Sustainable Materials and Green Buildings
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Lecture 14 – Life Cycle Embodied Energy and Concrete Sustainability Issues

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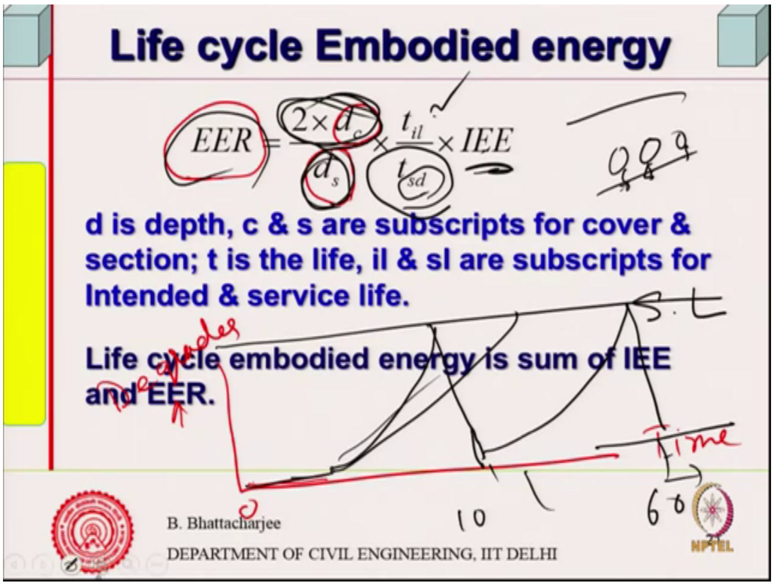

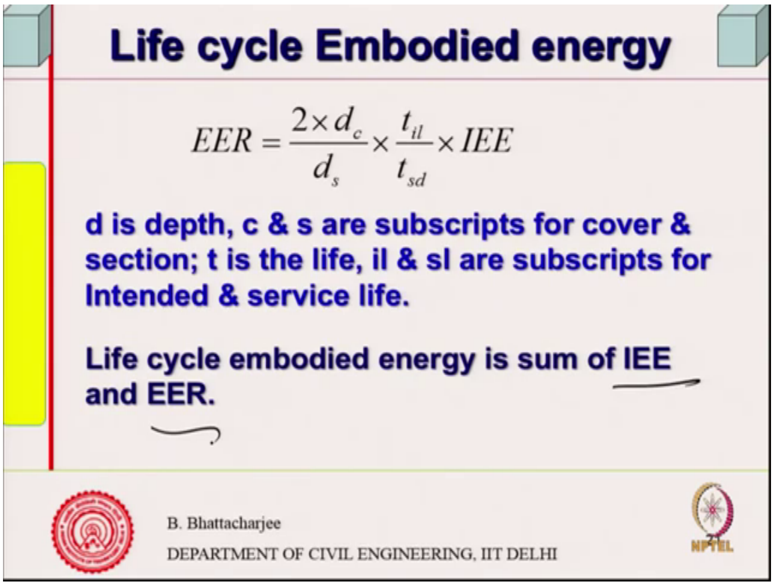

So let us look at this again, the life cycle embodied energy, embodied energy of repair. So as I was saying, all deterioration process in reinforced concrete when you look at, they finely cause cracking, expansion of the material inside and cracking, you know, and finally cover concrete gets exposed. For example, I mean the reinforcement gets exposed. For example, if it is freeze-thaw reaction, right, the water freezes and there is little more complex mechanism but I am not going into this.

So water freezes inside the concrete in cold area and ice occupies more volume than the water, it exerts pressure and this process also cause cracking. Over a period of time, the cover concrete will come out, you know there basically you will find initial some cracks then some kind of removal of the cover, slices of concrete will come out sort of so cover concrete comes out. So the moment reinforcement gets exposed, it is now, it is bare and it has got no protection, will corrode finally.

So basically when I want to do a repair most of the time I will be requiring to replace either the full element is another thing but cover, so an assumption here is made is that you are replacing the cover and if it is a slab both sides. This is our estimation but it is okay, conservative way and this is the depth of the section.

Now how many times you will repair this? Because I said that supposing my process of, you know, this, this is typically the scenario, time let us say and this is the condition or material degrades or you know material degrades and elements will deteriorate. So the terminologies are, so degrades or deteriorates are let us say, initially deterioration is 0.

It is condition let us say or something like that and then for sometime it will not show anything, may not show anything depending upon the type of deterioration but after that it will start deteriorating and there is a level after which I cannot accept it. The crack has come, I can, what you call serviceability limit. So it has reached the serviceability limit, crack is, crack has appeared at the surface of the beam or column element. I cannot accept it, I have to do the repair. So when the crack has come onto this one, this is your reinforcement and the crack has appeared here and visible cracks are there, then I go to do repair.

Now I will be repairing the cover concrete. So if i repair, I bring it back, same repair I do, I bring it back and again it will go and again it will go, right, you might be doing it a number of times. How many number of times you will be doing it? If this is my intended design life IL which is for buildings could be around 60 years and this is the basically repair life this cycle, repair cycle, this cycle, then number of times I will be doing it is, number of times I will be doing it is, this is service. s stands for service life actually, service life of element, number of times for the service life of the element or d is the cover, then that many number of times, so for example if its life is 60 years and every 10 years I have to repair, 6 times I will repair it and every 6 time, I will replace this much of concrete.

Original section had this much, so total proportion of the concrete that I will replace during its life cycle because of repair is given by this equation. And if you know the initial embodied energy simply assume that same amount of energy will go again, same amount of energy will go but there is a proportion because there is the proportion of the cover, compared to the whole section, IEE was calculated for the whole section. Now I am only doing it for the cover and this many number of times I am doing so this is the embodied energy of repair, embodied energy of repair, embodied energy of repair.

As many number of times I do the repair, it will go that much. That means this is a point, this is a point, if I make it more durable concrete which does not show up that kind of you know my more sustainable that is also an issue, your embodied energy required will be less. So that is what it is, so life cycle embodied energy is then the sum of these two, life cycle embodied energy is a sum of these two, initial embodied energy and embodied energy of repair.

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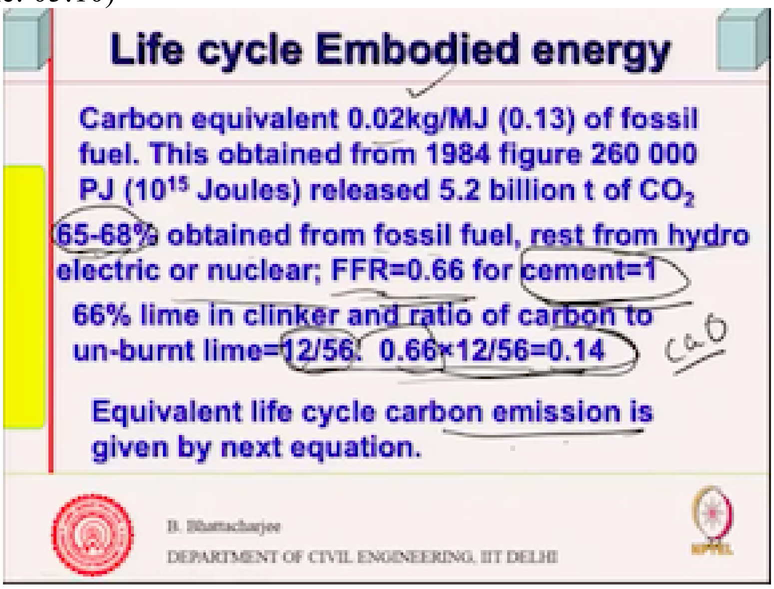

So now this I can, equivalent carbon I can find out, equivalent carbon I can find out from I know the embodied energy, equivalent carbon I can find out, right, now this carbon, equivalent carbon is not taken in account of the carbon dioxide that has been already emitted by in the cement production, that is separate. I am not talking about carbon dioxide production, I am only looking at the energy that is going, but this energy supposing a part of it is fossil fuel, part of it is fossil fuel, that will add to carbon. So you know that would depend, it will vary from nation to nation.

A nation which uses most of its energy not from fossil fuel will have much less, because if you are using electricity for production and transport, supposing you are transporting by rail and you know, it is electrically driven rails, this could be different, then where let us say it is a diesel locomotive switch actually does most of the work. So one can calculate this out.

Now carbon equivalent of fossil fuel and you remember I said this earlier is 0.02 kg per mega joules, 0.72 kg per mega joules, this was obtained from 1984, a figure of this much peta joules of energy was used from fossil fuel in the world. See there are people who did all kind of accounting, it is a laborious work, it needs a lot of workforce to do this job and collect the statistical data and find out.

So this is 260 peta joules released 5.2 billion tons of carbon dioxide, right and then, from this, one can calculate out 1 mega joules, 1 mega joules will require, will produce how much carbon dioxide? You know it is 5.2 billion, so in fact 0.02 kg per mega joules, so because I think I have done this calculation once before 2600 so, I do not think I will repeat this now. So this calculation we have done. So 0.02 kg per mega joules.

Now supposing the one case, India is somewhat different now. Supposing 65-68 percent obtained from fossil fuel and rest from hydro electric and nuclear power, right now you know so this would be for cement this is 1 because cement production, all the energy that we use, majority I mean it will be 95 percent energy comes from fossil fuel. You mix petcoke or furnace oil with a raw feed and then burn it, clinkerization process, you cannot use electricity, electrical uniformity, there is you know technological issues, chemical technological issues are there.

So for cement this is 1 but for other one, supposing we get 65 to 68 percent from fossil fuel and rest from hydro electric power, nuclear, solar energy etc. etc. then you multiply the total energy by this factor except for the cement, say, let us say fossil fuel ratio is 0.66, in fact it is said in India, it has now got reduced because we have started using a little bit more solar energy, at least solar energy, society of India that claims quite a bit. More the renewable energy used, this value will go down. I mean less the fossil fuel used, this will go down.

So this part is, so when it comes to concrete of course this, this part we know that I am going to underline, that production we know separately, so equivalent life cycle carbon emission one can find out.

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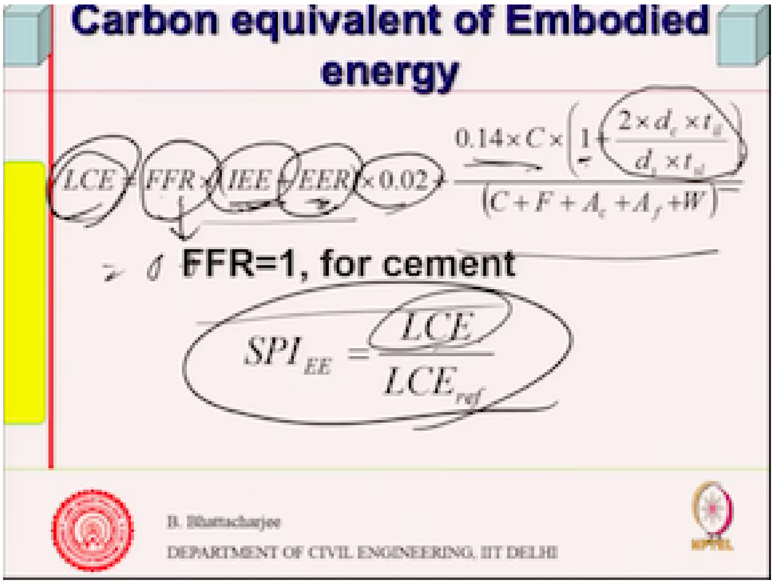

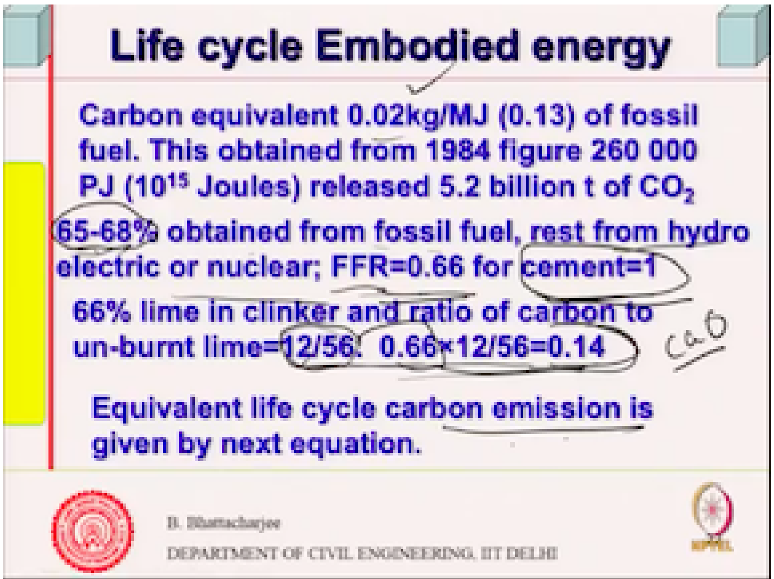

Then you can take the carbon dioxide from the cement also because in the repair also you will use cement. So, one is from the energy, so one from the energy, other from the, one from the energy, other from the fossil fuel part of it. So you see, if I know the fossil fuel ratio, initial embodied energy plus repair energy, this into 0.02 because 1 mega joules, so this is expressed in mega joules let us say, 1 mega joules produces this much amount of carbon dioxide. This is, this is for energy for repair, etc. etc. but for cement this is I have to multiply, I will not multiply this by 0.66 or whatever, I have to multiply it by 1 and this is 1 plus the repair part, 1 plus the repair part and if the fossil fuel ratio is 0.02 multiplied by 0.14, how does it come?

0.14 because 0.14 is the carbon dioxide produced from, carbon dioxide produced from 1 kg of cement because 56 carbon carbon you know 56 like, 56 is what? 40 plus 16 so calcium oxide so from 56 grams of calcium oxide produces 12 carbon, so this is carbon equivalent, not carbon dioxide equivalent, carbon equivalent because this is carbon equivalent, so everything they are putting it in carbon terms, not in carbon dioxide terms, so carbon terms and if you calculate this out, so this multiplied by 0.66 because 0.66 percent is calcium oxide in the system not calcium carbonate so I am talking about calcium oxide. So this is 0.14 and that is where it comes, so 0.14 C into 1, that cement you have used plus additional carbon dioxide coming form there, coming form the repair part, so total carbon dioxide that comes out from the cement is this.

In addition to this, initial embodied energy of repair and, I mean initial embodied energy plus this is for the repair purpose, so this is the direct carbon emission from calcium oxide production and here when you are using the cement fossil, the fossil fuel factor would be 1. So this is not a constant fossil fuel factor, for rest of the thing it could be 0.5, 0.6 or whatever it is. This can vary from 0.5, some countries uses 50 percent only fossil fuel, rest all comes from elsewhere, alternative fuel, you know or nuclear or hydel, solar energy and all that, renewable resources and so on.

So this would vary and for cement, this energy, part of this energy is, majority of this energy in production is, this ratio is nearly 1 because, we you are using directly fossil fuel. So one can, yes this is what I am saying, so therefore one can in fact, if you make a reference concrete, you can even compare different concrete because life cycle energy you have looked into not embodied energy in terms of carbon, life cycle energy in terms of carbon production, that is what you are looking, or life cycle carbon emission if you call it. So that and you can compare it with the reference if you have established one, that okay how good or how bad, or you can compare two concretes, which is better, which is worse.

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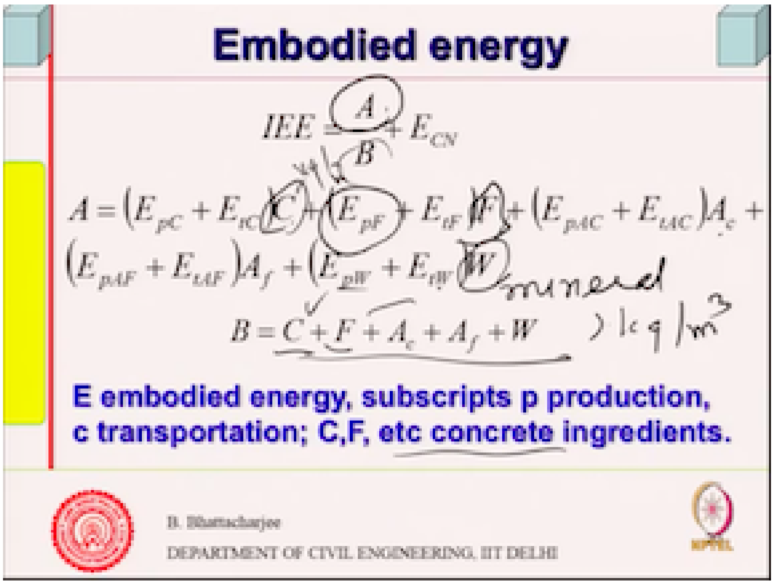

You can compare two concretes, which is better and…For example if I use more fly ash, for example if I use, if I decide to use more fly ash here, more fly ash here, it will have this 0 because remember I gave you the energy of production of all of them. Fly ash is available as waste, so transport energy. For example if I use instead let us say GGBFS which will have somewhat less than cement, it has got some values, I gave you a table, 372 or something for cement or relative values are there. So if you use more fly ash, this would be lower. If you are using some natural sources of water as it says, the production energy will not be there, transportation energy will, and if you are close to the source, then also transportation cost is going to be run.

So the point that, how do I calculate the data is a problem. Then every nation, or every zone, every area has to generate if they want to do this kind of accounting. It is a laborious process but that can be done, so that is it.

As I said there is a table available in net, Bath University has done for UK all, I do not know whether I have kept the table here but that does not mean much because it is only information, so that information you can collect. They have got, they have collected a lot, in India it has been less, few I will show you that.

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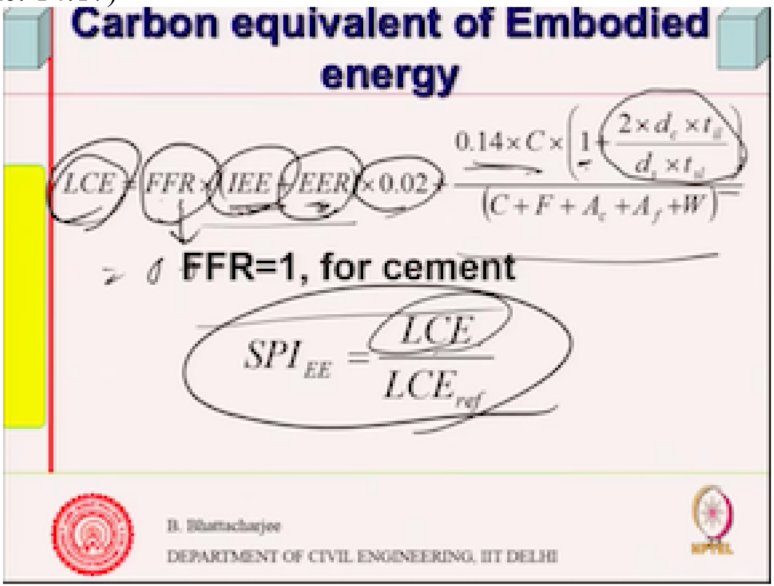

So equivalent life cycle carbon emission is given in this equation, equivalent life cycle carbon emission and this is how it is.

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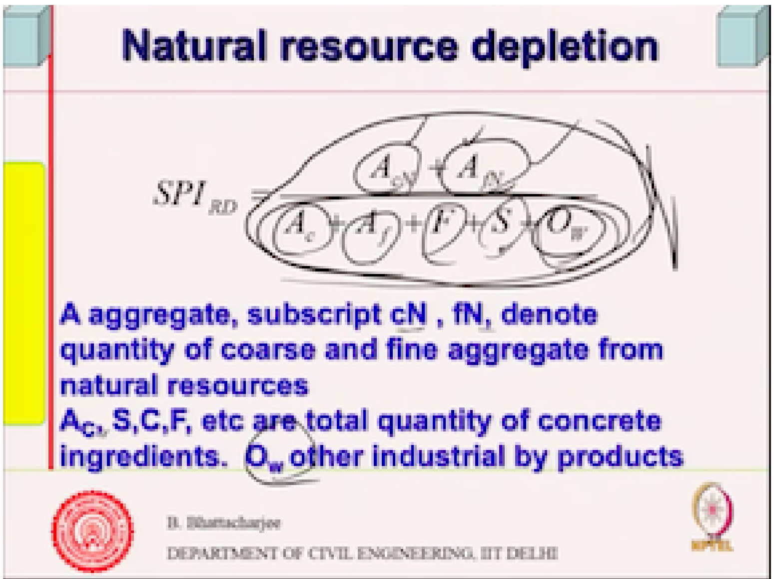

The other issue is natural resource depletion in concrete production. So far we talked of carbon but sustainability must take account of, remember I just gave you one slide. I said that it must also look into depletion of natural resources. So if you, if your aggregate, coarse aggregate is natural, fine aggregate is natural stone, energy will go definitely there, then the proportion of natural material depletion is this because this is a concern. Many places sand is not available now, the fine aggregate is difficult to get, so you have to use them judiciously. Point is that you will be using but you have to use them judiciously. So as I said that in UK they have open cast mines. So (())(15:23) and they produce scientifically. Even in India there are people now what is called manufactured aggregate.

So manufactured aggregate comes from crust stones but in a computer controlled, through a computer controlled process which will maintain the shape best suited for concrete production, you know and sizes as desired more uniform within the size itself, within the size reduction itself. So that would be more efficient, use of the natural depletion would be less. So this is a factor for natural material depletion.

Ac is the amount of coarse aggregate, Af is the amount of the fine aggregate, F is pozzolana or supplementary cementitious material you know and then if you are using, totally he is trying to find out the total material which is there in the system, S are quantity of concrete ingredients. Other industrial byproducts if you are using then that gives an advantage in the total volume of the material, as much as industrial byproducts you are using. So this factor gives you an idea of how much natural resources depletion is occurring, right, okay.

Yes, this is fine aggregate right, coarse and fine aggregate, that is what it is and coarse aggregate, fine aggregate may be superplasticizer or something I might have added but that is also small quantity that does not go. But supposing I am using some other material and any other industrial waste material, so this is, total proportion of this natural aggregate will be, natural material will be less and therefore depletion ratio will be less.

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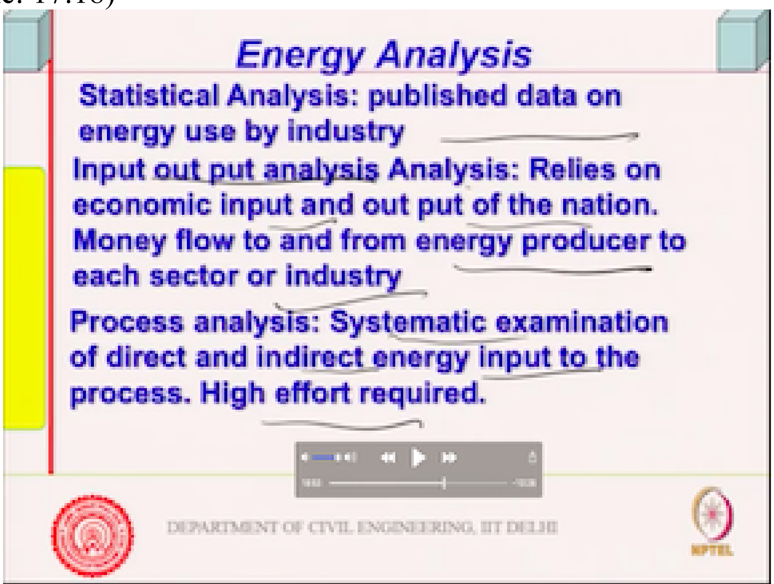

Now that is what I think I did not mention, now I am mentioning how you find it out. Statistical analysis – published data on energy use by industry. Supposing I know the accounting is done, cement production they do accounting of the energy. How much energy they have used, from what sources electricity, from board electricity authorities and all and construction site supposing this is done then you can, some of them are published. Energy, they do not mind publishing but financial thing they may not publish it so easily. Then input-output analysis relies on economic input and output of the nation, if nationally if you are looking at economic input and output, money flow to and from energy producer to each sector of industry. For example you know the, in Delhi it is supplied by BACS, so it also find out how much is going onto the residential area, but I am talking of cement and concrete industry, it can be true for anything else.

Supposing there is an industrial area where we are producing you know the cement is being produced also, so if the authority electricity supplying agency tell us how much energy was consumed by the all cement factories, electrical grid and those kind of things, so collecting data from there, systematic then process analysis if you want to do systematic examination of direct and indirect energy input to the process, high effort required. But one can estimate them and possibly one can do a research sort of thing to see how it is changing with time, get some ideas and things like that. Generally one can use combinations, generally one can use combinations. Generally one can use combinations.

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So concrete sustainability issues, cement and carbon that is what we have looked into, efficient cement use quality and admixture they help, we will see that now next. Efficient aggregate and water use and of course modern concretes, they can be sustainable. Modern concretes can be sustainable because you have you know as I said, you have varieties of concrete today which I showed once I might have. I will come back to this again. Contribution of concrete towards operational energy saving that is of course in buildings, that is only for buildings. So all these issues are concrete sustainability issues are there. So if I am looking at sustainable concrete, I must look into all these issues actually, all these issues I should look into, okay.

So quickly we will look into, quickly we will look into okay, quickly we will look into first steps out from there, first step out from there. Cement and carbon we have looked into, we will look into quality and saving of material, you know some of them we will look into quickly. Quickly I will look into that. Start this and then quality has got a role, quality of construction. Why we do not talk about quality so much of other material but we do talk for concrete? The reason is concrete has been produced largely manually or semi-engineered way.

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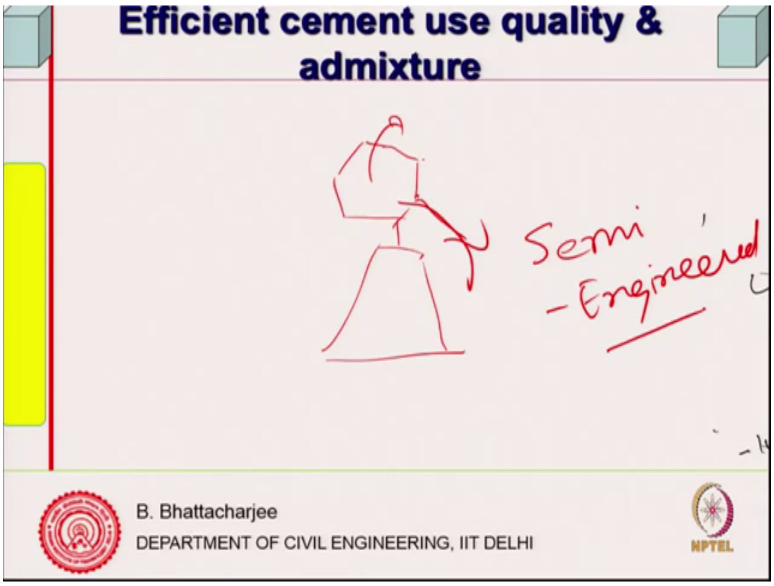

For using a, you know, using a this kind of thing which you might have seen, you might have seen something of this kind, quite common, sorry, quite common is this, you might seen something like this, you have titling drum mixture of this kind discharging concrete, rotating, you would have seen this kind of mixture which is very common. The volume, volume would be very small, volume would be very small, quantity per batch. Now this concrete you add manually, you add aggregates, I mean I might have a small batching plan and if you add even water manually then it is a disaster because unless it is, supposing it is a controlled batching plan, things will be better. The proportions will be maintained better.

So you will not get variation from point to point. If it is done, this is, this is semi-engineered concrete so semi-engineered concrete. I will not call it engineered concrete, semi-engineered concrete as opposed to a computer controlled batching plan but there the cost might be slightly higher but in the long run you will improve everything. Number of repairs required will be less, and even in the beginning you will require lesser material, let us see how it is. So quality is an important issue in terms of sustainability also right. So quality is very important issue. Because it can reduce your cement consumption, it can reduce your cement consumption, so this sort of mixture we talked about.

By the way mechanization is not new in concrete, as I have mentioned maybe in sometime if you have taken concrete technology course where we talked about RMC, first RMC truck was actually used or developed or invented I will say in 1903 in Germany, something of the similar kind but actually it got its, it got, after the war, many countries it became very popular, second world war I mean, so it is about 100 years now easily. And many countries do not use any, it is difficult to find a small mixture if you want to use it except for one or two repair.

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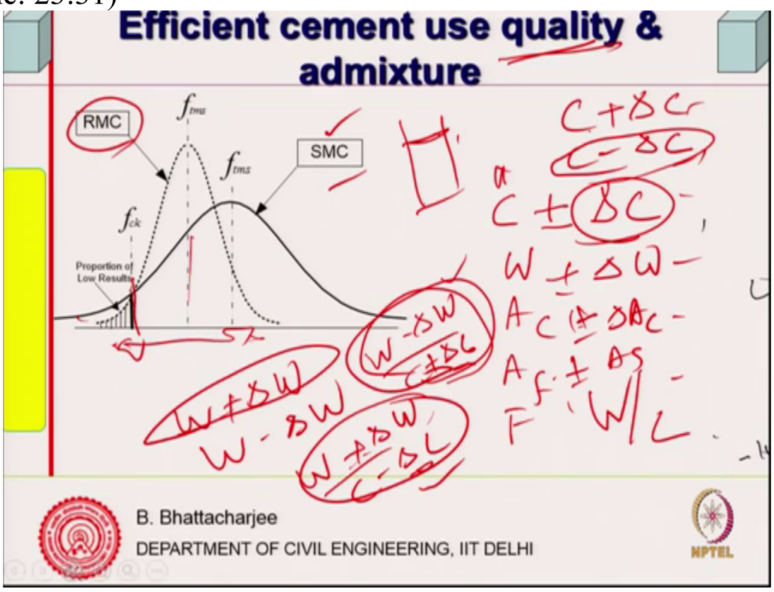

Now the implication of quality, let me look at it, I will just take a few minutes more from you. Supposing I have a, you know I have batching done manually then if this was my cement quantity, this was my water quantity, this was aggregate quantity, this was fine aggregate quantity and then I might have added another F etc. etc. Now I cannot in any measurement, I cannot get C all the time, any measurement, any process used, there will be some sort of tolerances in the balance itself, there is a least count of the balance, so there is always error in measurement even in batching. Now higher this error, higher this error, so sometime you will give C plus delta C sometimes will be C minus delta C. Water will be delta W plus minus, so amount of water will be again W plus delta W or W minus delta W and if you know from concrete science W by C controls the strength.

So one case you will have C let us say very low and let us say extreme case, this is very high. So one extreme would be W plus delta W divided by C minus delta C, other extreme will be W minus delta W and C plus delta C.

Similar problem will be there, similar kind of delta plus minus delta Ac plus minus delta Af etc. will be there, so the, if you can see in this case the strength would be high, in this case strength will be low because higher the water cement ratio, strength is lower. So where my delta W is plus this is the highest water cement ratio, this is the lowest water cement ratio, is not it? So this will have highest strength and this will have lowest strength, now if my delta C is small this will have less spread, so that is what I am talking about.

So concrete strength is normally distributed. If you do large number of cube test, cylinder test or whatever it is, you will find they follow this sort of well-shaped curve, that is normally distributed. Now the standard deviation is lower if you have these values lower, that means you have a better control, you are not just mixing by, you know not by just gas. In semi-engineered concrete sometimes water somebody will put it like that without even measuring it properly or if you are doing it volumetrically with a can of this shape can, okay there is a mark you fill it in water upto this and put it. Now this cannot be accurate, visually seen and which you have to see not in a transparent glass or plastic glass or something, so spread should be more if you do, side mixed manually. So side mix manual concrete is something like this.

But if you have ready mix concrete with a computer controlled batching plan you will have spread lesser. Now what is its implication? Your structural design is based on something called FCK, FCK. FCK is characteristic strength, the strength that would be exceeded by 95 percent of the sample. So this is FCK and how is FCK related to this mean strength, this is related by this formula.

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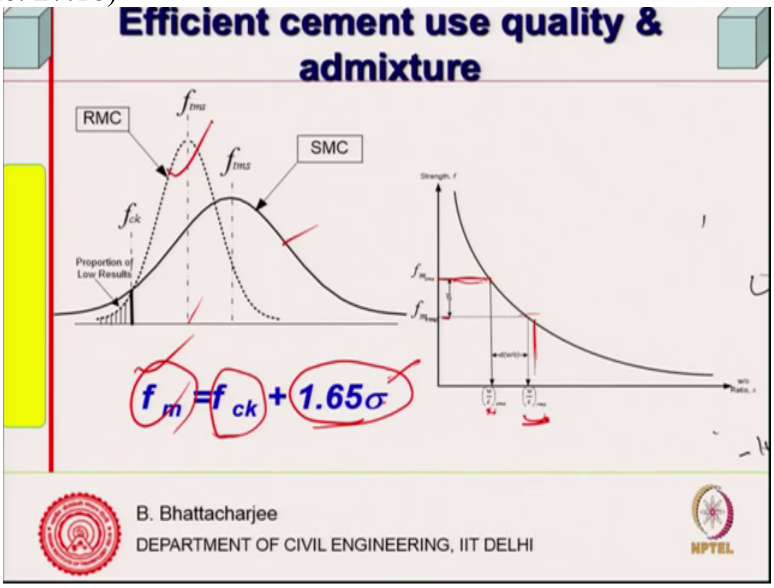

Mean strength is FCK plus 1.65 standard deviation. So if my standard deviation is higher, I will need more that means if my quality is bad, if my quality is bad if sigma is larger, I will need more mean strength which means more cement and you know lower water cement ratio. So that is the, that is the issue because water cement ratio dictates the strength typically I can draw it like this right, so higher water cement ratio lower strength and lower water cement ratio, higher strength. So if I have water to cement ratio I am talking of, so in this case I might require here. If this case I might be able to operate with this provided I am satisfying the other requirements, durability etc. etc. So therefore you see I am going to use less cement in this which means more sustainability, which means more sustainability.

So if you work on better construction or better production process, more mechanized production process you will be saving onto your cement and it is definitely cheaper in the long run and also more sustainable. So that is the issue of quality, the issue of quality.

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I think we will be just stopping. So this is just variation in properties of materials, variation in proportions, variation in mixing process, variation in compaction quality, all these add to the standard deviation. So if you then control more and more of it, you will be actually making concrete more sustainable, so mechanization gives you better. So I think we will stop at this point. If you have some questions, I will take.