Fire Protection, Services and Maintenance Management of Building
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Lecture - 10
Design for Fire Resistance: Concrete

If you look at concrete, as I said it is relatively complex.

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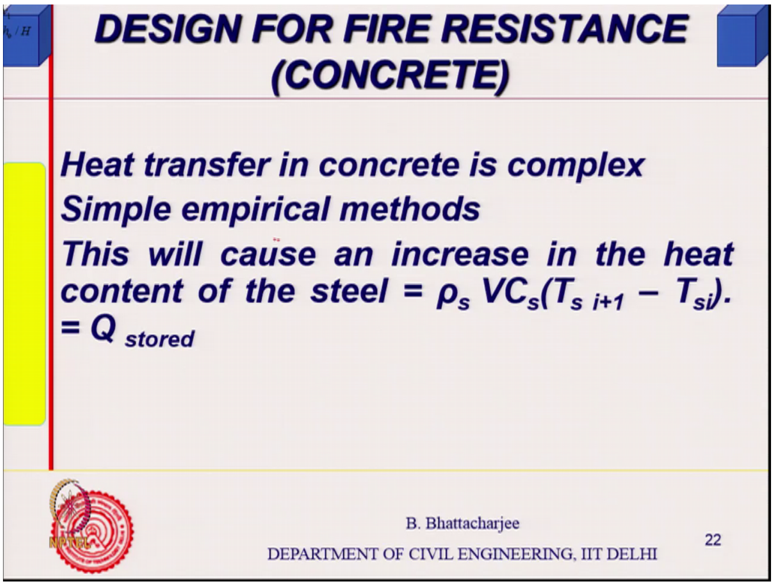

So, there are some empirical methods, semi empirical methods are there, right. So, essentially this is the amount of heat stored, right.

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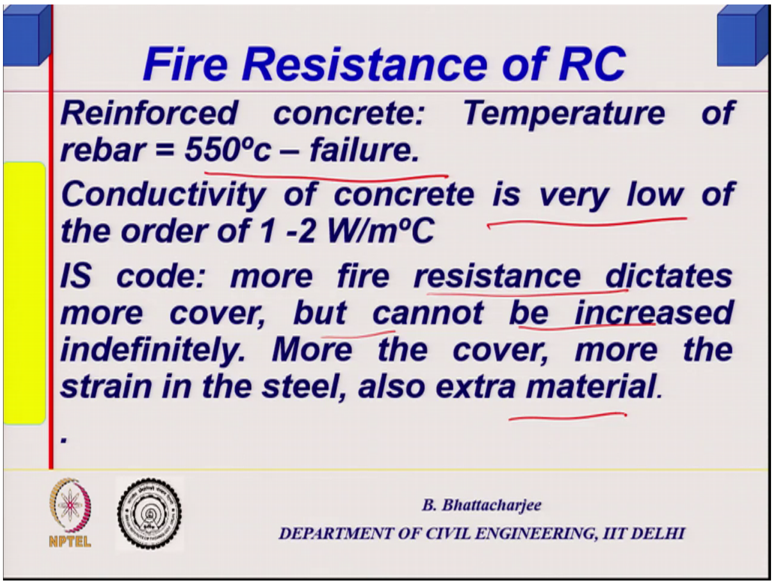

So, that is you know again we assume the reinforced concrete temperature of rebar is 550 degree centigrade at failure; 550 degree centigrade at failure. Conductivity of concrete is very low 1 to 2. And the as I told you more fire resistance dictates more cover, but cannot be increased infinitely or indefinitely. More the cover more the strain in the steel also extra material, so, cost will increase.

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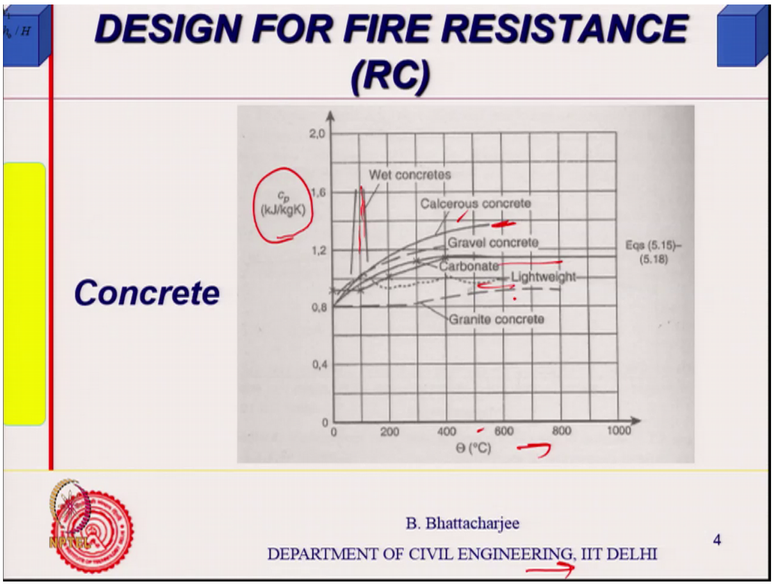

So, properties if you look at it, how does properties very thermal conductivity? For example, sorry specific heat for example increases and say a function of type of aggregate. Yes, temperature function of temperature and with temperature it also depends upon aggregate. Wet concrete of course, has got a very high specific heat, because wet concrete means water.

Water has got very high specific heat. So, it increases significantly the relatively dry concrete, calcareous concrete is somewhere here calcium carbonate based, right. Gravel some other gravels some other carbonates, lightweight aggregates, granite concrete. So, specifically it varies in this manner. So, there are formula available they are formally available.

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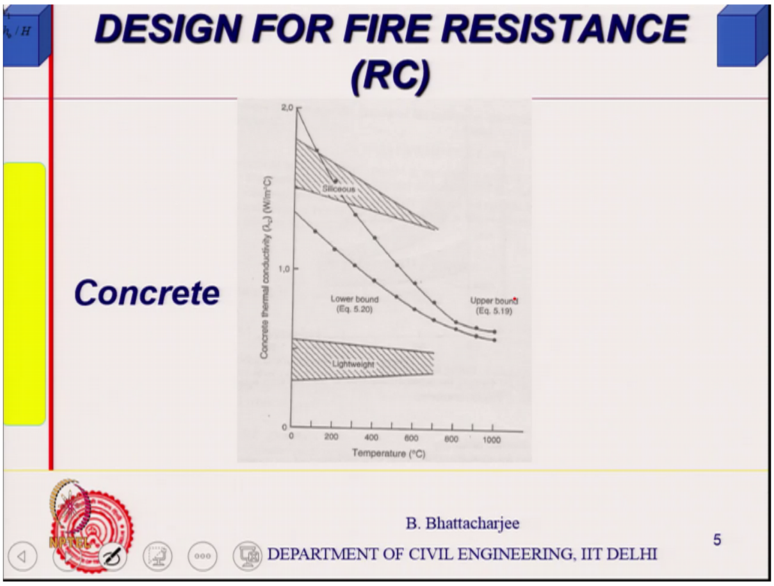

For this I will just give you thermal conductivity lightweight aggregate concrete, it is nearly constant over a bend.

And for other concrete siliceous is somewhere there, right. So, generally for concrete it is seen upper bound and lower bound, we will have something like this. So, you can see it varies from 2 to 1, and again it reduces with temperature.

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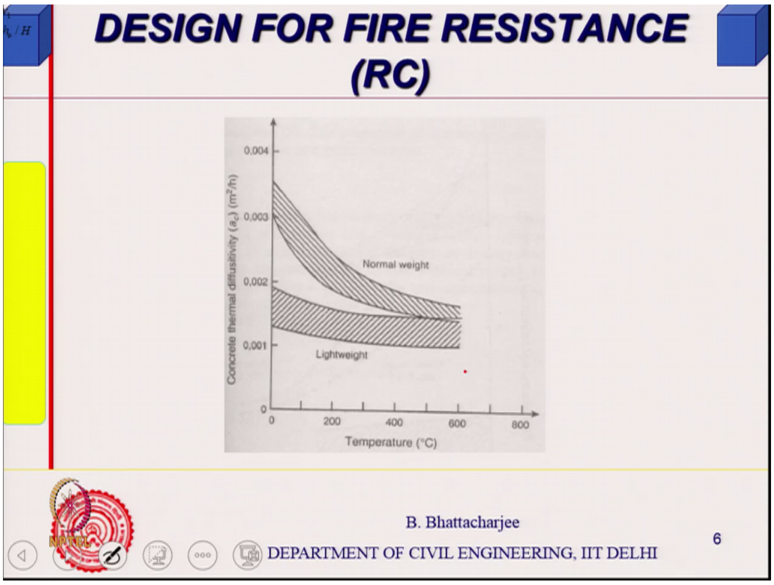

So, the some other results normal weight concrete, light weight concrete, that is a kind of band. So, lightweight concrete it does not change much thermal conductivity, but for normal weight concrete conductivity changes with temperature, reduces down.

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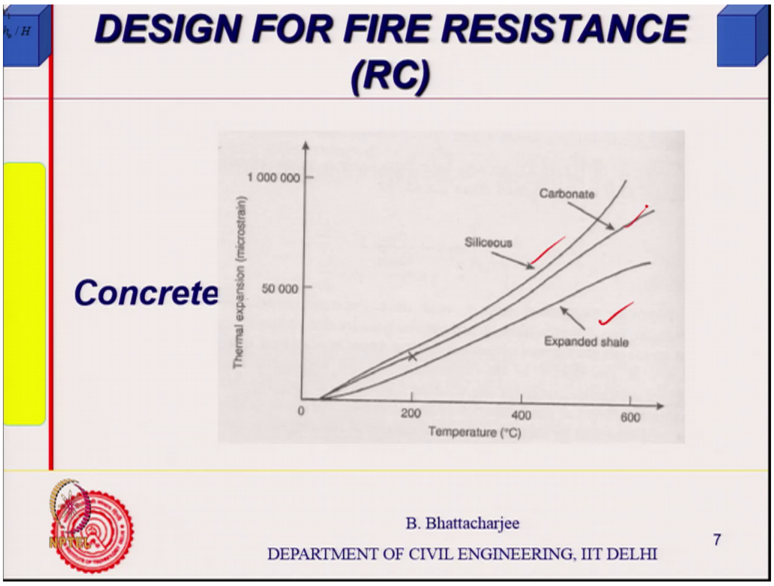

Thermal expansion, it increases depending upon type of aggregate shales, siliceous, carbonate aggregate etcetera.

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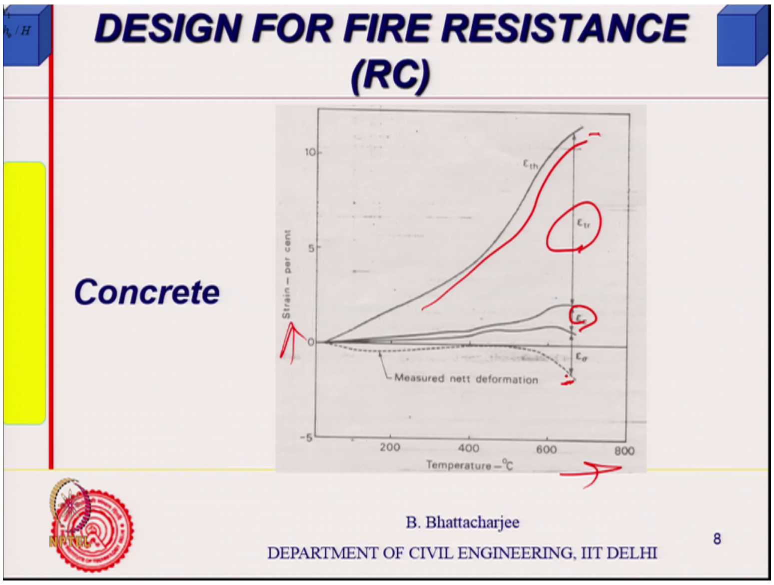

And you can see there are 4 components in the expansion of concrete. What are those? Simple components; say with temperature is on this is axis, if I look at the strain, if I try to do and you know experiment on a cylinder or cube. Put them under compression and subject it to fire. What will happen? There will be some amount of thermal expansion. I put it under a compression remember. So, the compression is there I am heating it some amount of thermal expansion will be there. It will compensate the compression, it will compensate the compression. So, this is thermal expansion.

Total and you might finally, find an expansion occurring. You might finally, find that there is an overall expansion. So, this thermal part, the compression part, then there could be some due to creep. So, measured net deformation might find it is much smaller compression then what you are.

Student: Having attribute.

Yes, what you are supposed to have. Because the expansion will compensate for it and the creep also would compensate relaxation might have you know some sort of creep would have also affected it. So, for concrete whenever you are measuring such thing under load, all these aspects are to be taken into account right, anyway.

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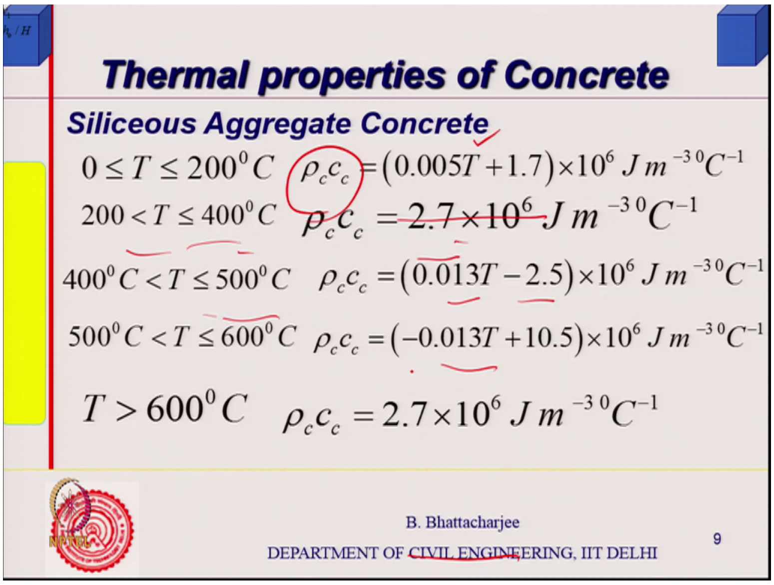

So, for siliceous aggregate again we have got thermal capacity given by this kind of a formula. It increases right up to 200 degree centigrade, 200 to 400, it is constant; 400 to 500, it is it reduces and 500 to 600, there is a reduction; 600 it is again constant. Now, for siliceous aggregate, some experimental results as I said it is available in literature. Specific heat of you know thermal capacity is a function of temperature in this case as well. And remember, I said last class or sometime when I was talking about I mentioned that concrete up to 200 degree centigrade is only free water will you go operate. So, all properties up to 200 degree centigrade is of one kind, 200 to 400 to 600 will be something different.

So, that is what it is 200 to 400 is again constant, 500 to 600, because some of those chemically combined water tends to go away and once those water goes away 600 and above your temperature you know it will be something else.

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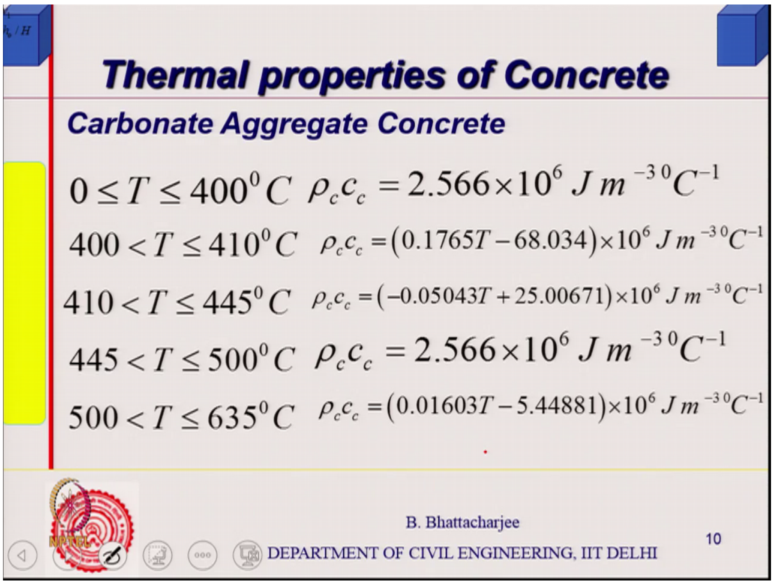

So, for carbonate aggregate the formulas are different, formula is somewhat different, but there similar nature and similar results are available. I again do not expect you to remember, but you understand that is a function of temperature and step functions. In fact, it is not cannot be defined by a single functions.

So, define as you know fitted results are they can be you know results fitted results shows there are segments, various segments said you can you know. So, that is what it is.

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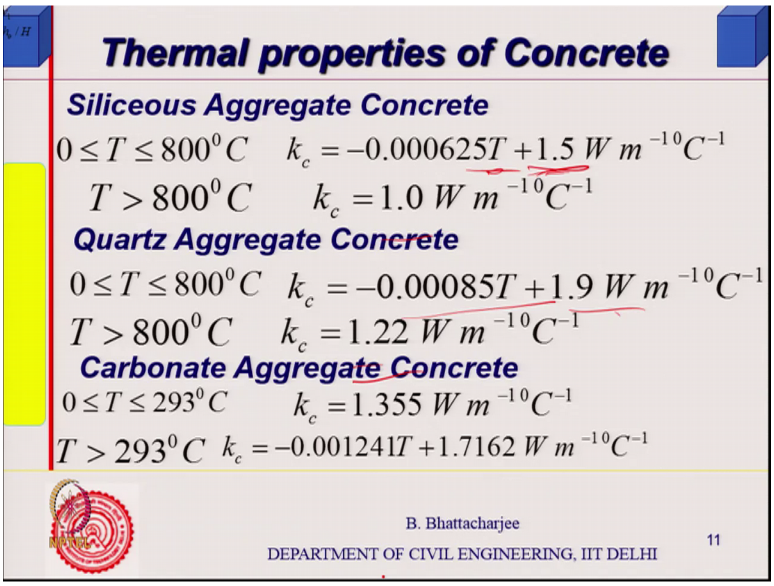

Thermal conductivity; again it is a function of temperature reduces it temperature. Then it becomes at you know temperature equals to 0 this 1.5 and this is temperature above 800 again it is constant and greater than 8 100 slightly more. For quartz aggregate these are the values.

So, up to 800 degree centigrade something like this. Quartz has got higher thermal conductivity; amongst all the inorganic material quartz has got highest thermal conductivity. Pure quartz is of the order of around 10, steel is 50, but aggregate should be quartzite with lot of impurities and things like that or similar sort of thing. So, from original quartz rock, if you have some aggregates they will have thermal conductivity relatively higher. Carbonate aggregate concretes also shows some values of this kind, right.

And that is how it is. So, the variation thermal conductivities heat capacity all varies with temperature. This much be understood.

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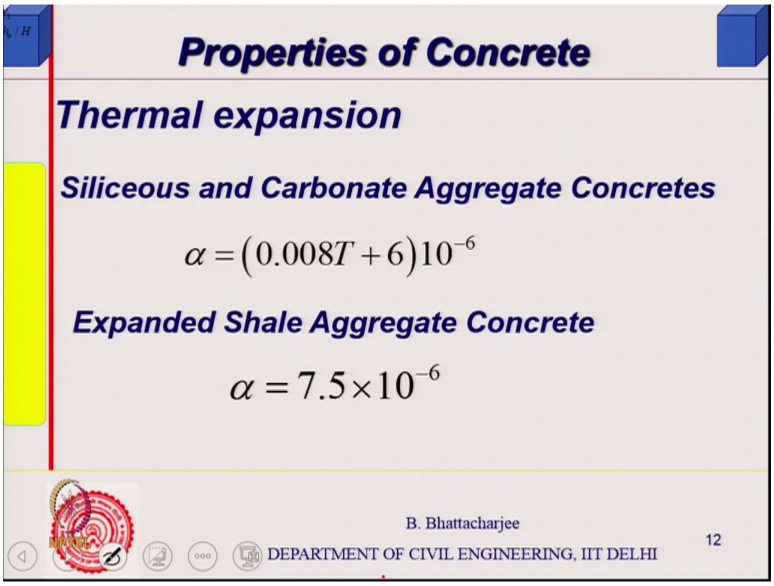

Expansion is again property is increases with temperature. And shale aggregate as I shown the earlier diagram. So, this how it is.

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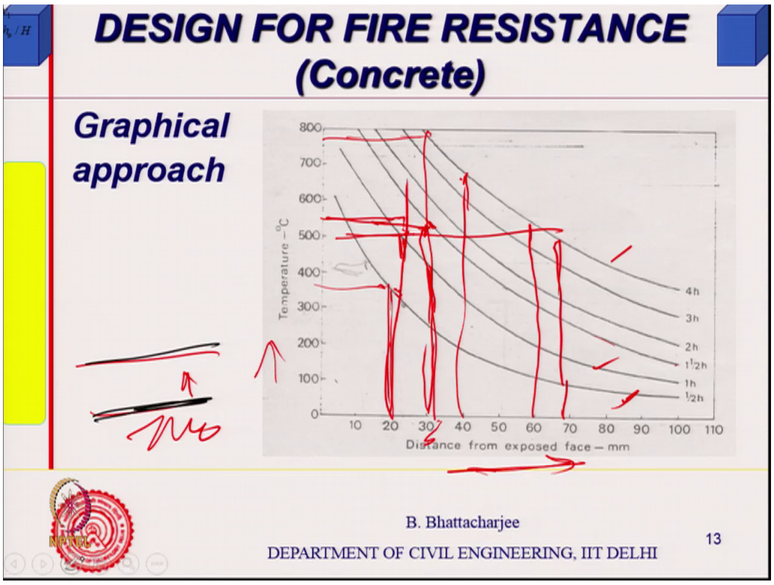

So, if I want to design for fire resistance I got to take all these into account and do the heat conduction, equation solution of heat conduction equation.

That is what we do not do, what do is in this class we are not doing this. The one way would be some people have actually done some experimental work in 1980's 70's and 80's 1970's and 80's. And what they have seen is if it is slab if this the fire increase in temperature, you know, temperature as a function of distance from the exposed face. For example, for a slab, if this is the slab, this is a slab and this is a slab, this is the slab right.

And exposed face this one, expose face is; this is the exposed face. Then this distance I am talking about, right. At after 4 hours, if I go to 70 mm from the exposed face the temperature will be 500, yeah something like that. So, 60 mm from the exposed face, it will be something like this, 20 mm it will be very high, 40 mm you know beyond 800 is not 40 mm. So, up to this it means after 4 hours, all concrete up to 40 mm thickness 30 to the mm thickness or so would have actually disintegrated completely. There would have been spoiling of concrete. There would have been spoiling of concrete right.

So, 800 degree centigrade I said that everything disintegrates. And half an hour if you look at it at 20 centimetre, 20 millimetre 2 centimetre, temperature is around 350. So, using this graph you can find out the temperature of the steel depending upon the cover depth. For example, if my cover depth is 30 mm, cover depth is 30 mm, right. For the kind of concrete that they tested, so, cover depth is 30 mm; 550 degree centigrade is my time, you know, condition criteria.

So, I draw a line at 550, 30 mm the fire resistance will be slightly less than one and half hours. It will you know this half hour line is this 1-hour line is this, one and a half hours line is like this. So, it will slightly less than one and half hour. If I have 20 mm cover, then 550 actually 20 mm cover, it would be more than half an hour. But this would be slightly more than 1 hour. So, this is how we can find out, this is how we can find out, this is a simple way to actually.

But then this is specific to specific type of aggregate where experiments where done. This is available in a book by Malhotra in UK you know. So, they did quite a bit of experiments anchor and Malhotra their books helps you.

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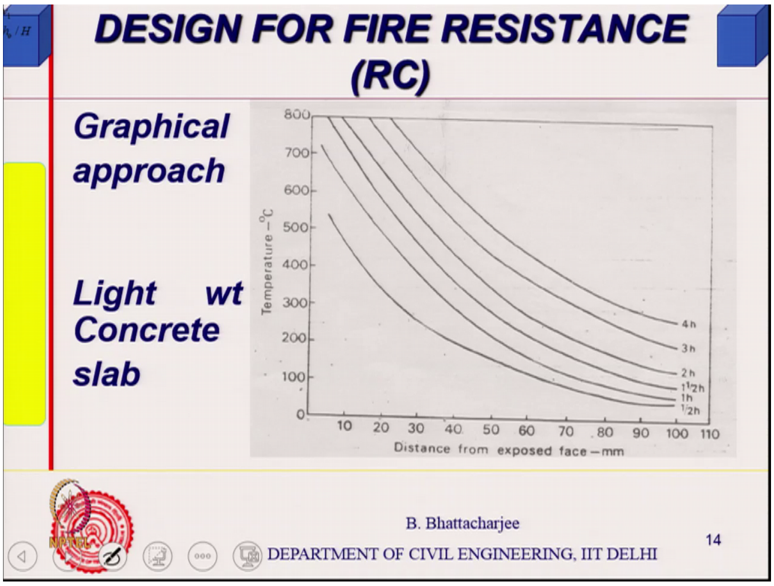

So, this is for dense concrete slab, for lightweight aggregate concrete similar curves are available. So, for slabs you can actually find out very simply using this sort of curves.

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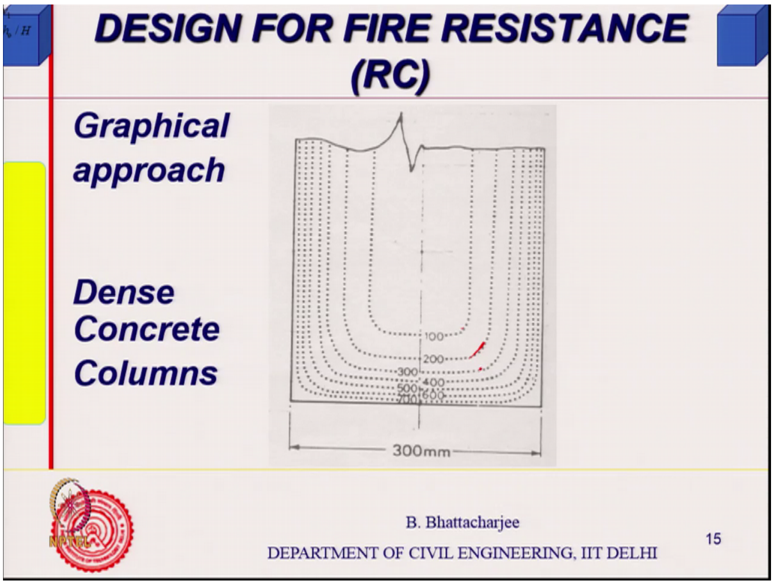

For column or beam members temperature contours are given, right. Temperature contours are given. So, this is for example, 100 degree centigrade, 200 degree centigrade at a given time. So, similar graphs are available for various times, right. So, supposing you know the cover depth, right. This is given at as I said at different times. The time at which that the cover depth this temperature reaches 550, you can find out the corner steel and so on.

So, such curves are given for various time, each curve for one time and the contour temperature controls are available. And it is assumed that is symmetric and fire it is engulfed in fire from all sides. So, this is a kind of diagram isotherms are given. And distance from the surface and temperature you know 60 minute exposure.

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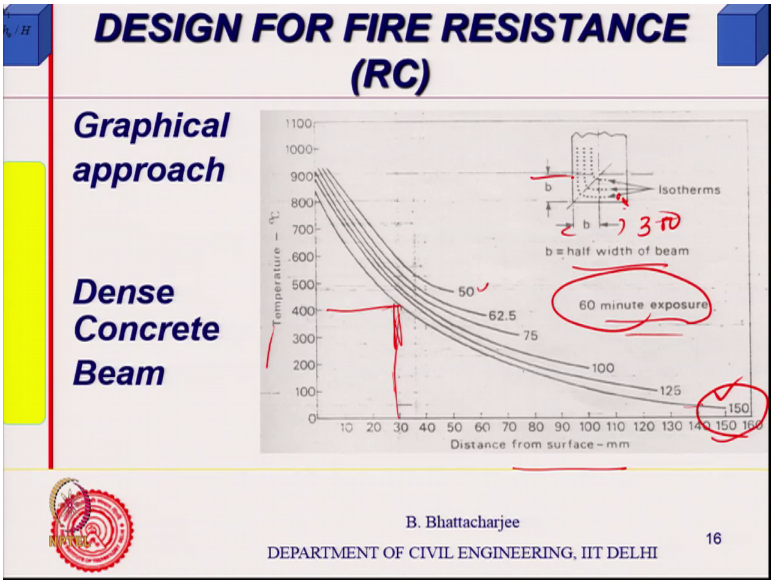

As I said for each time there is one set of graph. So, 60 minute exposure right this is 50 degree centigrade, ok. And 150 degree centigrade etcetera etcetrea distance from the surface. So, distance from the surface 30 say let us say 30 mm, distance from the surface wherever it is corner steel you will consider the diagonal distance.

So, 30 mm you can see that 400 degree centigrade; for, this is 1, you know, this is half width of the beam depending upon the beam size. So, if the half width of the beam is 150, in other words this is?

Student: 300 mm.

300 mm, and this is also 300 mm. So, that is how you can actually such curves are available for concrete and one can obtain them. So, this is one way, but looking at graphs and things that is fairly complicated these days and this was for a specific case.

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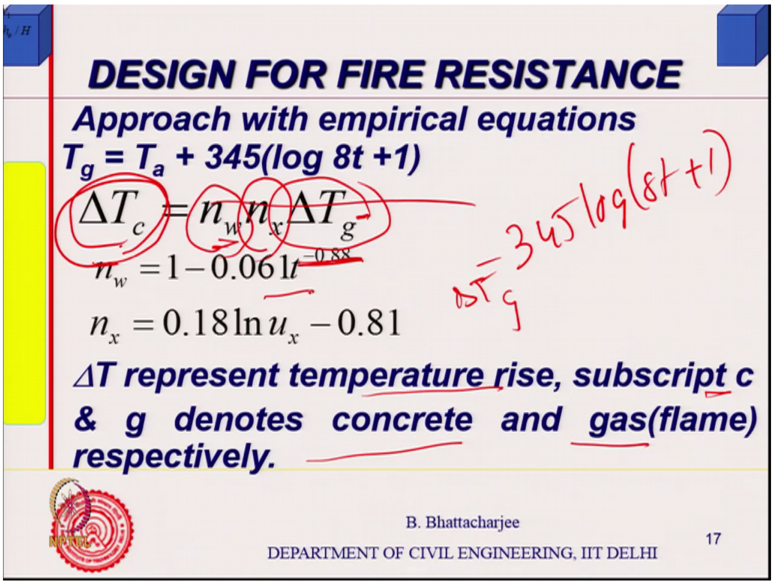

There was slightly better formula empirical equation. And that is easy to calculate because you can put it in excel sheet spreadsheet or somewhere and much easy to calculate today. This we know, now the formula is given is that the temperature rise of the concrete is given delta T c is a function of some n w n x and delta T g. Now let me define each one of them. n w is a function of time; n w is a function of time. n x is the function of distance from the surface. So, n x is given like this, delta T represent temperature rise, subscript c and g denotes concrete and gas.

So, delta T g, so, this is a concrete temperature rise, delta T is a gas temperature increase that I can find out as 345 log, 8 t plus 1, that is equals to delta T g right. This is I can find out. And this you know delta T c concrete temperature rise, I want to find out. n w is a function of time, as the time increases as the time increases as the time increases you know this value would be this value would be smaller.

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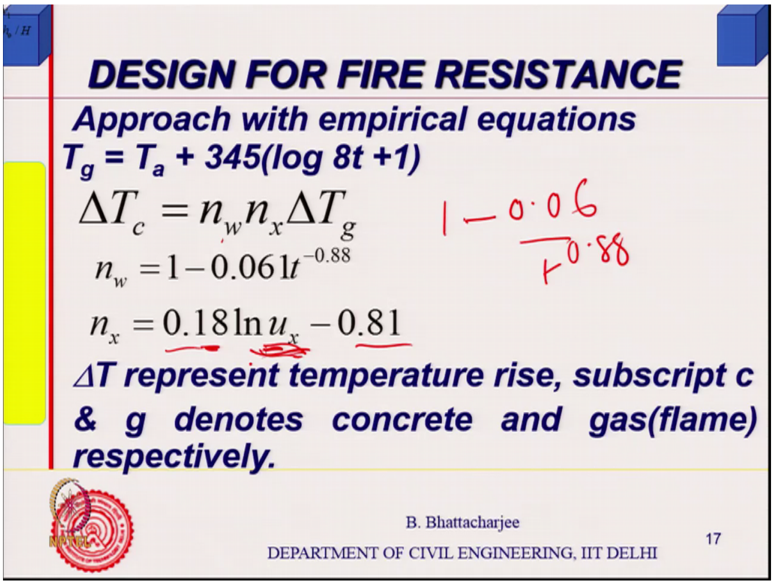

because 1 minus 0.06 divided by t to the power 0.88. So, this tend to be, so when this t is actually infinity this term should tend to become 0. So, you know this term will tend to become 0. So, n w will tend to become 1; that means, nearly same as you know it is one the factor is maximum 1 minimum is some smaller value fraction. And this is related to properties of the concrete and the distance from the exposed surface.

Let us see how it is because this is given as u x. So, n x is equal to 0.18 ln u x minus 0.81 empirical. As I said u x is a function of x, the distance from the surface and thermal diffusivity with the concrete.

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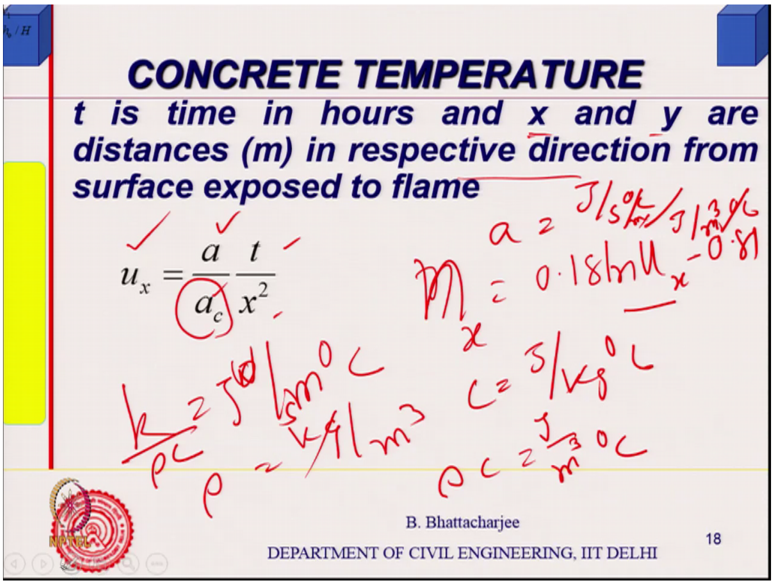

So, t is the time in hours. Now since the empirical, the unit is very important, t is the time in hours, x and y are distances in respective direction from exposed surface; u x that was I just talked about, because I said that n x n x is equals to, you know, it was how much? n x is equals to 0.8 right. So, 0.18 ln u x minus.

Student: Point.

0.81. So, u x is given by a by a c t by x square, right. Now what is a and a c? a is, you know, a is a and a c's are thermal diffusivity because it depends upon thermal diffusivity. If the thermal diffusivity is high, it would cover more distance. What is the unit of diffusivity? Unit of diffusivity is unit of conductivities watt meter degree centigrade, right. And density is kg per meter cube, c is joules per.

Student: kg.

kg degree centigrade. So, rho c is simply kg will cancel out, joules per meter cube.

Student: Degree centigrade.

Degree centigrade and if I have k over rho c which is thermal diffusivity, k over rho c. So, what is nothing joule per second. So, you will have k over rho c. So, thermal diffusivity a is joules per second degree centigrade divided by joules per meter cube degree centigrade. So, degree centigrade cancels out, right and there is a meter also, joule is a thermal conductivities what meter degree centigrade. So, there was a meter there is a meter here; so, this meter.

So, actually you can see a simply meter square per second. You know, let me just write it clearly to for you to recollect.

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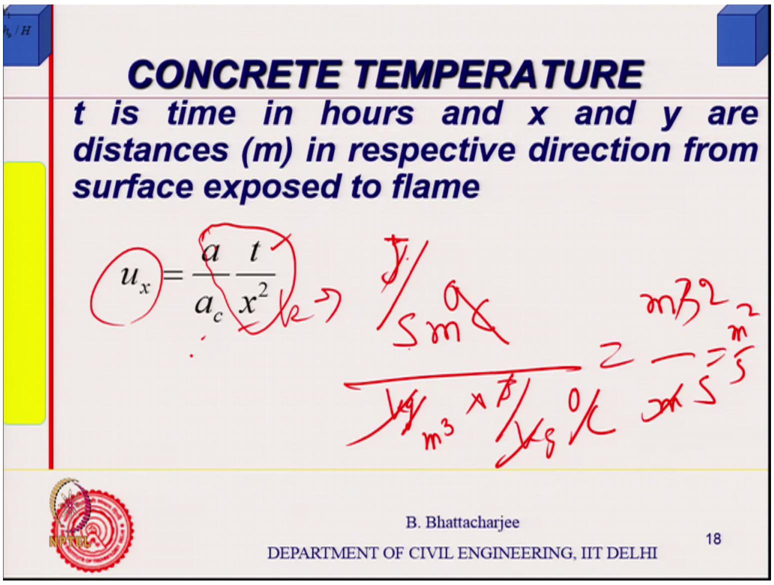

What is joules per second? So, conductivity unit is this, conductivity k unit is this joules per second which is what meter degree centigrade right. And specific rho is kg per meter cube multiplied by joules per kg per degree centigrade.

So, you will have this this cancelled out. And this and this cancels out. This and this cancels out. So, you will be left with meter cube divided by meters second. So, it is meter square per second. Now you can see that t is what? Second, x is meter square, same unit. So, this actually this term is dimensionless. So, u x will have a term, you know, u x this term will be dimensionless because a is thermal diffusivity, these also thermal diffusivity. One of them is taken as constant, one of them is taken as constant, we shall see that. So, one of them is taken as constant. So, u x is related to you know it is it is in this manner.

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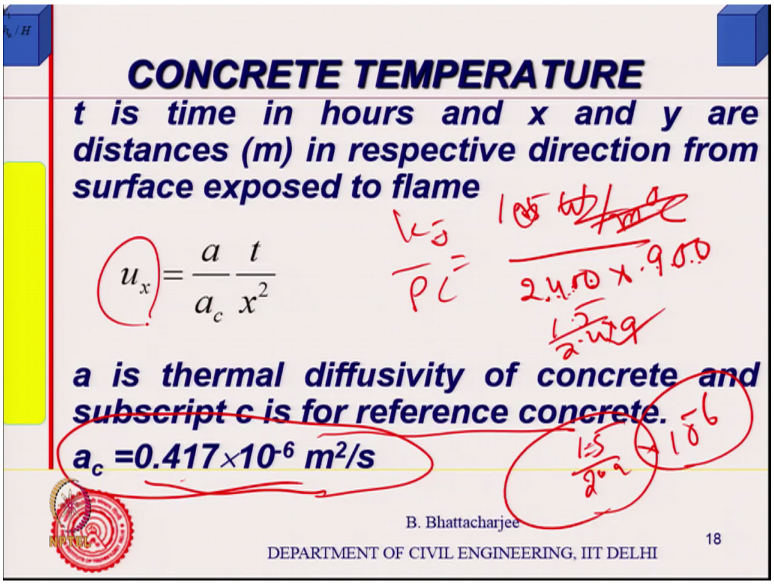

Now a is the thermal diffusivity the concrete that your concrete. And subscript c is for some reference concrete which is constant. So, reference concrete value is taken as 0.417 10 to the power minus 6 meter square per second, right.

Now let us see typically what will be the value of thermal conductivity thermal diffusivity of concrete. You see, if it is 1.5 watt meter degree centigrade right k, rho of concrete is 2000 by rho c. So, rho is 2400, c is around 900 or 1000, let us say, right 900 and 1000 joules per kg per degree centigrade; so, 1.5; so, 1 2 3 4. So, you know it will be something like 1.5 divided by 2.4 into 9, right.

Or it would be how much? 2.4 into 9 let us say is 22 point something. So, it will be 1.5 divided by 2 point something into 1, 2, 3, 4, 5 10 to the power minus 6 or minus 6. Something of this order right, something of this order. So, if it is less conductivity this value will be still lower. So, reference concrete is taken to you. So, you can see this order of 10 to the power minus 6.

Because 1.5 or 1 divided by let us say 2.4 into 1, 2, 3 1, 2 you know 0.9 you take, so, 2.4 so, 10 to power minus 6. So, this is the order and this is the reference concrete. So, reference concrete is taken to be this, u x will be found out in this manner. Then you can find out delta T c.

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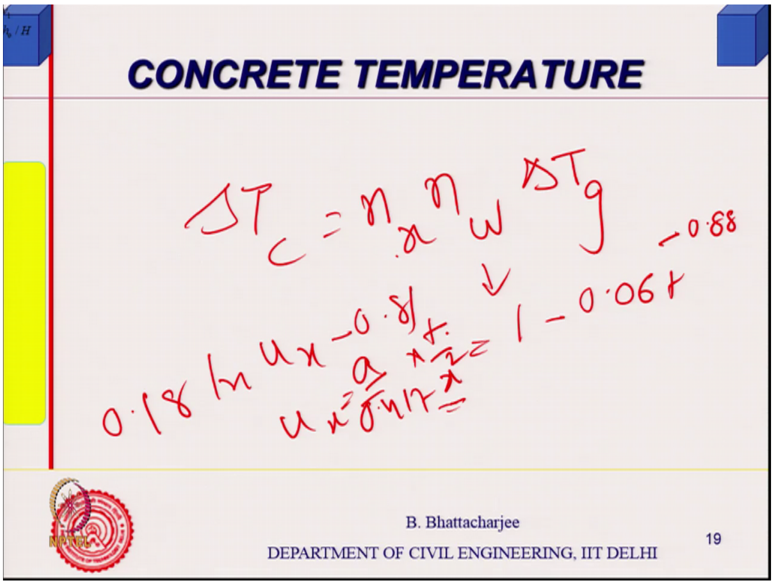

Delta T c was equals to n x n w delta T g, n w is 1 minus, you know, 0.06 t to the power minus 0.88 or something, right. And this was 0.18 ln u x.

Student: Minus.

Minus 0.81.

Student: Minus.

And u x is simply.

Student: a upon.

a yours thermal diffusivity of your concrete divided by 0.417 into time at which you want to calculate out and into a.

Student: (Refer Time: 20:35).

Distance square. So, you can find out at any distance from the surface at a given time.

Student: (Refer Time: 20:40).

What is the temperature?

Student: Rise.

Rise. So, if your cover depth is 25 mm, take x is equals to centre of the steel bar. So, not the clear cover, clear cover plus diameter of the bar nearest steel, and x you will find out x has to be meter, t has to be in hour and that is how we can find out we can calculate this out.

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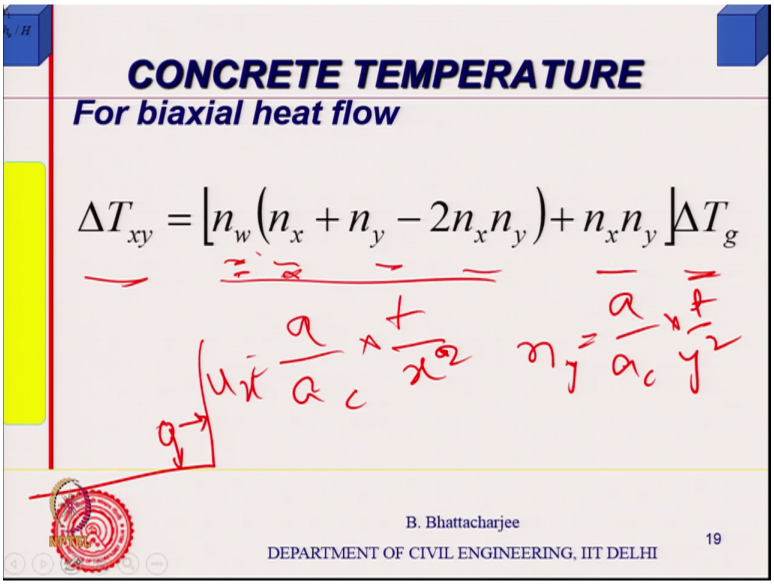

You can find out and find out the temperature, when it becomes 550 t you can in find out corresponding to 550. And that would give you the fire resistance.

For biaxial, the formula is somewhat modified; like, this was for slab, for a column or a beam, you know, biaxial scenario. So now, n w remains same, n w remains same, delta T g remains same, n x and n y formula gets modified. Now what is n x? Same a by a c into t by x square. What is n y? n y is simply same a by a c t by y square you know. So, if it is something like a.

Student: (It was u x and u y.

Yeah u x and only. So, correspondingly it will u x will formula will be same. So, u x you find out in this manner. So, this is x, this might be the y. This must be the y right. So, you find out in the same manner u x and u y. So, formula will becomes now something like this.

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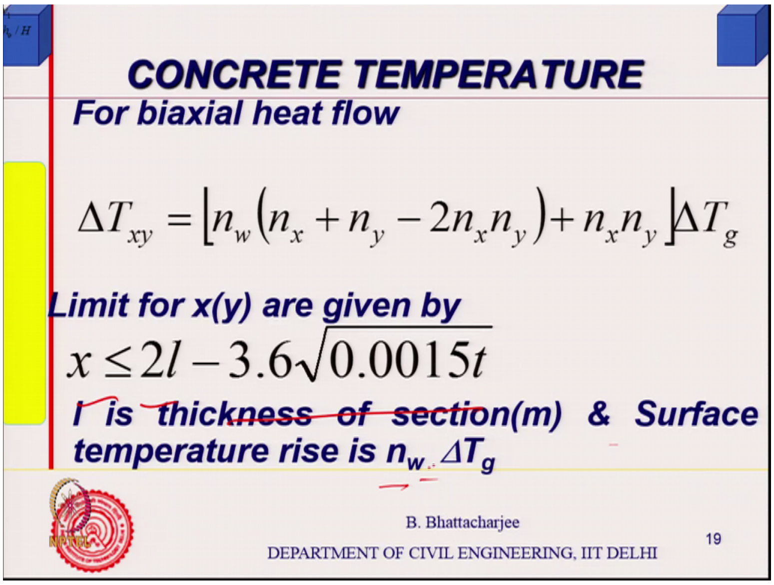

But there is one problem. Limit for this formula is valid for certain cases, because it assume the heat temperature on the other surfaces are not increasing. It is remains constant; that means fire temperature never reaches there. Assume 1-dimension heat transfer or 2 dimensional heat transfer and the other boundary is constant at ambient temperature. So, that is why this condition is there x should be less than 12 minus 3.6 0015 t that you are finding out. What is l? l is the thickness of the section in meter. And surface temperature rises n w into 12 that surface temperature we are assuming is n w into T g. Because this will, you know, this will depending upon the time where at infinite time temperature this will become 1, this will become 1. So, using this formula you can then therefore, find out the fire resistance of RCC section also; thermal design for fire resistant. Structural design would involve computing the structural capacity stability and know that. But thermal design, structural design whichever is more critical that would govern the overall fire resistance, right [FL]. So, just as an example like we did for a steel let us do it for a slab.

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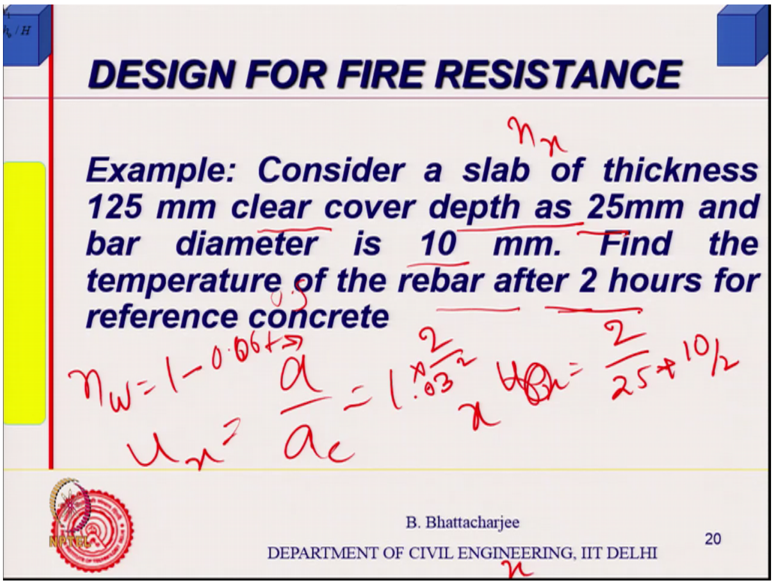

Simple case, of thickness 125 mm, thickness of the slab, cover depth is 25 mm and bar diameter is 10 mm. Clear cover depth is 25 mm.

Find the temperature of the rebar after 2 hours for reference concrete. So, just made it simple.

Student: (Refer Time: 23:59).

Now a by a c will be 1 because it is for reference concrete. So, u x will be simply t is 2 hours divided by x is 25 plus 5, plus 10 by 2, right. You know, sorry x is equals to 25 mm is the clear cover. At the centre of the bar 10 by 2 so, which becomes actually 30. So, x is equals to; so, x you know t is 2 hours by 30’s 0.3 square because it has to be in meters, 30 mm is 0.03, 30 mm because 10 mm plus 25 mm; 30 mm is 0.03 square. So, that is actually our u x, and use this formula to find out after 2 hours. What would be the temperature? Because n w is equals to simply 1 minus 0.06, you know, into t to the power 0.88. So, this is 2 hours, u x you can find out.

Hence n x you can find out, and then you can find out that delta T c. Because delta T g after 2 hours is known, you can find out delta T c. So, that is how one can obtain right. So, fire resistance of concrete also you can estimate for temperature or thermal you know for thermal since scenario and approximately why this formula, right.

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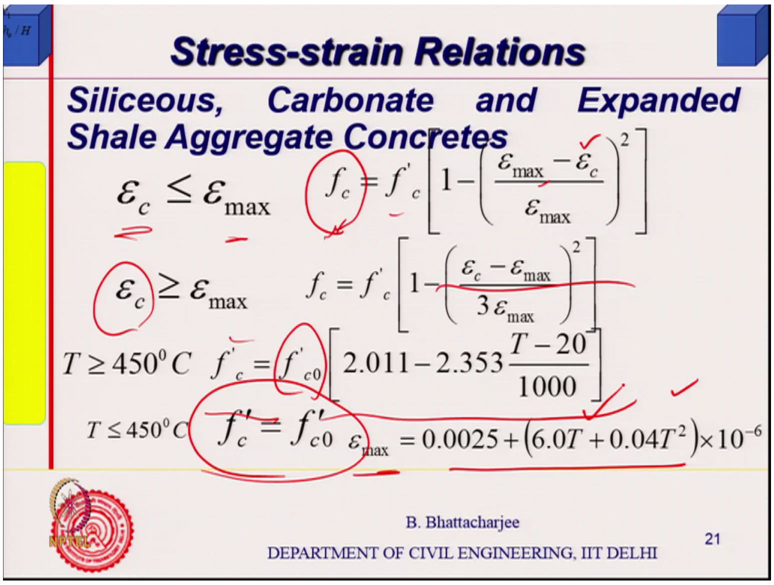

Now, some more data related to mechanical properties of so, this is one formula the cube strength as a function of, you know, sorry epsilon c is, you know, the relationship between stress strain relationship.

The compressive strength is related to epsilon c stressed in curve, right. This is the maximum value epsilon max is the maximum in normal temperature condition. And if E c is greater than E max this is the formula. So, stress strain relationship for concrete as a function of temperature is also available.

If it is greater than 450 degree centigrade this is the formula, where this is the original ambient temperatures, maximum strength. So, such formula is are available greater than 450, this is the value. So, epsilon max is given by this formula as a function of temperature. So, one can obtain stress strain relationship of concrete depending upon the temperature if one is interested in calculating in detail mechanical performance, right. But simple case this is simple, this much easy to even remember.

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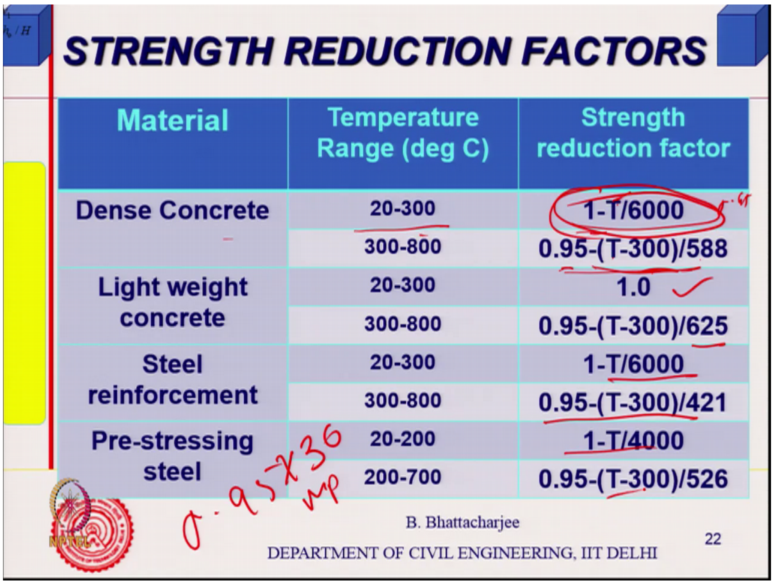

Material	Temperature Range (deg C)	Strength reduction factor
Dense Concrete	20-300	1-T/6000
	300-800	0.95-(T-300)/588
Light weight concrete	20-300	1.0
	300-800	0.95-(T-300)/625
Steel reinforcement	20-300	1-T/6000
	300-800	0.95-(T-300)/421
Pre-stressing steel	20-200	1-T/4000
	200-700	0.95-(T-300)/526

This can be used in residual post fire residual evaluation as well. So, 20 to 300 degree centigrade for dense concrete, it is taken as approximately strength reduction factor is taken. So, this reduction factor is less than 1. If the concrete strength mean strength let us say is 30 multiplied by this factor. Say 200, if 3 is equals to 200 or 300, let us say T is equals to 300, how much will this value we? 300 by 6000, so, it is 0.5,

0.05.

Student: 0.95.

So, this would be 0.95. So, at 300 degree centigrade, the strength would be 0.95 into.

Student: (Refer Time: 27:40).

30 MPa; say strength reduction factor fraction. At 300 to 800 then you can find out how much the value would be using say for examples, 600 this will become 300 divided by 588 0.95 minus this. Similarly, for lightweight concrete up to this we do not consider strength reduction. Beyond this reduces the reverse rho, steel similar.

And beyond 300 this is the formula pre stressing steel, this is the formula. So, one can actually obtain how much is the strength after it has been exposed to a void temperature, right. This is from UK results. Well, such results are not available when many places in the world because they experiment doing experiment in empirical results. But one can roughly use them for our proposal.

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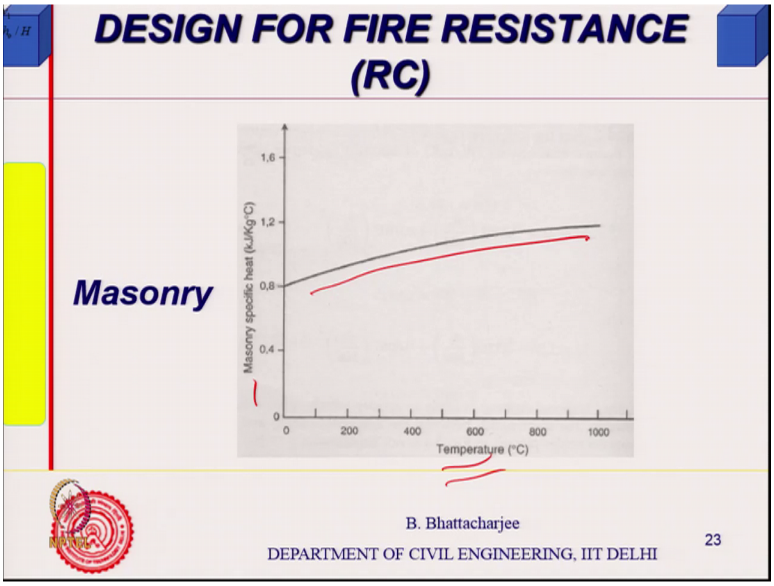

Design for fire resistance is of course if you look at it masonry, if we look at quickly. Masonry temperature versus specific heat increases.

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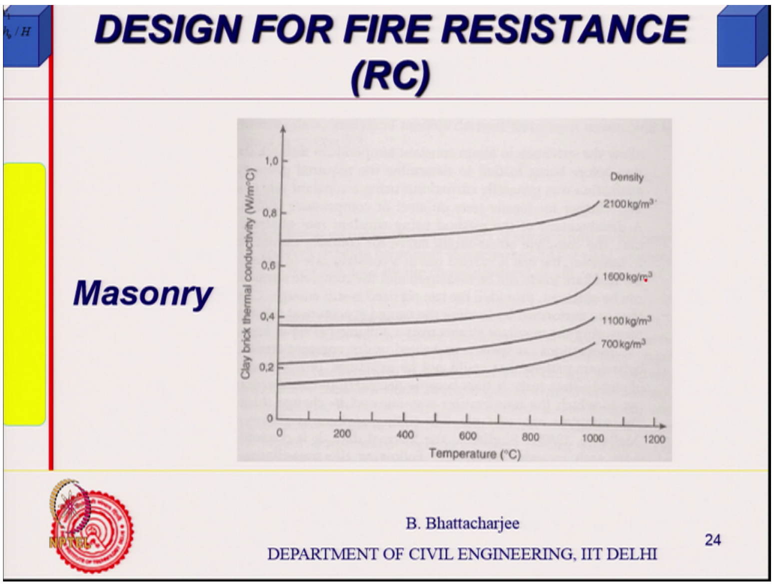

And the same brick thermal conductivity is of this kind, not much studies are available on brick. So, that is what it is. So, having looked at the having looked at the fire resistance concepts and design of structural member, some members not structural, it could be for non-structural members also; for, you know, fire resistance design for fire resistance from thermal point of view.

Now we can look into some of the planning aspects. Fire protection is not structural fire protection alone that is actually much later because first I should to have a good planning. So, that as I said fires should not initiate and if it initiate it should not spread. So, then we should look into some of the concepts of functional planning. A little bit concepts, because it is related to occupancy type and all that and since my course is also related to course is also related to you know some little bit of functional planning otherwise. So, we will define certain things.

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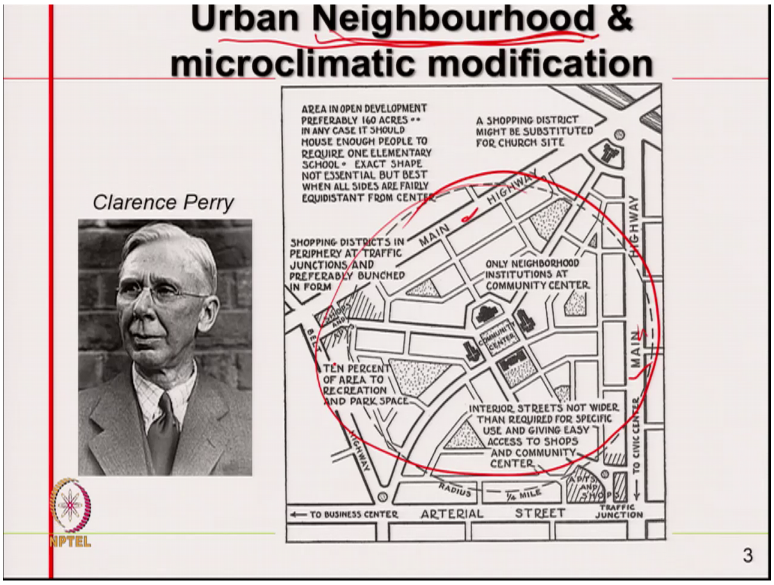

For example, urban neighbourhood and microclimatic modification I will just mention. Because as we have seen, as you see it maybe some other course related to functional planning of building. Functional planning of building starts from urban planning stage itself. And smallest unit of urban you know smallest unit of urban neighbourhood urban area for planning concepts is called a neighbourhood. And this was given by this gentleman, Clarence Perry in 1925 in United States of America. Residential unit, this is for residential unit; you know the unit neighbourhood is the smallest residential.

Student: Unit.

Unit in urban planning, right. Now whole thing here you know, it would look it should be bounded by main artery. So, this is a kind of a neighbourhood, this is bounded by main arteries, main arteries they call it universe they would call it highways. Because there are highways in the city, no major artery should pass through, then no major road. And you can interestingly see many of this concepts have been actually used in Delhi, new Delhi area later on in after post independence.

For example, RK Puram. So, you find go to RK Puram sector 1, sector 3, which is very close to IIT actually; RK Puram sector 3 4. You will find no major artery passed through them. It is actually private route for those people. And the primary location you know primary aspect that what is the most in the focal point of a neighbourhood is usually the primary school.

The concept that was developed by this gentleman is excellent concept actually although it is a bit consumes a lot of space; is that no children primary school children should walk to the school, maybe play around, kick a ball or do something and reach to the school, right. Well, that is not the case in Indian society there; So, pressurized the children so, pressurised, Even in necessary level. Because they have to go through a competition, sometime they in fact, you have a pre-primary school or maybe a play school who where they teach you such things which will make you to be get into the regular school on things like that.

Of course, now they have made it a little bit over last couple of years, the you know, the judicial system and all coming in, they said that the school should be within certain distance, right. Otherwise you know all messy. But in any case according to his concepts you know the primary school is a focal point, so, it should be somewhere here.

So, primary school is a focal point of such a neighbourhood, all right. And community centre may be a charge that is shown here. Similar sort of thing you know or temple or a mosque or whatever it is depending upon the community, that would be at the centre in the market local market not a big market. This was a concept, but this concept keeps on changing, maybe with the modern malls things could have been different maybe 3, 2, 3, 4 or many neighbourhood would have such a mall.

But irrespective of that this is the concept. And this arterial road and the interior roads are light surfaced, right. Though there will be some local recreational area. And light surface only for private vehicles no really through.

Student: (Refer Time: 33:26).

Thoroughfare should be there to such an order right.

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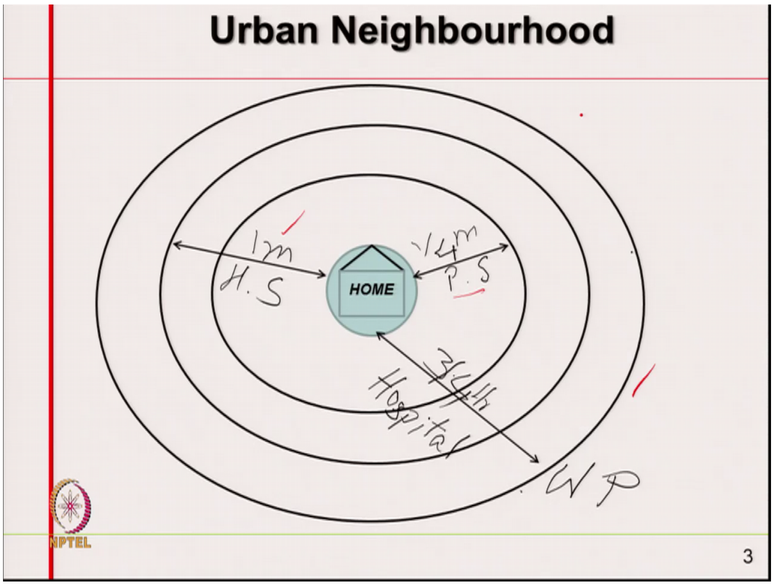

So, basically what it assumes is, home is the; it is the home. So, comfortable distance from the home to primary school is considered to be one-fourth of a mile because this was in US and high school is thought to be about 1 mile. Now one-fourth of a mile means a child should be able to walk.

One-fourth of a mile, you know, something in our kilometre terms would be about 0.4 may less than 500 meter, some around 1.6 kilometres or mile. So, divided by you get around 400 meters.

Student: (Refer Time: 34:08)

Now, a small child 3 years old 4 years you know they might go to kindergarten even still slightly higher age. But in 19-25 maybe people might have been going up to 5 6, and you know so, whatever it is, 3 4 years child they should be going on their own and should be able to walk, no vehicle should be taking them. High school is 1 mile. And then working place should be about three-fourth of an hour travel. And hospital etcetera should be here. Recreation could be one and half hours, so, travel and things like that. So, this was the concept that your main workplace let us say central secretariat connaught place or for that matter something of that kind should not be more than three-fourth of an hour. Major hospitals, local hospitals should be you know, so, hospital working place there should be three-fourth of an hour.

So, local hospital could be there or local medicine center or something at the connaught center. So, there is a concept of urban neighbourhood. So, therefore, based on this kind of concepts you know occupancies are developed.

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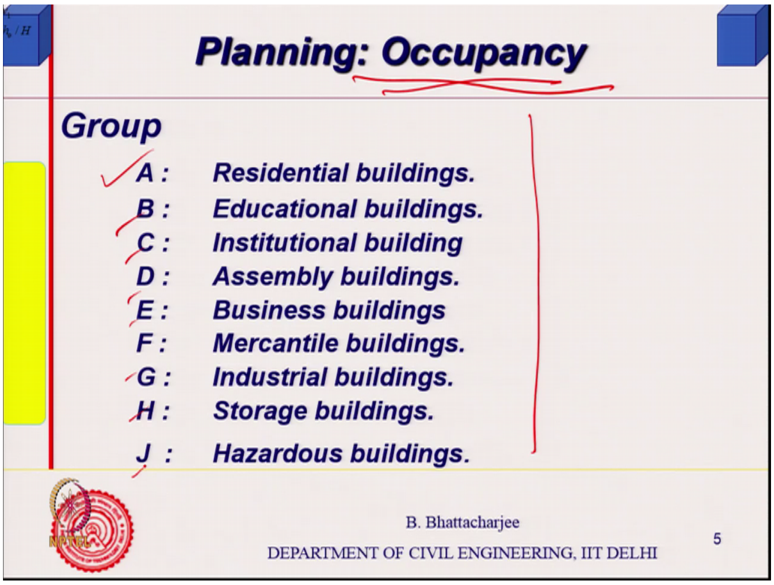

So, this is just I briefed it, because urban you know urban planning could be itself something by itself.

So, there are varieties of occupancy which are there in varieties of occupancy which are there in; 9 types of occupancy which we have divided all the types of building. National building code gives you A B C D E F G H I J occupancy. So, we will start from here in a next class. Because planning everything has to be looked into it starts from urban planning, we have this different types of occupancies and we segregate that in such a manner that the one which is sensitive to fire is away from fire generating one, fire hazard one. So, I think will close here, we will stop here, next class we will look into it.