Fire Protection, Services and Maintenance Management of Building
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Lecture – 47
Effect of corrosion and Alkali Aggregate Reaction

Related to visual survey starting from crack pattern for intrinsic cracks in concrete, you looked into manifestation of certain types of deterioration like; you know in last two classes. In fact, you looked into those especially related to alkali aggregate reaction, earlier we saw shrinkage cracks then, plastic settlement and all that.

And then, will look into cracks related to some of the deterioration processes which we now continuing, we looked into alkali aggregate reaction cracks in details also looked into freeze thaw. And now we look into effects of corrosion where we have stopped in the last class.

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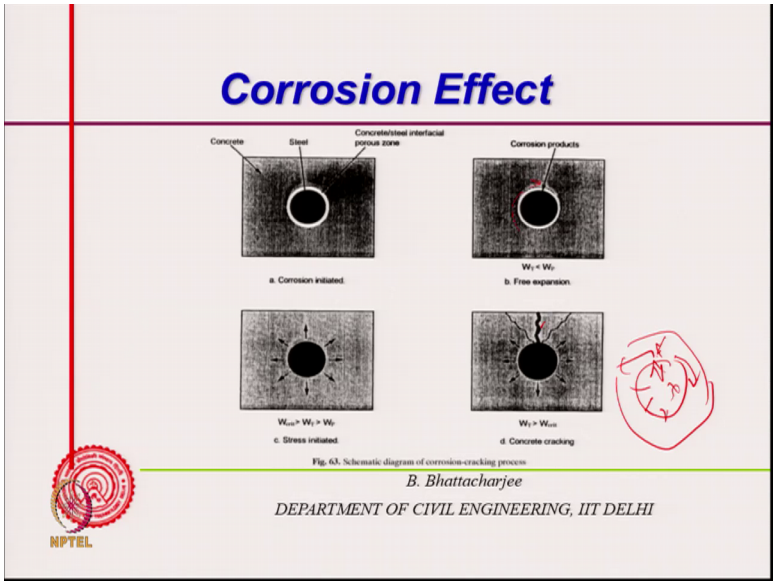

So, what I said was in the last class that corrosion effect is something like this, you know normally to start with we stopped somewhere here so, this is your rebar and the concrete in the surrounding. Now as the process of active corrosion starts, corrosion product which occupies 3 to 4 times the volume than that of steel because, corrosion products oxides hydroxides their densities are much less compared to that of higher.

So, they occupy more space, initially they will fill in the spaces around the rebar you know, they will fill in the spaces around the rebar. And then gradually the more product comes in they will actually exert pressure to the surrounding concrete. And further to that as it exerts pressure like a, like you know like in case of a tube if pressure is exerted in all direction.

So, it causes crack into the you know it will it tensile stresses are generated along which direction because, the peripheral will try to expand and finally, you will find crack of this form. So, tensile stresses resulting from expansion actually finally, cause cracking.

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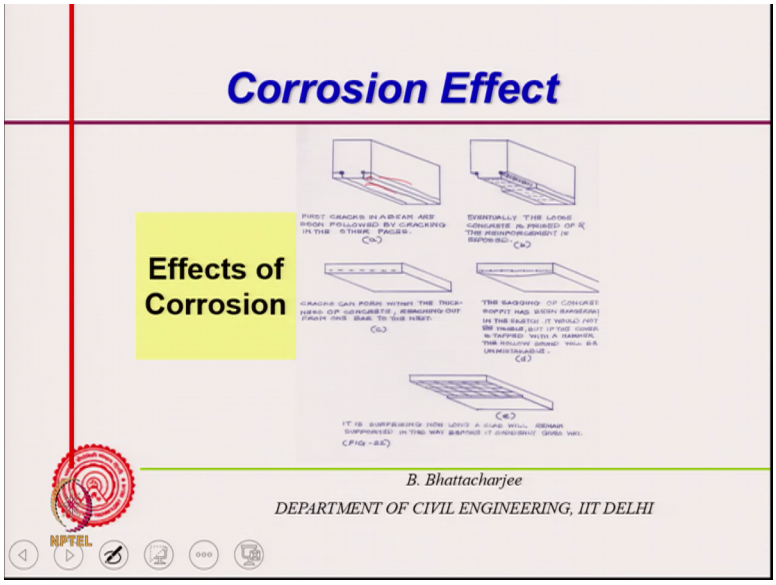

So, that is what it is and then there if it is manifests in the form of so, for example, in beams you might find that pole initially some cracks will appear, visible cracks will appear along the length of the rebar, you know parallel to the rebar, in case of beams in both the direction.

Because, you know covers are covers are usually same; if one side cover is less then, first it will come on that side, then later on onto the other side so, we will have cracks of this form. Then chunks of concrete will come out eventually, because further pressure develops. In case of slab first of course, the cracks will internal cracks will generate, but that would not show up much till sometime later when there will be sagging on the slab. And finally, something like this chunk of concrete will fall down so, spoiling of concrete would occur so this is the manifestation of corrosion.

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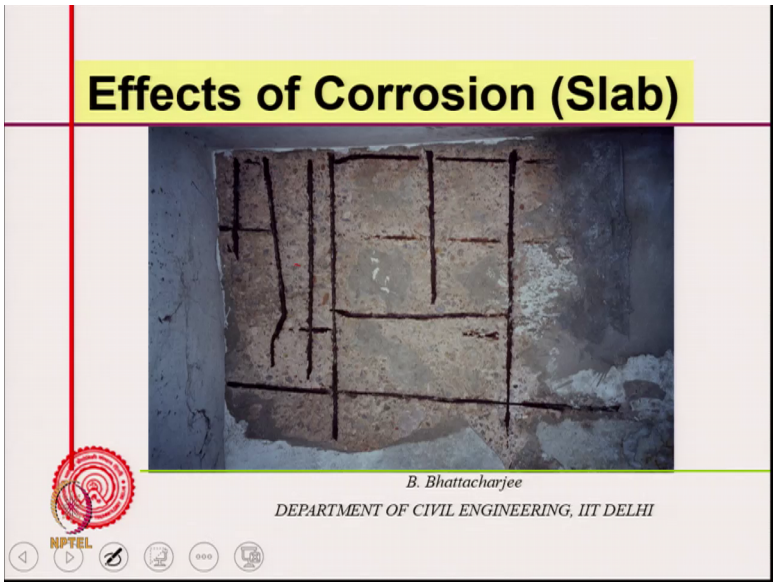

But then you can detect quite early, if you see rust staining, moisture marks, then you have already you know you started detecting them early. And later on you can if in some later stages; obviously, the cracks will come they will become wide and if you break it you will find rust there.

So, examples are, typical examples are something like this is the next you know a case where already law of corrosion is occurred, so you can see the rusted rebars and the concrete has spalled off. So, that is almost in a final stage.

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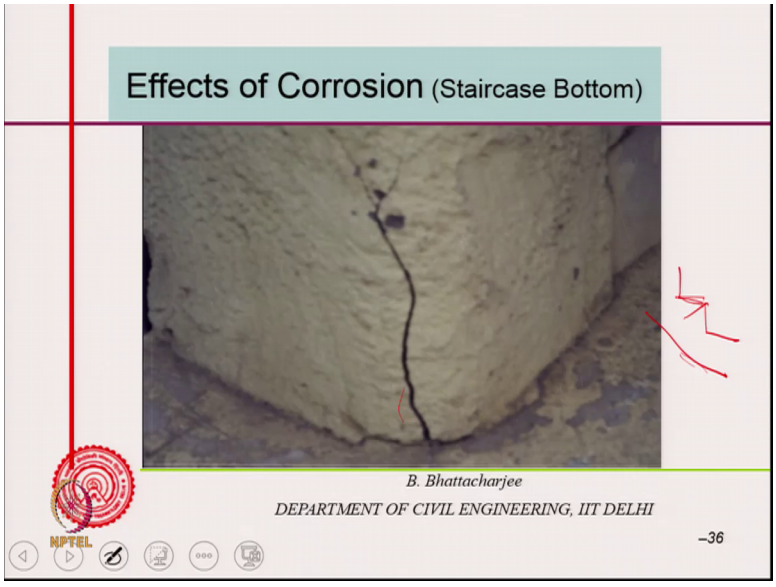

This is a case interesting case they actually repaired it from the bottom; a staircase slab, you know it is something like this staircase slab something like this, I mean you have something of this kind you know so, the slab is something like this. So, this people what they have done they have actually repaired it from bottom, repaired from bottom by doing guniting did not do anything else.

Now, they did not stop the cause of corrosion, corrosion continued and eventually the repair cracked. So, there is an I kept this example this is a real case corrosion crack you know so, if the repair is not done appropriately it the you know the cracks might come again and again.

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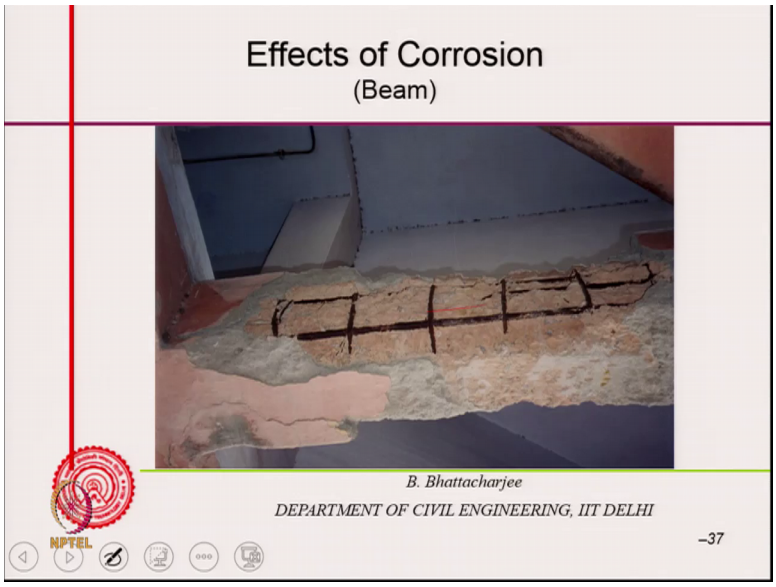

This is the case of a beam and this is again lot of falling has occurred they did not initially did pay heat to it so; lot of spoiling has occurred.

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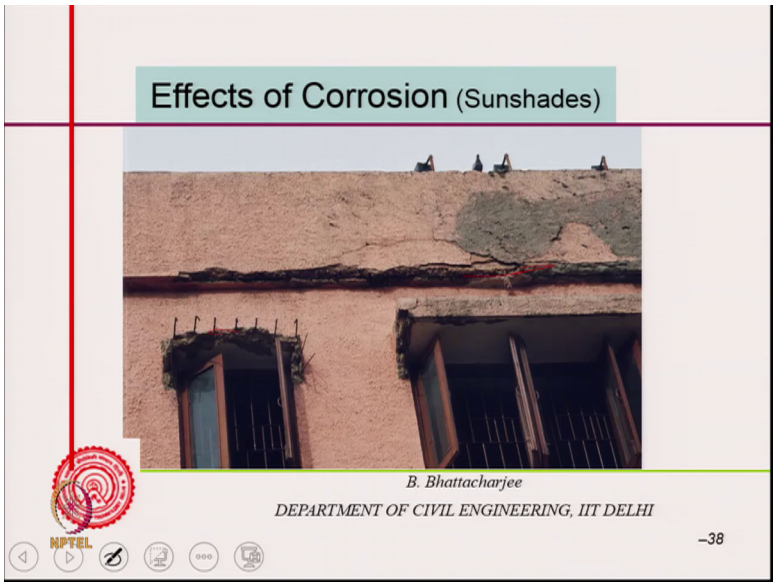

So, this what could be the beams sunshades very common, you will find something like this, you know that parapet, below parapet there is lot of cracks.

The sun shades have gone here, it started falling so, that is a kind of manifestation occurred. If you see rust staining, if you cracks with rust straining when you might open the crack and you might find there is an expansion is occurred and it might be parallel to the rebar right. So, corrosion can be identified very easily.

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Now, next is sulphate attack on concrete; now, sulphate attack results in formation of calcium, aluminate alumina sulphate you know as we call it C 3 A S bar some H 2O would be there you know so, these are called ettringite calcium sulphur aluminate; calcium sulphur aluminate. So, C 3 A will react with calcium sulphate and form this sort of thing now, this is white colour, white in colour.

So, you will see all white and cracking is patterns are because it is internal cracks so, expands should now occurring within, it will not follow any rebar line or anything of that kind and white marks will always will get calcium sulphate white you know formation of calcium sulphate. Because normally, calcium hydroxide is there in the cement hydrates, sulphate comes from outside, usually in form of sodium sulphate, sometime maybe directly as in the form of you know calcium sulphate itself, but often it is to the sodium sulphate is soluble, sodium sulphate potassium sulphate.

So, they come that form react with calcium hydroxide forming calcium sulphate and then this calcium sulphate reacts with the C 3 A hydrates forming a ettringite etcetera or this is the white marks. So, you can see the white marks of calcium sulphate and ettringite and you know lot of salt is there and cracks, patterns are of this kind random, I mean you do not see really. So, you have to actually visualise expansion how can it happen? If it is an internal expansion how can it happen right?

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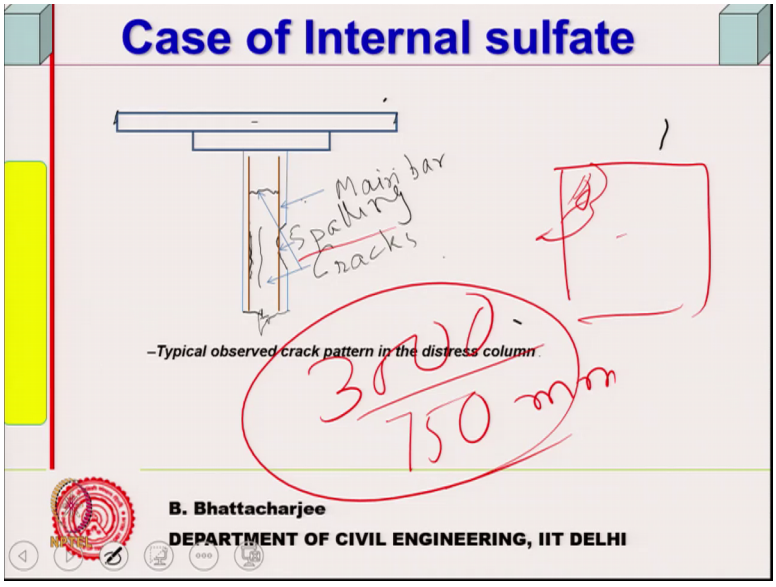

So, this is external chloride coming in, now this is an example of an internal chloride that I came across 8 months old concrete, cracks vertical direction inside flats slab instruction. Now, you know chunk of the concrete even came out from the centre of the column, spalling is occurred particularly in the corner I mean the centre height in the corner.

This is you know I suppose there is another diagram or if not I will see yeah, something like this the corners so you know this come out from the corner. Corner concrete exposing the rebar somewhere like this it is exposed and at the centre of the bar. Now, the centre of the bar if you have vertical cracks either the buckling is occurring right of the either is buckling.

But the dimension of the column was very large, something like 750 mm a meter you know square, square column 750 mm nearly close to 800 mm or so, nearly close to a meter size very large size you know it is storey building. Now, height is about 3 metres so, if u see l by d you know 3000 by even 750 if you take it, it is only 4.

Now, it is actually a short column, very much short, long column is 12 l by d is should be 12 so, this is this is short column no buckling is possible. In 8 months old concrete it is not possible to have rebar corrosion or similar sort of thing. So, then all that you know there horizontal cracks also and especially in the corner.

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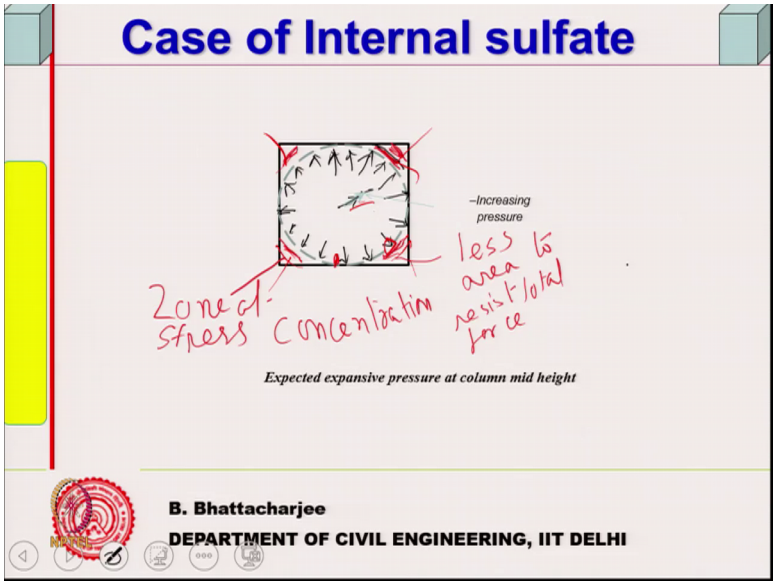

Now, visualising this stress pattern what we thought was, I thought was there must be the crack patterns you know this concrete spalled off this concrete spalled off because, will be stress concentration there, assume if there some kind of internal pressure.

If there is an internal pressure that will first results in this corner to go off, zone of excess stress right. So, stress concentration here less area to resist the force and this kind of you know chunk of concrete were seem to have gone from this corners. But rebar protected them, those were even if the pressure is there supposing there is a rebar, it will protect it will not allow the concrete to go away. So, leaving the rebar surrounding concrete has gone away and the cracks have also developed in some places like this vertical crack.

So, this was my first conjecture looking at that this must be because of some internal pressure. Now in a new concrete which is about 7 8 months old internal pressure can confirmise must be from cement system. And in cement if you have un-reacted sulphate gypsum remaining, excess overdosing of gypsum or something. And it remain un-reacted or delayed ettringite formation that normally occurs in case of; normally occurs in case of co specious concrete what they called delayed ettringite formation.

Here this was not a presets that is ordinary, but some or other possibly there are some calcium sulphate came from somewhere, possibly might have been from cement itself. The tested the water this there is no sulphate in the water of curing or anything of that kind, but there was some sulphate.

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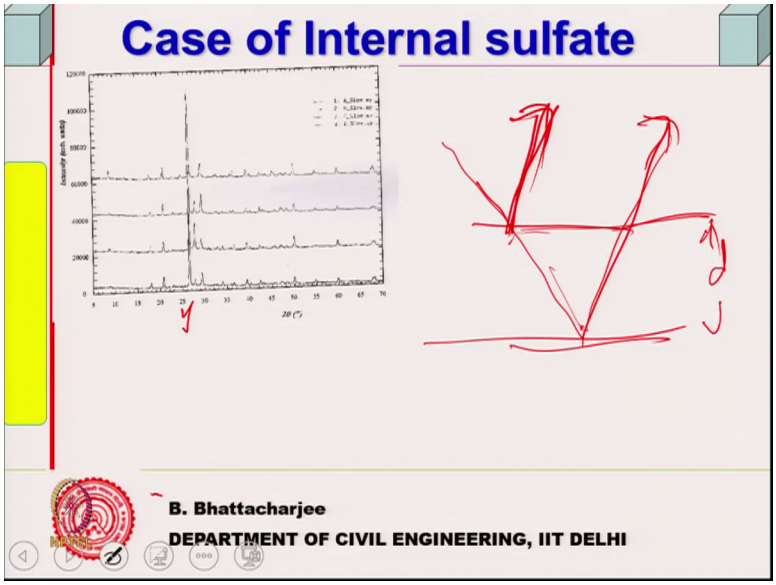

So, to verify this of course, you did instrumental test and X-ray diffraction of the product. Now, we need to X-ray diffraction of the product, then it was it you know it at around 9 degree and 18 degree you see normally this one, normal concrete normal hardened concrete XRD of concrete specimen right, generally from produce from ordinary cement and good water. So, this is X ray diffraction pattern of normal concrete, we do not find it ettringite peaks there after 7 8 you know old concrete we do not find.

But this concrete when we looked into there were always ettringite peaks, you know in x ray diffraction you find out the crystals because, I am not here to explain much of the x ray diffraction. Because you know the X ray wavelength is such that it can get diffracted from crystal planes. So, this is if there is a crystal plane is here another crystal plane is here, the first ray will diffract from here reflect get reflected from here. And the next ray some ray will get reflected from the and this is the d then this two since is a coherent source right.

These two can interfere constructively depending upon the angle of incidence because it is related to path difference you know should be equals to n lambda. So, you can actually show Braggs equation to design lambda is equals to you know n 2 d sin theta is equal to n lambda. So, I am not interested in this.

All I am saying is by X ray diffraction you can identify crystals, ettringite can be identified and this is exactly what was done in this particular case. So, we compare with the normal concrete, normal hardened concrete where they you know no problem would be there.

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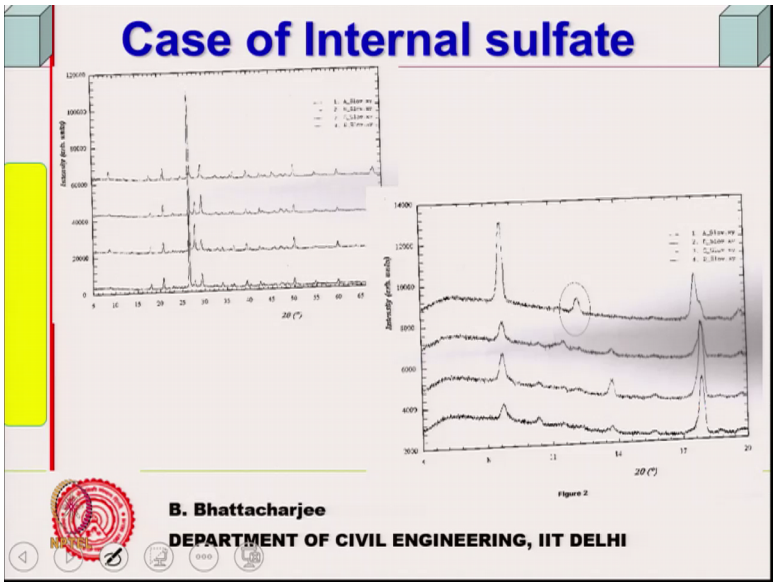

But then, this one this particular one concrete what we find was there are patterns of ettringite probe possible, which means there is a sulphate attack. So, confirming sulphate attack first thing is of course, you will have you know visual observation will show the cracks of the kind that I showed earlier.

You will find white crystals and you want to further confirm you can do some analytical testing like this, analytical testing like this; analytical testing like this right. So, this is how we do it. You know there are other cases also if you go and see perhaps some cases where sulphate attack has been extreme, say I came across one of the chimneys of a thermal power plant, now you have sulphur dioxide comes to the flue gases.

So, internal lining of the chimney was gone first, they did not repair it the lining some or other was not there and the concrete got exposed to flue gases. Moisture would be present so, sulphur dioxide reacts with water forming sulphurous and then oxidise14:11 to sulphuric acid and therefore, this sulphate part of it attack the concrete.

So, white you find white crystals so, all over the thing and when you scratch it you find there is a simply the powdered white coloured things coming out. If we did not do further because you know the client was not interested in doing further investigation in that of time. Otherwise, one could have done actually test them either chemically for presence of sulphate or do X ray diffraction as I did to find out the presence of sulphate.

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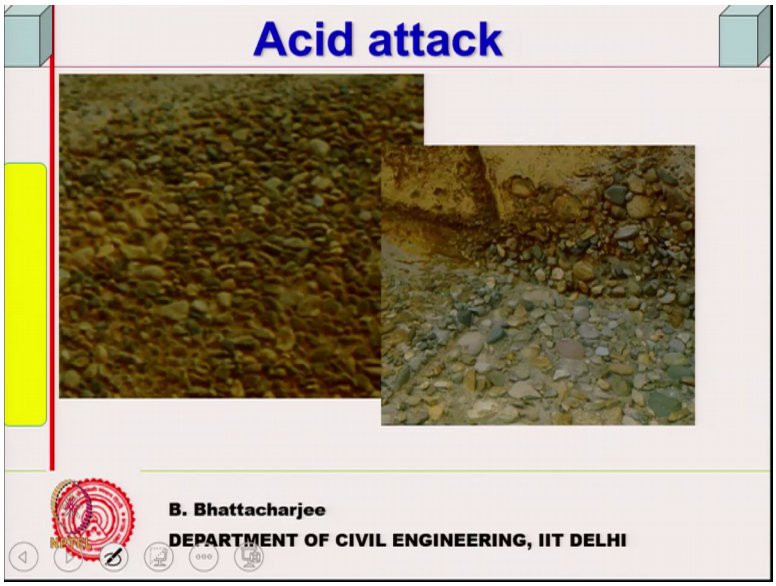

So, that is how you can find out alkali, I mean sorry sulphate attack cases. Acid attack cases are something like this, you might find simply powdered concrete, simply concrete you know the acid when acid attack because concrete with alkaline. So, we find lot of leaching has occurred of the model. So, this the kind of you know photograph of acid attack right, quite often it can it can happen in some of the waste drainage lines pipe because, industrial effluent or something acid is there it can attack.

And see the concrete is alkaline so, even at pH at 7 there is a tendency of some leaching and a at pH and 4 there will be excessive leaching and weakening of the surface concrete. So, these are the science of some acid attack, but you just cannot I mean this symptoms; the first thing is you have to also get the history documents survey done or history known that there is a possibility of some acid coming and then you find something like this, then you can diagnosis acid attack.

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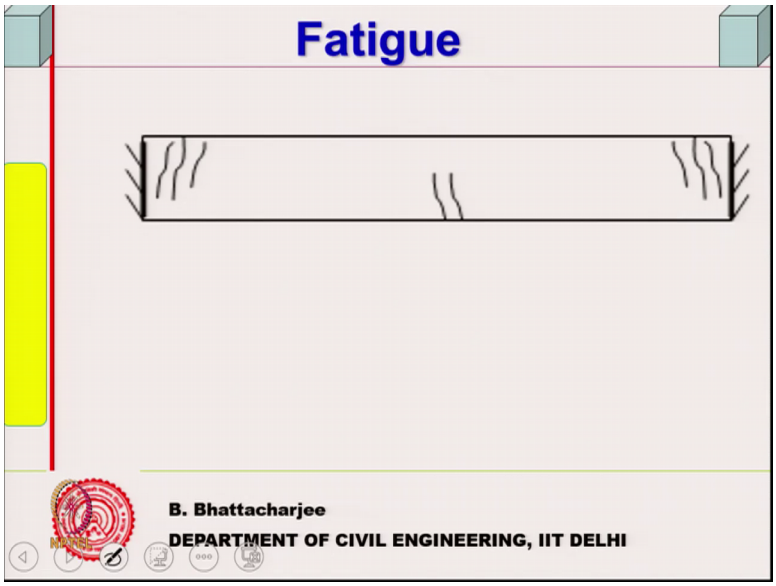

These are all the durability related attack that I talked about since last class. If it is fatigue or structural cracks, then you will get something of this kind, you know the reflection beams, the load because at this point near the support negative bending moment. So, flexural cracks, fatigue also over the long period of time, if you have not seen at the beginning might have seen long period of time, after long period of time it might be like this.

Poor concrete in the very long run right might show huge deflection and cracking at the structural level very poor concrete I mean we just came across on a cases, the concrete was extreme, when we tested the concrete it is extremely poor. So, it shows all flexural cracks in beams; you know shear cracks, inclined cracks resembling structural cracks.

And then, we tested the concrete it was IFCK was coming somewhere around 9, so bad concrete then we calculate the creep effect. Did not see the crack in the beginning, after 10 15 20 years they started observing cracks. So, if you calculate out the creep, take the creep coefficient etcetera you know specific creep coefficient etcetera. And calculate out effective modulus reduces significantly after 20 25 years taking the creep effect and it showed up when you take that the modulus is low and therefore, deflections and cracking can occur.

Fatigue is also a long term behaviour of the similar kind. So, structural cracks can be identified by looking at the nature of the cracks, maybe I will have some more diagrams

of structural cracks later on. But, they are relatively less common because both design and construction for both must be there particularly, if it is extreme construction for like the case just I was mentioning.

But most other cases it will be designed for also then, only you find you know that may be steel there I mean mix some steel during construction phase, poor concrete, all this results in structure cracks. So, normally structural cracks are not very often occurs, damages can occur because of excessive loading, but that is separate.

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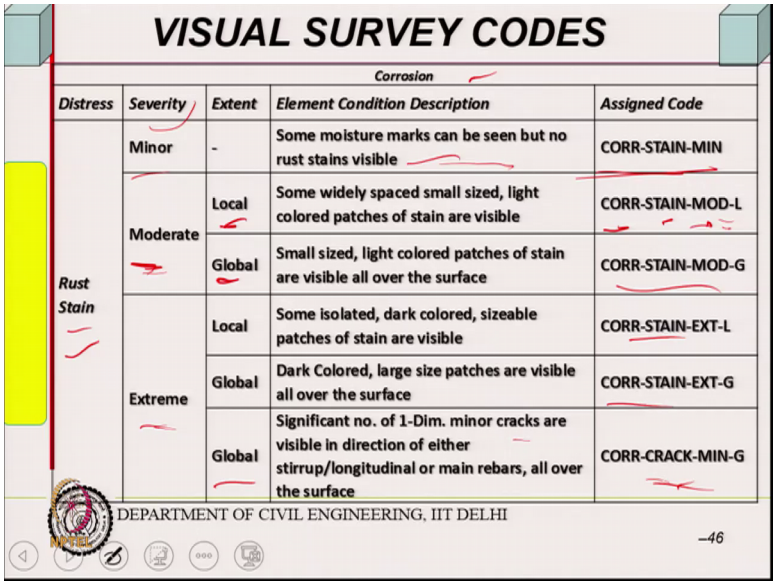

So, one can actually record this visual survey through visual survey codes, for example, as I said you can you know, I think I must mentioned earlier; now this is for corrosion. So, minor moderate extreme severity you can talk about, then description I think I have talked about this similarly earlier once and this again I am saying and you can do the code like.

So, visual survey somebody is doing can use this kind of code which I have talked earlier, again another scenario I am saying rust stain for corrosion, you have observed rust stain. Then you see first some moisture marks can be seen, but not rust stain visible, then this is a state you know state, then extent nothing is this you are not bothered about, but some widely spaced, small size light, coloured patches of stains, are you are seeing. So, this is rust staining, if you just seen rust staining you know corrosion cracks, then locally this is local, not over spreaded over area, global this is our very large area.

So, it is corrosion, strain you know moderate local, because this is a moderate local. So, you can codify this and record in your visual survey record simply this with a photograph maybe that is good. And similarly, you can do for extensive extreme global you know situation where the very large area, you find lot of significant one dimensional minor cracks visible in the direction either stirrup or longitudinal main bars because, this is parallel to bars all over the surface.

So, you can have coding of visual survey coding can be done in this manner right, which I have told have earlier also. So, this is for example, for reinforcement corrosion in a slab.

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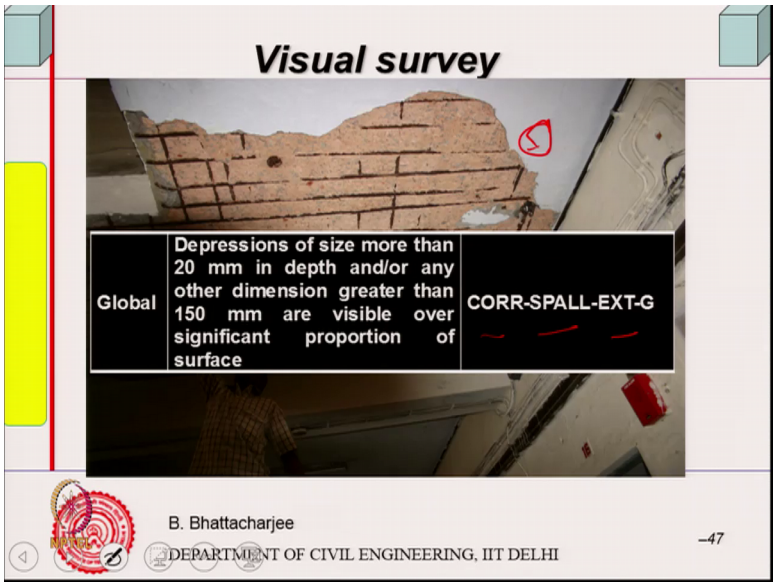

And this therefore, would be something like this global because, it is all over the place, whole of the slab is gone. So, if you call it as globally if it is only for a small area instead of all this may be the just this corner I have something like this. And rest all rest all is all intake then I would have called it local, this is global sorry this is global, and then depression of size more than 20 millimetre in depth and or any other dimensions greater than 100 millimetre are visible over significant proportion of surface. So, this is corrosion, spalling extensive global, this kind of complete code actually we have developed actually it is available I mean one if one once.

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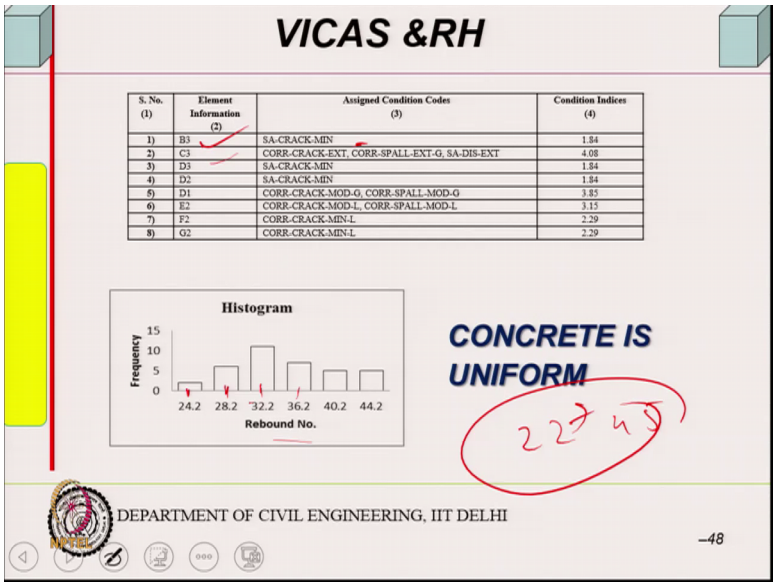

And then such coding you can put together and come out with a kind of a index for the whole building first for the element and then for the building. For example, you know like element number right so, this is the code and this is so, the codes are something like this. Now you can combine them and we and have developed actually mathematical tool also I am not teaching you here, but you can yourself also develop some kind of tool to come out with academy in index.

So, that you can relatively compare and if you get that index for the whole building, you can compare this from previous years 5 years earlier to now and you know what you how it is likely to progress in future some ideas you can get. So, using index, equivalent single index for the building first for the element combining those elements together I get for all the buildings. Some buildings may have only one or two elements affected, another building might have many elements affected. So, combining all these I can get index for the whole building. And comparison can be done with another building, if you have past experience this very bad this not so, bad requires repair immediately or I can delay the repair this sort of decisions can be taken.

Such you know state matrix and coding, codification of the state of defects of distress can easily be done for any kind of thing also so this is just as an example right. And then you will come to this is something different, this is for a specific case I will come back to this later because I am not already told you.

So, this was related to visual inspection right. Now I will come to this, but I think do I have anything related to visual inspection available here, if it is not I will come back to I will just come because, this is related to just quickly I will come back and you know look into look into this right.

So, essentially number of its area so, this is related to number of tests we go to do finally, so, in order to understand that we understand you go to understand the limit of variation of properties in concrete. For example, if you look at it, there is a we will see that we measure hardness surface hardness of concrete something called rebound hammer test.

Now, if you test a large number of them and then, you have got a range from somewhere I have let us say 22 45 or some such things, range of this rebound number, what is rebound number I will explain you later. Then you can divide them into classes, class intervals as we call it whose mean for example, here it is 24.2 28.2 30.2. And then number of results that falls into this class interval that we can show, that is the histogram plot.

Normally, it is expected that properties of concrete would vary normally normal distribution, what is normal distribution? I am sure you are familiar with, but even if you are not I will give you a brief you know quickly I will tell you what it is. Now, so, anything you measure on concrete it is likely to show a variation of this line, a peak and then symmetrical distributed about the peak right, so for example, strength variation of strength if I have look at and large number of Q's I test.

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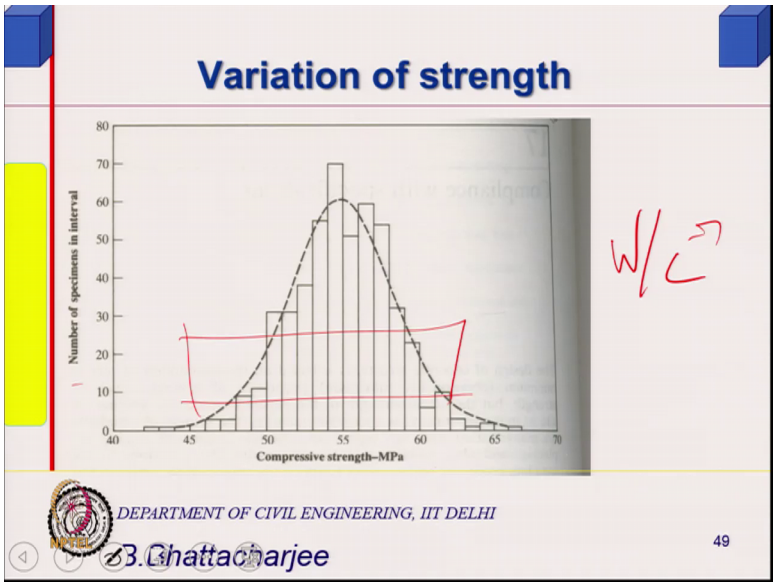

And I plot similar histograms frequency histogram, I get variation and which I can fit with a bell shaped curve. Now why it is so, because properties of concrete depends on any property that you measure in concrete large number of measurement you take.

You see there are many factors which will actually affect the property that properties. For example, strength if you look or surface hardness now, strength would depend upon first of all proportions variation in proportions, there could be from one cube to another cube, there can be variations in water cement ratio. You would not have exactly save water cement ratio for all or if you go to actual site and take rebound number every point you will not have same proportions, rebound number you have not the same, but proportion might be different right.

So, that is number 1, also the compaction level will be different and many such factors not one. So, when you have many such factors the tendency would be to vary in this manner. Slightly going a little bit more because many of you are would not have taken my concrete technology course or similar course, for example, you know I think I might have told you already when I have talking about services.

And I must mentioned about normal distribution, I told you about case of a die, did I tell you about this? Yeah so, this is this reminds if you have too many number of factors you know controlling your measure property right. Even of the individual factor varies

uniformly, their sum total you know too many factors affecting the property would essentially lead to a normal distribution.

I think I have already talked about it in my earlier services class. So, therefore, concrete also one of them so, it varies normally so, normal distribution for concrete, normal distribution for concrete right. So, concrete strength or you know any other property actually exhibit normal distribution.

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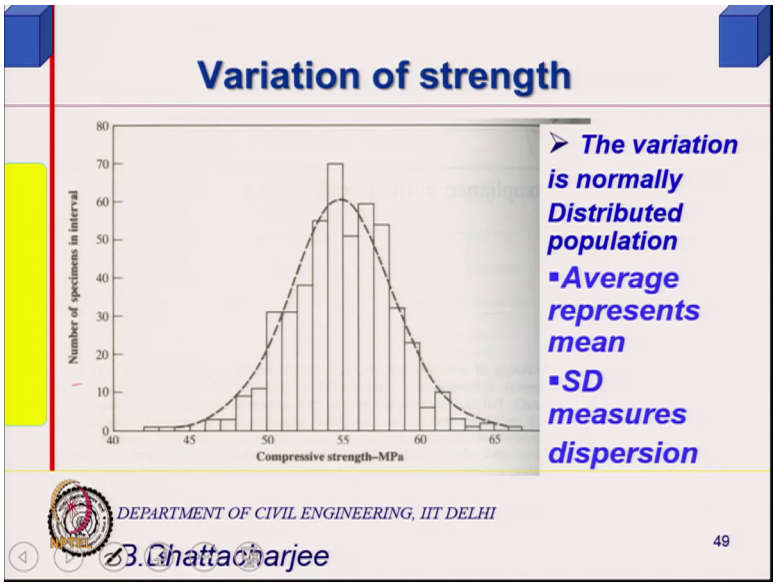

And we define our characteristic strengths right so, this is this has got 2 parameter one is a mean another is a standard deviation. So, these are the 2 parameters which we describe standard deviation explains you know another is a measure of the dispersion. And mean is a central tendency where you know so, it is actually the distribution is symmetric about the mean both sides same. So, the peak what is call we call it mean, mode and median all are the same point in case of normal distribution.

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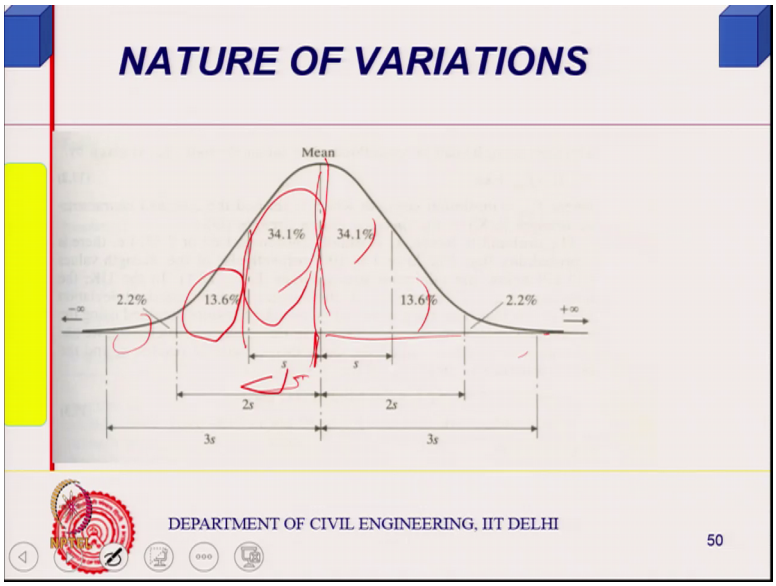

So, this also we know that this if I normalise it, I get the total area under the curve is 1 and total area under the curve is 1 and this side this area is 50 percent. So, 50 percent of the samples will have higher value than the mean values. So, for example, strength in case of strength you have test large number of samples, 50 percent of the samples will exhibit strength more than mean. And 50 percent will show less than mean because, mean and median are same, median is a one which corresponds to 50 percent of the samples right.

And this is up to one standard deviation you go; this area is 34.1 percent, this 13.6 percent 2.2 and so on so forth. So, this is how you know the behaviour I mean normal distribution behaviour is like this.

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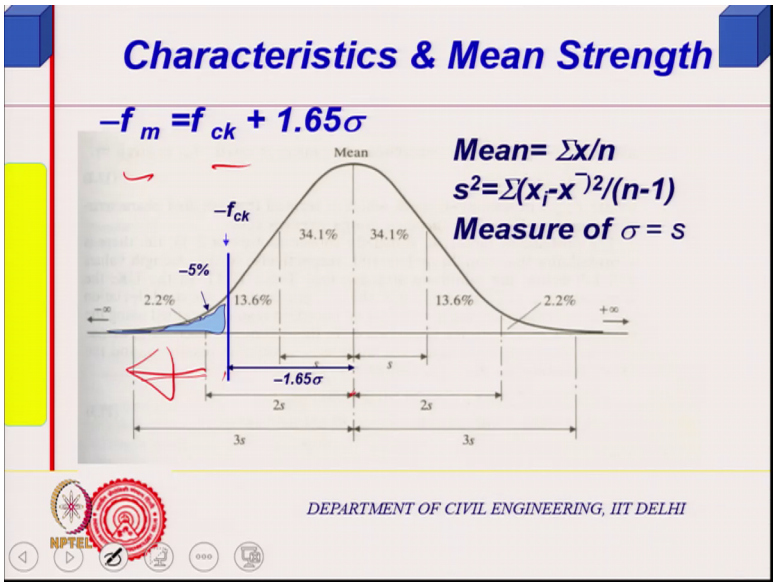

So, one can calculate out the mean for small sample, one can calculate a measure of standard deviation as a square this we know. Now, in case of concrete of course, you are we talk in terms of characteristic strength of standard cube right f ck. So, f ck is defined like this, only 5 percent of the samples will show results less and in structures I would like to know what is f c k? I would like to know f c k.

So, 5 percent of the so, it is somewhere here mean is somewhere there. So, f c k plus 1.1 1.65 sigma because, corresponding to 5 percent, corresponding to 5 percent, area this 5 percent, it is 1 point sigma distance away from the mean. So, mean is f c k plus 1.65 sigma alright 1.65 sigma mean plus 1.65 sigma. So, that is what it is? So, at site I would like to find out this f ck that is why later on we will talk about this.

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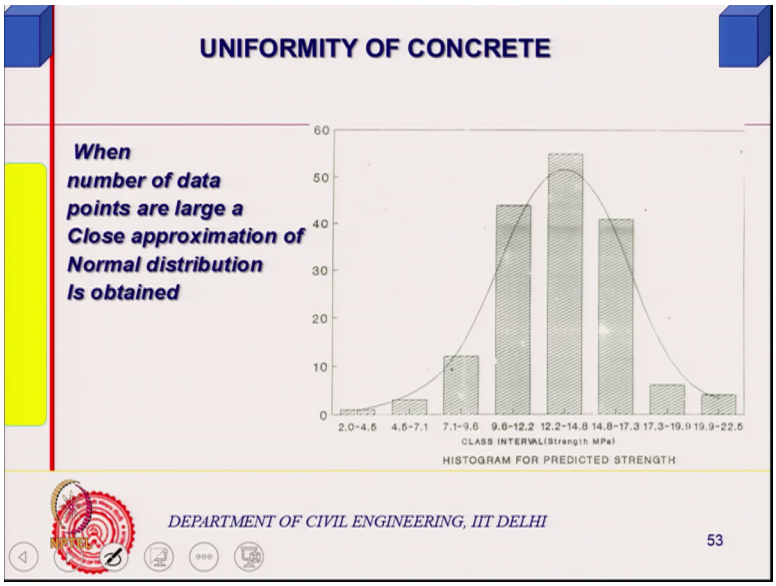

But also the normal distribution concept is required to understand the number of samples it would be should be testing in order to get a given you know have all the results within given error. So, when you have large number of points it is something like this right normal distribution.

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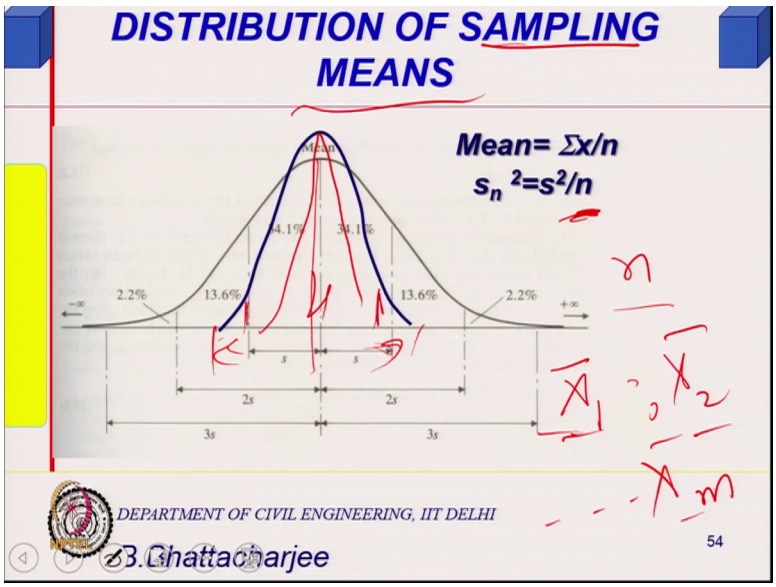

But supporting I take some n number of samples and find out the mean, then find out the mean right n number of samples find out the mean. And then again take another n number of samples I will find out the mean. So, each mean let me call it as x 1 bar x 2

bar etcetera and I repeat this process x m time m times right or large number of times. Then this beams will also be distributed normally, because you know they will also show normal distribution because I have picked up randomly n number of them, but they will have less standard deviation.

Because, the mean spread would be less because, the depending upon number of n. If my n is very large spread will be small, if n is 1 then it is same speed as the origin and parent distribution. If n is 1 it will have same you know parent distribution will same as parent distribution, but if n is infinity then standard deviation of this means will be 0, I will just explain further more on to this.

So, this distribution of this means we call it distribution of sampling means, if I take set of means you know set of you know set of samples and then find out the mean and now mean of the means and standard deviation of the means, I can find out. Because, I can find out the distribution of those means this is we call distribution of sampling mean, distribution of sampling mean, right distribution of sampling mean.

So, distribution of sampling in this concept is used because that is why you do not test one sample. For any test you are doing either lab or institute you will test a number of them and find out their mean. And that mean is supposed to represent the true mean, true value, which is the you know mean of the population as you call it large number of values.

So, true mean, the mean of the means that is the mean of the sampling mean is represents the true mean. But then, if this is the distribution of the sampling mean you might get a value here or you might get a value here, because you have taken you know you have taken let us say 4 number of samples or 10, 3 number of samples found out their mean.

Now, this mean will be distribution spreading over this spreads 99.95 percent or 99.9 percent of the type. So, you might get anything within this, but if I want to get closer to this value, you know then I might take large number of samples, more the number of samples this spread will get little closer to this, your error will be less. That is the basic concept of you know, if you have more number of samples you will have higher accuracy less error, you have less number of sample then you are likely to you know may not may be away from the true mean.