**Fire Protection, Services and Maintenance Management of Building**
Prof. B.Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

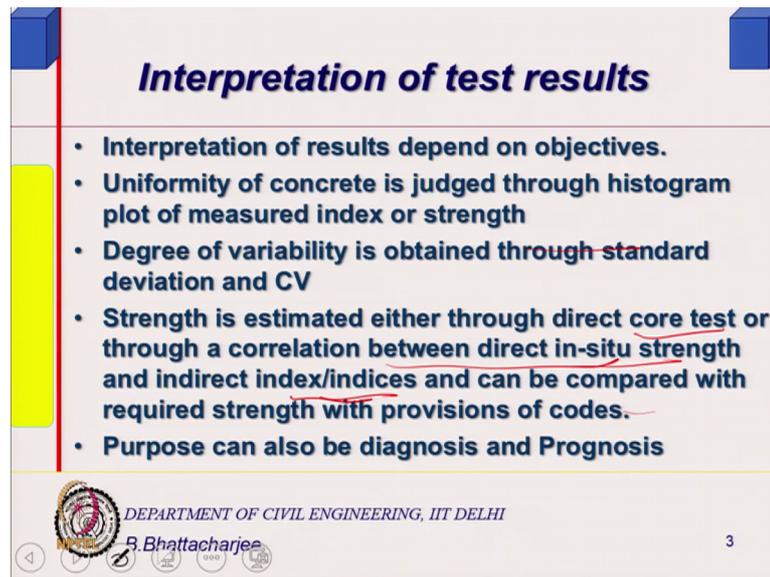**Lecture – 56**
Interpretation of test results

So, we will look into now Interpretation of test results right, interpretation of test results. So, we have already seen that condition survey has this kind of a flow diagram remember.

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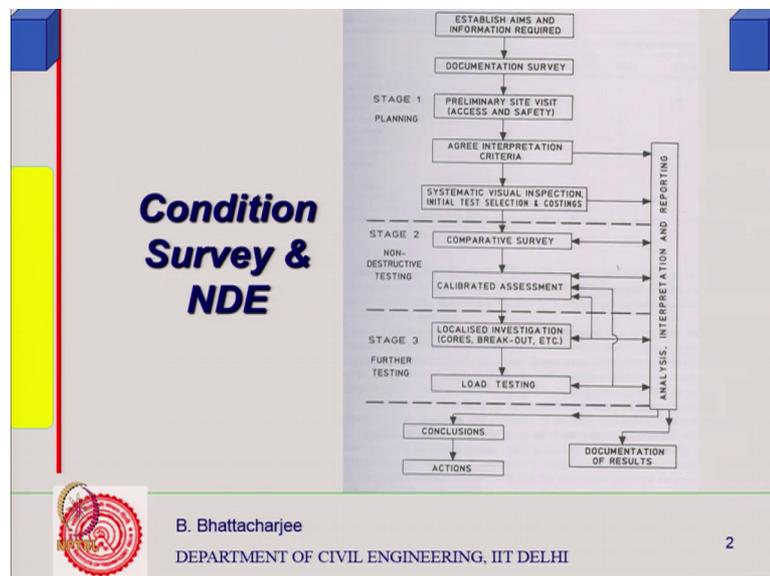
And, I come to a conclusion and I you know suggestion what should be done.

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But in the process therefore, it is important that I look into interpretation of results you know test result interpretation and all that. So, this is there. So, we will discuss this right now. It depends upon objective, first it depends upon objective. Now some time as I said there is a little bit of doubt about the quality of concrete nothing else, strength is soundness you want to find out whether concrete is sufficiently sound or not.

So, you can do a histogram plot of any one of the measured values. For example, rebound number index or ultrasonic pulse velocity or if you have taken core too many number of core or some strength index like CAPO or something like that, you can actually plot histogram to judge whether concrete is uniform or not. So, uniform concrete will show a particular type of variation pattern, we will see that it should show normal distribution. Degree of variability is obtained through standard deviation. If I have high standard deviation; that means, something wrong with my quality and coefficient of variation I can find out because standard deviation divided by mean. And I can find out through this.

So, if you want strength then you have to do little bit of core testing by some means either the cube or core testing. If you have the cube because it is not a very old not an old structure you might use the currently available cube correlated to the indirect indices and then obtain the strength. So, basically in case of no cubes is available the core test and some you know in some indirect index and direct in situ strength this you can put

together and obtain a correlation and use this correlation to predict the strength later on. And simply if it is deterioration oriented for example, you know like this you one you know somebody there is a corrosion somewhere say river corrosion has been seen like I showed some where not very serious actually, but you have seen some patches.

Now, then there is no need really not there is any need really to do look into core test and things like that unless somebody also wants no since this has happened the core possibly the strength is also bad. Even if your strength is still also river corrosion distress can occur because, that is related to the chemical thing right; that is related to the chemical thing. Because, it might be contaminated with chloride from right from the beginning and moisture is available right from various sources let us say. May be your pipe is leaking continuously subjected to moist conditions in the surface no concrete can be 0 porosity.

So, moisture will in penetrate into the cover concrete it might corrode. Although, structurally it is still safe satisfying the grade of concrete required for structural design. So, in that case why do core test or you do not need the core result right, if you it first of all you must know what is it and diagnosing the cause you have to you know is also a part of interpretation of the results. So, uniformity of the concrete can be judged through histogram plot.

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UNIFORMITY OF CONCRETE

Velocity Criterion for Concrete Quality Grading
[Ref: IS13311(part-1)]

Sl.No.	USPV by Cros Probing (km/sec)	Concrete Quality Grading.
1	Above 4.5	Excellent
2	3.5 - 4.5	Good
3	3.0 - 3.5	Medium
4	Below 3.0	* Doubtful

Note - In case of doubtful quality it may be necessary to carry out further tests.

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For example, supposing it is a velocity ultrasonic pulse velocity quality is judged through IS 1331 or any other literature will give you. First thing you do is it says that if the velocity is more than 4.5 the concrete is excellent. So, soundness of concrete you can judge through, this it is between 3.5 to 4.5 it is good. And it is 3.0 to 3.5 it is medium below 3 is it is doubtful, in such case you going to do some other test to find out the core because, in that case you must do some other test like core test to find out the actual strength of concrete.

So, if you are just in doubt you need not find out the strength, even if you see some sort of chemical distress and you think that let us check you do this test and that is over you do not damage the concrete further. So, that is it and this is the interpretation that is done. So, first if you find that everything is here I am not really I am not going to ask for further strength testing, I am not going to ask for further test strength testing unless somebody insist. Now, we have seen that strength variation would be something like this.

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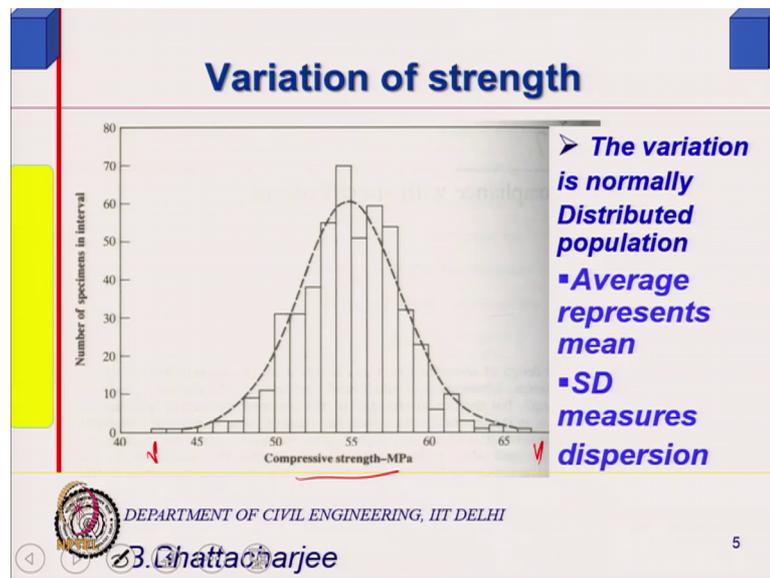
If I do large number of tests for example, in this particular case compressive strength varies from 42 to 67 and there are large number of data here it is a population practically. And, since the concrete strength is function of too many factors many uniform distribution might make it normal distribution that is what we have discussed earlier. So, concrete strength is expected to be normally distributed. Similarly rebound number index

is also expected to be normally distributed if it is same population. So, if it is same population then you will get a histogram plot like this with single peak.

If the concrete has come from same source it is uniform concrete you will get one peak right. So, uniformity can be judged looking at the variation with any index it can be rebound number, it can be ultrasound it can be strength. So, soundness of concrete by ultrasound state and uniform to a concrete by any of this; so, now, you need not to core test to do this strength is not necessarily be to be done. So, variation is normally distributed population.

So, any index in concrete is likely to be normally distributed unless there is a reason for not if it is random occurring everywhere then it is like to be similar. So, average of course, and standard deviation we know; now standard deviation give me an indication of the quality of concrete quality of concrete larger standard deviation means poor quality of concrete.

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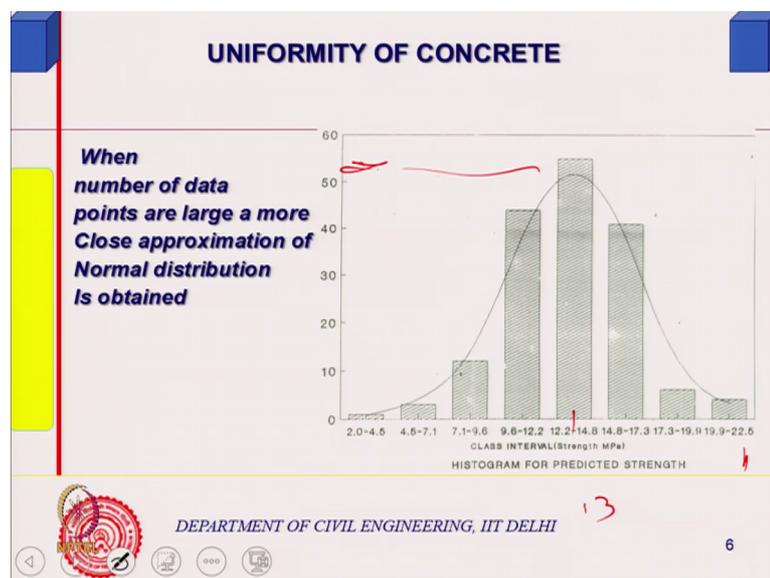
So, this is let us say typically from a site you know this is a bad site as you can see the strength varies from 2 to about 22.5 large number of test, but it is a predicted strength predicted from correlation between rebound number and core types core test right. So, you can see, but the concrete is uniform its bad concrete the average strength is somewhere around 13 or so if you see mean would be 13 or so. This is around 13, in situ strength now you know equivalent cube strength maximum is 22.6 it is in an actual

structural building. Now, this strength is not very good, but its uniform; that means, it has come from the same source contractor was one material sources are similar you know within reasonable variation; they are not different two different contractors has did not bring it neither they were done at two different times and so on.

So, this is uniform concrete right;so, when number of number of data points are large a more close approximation of normal distribution is obtained. If you have small data something like 15 16 we will get some sort of one peak variation right, but if you have large number of data as it is here because you can see the maximum is some around 60 70 or. So, maximum the peak you know its peak is some around 70 60 close to 70. So, large number of data predicted strengths were there in the whole building its a 14 storey building, specific building. And, this one can see that concrete was uniform it was not quite good concrete might needs strengthening may might have, but you know supposing you have some small lesser number of data sometime you get this sort of the thing.

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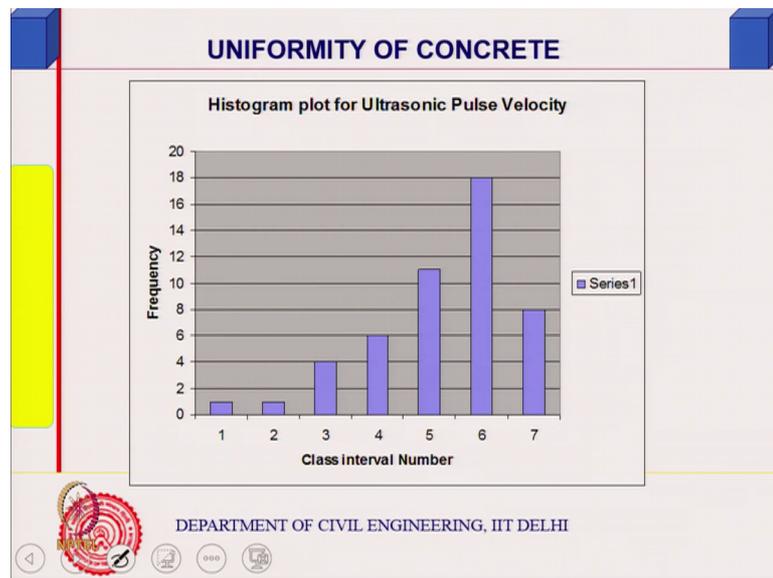
Now here actually we know that this particular cases two set of data they are skewed on the left hand side, that means, this some concrete might have come later on and we knew in this particular case they have constructed some columns were constructed later and arrayed later. In fact, since below balcony because there is so, some distress is also added two three columns right. And we tested there them they were not again of very good

quality something like that. So, even skewed net skewed one would show that whether some you know or some bad concretes is there or not.

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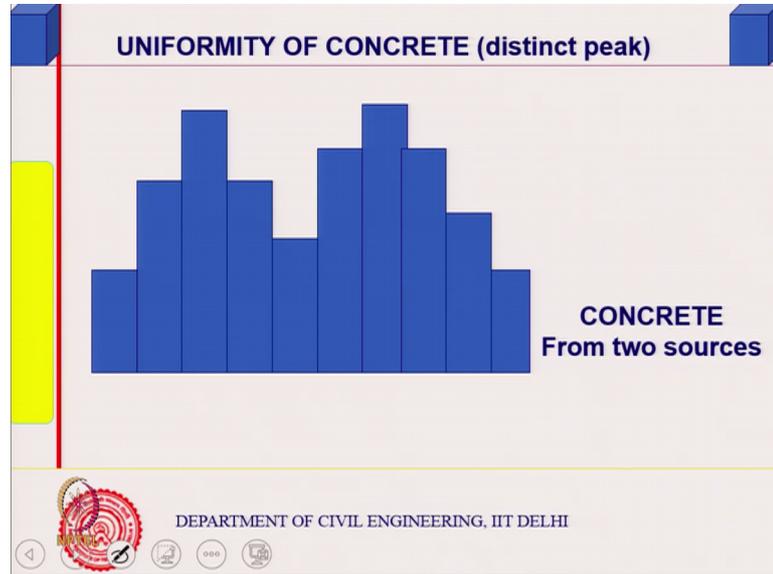
This is two distinct peak which means that it would have come from two sources to distinct peaks means, it would have come from two sources two possibly two contractors would have supplied from two different sources of concrete or maybe it was constructed at two different times. So, uniform single peak tells us there is an uniform concrete it does not talk anything of the strength strengths has to be estimated. So, this is from two different sources right.

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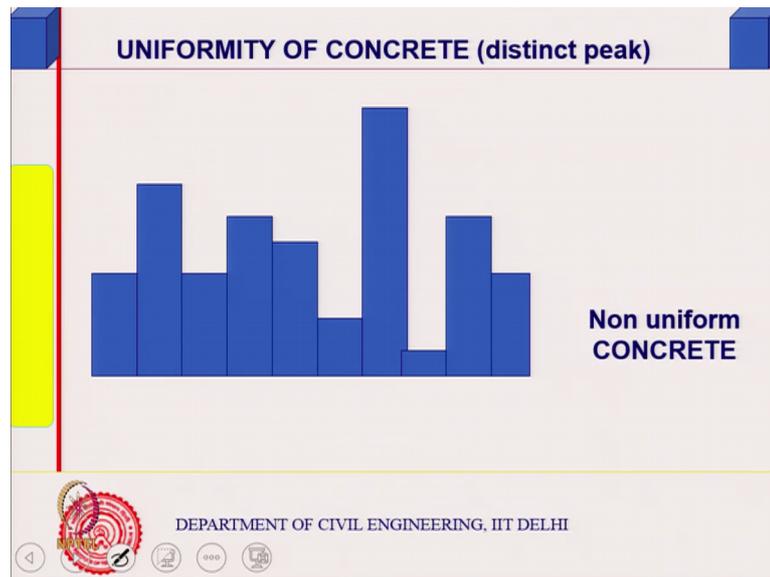
And this is all haphazard non uniform concrete distinct one distinct peak no distinct peak actually so in fact, it is no uniform concrete. So, actually is all bad concrete you know no uniform concrete it is a bad concrete. So, you can actually from such histogram plot you can judge for any index you take large number of data if it is available is better you can judge whether it is uniform concrete or two uniform two suppliers were there two times it was the two distinct concrete or totally non uniform concrete. So, this is the next interpretation non uniform concrete. So, it is the next uniform interpretation.

If you are looking at the quality then; obviously, you know you can find out the standard deviation is one thing and large standard deviation; obviously, for each one peak if you can separate out in this particular case then for each one what was the quality that you can identify in a single peak. Then you can find out the standard deviation or C V and remember we had a C V verses strength graph earlier when we were selecting number of locations we can use that to find out there was one was in situ concrete good quality bad quality three qualities were there. So, where your quality lies you can actually find out right.

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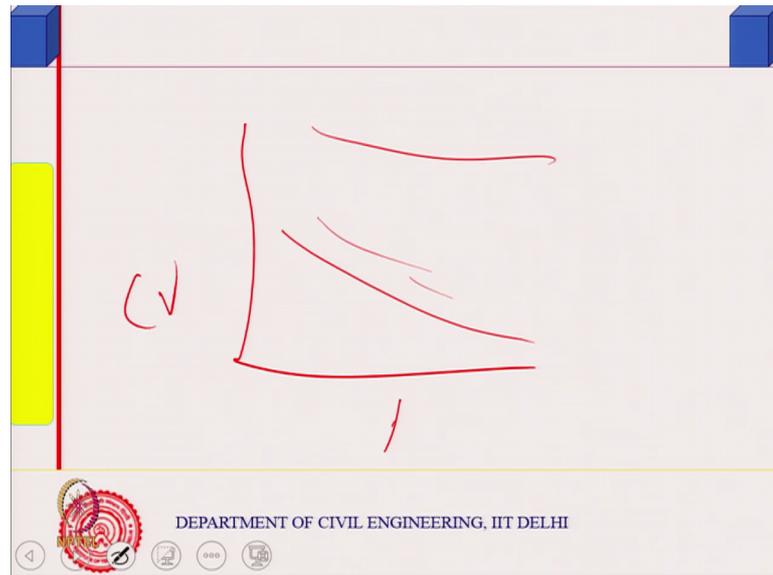
For example it was something like this if you remember you know this was strength verses C V for very good quality concrete in situ and cube standard cube, it was somewhere there bad concrete was somewhere up there I showed you a graph earlier. So, you can make use of such available information to identify your concrete quality.

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CONCRETE QUALITY

Zone	Doubtful location	Medium location	Good Location	Excellent	Total
Up to 6th Floor	6	5	285	28	324
7-13th Floor	26	100	325	3	454
14th-17th Floor	10	82	221	2	315
Total	42	187	831	33	1093

Now, this is a this is a particular case of large number of ultrasonic pulse velocity measurement being done up it was a actually as you can say 17th floor building up to 324 locations were tested up to 6th floor, because the concrete were distinct we can find

out there are three different concretes and 5 medium 6 doubtful location. So, out of 324 in this case these are different concrete 454 tests are done on ultrasonic pulse velocity 26 locations were doubtful. So, this concrete this set of concrete was relatively bad you can see histogram plot we did same they are normal distributor. So, you can separate out the concrete and when you separate out the concrete of course, total 42 have bad, but most of them were 7 to 13 floor.

In fact, we found out that the bad you know different cement was used or something of that kind. So, we can actually do a lot of play around play around with a statistics when we are planning to do this kind of test. So, you can see that this zone you know you can calculate out excellent concrete was maximum here; it was not sure not many, but good locations were also pretty large out of the 324 285 were good. So, bottom lower level it was better it was 221 out of 315. So, not all that bad, but this had got 100 medium 26. So, relatively this was much worst concrete.

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NDT results

Cases	Range of Rebound Number values	Range of USPV values km/sec	Range of in-situ cube compressive strength Value at age of testing (Direct/through correlation) MPa	Crack Depth range (mm)
A	32-37	3.03-4.96	42-51	-
B		4.1-4.7		32- full depth
C	44-69	4.4-4.8	38.8-59.8	Full depth
F	17-27	3.0-3.5	17.4-27.0	10-120

Cases	Cement Content kg/m³	Water Content kg/m³	Coarse aggregate Content kg/m³	Fine aggregate Content kg/m³	Average Slump (mm)
A	406	162	1218	609	40
B	360	162	1146	690	145
C	400	180	1140	680	150
D	425	160	1214	657	100
E	352	170	1228	640	45
F	350	198	1120	660	125

B. Bhattacharjee
DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI

So, this kind of interpretation you can make right NDT from NDT results you can use rebound number also for similar kind of results. So, for example, you know you can you know like the tunnel lining I was showing there this kind of results were available. Range of rebound number was some for A type of remember that A I talked about that time when I was talking about 32 to 37. So, this data can be use for various cases for interpretation.

We did use them earlier the mixtures were also known to us in A B C D where some cases A, case range of rebound number was 32 to 37 ultrasonic pulse velocity was 3.0 in situ cube strength was better and we also knew the mix of this informations. So, some you know this from this kind of index histogram plot informations about uniformity and quality of concrete and where bad which one is better that is sort of you know conclusions you can draw.
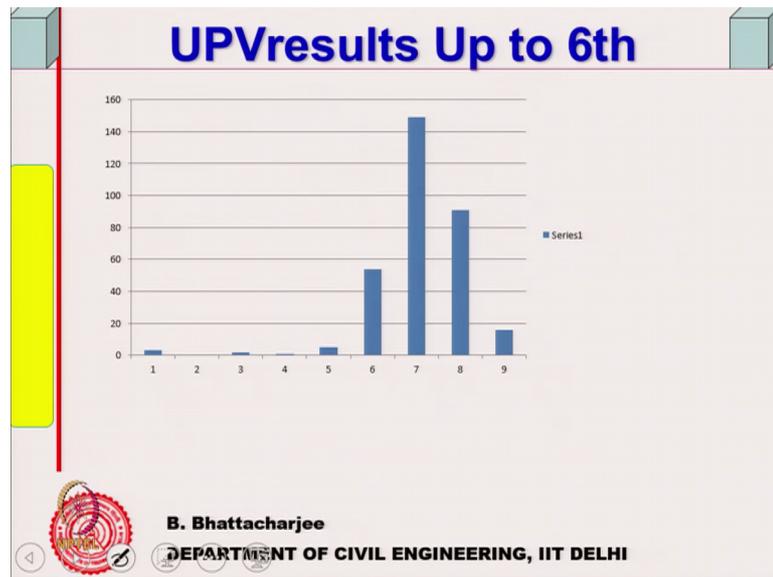
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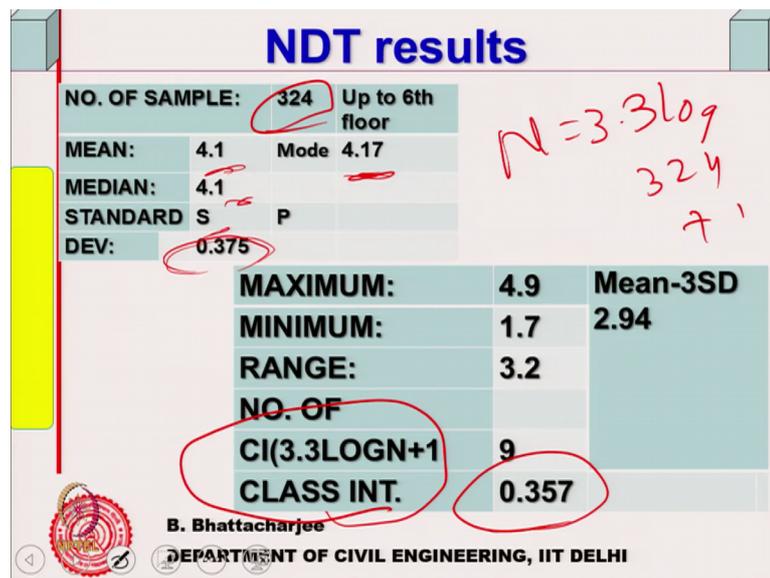
So, standard deviation for example if you have this standard deviation if you know standard deviation is this then up to 6th floor mean you know number of sample etcetera I mean basically mean was 4.1 the ultrasonic pulse velocity mode was 4.7 median was 4.1; that means, all normally distributed. So, from mean median mode calculation also you can find out. Standard deviation was 0.375 population standard deviation in this case it was 0.357 right. So, this is for the next range that was and you can determine how many number of in frequency diagram, how many number of class interval you should have using this formula. 3.3 log N plus 1 there is a number of class interval

If N is your data for example, if it is 324 number of class intervals will be equals to three 3.3 log 324 plus 1; so, that many number of class intervals. So, total data you divide into that many number of class interval and plot the histogram plot right, plot the histogram plot and also find out standard deviation etcetera.

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So, you see this same up to 6th floor this was the kind it was uniform concrete right, but there are some bad concrete down they are. So, it is skewed there some concrete bad, but not many bad.

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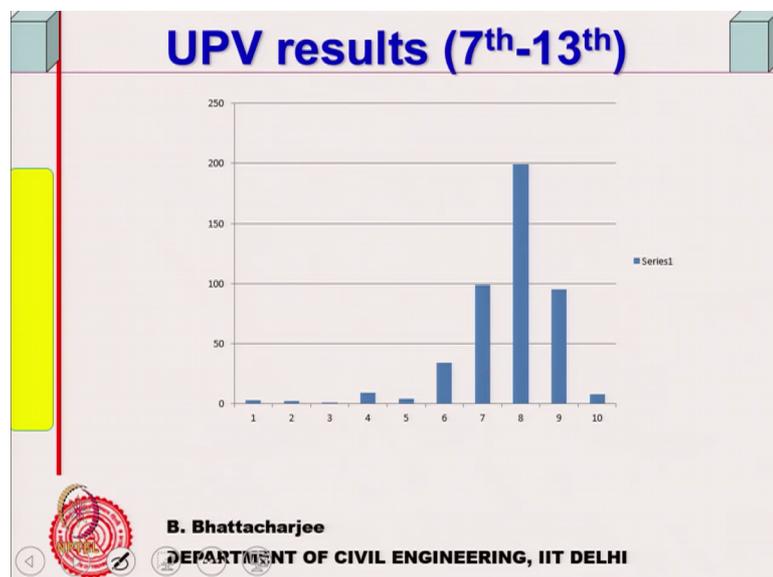
7 to 34 it was still increasing on this side right ultrasonic pulse velocity results same one I am plotting histogram. And, this histogram did not match with each other initially when we plotted we found different peaks when we separated out we started getting individual peaks.

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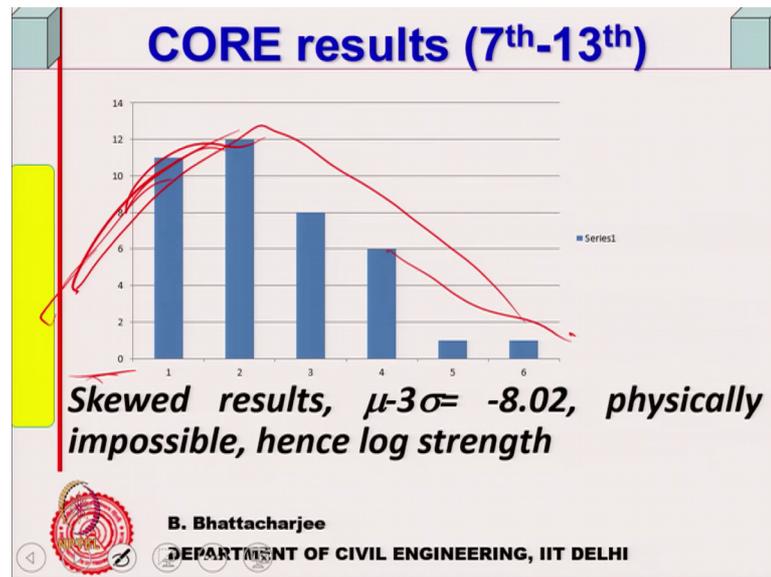
And then seventh core test results of course, 7th to 13 showed some sort of thing. So, there is a skewness in the strength 7 to13 worst. So, we did not do core test there much here we did number of them and we found that there are many of them having bad strength because it is you know the good strength is less bad strength is much higher.

So, this can this kind of actually it is a distribution would be something like this partially you know this is not feasible because below 0 is not feasible. So, partially distributed are on. So, you know so, this is what it is. So, skewed result physically impossible then we plotted with log of strength then it got it to log of strength of course, and it showed that again two peaks.

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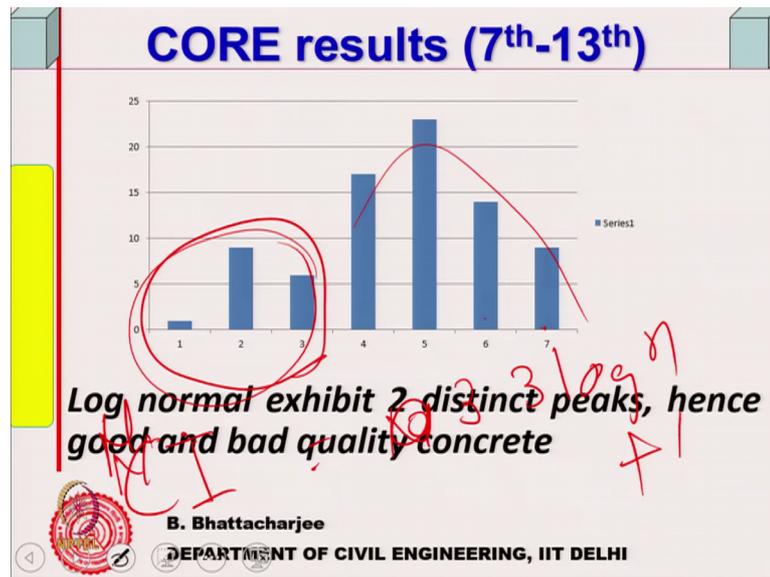
From 7th to 13 floor the same building 7th to 13 floor had bad concretes that we have seen we started going examining it more. And now after a log strength plot we could find out some concrete is bad somewhere something went wrong rest of the concrete is perhaps two different distinct peaks we found out. So, analysis of interpretation can involve I am giving the examples in the basic theory you can apply those statistical concepts not very complex pretty simple take the total data divide it into n if the number of the data let us say the of class interval number of class interval C I let us say N C I will be equals to 3.3 log n plus 1.

So, 1 2 here 7 number of class interval because 324 whatever the value was 454 log of 454 will be how much something like 2 point something 2.6 or 2.7 or something. So, you calculate out that and you will find that we can actually you know it would come something of that kind or may be less than 324 or something I do not remember how much 7 to 13 data were there how much does it come. So, number of intervals can be determined in this manner and then if you find 2 such peaks; obviously, it is core strength yeah core strength was not 454 it was less.

So, even 454 if it was how much it is how many number of class interval I should have how many number of class interval I should have 10 I should have 10. So, that is what we do you know. So, you do it class interval for core it was number of cores were less. And, when we do log we get two peaks log strength we plotted now and we find 2 peaks

because normal strength plot was not giving me a good one this because skewed to the standard deviation minus 8.72 which is infeasible without why not relate to the lognormal distribution. So, you know. So, this is what we did and it works sometimes that is what I am saying.

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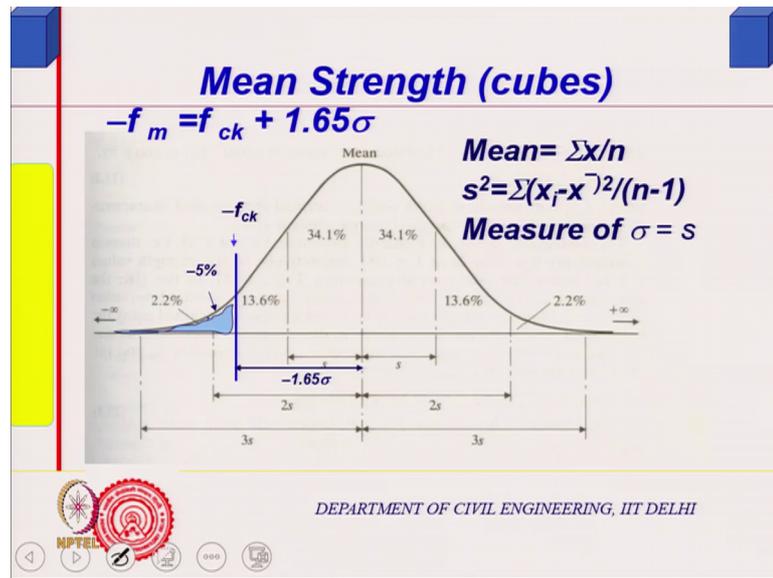
And you know the f ck is 95 percentile. So, grade strength one can obtain using some of those.

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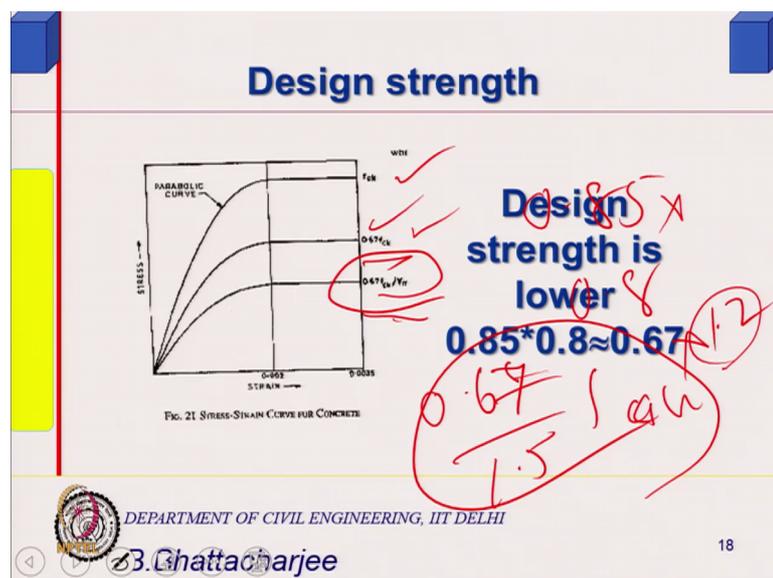
So, one thing you must know the design strength is strength used in design is basically first to take care of the actual structure condition and standard cube difference. Because of the adverse loading effect and also production is not same as the cube, cube is produced in a standard manner cured in a standard manner and tested under uniaxial compressive standard strength in a standard manner under given type of load. What in while in actual structure things would be different and that is why you multiply this actually this 80 percent of the 85 percent of cylinder strength right. So, 0.85 and then cube strength if you are doing; so, this is I think I might have explained some time its $0.67 f_{ck}$

Then partial factor of safety over this is $0.67 f_{ck}$ divided by $1.5 f_{ck}$. So, actually strength you use in design is this right. So, one other thing it says is that you find out the f_{ck} value in situ f_{ck} value an earlier code British code would say that your actual measured f_{ck} in situ f_{ck} should be multiply you know it should have a factor of safety of at least 1.2. So, if you are in situ you know 0.67 divided by $1.5 f_{ck}$ multiplied by 1.2.

Because this is what you have used in design multiply by 1.2 which is a factor of safety your strength should be at least more than that Indian code of course, adopted this should be at least mean should be 85 percent I will just look at that interpretation right now, So, design strength is lower that is what we know strength used in design is lower then there is a partial factor of safety. So, you use $0.67 f_{ck}$ right.

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The strength estimation strategy:

A minimum factor of safety of 1.2 is recommended. Hence $0.8 f_{ck}$

For small job direct

Core test may be sufficient

COMPARISIONS BETWEEN DESIGN STRENGTH AND ESTIMATED IN-SITU CUBE STRENGTH

DEPARTMENT OF CIVIL ENGINEERING, IIT DELHI
B.Bhattacharjee

And this is what British code was doing earlier one the British codes strength estimation strategy have minimum factor of safety of 1.2 was recommended therefore, that they said that you determine from the worst location in the site f ck and you know in situ f ck and that should not be more than 0.8 f ck value. Determine the strength in situ strength average in situ strength in worst location in the site which is most doubtful and it should not be less than 0.8 f ck that is a British code earlier British code say says right.

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But Indian code of course, does it in a different manner mean strength should not be if you measure in the site mean strength should not be in situ strength should not be more than 0.85 f ck. And I have told you how to find out mean in situ strength to cube strength; so, and core strength sorry core strength. So, core rebound hammer correlation core CAPO correlation core USPB correlation anything you use you are able to find out in situ strength that in situ mean in situ strength should not be less than 0.85 f ck and the least value should not be less than 0.75 f ck least value lowest value in situ strength because in situ strength average should not be more than less than a 8.5 f ck and this is actually again you know kind of a guideline.

EN 65 EN you know now European code which is also a British code is part of the European code 1379 says f ck i s first you determine f ck in situ and this not be less than 0.85 f ck. So, you see the earlier British code was different it says that you find out in worst location average in situ strength that should not be less than 0.8 f ck Indian code

says you find in suit strength average in situ in situ strength should not be less than 0.85 f ck and minimum in situ strength should not be less than 0.75 f ck and this en code goes a little bit its it gives you an way to estimate the f ck in situ.

How it does it takes three cases if you have 3 to 14 cores you use the approach B I will tell you what is approach A which is number of cores more than 15 then you use approach A and indirectly through correlation is approach a right. So, alternative there it gives you alternative one direct correlation with core alternative two limited cores. And they gave a basic curve and from there you establish your own correlation. So, something let us see what each one of them is actually that is very elaborate.

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So, it says that if you have more than 15 cores find out the mean in situ strength. So, 16 17 cores you have found out for the mean in situ strength then f ck in situ is given by f ck mean you know f mean in situ strength minus 1.48 standard deviation this is that z value or equivalent t value or whatever it is they have suggested this value right.

And f ck or f ck i s plus f ck in situ will be taken as f ck lowest plus 4 whichever is lower s should always more than 2 it cannot be less than 2 it is not feasible if it is less than 2 then also it is good to take it as 2. So, you find out f ck i s now this f ck i s should be greater than 0.85 f ck. So, if it is m 30 concrete or m 20 concrete 0.85 f ck is 17.17.17 I mean 17 MPa. So, in situ strength mean strength minus 1.48 standard deviation should be more than 17. So, in situ strength you know mean in situ should be minus 1.48

standard deviation which is f ck i s. So, this value should be greater than 17 then it will be satisfying m 20 grade of concrete right.

So, this you determine this number of take from 16 cores find out mean strength that minus the standard deviation from those cores then you get this. So, this was taken an average value for a given confidence level right or f ck lowest plus 4. So, it is also taking care of the lowest plus 4 whichever is lower.

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So, that is the E N code if it is approach B is something like this it says if it is you cannot have less than 3. So, if you have 3 to 14 then approach B where it says f ck same, but here it is not specified 1.48s, but it says k. Now, k varies k is the number of you know k depends upon number of cores supposing it is 7 for 3 to 6 cores 5 for 7 to 9 cores and 5 for 10 to 14 cores. So, this k value now know 1.48s it is a simply suggesting a values basically is the same how much is a because if you test small number of samples estimated standard deviation is not the true you know it is it is different than the population standard deviation because of sample size effect.

So, use what you called t distribution s and sigma s is for samples sigma is for population. So, to take care of this kind of situations for small number of samples it does not want you to get into too many statistics, but simply it gives you some guideline based on, but the concept behind this is same sample size statistics related to small samples size

of small sample size. So, it gives you this and you can see that this is much more elaborate.

In fact, if I have to use and nobody insist that you have to use Indian standard code has used this 13791 which is much more elaborate right. So, that is how interpretation of strength is done.

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So, this is what it is and that is what it is.

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Now, if it is other approach is there you know other approach is there then also it says you can you can establish the correlation strength from correlation. In that case it is this value gets changes standard deviation should be greater than 3 at least right if you are using the other approach.

One approach is direct code 3 to 14 or more than 14 the other approach is through correlation 2 approaches I talked A and B. So, A is through correlation in that case it says that you establish your correlation concrete specific correlation based on some basic curve it is given. So, basic curves are of something of this kind x axis will have some index rebound number index ultrasonic pulse velocity or strength and this is the in situ strength or core strength or whatever you have found.

And it gives you a basic curve for you know each type of correlation that you are trying to establish yeah. So, each type of correlation you are trying to establish and then you say you find out your deviation you know it gives you a way to a actually establish your own correlation. But, I found it that it does not work in Indian condition because, your curve will be something like this you know it does not match may be they have arrived at it from the European conditions in India you have to establish your own correlation using all the statistical regression and there is no other way using statistical regression no other way.

So, the basic curves are available for rebound number ultrasonic pulse velocity pull out test etcetera several curves are given and you can use them if you want to, but my own experience that in India perhaps its better no do not use basic curves you try to establish your own basic curves simplifies the regression process, but today with. So, many statistical softwares available one can develop their own curves, but you need large number of data in that case. So, basic curves are very much there.

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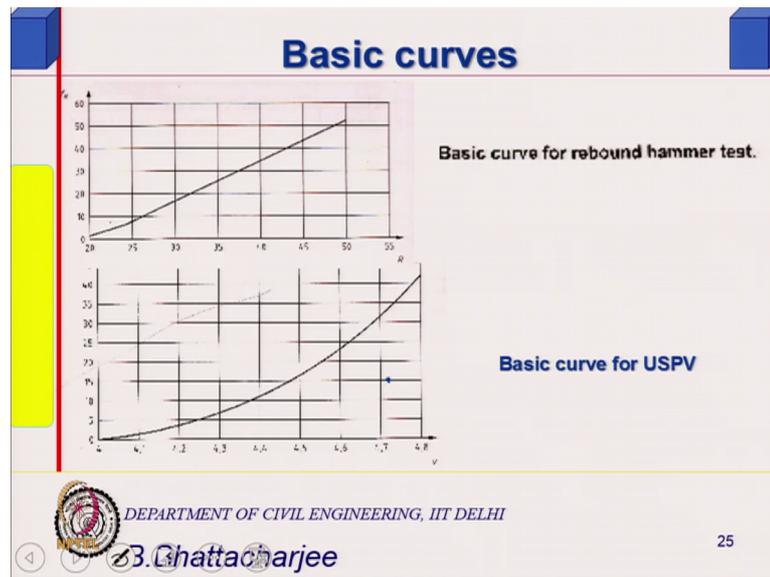
So, basic curve for rebound hammer test is like this basic curve for ultrasonic test. So, deviation of your curve your points from the basic curve we find out and then it gives a procedure to establish a new curve which was a top curve which is your curve which is your curve, but if all your results are coming down below here you cannot actually use this thing. So, there is a problem we cannot have I mean; so, far I was not able to use this basic curve for pull out test.

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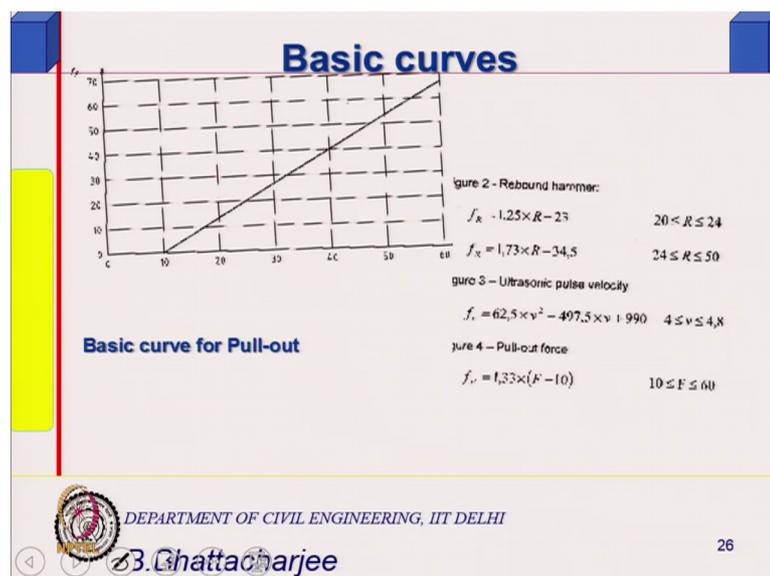
So, b bs code provides all this right ok.

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So, that is now, you know this already I have told you.

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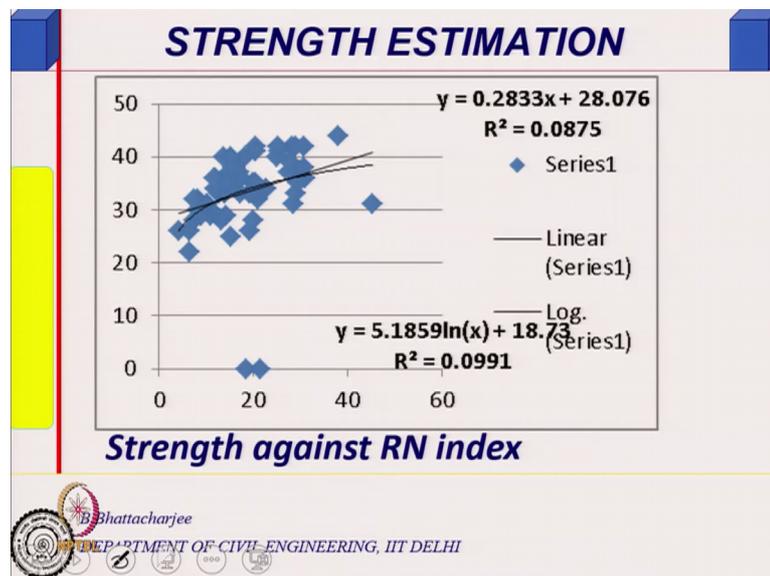
Now, this is a correlation that sometime you might get. For example, this is a correlation I am showing between rebound number and strength from actual site. So, this is what it is, but if you take log strength then it comes out to be better may have to do a little bit of statistical jugglery depending upon sometime log curve fits. So, you have to fit a best curve this is a log curve fit much better you know this was sorry this was neither was fitting very well, but then something we did actually we did something.

A multiple correlation so, use this so, this was single if I was using single rebound number index I was not getting good curve, but I have data available for both rebound number and ultrasonic pulse velocity data. So, then I use a multiple regression and I use log strength and in that case I get actually relatively much better coefficient of determination it is not very good, but still it was order of around 0.61 or something of this kind I think you know. So, the equation came out to be something of this kind 0.16 rebound number plus 2.74 v 10 log strength.

So, this kind of you know you can improve over your correlation if use more than one variable multivariate regression and in we have done simple linear regression using excel. So, statistics can be used first you try to do your own correlation otherwise you have to do too many cores. So, we restrict it maybe take 20 cores in a large building that was 6 to 13 storeys 17 storey building. So, you could take a lot of cores and, but then we have to take only between 6 to 13 because we stratified now 6 to up to 6 we found things were better and above 13 was not.

So, bad problem was with 6 to 13 which was a different concrete. So, we took 6 to 13 means 7 floors large area you can take 20 30cores to establish your 30 cores you know large more number of test you can establish your correlation. But there also you are finding that correlation was not very good then we use rebound number and ultrasound together and multiple linear regression we use using excel linest, linest is the function

available in excel. So, it is not a problem these days to do all this and it gives us better at least 80 percent of the.

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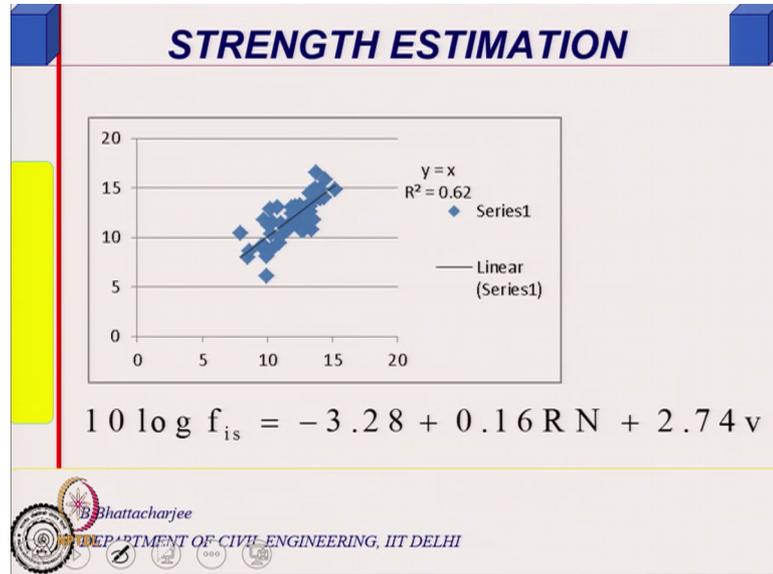
Nearly 80 percent of the results were. So, this is the kind of curve 0.62 it was coming R square it is improved 0.9. It was showing earlier no correlation actually now it is 0.62 which means about under root of 0.62 is around 0.7576 76 percent or 77 percent of the results are explained by this kind of correlation.

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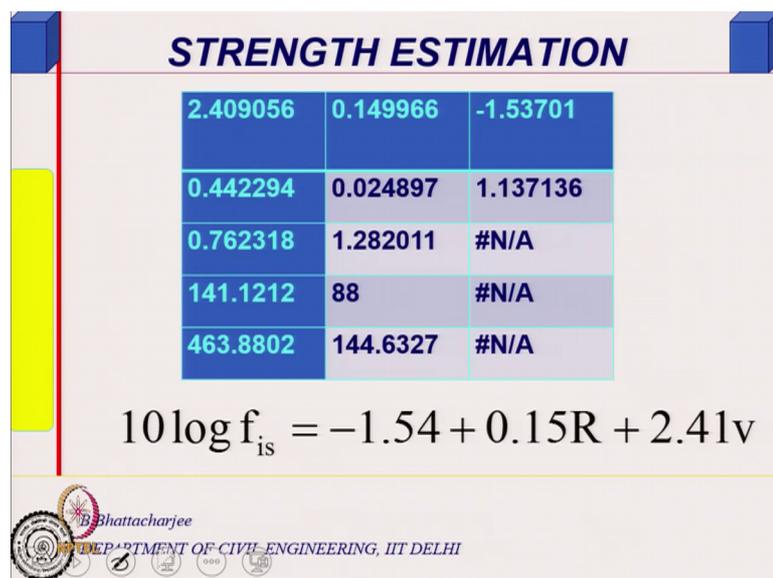
So, that is it so, you know that is what it is. So, we used yeah this more data then you said you do more tests, few more test were done, few more cores were taken and we did improve the situation even better. So, we get got somewhat better right. So, this was you know this is the kind of scenario you can actually improve it by doing then you do more core test result establish better correlation. So, finally, we did a better correlation we established and this line seems to be fitting better both the strength.

And then we predicted strength in many places where we have only taken rebound number and ultrasound which was 350 or something of that order cores were much less where. So, we could not get full information about the strength and which need at which column need a strengthening. Which it did not need strengthening, you can segregate out actually you saved on to the cost because all columns some columns you could say it was all problem of columns nothing else. Some columns you could say that this you know earlier we would have done (Refer Time: 34:34), but we decided that only some columns will strengthen some columns will not strengthen. So, this sort of things you can do ok.

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So, this is you know some cases you may have to predict shrinkage right shrinkage stresses and ACI 209 gives you how to estimate shrinkage cracks some cases we did use this I think I will not go into details of estimation of shrinkage, but shrinkage can be estimated from ACI 209 R. And the relation you know if you have this data and if that calculate the shrinkage we have seen remember we talked about the tunnel lining the

cracks and we thought some of them were due to shrinkage cracks early shrinkage drying shrinkage cracks. Then we estimated the shrinkage using ACI 209 R and then we found out actually found out that ultimate shrinkage that is possible.

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Analysis for Drying Shrinkage (ACI 209.R-92)

- K5 on fine aggregate(Af) to total aggregate (A) ratio (Af/A); K6 on cement content(C) K 7 on air content a1 For moist curing condition drying shrinkage strain Sh (t,d) is expressed through the expression:

$$S_h(t,d) = \frac{(t-d) \times S_{hu}}{[35+(t-d)]}$$

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Analysis for Drying Shrinkage (ACI 209.R-92)

$$E(t) = E(28)\left[0.4 + 0.6\frac{f_{cu}(t)}{f_{cu}(28)}\right]$$

$$\sigma_t = E(t) \times S_h(t,d);$$

$$E(28) = 20 + 0.2f_{c28}\text{GPa}; \quad (BS8110)$$

$$f_{cu}(t) = f_{cu}(28)\left[\frac{t}{(4+0.85t)}\right] \text{ for OPC moist cured}$$

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And calculated them and calculated value then we correlated.

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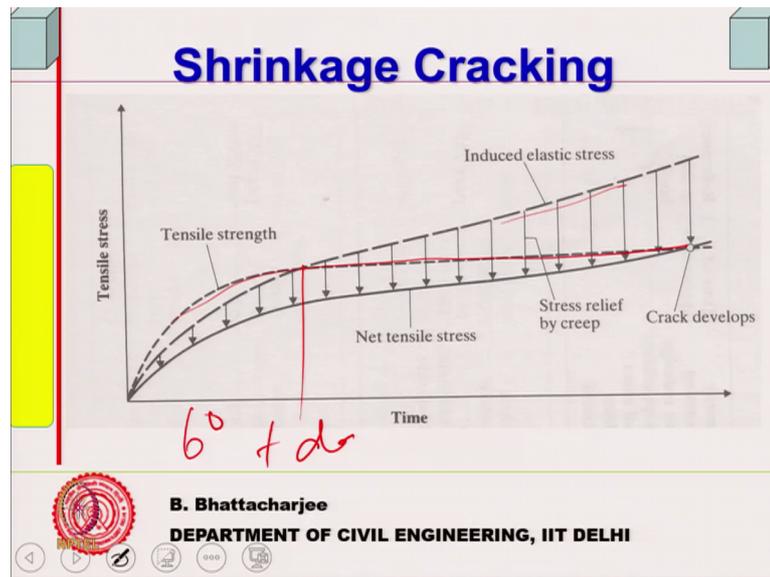
And, then what you did was you know the strength development how the strength will development. So, strength Tensile strength will develop in this manner as a function of time. This was based on again E will change in this manner Tensile strength formula is available for moist cured scenario, for other curing scenario this is also available. How the strength will extend this is a British code practice I mean BS 8110 it will give you how to find out the strength.

Therefore, Tensile strength how it increases that is known to us we found out how the strains shrinkage strains therefore, multiply by the elastic modulus taking care of the positive creep effect we also calculated creep and we can predict when the Tensile strength the induced elastic stress will exceed the Tensile strength it was induced stress will exceed the Tensile strength it the number of days. So, t days you could find out and t days when we tested it was say this t days comes out to be let us say something like 60 days and we did testing at 6 months or 1 year.

So, therefore, we could actually say that diagnose this it is actually shrinkage cracks. First visual observation we identify from the nature of crack that is shrinkage cracks, we can do some calculations also. This is available in (Refer Time: 37:14) books, this is available in (Refer Time: 37:15) books or many other books.

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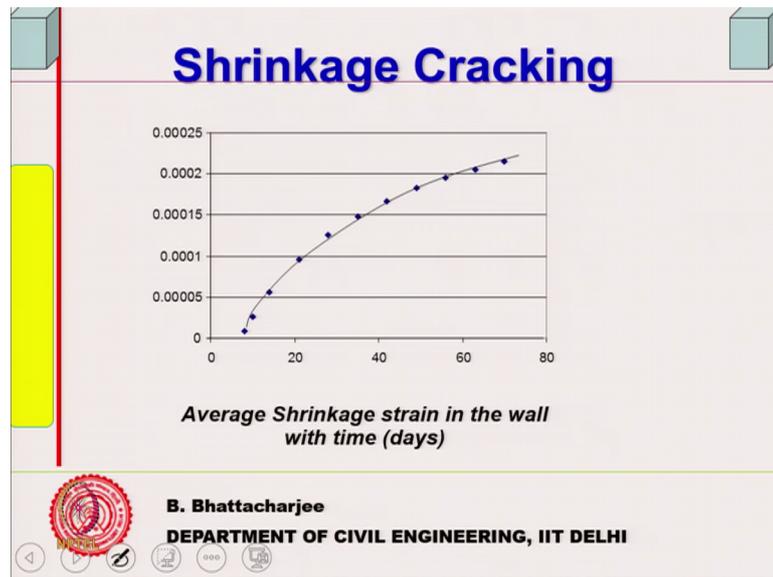
So, this is what we did we plotted the Tensile strength average shrinkage in the wall with time based on these ACI formulae.

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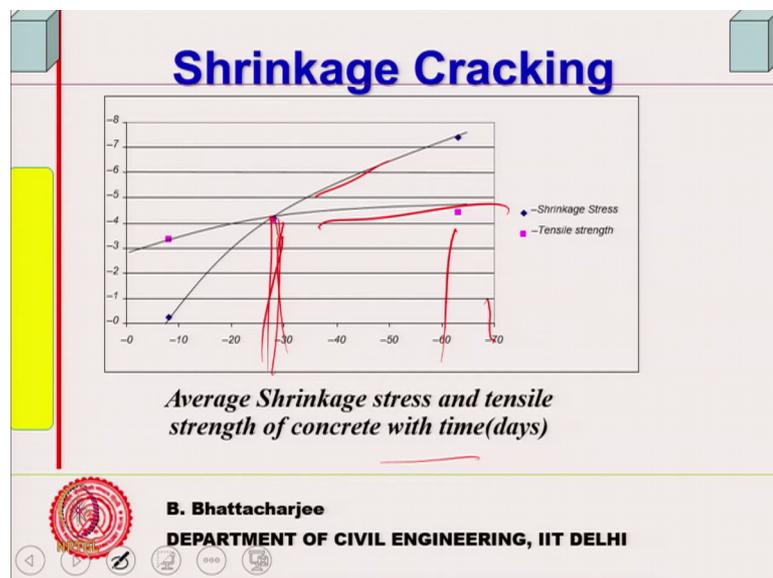
And average strength development was given by Tensile strength is that pink ones this curve therefore, the edge at which actually this is not minus this edge at which actually cracks should have started you know initiated we could find out. So, average shrinkage stress and Tensile strength of concrete with time. Therefore, since the stress exceeds at the Tensile strength, it would have cracked at this point of time and we might have tested

some around you know 60 last test we did 2 months later I mean whatever it is 60 days after 60 days.

So, therefore, one can justify your diagnosis by theoretical calculation interpretation will include all this it is just not purely you know something some simply you can some notional thing one can right lot of you know science can concrete science can go into it. Last case I will just discuss in 2 minutes 2 to 2 to 3 minutes this is a case where we have to compare.

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This is a case where you know the cement strength should have been 53 grade cement should have been 53 grade when they tested they found it out to be 47 MPa. So, it did not satisfy 53 grade requirement it was a pre stressed concrete actual structure in Delhi right. So, concrete cube test was also satisfactory, but there was a query from the investigation agency financial investigation agency like you know cbc and things like that. They are said that it was 53 grade you use 47 grade, but then you cannot do the test the structure is already it is a you know it is a bridge structure it was of flyover structure it was actually in operation.

So, I cannot take any core or I can take limited you know I can limited damage I can do. So, what you did you did CAPO test very limited core test and lot of ultrasound test and compare the results of those places where you know cement not satisfying 53 grade that is span where cement not satisfying 53 grade was used then some other span where

cement satisfying 53 grade were used. Compare the properties and if the properties were same and I have already said that that satisfactory the one having correct cement is satisfactory then this should be also satisfactory. So, we would used a comparative evaluation this can be done you know compliance to specification basically. So, implication is we just looked into investigation by comparison.

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And what we did we actually set the ones. So, we called this the one satisfying requirement we call is concrete B one not satisfying requirement we call it concrete a requirement of cement not the concrete because it is the v requirement of cement. And then the grade of cement existing concrete cannot be conclusively identified I cannot do chemical testing and identify grade of cement. So, therefore, we went to the final product.

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And what we did we did lot of non destructive testing we said that concrete B is deemed to satisfy all the properties requirement envisaged in design including those required for adequate safety and structure provided.

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It is as good as you know concrete A and B are same that is what the point and if the statement says all which the slides you have. So, to test hypothesis that surface hardness soundness and solidity of concrete A is as good as B would compare them. So, what we did?

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We did USPV CAPO rebound hammer and limited core test to see that things are you know correlation is the hypothesis testing we used statistical hypothesis testing we used that concrete A is as good as concrete B. So, basically statistical hypothesis testing we did right.

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So, null hypothesis we established mean rebound hammer standard deviation for concrete A was this concrete B was this USPV was this and CAPO was this then we used simply the hypothesis testing right.

So, CAPO correlated you know. So, there are two three types of statistical test is there we looked at integral absolute error for all of them with I mean this with the core. So, we found that this is reasonably good CAPOs gives you reasonable understanding of the in situ strength that is one thing we use that integrate integrated absolute error to in order to find out whether CAPO and core matches or not.

And then what you did this is the z value null hypothesis that mu A plus mu B is equals to 0 and alternative is hypothesis mu A is greater than mu B because one mean of one

concrete is better the other you know. So, this hypothesis testing we did and calculated using statistical formula. And you know all these values are here actually and we found out the critical z alpha value for this case with the level of significance of alpha equals to 0.05 it is 1.645.

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And used statistical hypothesis testing right and we could conclude I am not going into the statistics unless you are interested, you can look into this detail is available here. And we could establish that concrete A is as good as concrete B, you know by doing simple statistical testing for each type of test; first for the rebound number test then for the ultrasonic test and then for the CAPO test.

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So, final finding was something like this you know. So, this is what it is and if it is corrosion distressed test then we do of course, all this number of test what we I just mentioned earlier half cell potential.

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RESULTS

Sr. No.	Element Information	USPV (Km/s)	Compressive Strength (MPa)	fin-situ/fck	Carbonation Depth / Cover Depth	Class Visual Inspection	Assigned Group
1	Col. F10 (LB)	3.035	5.38	2.07	0.52	2.36	1
2	Col.C8 (LB)	3.2906	3.27	1.26	1.12	2.97	1
3	Col.C7 (LB)	3.503	3.27	1.26	1.5	3.03	2
4	Col.B3 (LB)	3.479	3.15	1.21	0.61	2.29	1
5	Col.D2 (LB)	3.564	3.27	1.26	1.57	2.29	1
6	Col.D3 (LB)	2.074	3.00	1.15	1.02	3.03	2
7	Col. F2 (LB)	3.721	3.08	1.18	0.83	2.29	1
8	Col. H2-3 (LB)	2.16	3.27	1.26	1.4	2.36	2
9	Col. B5 (LB)	3.527	3.15	1.21	1.05	2.29	1
10	Col. C9 (UB)	3.048	1.54	0.59	1.44	2.29	2
11	Col. C5 (UB)	2.796	1.73	0.67	1.63	2.29	2

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REMEDIAL SUGGESTION

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And, this is another case of then you suggest remedial concrete, some remedial measures suggested based on this.

So, I think with this I would like to conclude our discussion right.