a group, it can cut a group, it can cut a group into the concrete and this pull out device, it will have a kind of flangia here right, then this is pulled out with the reaction taken you press it from top press it here and pull out here press it here and pull out here.

So, what happens? This flangia which is there what of these dimensions frequency is 25 millimetre. So, this dimension is simply 25 millimetre this depth is also very small. As you can see, this is around you know this is this diameter is 55 mm and it would actually cause fracture of the concrete fracture cone will be there and it would fracture in this manner; that means, this concrete will because you have pushing here and pulling through this.

So, this concrete will tend to come out. So, in fact, this concrete is subjected to the concrete in this zone is subjected to a kind of compression. So, the tension will be in the normal direction which causes cracking then this come out. So, since you have actually crashing it in a way sort of you know subjecting into compression. The result that you get is a measure of the compression strength measure of the compression strength.

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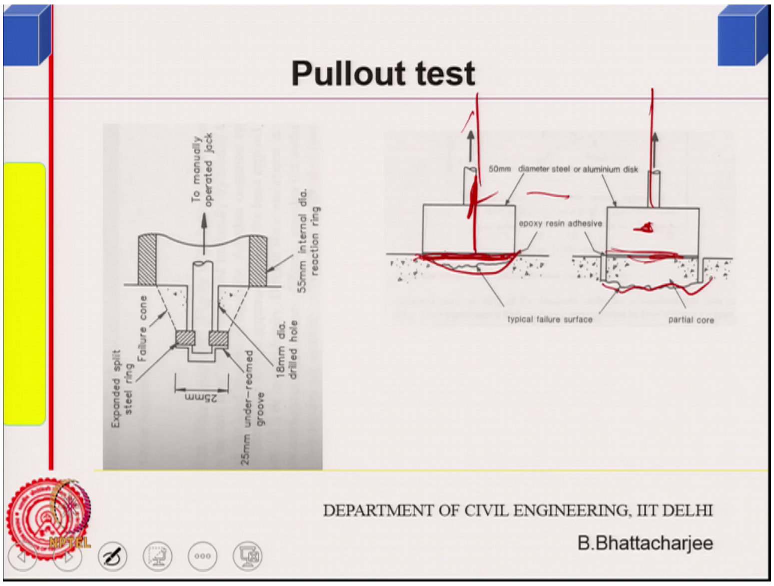

So, that is the idea of the pull out test. So, you got to have something like this now you can test this is called pull of test you can actually measure the tensile strength of concrete surface concrete. So, bond it here the same instrument can do the job bond is sort of air you know 50 mm diameter sort of a disk and bond it here with epoxy pull it. It will take a chunk of concrete out. So, this gives you an indication of the tensile strength you know. So, because it will fail directly and you are trying to pull this concrete. So, you are subjecting it to tension.

Or you can do a partial core just drill, but do not break core. So, then you know put epoxy bond it and use this disk pull it out it will break from here will be a measure of tensile strength. So, you can actually get some idea about the compressive strength as well as idea about the tensile strength and you need to have calibration it is look something like.

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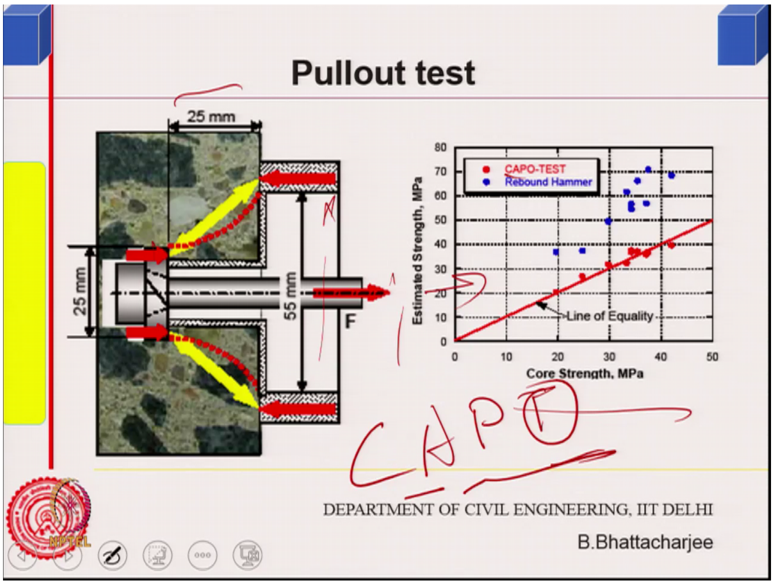

So, this is how it looks like right this how it looks like you pull it like this 25 mm here 55 mm is this and 25 mm. So, you are trying to pull like this you know fringe it pulls it and does it pulls the pull out force can be correlated to strengths. So, strength versus estimated strength people have estimated strength from this cut and pull out test CAPO test, cut and pull out test CAPO cut and pull out cut and pull out cut and pull out test CAPO test. This is developed in Scandinavia basically.

So, that is you know they actually commercial equipment available are developed there and seems value successful. So, you get some sort of correlation between the core strength you can get core strength red ones are the CAPO test result. This is the core 45-degree line is here right. So, 10 45-degree line is here and apparently the CAPO results match with the core quite well rebound (Refer Time: 26:55) prediction may not go may not go well.

As I said, it can go well provided you have your own correlation own correlation you just cannot do the rebound test and predict the strength you have to do lot more work use some cores together with. So, that is what it is. So, this is how the pull out test looks like right and you can put it during the casting also. So, this is the insert you putting during casting.

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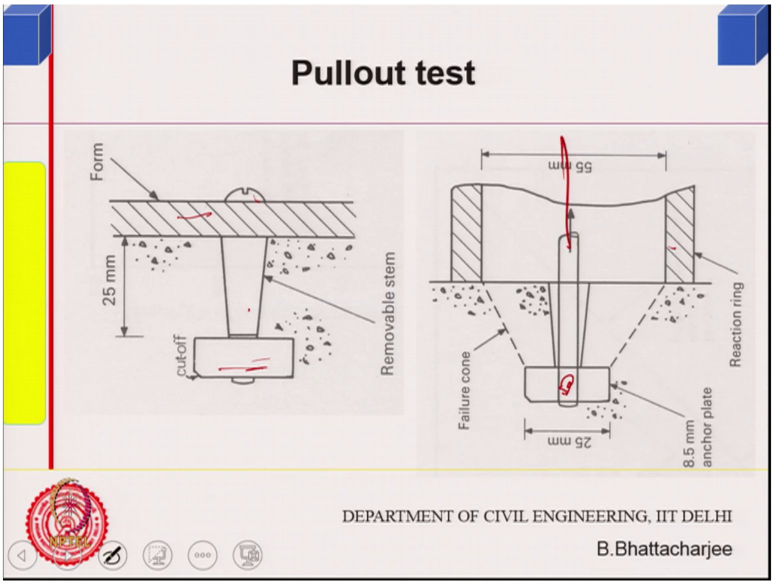

This is a insert that you are putting this is our form work this is threaded and this insert has gone right in the beginning right and then after the concrete has partially set, you know before final setting you just unscrew it and take it out.

So, this whole remains these whole remains and this one also remains then you put your pull out rod which can get threaded here. So, you just put it and thread it on right and then pull it out in the same manner as you done. So, in this way, you can actually determine the strength development in concrete. So, if you have done this put this inside right, in the time of casting you can actually also find out the strength developments strength development also you can find out the this is same, 25 mm 25 mm 55 mm etcetera. This remains same right.

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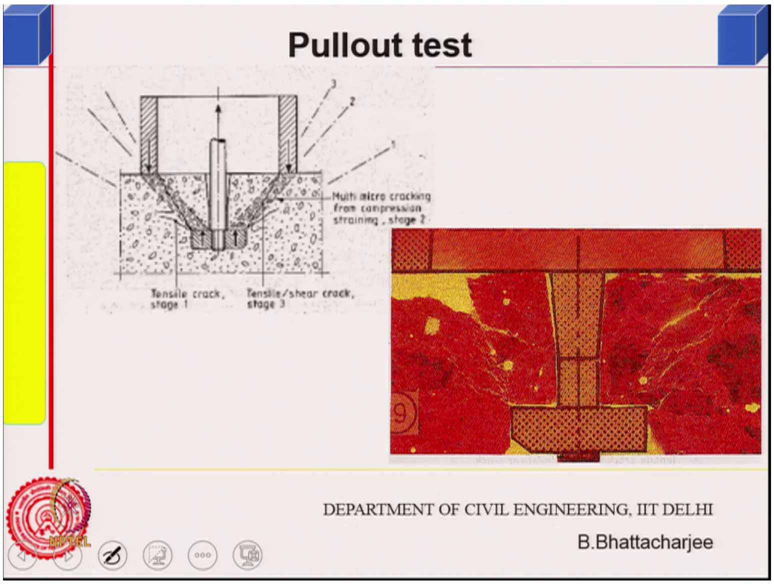

So, this one could actually people have done some analysis and this is the you know finite element analysis fracture analysis and all that. And by doing this, one could see the kind of stress developed fracture plane developed and all it matches by enlarge with this. So, it matches by enlarge with the you know theoretical and experimental results by enlargement. So, that is the claim that is the claim of the that is the claim of the claim of the you know manufacturer and we did ourselves did some test and we found that it does a good job.

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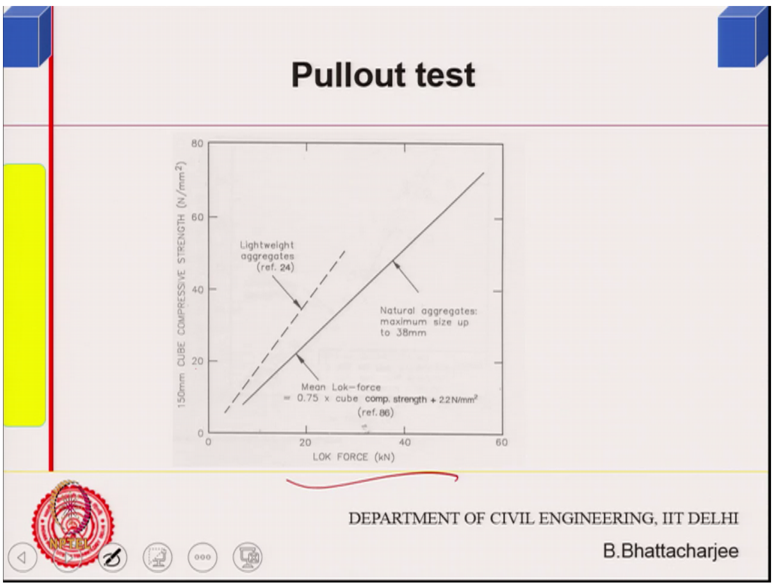

You know, so, basically correlation can be established the force required to pull out force required to pull out is a measure of the compressive strength. So, some sort of correlation with 150 mm cube one can get with different types of aggregate and this are the available.

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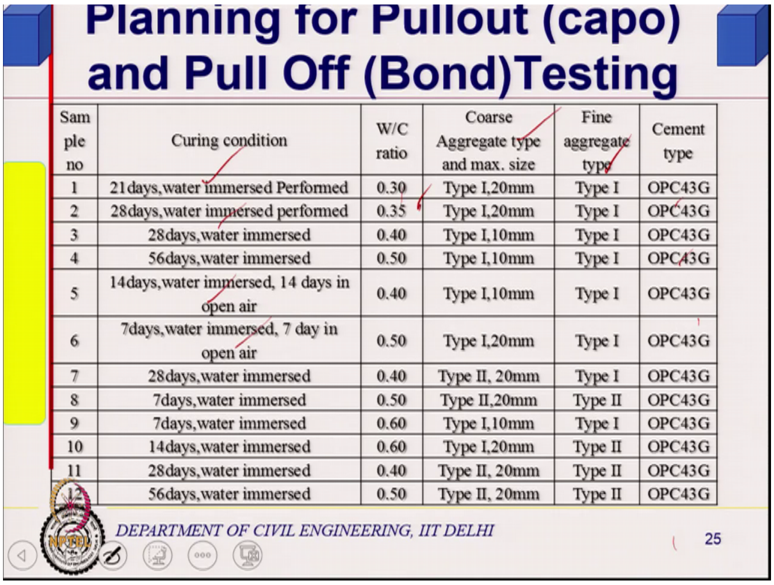

Sample no	Curing condition	W/C ratio	Coarse Aggregate type and max. size	Fine aggregate type	Cement type
1	21days,water immersed Performed	0.30	Type I,20mm	Type I	OPC43G
2	28days,water immersed performed	0.35	Type I,20mm	Type I	OPC43G
3	28days,water immersed	0.40	Type I,10mm	Type I	OPC43G
4	56days,water immersed	0.50	Type I,10mm	Type I	OPC43G
5	14days,water immersed, 14 days in open air	0.40	Type I,10mm	Type I	OPC43G
6	7days,water immersed, 7 day in open air	0.50	Type I,20mm	Type I	OPC43G
7	28days,water immersed	0.40	Type II, 20mm	Type I	OPC43G
8	7days,water immersed	0.50	Type II,20mm	Type II	OPC43G
9	7days,water immersed	0.60	Type I,10mm	Type I	OPC43G
10	14days,water immersed	0.60	Type I,20mm	Type II	OPC43G
11	28days,water immersed	0.40	Type II, 20mm	Type II	OPC43G
12	56days,water immersed	0.50	Type II, 20mm	Type II	OPC43G

So, we actually did some test and of different types of cement and all that you did find that it gives you an error within plus minus 10 percent of the core result. So, for example, coarse aggregate type fine aggregate type there are 2 3 types of fine aggregate. We use different types of cement grades, of course here it is single grade water cement ratios 0.3 to 0.4. So, right and 21 days 28 days 14 days 7 days etcetera whereas, variation used and we found this CAPO test gives us fairly good results, you know this is the testing that we are doing.

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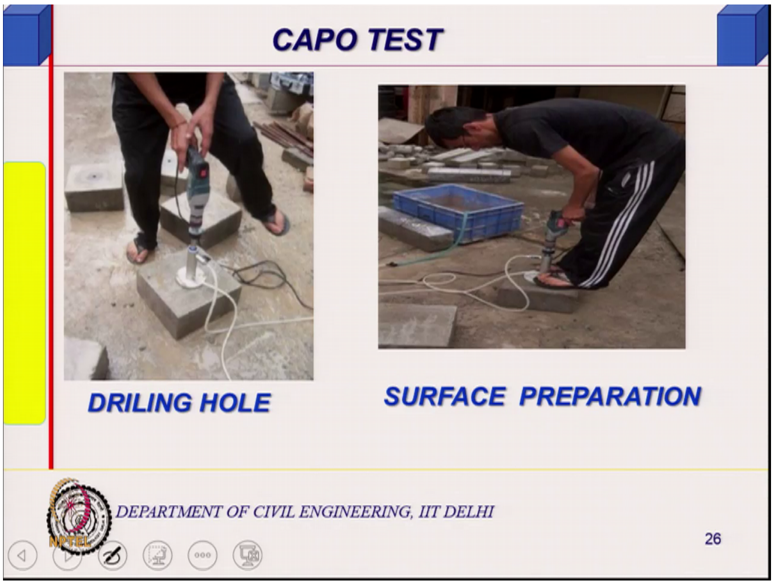

Drilling hole surface preparation.

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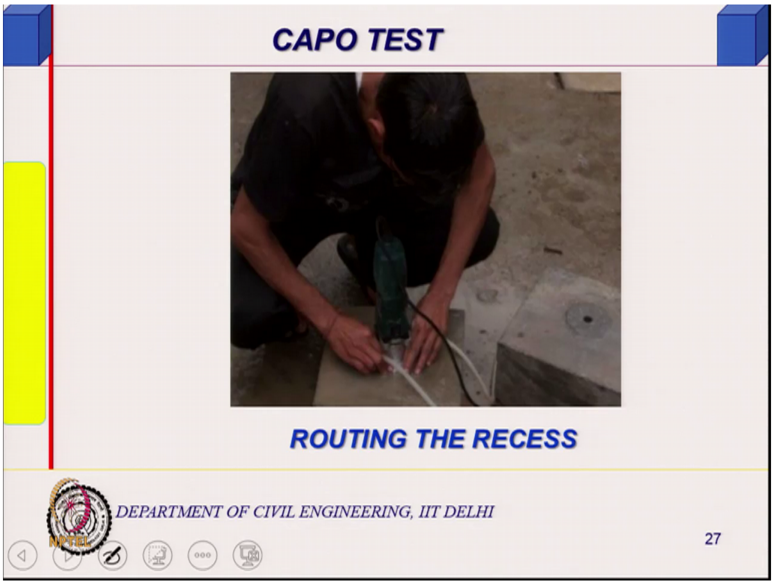

And, routing the you know routing process and all that.

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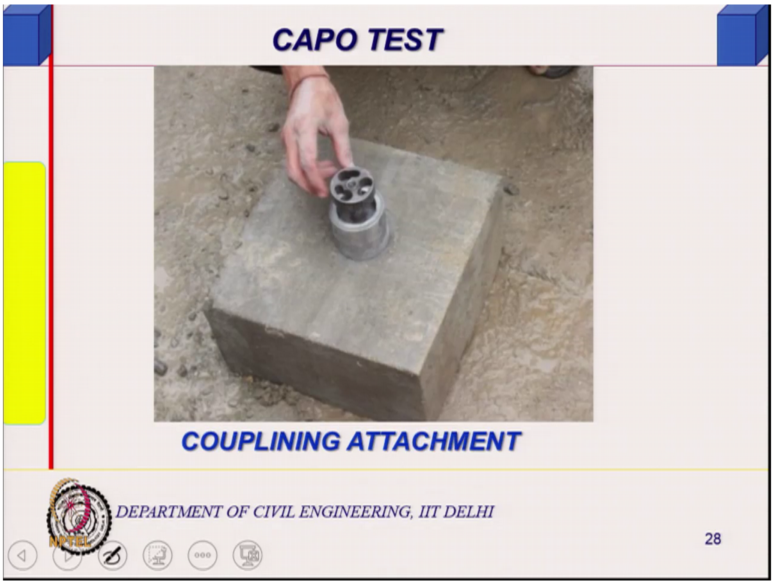

So, placing it and then placing the inserts and pull off test also we did.

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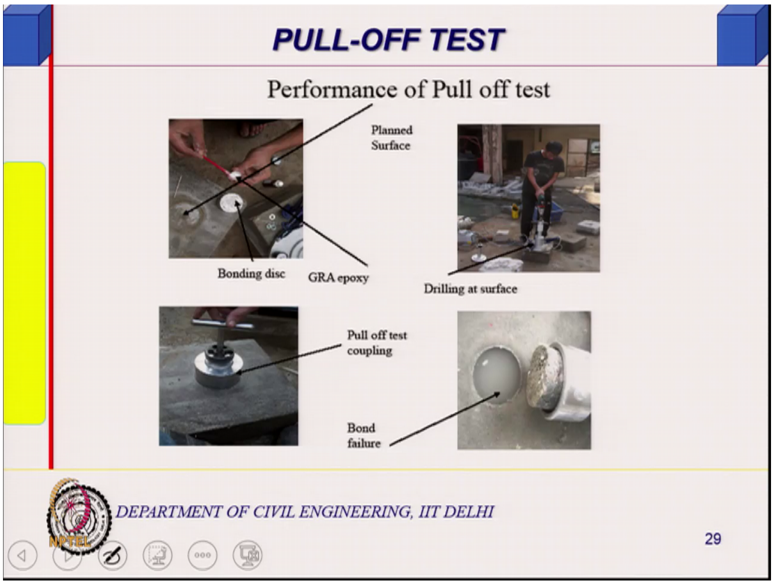

Similarly, both shows that within plus minus 10 percent you can get the result. So, this is what finally, you know as you pull it out on something like this chunk of concrete will come out.

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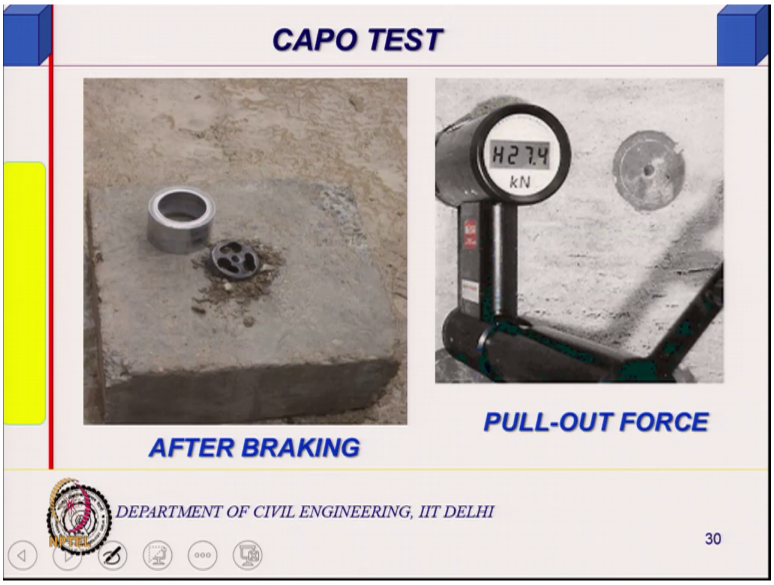

And this is you know, this is how after breaking you get some sort of thing this is the machine where you read how much kilo Newton is a pull out force from here it came out.

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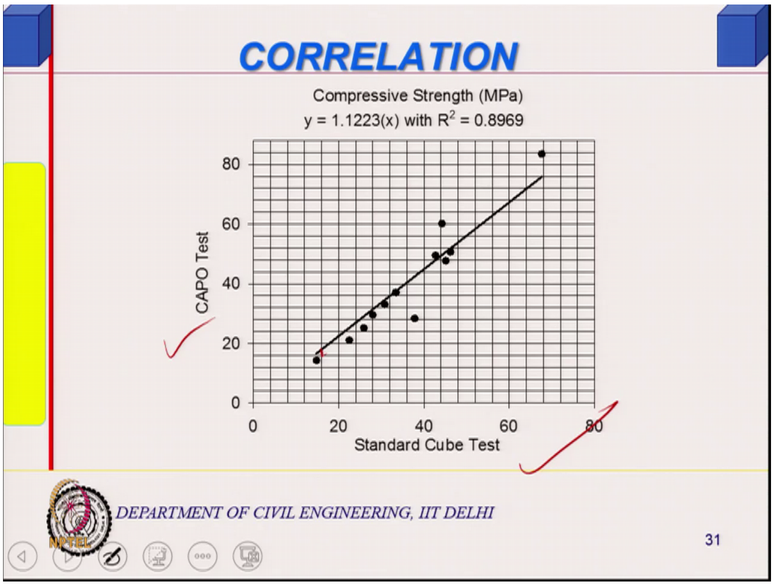

And the calibration correlation that we obtain, but something of this kind you know correlation that we obtained was something of this kind standard cube test CAPO test. So, by enlarge there is something close to the 45-degree line. So, it plus minus 10 percent error, right. So, reliability is good, but then European code example for example, it says that you establish your correlation yourself preferably.

So, some limited amount of code test should also be done with this. This is semi destructive core is more destructive compared to this because core would be taking 75 mm core minimum with 20 mm aggregate.

Where this is only penetrating up to very small depth you know. So, therefore, you go do not get too deep um. As a result, this is less damaging less damaging and easier to do cost wise still not you know like because the instrument cost still the cost is similar not vary far different in India. So, correlation source is a good one right. So, this is correlation with some S C A relationship bond stress test that pull of test. So, that is the kind of relationship you have. The next, we will look into core test.