Modern Construction Materials
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Module No - 1
Lecture - 1
Part 2 of 2
The Science, Engineering and Technology of Materials
An Introduction - II

This is the second part of the first lecture on modern construction materials.So in the first part,what I discussedwere the important aspects that go into the choice of the material, why we have to learn about the material science and the technological aspects of different materials and we also looked at typical properties that are useful in design for a range of materials such as metals, concrete, glass, polymers and so on. In this lecture, we will continue in the same spirit of looking at why we have to understand the physics, why we have to optimize, why do we have to make a careful choice of the material, why do we have to keep in mind the application and how the choice of the material could vary from one application to the other and which are the properties that come into play.

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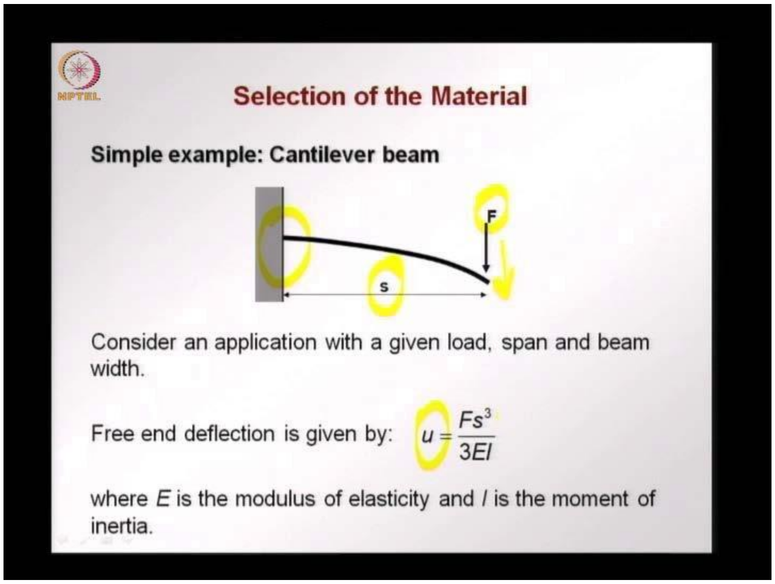

So, let us take a simple example of a cantilever beam. And all of you know what a cantilever beam is. It is a beam with a fixed end and it projects out and you have a certain load acting on it.

So,let us take a cantilever with a span ‘s’ and a load applied at the end equal to ‘F’ and when we use the beam equations,the elastic equations, we find out that the deflection, the movement of the end ‘u’ is equal to the load multiplied by the cube of this span divided by three times the young’s modulus multiplied by the moment of inertia.

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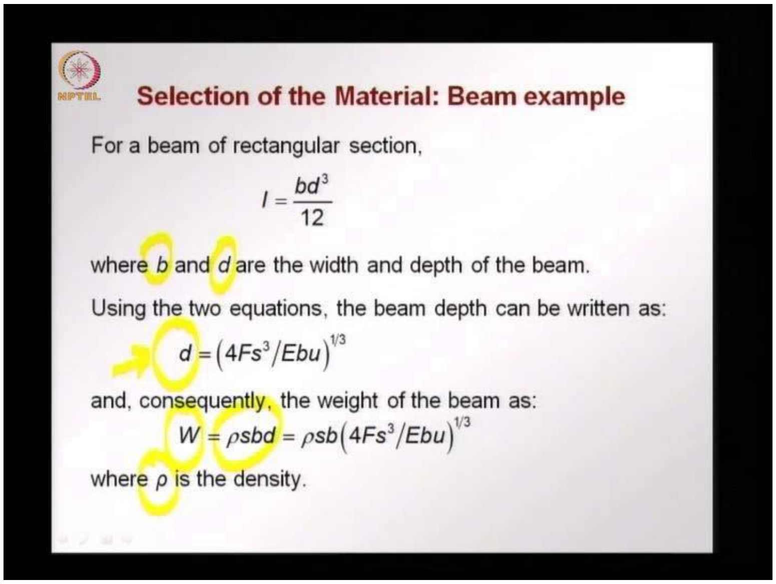

Let us take a simple case of a rectangular beam, where the moment of inertia is given by $bd^3/12$, where ‘b’ is the width of the beam,‘d’ is the depth of the beam and therefore the moment of inertia is $bd^3/12$. Using the two equations that we’ve looked at, we can put these two equations together to give us the beam depth in terms of the other parameters. So we have the beam depth given as the cube root of 4 times the load applied at the end of the cantilever, times the cube of this span divided by the young’s modules, the width of the beam, and the deflection. Now this gives us the beam depth in terms of the other parameters. We use this now to find out what would be the weight of the beam. The weight of the beam obviously is the density times the volume. So we have ‘W’, which is the weight of the beam, given as the density (ϱ) times the volume, which is the length or the span multiplied by the width multiplied by the depth, so this is the volume times the density.Now what we do is substitute‘d’ with this equation, so we have ‘W’ given as ϱ times sxb multiplied by the cube root of 4 F s^3/ E b u.

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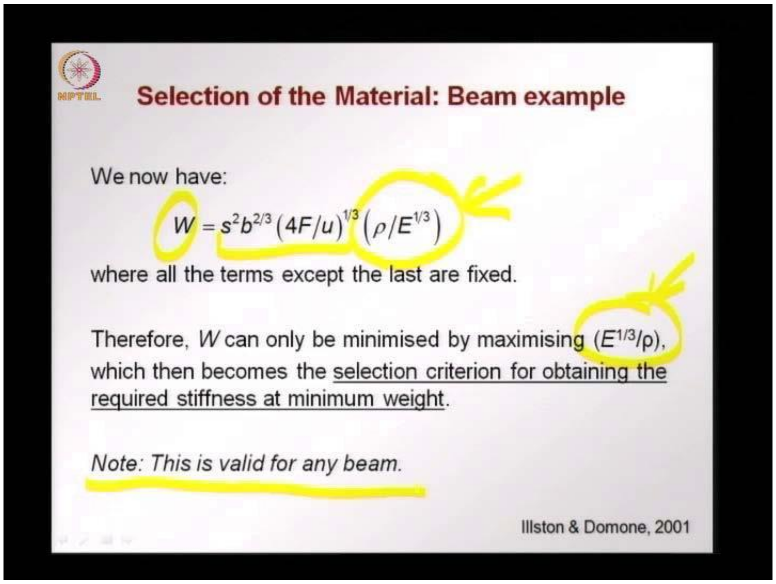

We now rewrite this equation separating them into different terms, where the first part is either fixed or depends on the other parameters.And what can vary and influence the weight is this parameter which is ϱ divided by the cube root of the Young's modulus. So, what we now find out is that if we want to minimize the weight, if we want a beam which weights very little, but still giving us the required stiffness, then we have to maximize this parameter. We have to maximize $E^{1/3}/ϱ$.Or to decrease the weight, we have to minimize $ϱ/ E^{1/3}$.

So, the selection criterion for getting a beam with the least weight but with the required stiffness becomes dependent on the least value that we can get for $ϱ/ E^{1/3}$ or the maximum of $E^{1/3}/ϱ$.And what we find out is that this,though it has beenderived for a simple rectangular beam which is loaded as a cantilever, it becomes valid for any beam.So for any beam, if we want to get an optimum solution which gives us the minimum weight for the required stiffness, we have to maximize the quantity $E^{1/3}/ϱ$.

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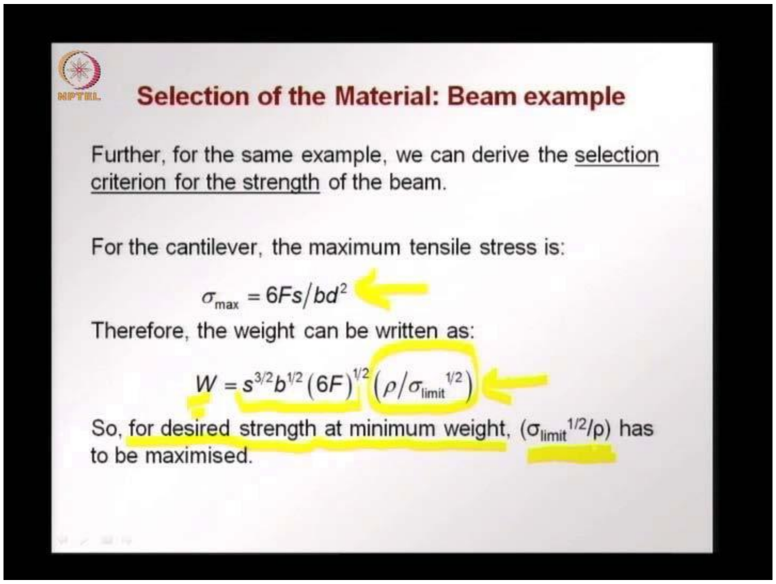

Now in terms of stiffness which is needed for minimizing the deflection, the deformation and so on, we can also optimize for the strength. We can say that we want a beam with a minimum weight but required strength, so that failure can become the main criteria.For the same beam, for the same cantilever, we can look at the maximum tensile stress, again from elastic beam formula, we can get the σ_{max} or the maximum tensile stress is equal to 6 times the load applied at the end of the cantilever multiplied by 's' being the span divided by bd^2, where 'b' is the width of the beam and 'd' is the depth of the beam. So, failure will occur when the limit strength of material is exceeded by this maximum tensile stress.

So in this equation, we substitute $\sigma_{max}$by the limit strength, that could be now a material property, and we rewrite the equations based on the formula that we have seen before and the σ_{max} and we get weight written as this.We have the weight of the beam is a product of a certain term or set of terms, which are fixed or dependent on other parameters and we have one term which now gives us directly the dependence of the weight. So what we find out is if 'W' or the weight of the beam has to be low, we have to have this quantity ϱ divided by the square root of the limit strength to be minimized. Or in other words, for desired strength at minimum weight, we have to maximize this quantity, which is the square root of the strength of the material divided by its density. And this again is valid for all type of beams.

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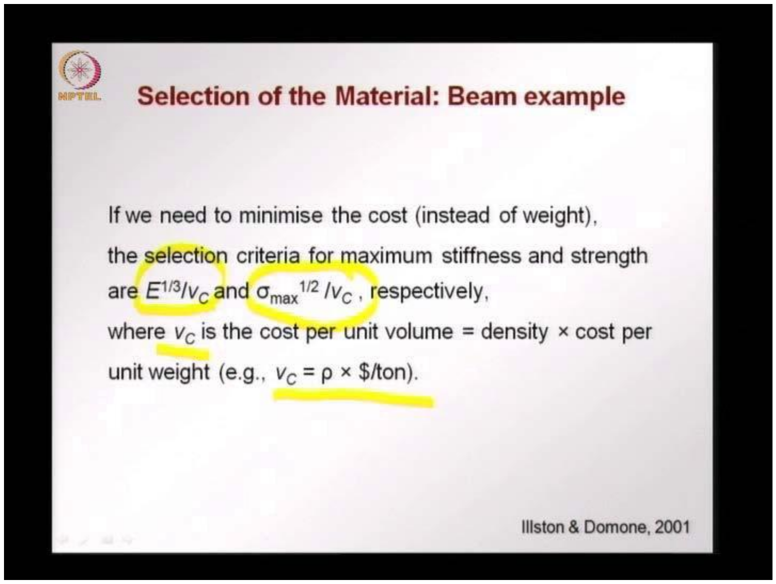

Now, weight may not be always the final objective of design.Often, it is cost effectiveness. In the last lecture, I talked a lot about how cost effectiveness is very important, because cost of the material would go on to determine the project cost, how much we spend for a structure, and budget limitations and so on apply. And so we have to often minimize the cost instead of just the weight of the material.And we introduce now V_c which is the cost per unit volume of a material given by density times the cost per unit weight. So that V_c is equal to ϱ, which is the density times cost per unit weight. Ihave denoted it as dollars per ton but it could be any monetary unit and for simplicityis denoted as dollars per ton.

And what we find is the two criteria that we looked at before for maximum stiffness and strength,when we look at cost becomethis ($E^{1/3}/V_c$). So, we have to maximize the cube root of the young's modulus divided by the cost per unit volume to get a beam with the lowest cost, but the desired stiffness or the required stiffness. In terms of strength, we find that we have to maximize the term given as the square root of the strength divided by the cost per unit volume, to get a beam of the lowest cost but the required strength.

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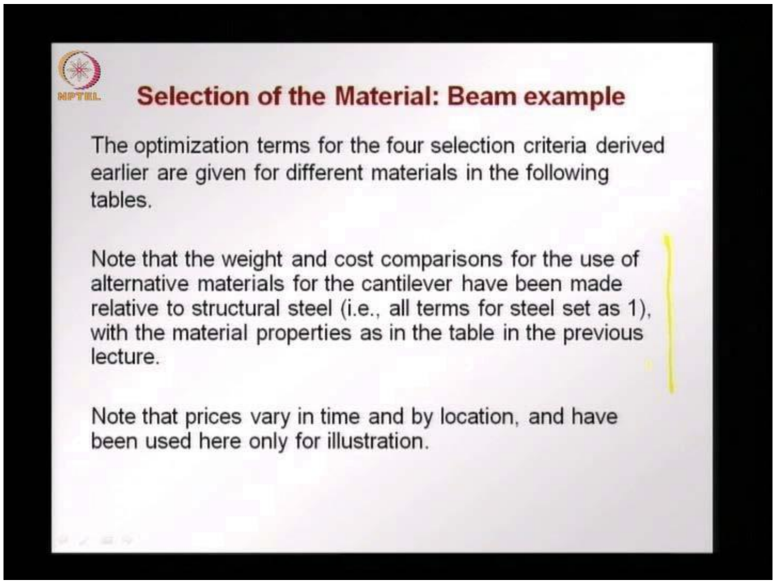

So these quantities we will try to look atin terms of numbers. We have looked at four selection criteria.We have looked at how to minimize weight,while getting the required stiffness.We looked at how to minimize weight, getting the required strength. We looked at a criterion for minimizing the cost for getting the required stiffness and minimizing cost to get the required strength for the given beam. Now,in what follows, what we have done is set all values such as weight and cost and so on relative to that of structural steel, so that we can compare the properties with structural steel. And as I told you before in the previous lecture,the prices given vary with time and location and here, they are just to illustrate the methodology that is needed for optimizing for the different parameters.

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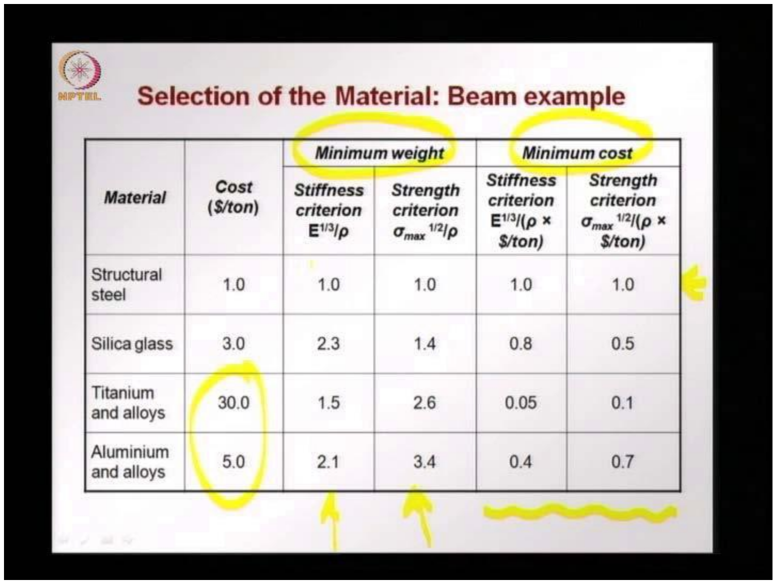

Selection of the Material: Beam example

Material	Cost ($/ton)	Minimum weight		Minimum cost	
		Stiffness criterion $E^{1/3}/\rho$	Strength criterion $\sigma_{max}^{1/2}/\rho$	Stiffness criterion $E^{1/3}/(\rho \times \$/ton)$	Strength criterion $\sigma_{max}^{1/2}/(\rho \times \$/ton)$
Structural steel	1.0	1.0	1.0	1.0	1.0
Silica glass	3.0	2.3	1.4	0.8	0.5
Titanium and alloys	30.0	1.5	2.6	0.05	0.1
Aluminium and alloys	5.0	2.1	3.4	0.4	0.7

So, we will takes some of the materials that we looked at before and these are used commonly in construction.And as I said before, we have set all the values for steel as one.So that means, for the other materials, we've normalized with the value of structural steel. So in case I have, sayfor silica glass I have the stiffness criterion parameter as 2.3, this means itis 2.3 times whatever value came upfor structural steel. And similarly for silica glass if the cost is given as 3, that means in a certain location of reference, certain time, the cost of silica glass per ton was 3 times that of a ton of structural steel.

So what we see here is that when we are looking at minimum weight, we find that glass, titanium, aluminum come out better in terms of stiffness. In terms of strength also, aluminum, titanium are much better than steel.We find that the numbers here in these two columns (minimum weight) are much better for titanium and aluminum than steel. However, when we looked at these two columns (minimum cost), we find that the numbers are not that good because titanium and aluminum are quite expensive compared to structural steel.So, when we bring in the cost, when we lookat the minimum cost, materials such as titanium and aluminum do not work out as well as steel. So to remind you again, if we have a parameter which is higher than 1, that means that the value of that parameter is that many times that of structural steel. So in terms of the parameters, we want them to be high. That means we are optimizing better.

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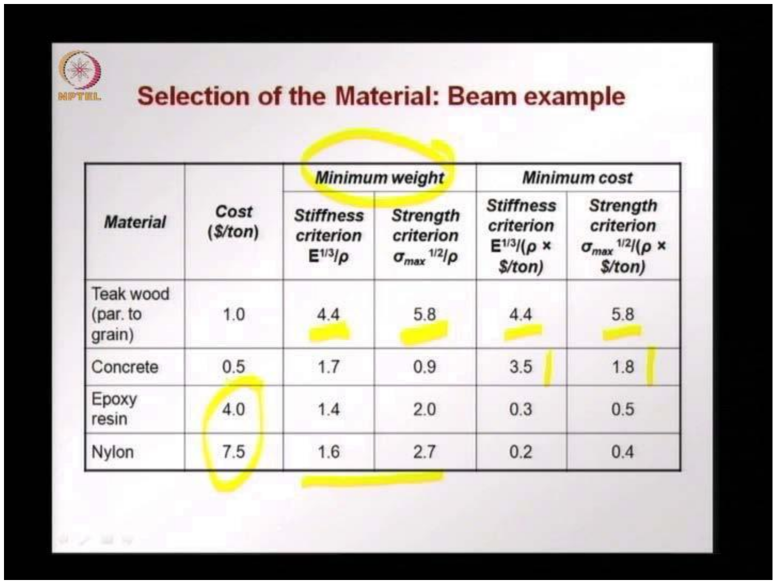

Material	Cost ($/ton)	Minimum weight		Minimum cost	
		Stiffness criterion $E^{1/3}/\rho$	Strength criterion $\sigma_{max}^{1/2}/\rho$	Stiffness criterion $E^{1/3}/(\rho \times \$/ton)$	Strength criterion $\sigma_{max}^{1/2}/(\rho \times \$/ton)$
Teak wood (par. to grain)	1.0	4.4	5.8	4.4	5.8
Concrete	0.5	1.7	0.9	3.5	1.8
Epoxy resin	4.0	1.4	2.0	0.3	0.5
Nylon	7.5	1.6	2.7	0.2	0.4

Now, in terms of the other materials we look here at teak wood, concrete, resin and nylon and again as in the previous table all the values have been normalized for in terms of the values of structural steel and we find here that when we look at the minimum weight criteria, wood comes out very well in terms of stiffness and terms of strength also and even in terms of cost, wood comes out very well. So, wood is a good material that you would use for a beam and that is one reason why wood is used a lot in flexural members. In terms of concrete, we find that when we are talking about cost, it comes out quite well compared to steel in both cases of strength and stiffness. Other materials like epoxy and nylon don't do very well because even though they may have better mechanical properties, their cost is quite high and that brings down their usefulness when we want to minimize the cost.

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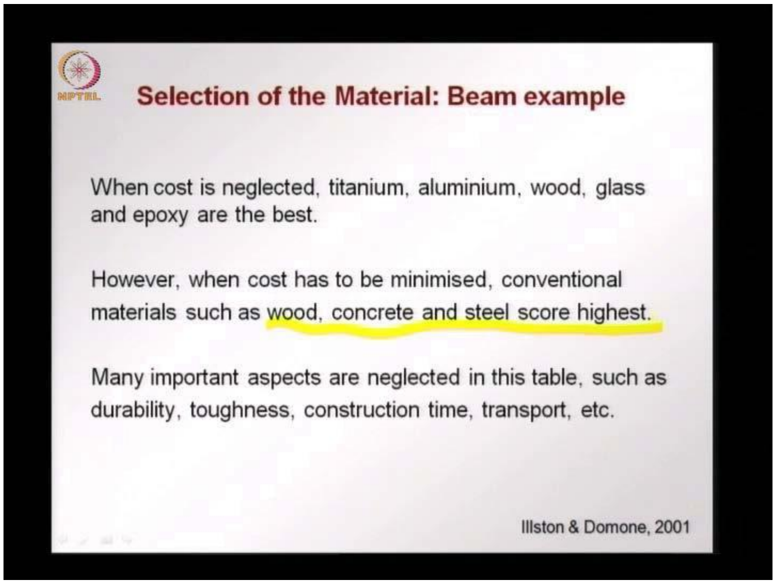

So what we have seen is when cost is not an issue, when cost is neglected and we are looking at only the mechanical properties, be it stiffness or strength, materials like titanium, aluminum come out very well; wood, glass and epoxy also, but for most civil engineering applications cost is an issue.We have to minimize the cost and therefore more conventional materials that we are all familiar with that we use a lot, come out the best such as wood, concrete and steel- structural steel, score the highest. Now, this was a simple exercise in how we can use the material properties to compare and eventually select an appropriate material for a certain application in terms of the mechanical response.

Now there can be a similar exercise done for other properties, which have been neglected in this table and this exercise such as durability, toughness and other aspects such as construction time, transportation, the feasibility of transportation, time for transportation and so on. So I insist that this is a simple way of looking at how we can compare different materials; this methodology can be extended to other structural applications, we can go on to use the same methodology in complex applications, and we can bring in other performance requirements that we did not consider here. We considered here only stiffness and failure strength as the main criteria for selecting the material to be used as a beam.

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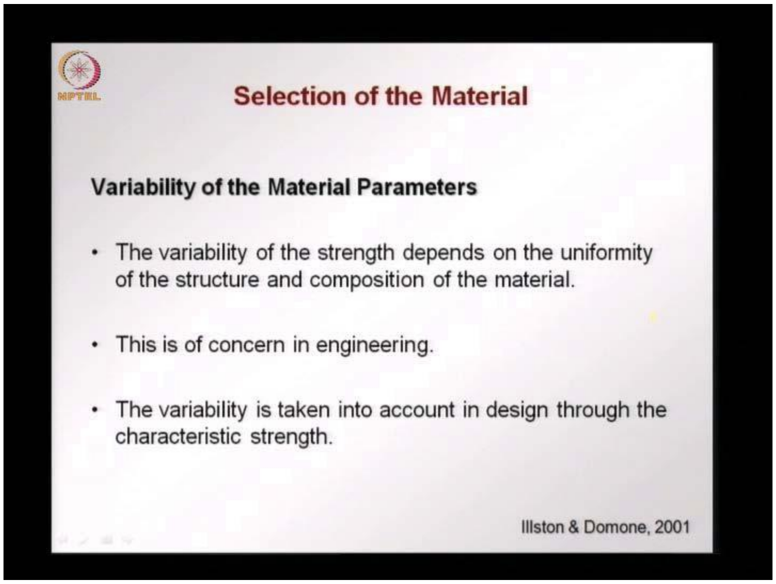

Now, another aspect that is very important when we are talking about the choice of a material, other than just the properties and the durability, is the variability of the material properties, say strength. The variability of the strength depends a lot on the uniformity of the structure, meaning the microstructure and the composition of the material. And when we talk here about variability, what I mean is that if I take several samples of the same material, what would be the scatter in test values that I'll get between these several specimens taken, samples taken? This is of great concern in engineering because we want to get a certain value that should be used in design we want to understand how safe a structure is in usage and this variability has to be taken into account through a parameter that we call characteristic strength. Now, allof you when you have studied design would have taken into account for the characteristics strength of the material, which is used in design.And we will go on now to see where that characteristic strength comes from and what are its implications?

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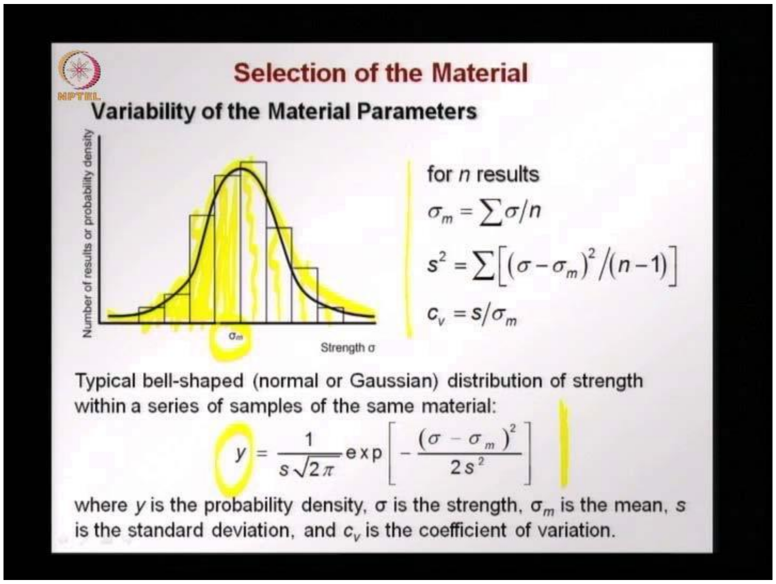

Now when we talk about the variability of the material parameters, I said that when we do a lot of test on identical specimens of a certain material, we would have different values coming from these tests. So in this plot, you see on the x-axis the strength of the different samples tested and on the y-axis, we have the number of results obtained for a certain strength. So, normally you would have these different numbers giving you the number of results for each strength value and that can be approximated by this bell shaped curve or a Gaussian distribution. The middle of this Gaussian distribution is the mean value and we can get other parameters which are given here say for 'n' results, we have the mean value given by the sum of all the values divided by 'n', that being the number of tests; 'S'is the standard deviation and 'C_v' is the coefficient of variation. These parameters define the distribution that we see here and given by these equations.

So, again the parameters are the probability density given by this equation(bottom),σ is the strength that is given by the test; σ_m is the mean value of all the tests that we have conducted, 'S' is the standard division and 'C_v' is the coefficient of variation. So what we find here and we will continue with this concept later is that we have half the specimens with a strength lower than the mean value. This is what important to remember. This mean value only tells us the limit for half the strength of the specimens tested to be higher than a certain value. And we find that that value ifwe use in design,we are having a case where half the material that is used or half the locations where the material has been used will have a strength lower than the mean value, which is unacceptable, because that means you are taking the risk where half the material could be of a strength lower than the design strength.

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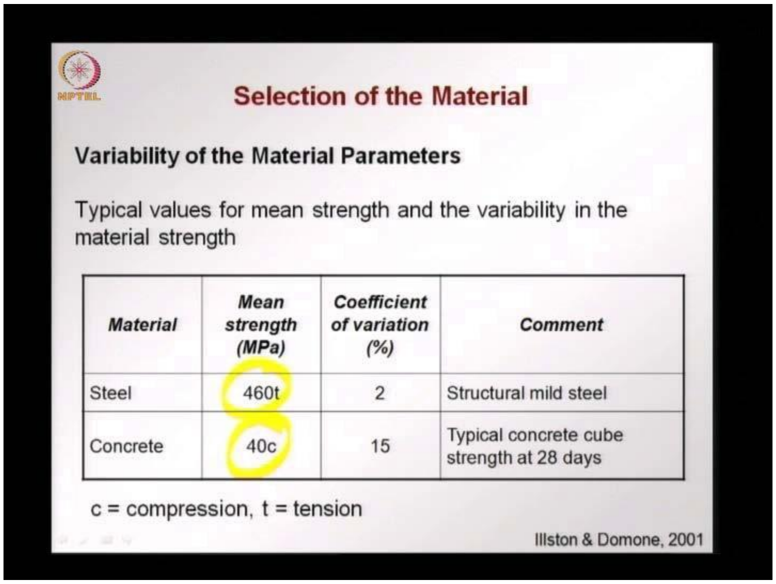

And when we look at the variability coming from different materials we understand the importance of this concept further. Here in this table, we have two materials steel and concretewith steel having say a strength of 460 MPain tension and concrete having 40 MPa in compression. These are again values taken form Illston and Domone and for these, you will have a coefficient of variation for steel which would be quite low, say for a structural mild steel we will have a coefficient of variation of say 2 %, because steel is a factory made product, the quality control during production is very good, so the co-efficient of variation is quite low, as low as 2 %.But when we test typical concrete cubes at 28 days, we do a lot of test of nominally identical materials. Even though the material is supposed to be same we would find that the coefficient of variation between the different tests conducted could be as high as 15%.

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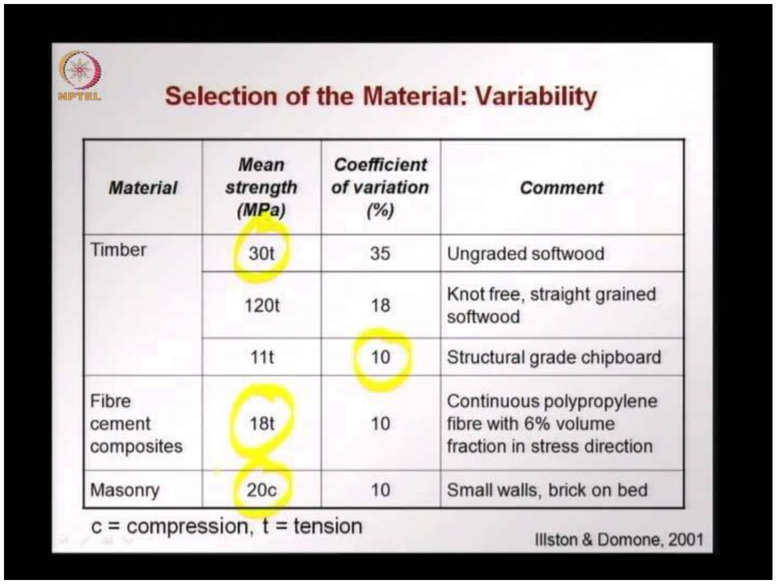

Selection of the Material: Variability

Material	Mean strength (MPa)	Coefficient of variation (%)	Comment
Timber	30t	35	Ungraded softwood
	120t	18	Knot free, straight grained softwood
	11t	10	Structural grade chipboard
Fibre cement composites	18t	10	Continuous polypropylene fibre with 6% volume fraction in stress direction
Masonry	20c	10	Small walls, brick on bed

c = compression, t = tension

Illston & Domone, 2001

Now, if you go on to other materials, we find a range of parameters. Timber we find has generally much higher coefficient of variations. Here, we have the values for un-gradient soft wood with the mean strength of 30 MPa intension, with the coefficient of variation of 35 %. Another material with less defects,knot free straight grained soft wood, with a high tensile strength 120 M Pa could have a lower co efficient of variation 18 %.

Now, if we have a product made out of wood, like plywood, chip board and some sort of an agglomerate, we find that the coefficient of variation decreases, even though the parent material could have had a lot of variation, we find that the final material which is made out of pieces of wood has a lower coefficient of variation.Because again this is a factory made product.This goes through a certain quality control and a fabrication process, whereas timber is as the tree grew and it has defects, it has a lot of variability between one tree and the other and between one location and another. Fiber cement composites say a cement matrix with 6 % volume fraction of polypropylene fibers in a certain direction, having a strength of 18 MPa in tension, could have again a coefficient of variation much lower than what we saw for concrete. Masonry, small bricks, so you have many bricks acting together, put along the direction of the larger face brick on bed with 20 MPa compressive strength, again has a coefficient of variation of about 10%.

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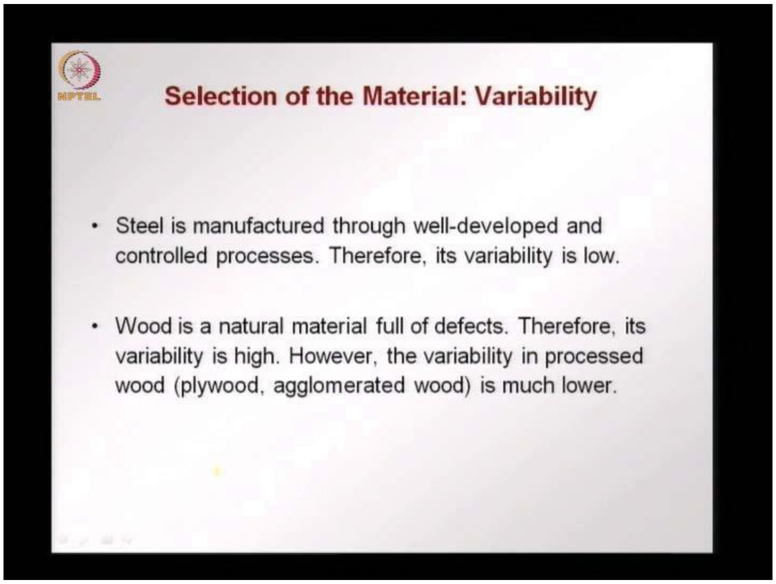

So we find that materials such as steel which are manufactured through a well-defined, well-developed controlled process, gives low variability i.e. that the material properties do not change a lot between different samples tested. Wood on the other hand is a natural material full of defects.As the tree grows, there is a lot of interference by insects, animals, birds and so on and also its surroundings. So it grows in an uncontrolled manner.The variability ends up being very high; we saw values of 35% for the coefficient of variation. However, when the wood is processed, to make it agglomerated wood, chip board, ply wood and so on, since now we have a manufacturing process involved, the variability comes down quite a bit and it can be as low as 10%.

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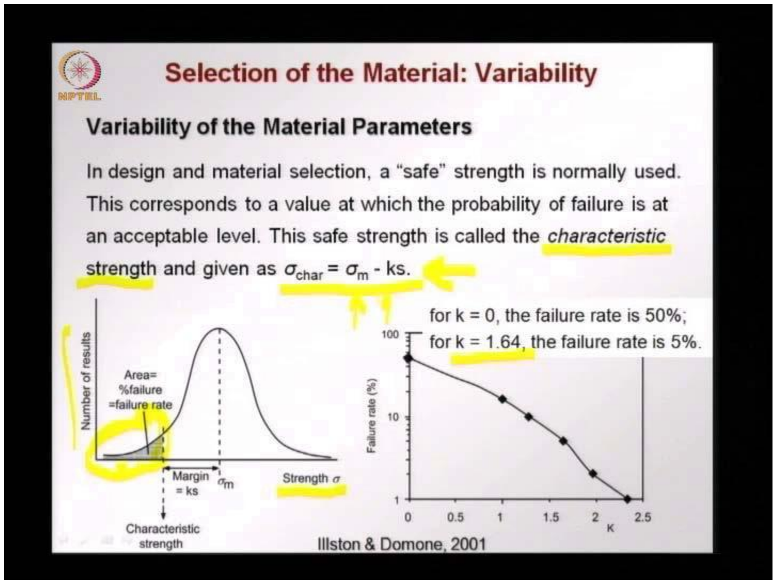

Now, how does this affect our design procedure?I refer to what we call the characteristic strength earlier. The characteristic strength is what is used in design and in material selection and this is a safe strength. It is not the minimum strength or the mean strength or the maximum strength.It is a safe strength that is used in design. This is the value of strength that we feel that we will be safe with or the application will be safewith, when we use to design a certain structure. So this corresponds to a value of strength at which the probability of failure is acceptable. Note that we are not saying that the probability of failure is 0.We are saying that the probability of failure is acceptable and this corresponding value is call the characteristic strength and this is given by this equation. $\sigma_{characteristic}$ or the characteristic strength is equal to the mean strength minus 'k', which is a factor that represents risk, multiplied by the standard deviation.

We can understand this better when we look at the figure on the left, which is again giving us the strength of material tested, several specimens tested, number of results obtained and we have the bell shape distribution that we saw before.The middle of the bell shape distribution is σ_m, which is the strength and the characteristic strength is now lower than the mean value by a margin given by k x s. So what we are saying is that the failure that is acceptable is about this much (refer slide time 26:15) when we take this particular characteristic strength. The area under the shaded part gives the percentage of failure that is acceptable or the failure rate. If we were to take the meanvalue for design or the mean value as the characteristic strength, then this failure rate would be 50%i.e. when k = 0, the failure rate is 50 % or half the results will fall below the mean strength and this is something that is too high to be acceptable. 50% failure rate is too high for any application, so we cannot have such a high failure rate. You will also see in this distribution that it's not practical to go for a failure rate of 0.That would mean that the strength that we will use in design is so low that we will have very massive structures and the cost will go up very significantly.

So generally in civil engineering, we use a failure rate that is acceptable as 5% and that from the graph at the right, you see that corresponds to a value of 1.64. So that means we say that the number of failure, number of results that could be less than the characteristic value should not be more than 5 %. We take 5 % as the acceptable value and the corresponding 'k' value, as seen in this graph on the right, is 1.64. So normally the characteristic value that we use in civil engineering would be this equation giving usthe characteristic value in terms of the mean value reduced by a factor of 1.64 multiplied by the standard division. So this is something that we always have to remember that in design, we do not use the mean value, we do not use the mean strength or a mean parameter, but we use a characteristic value, which is a safe value to use in design.

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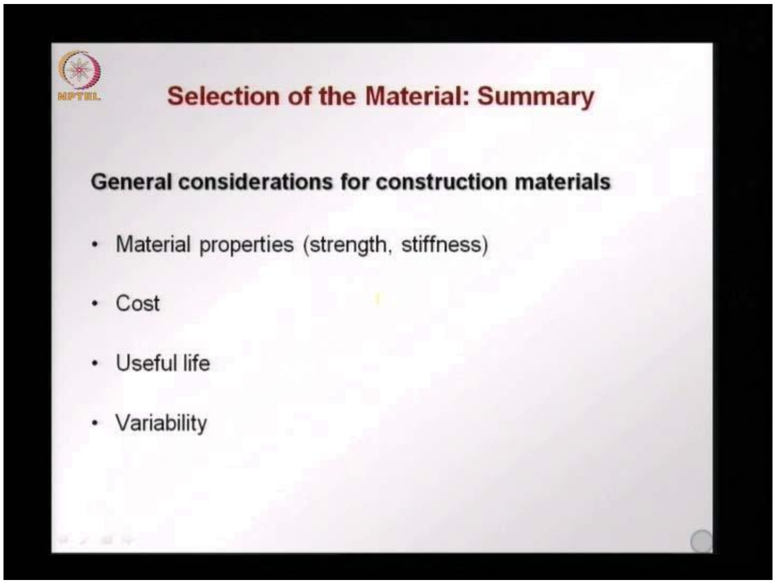

So when we talk about different construction materials, we have looked at the importance of properties such as strength and stiffness, we carried out an exercise for optimizing for strength and stiffness.We looked at two possible ways of optimization: one in terms of minimizing the weight of a structure, structural element, in terms of getting the required strength but at the minimum weight, we also looked at the possibility of having the required stiffness at the minimum weight and this could be extended to different mechanical properties and other properties such as durability and so on, where we can optimize for a certain life may be, we can optimize for any other quantity that can be well defined and can be calculated. On the other hand, we also looked at minimizing cost for the same two above parameters- strength and stiffness.We looked at how to calculate a minimum cost or compare materials based on minimizing cost for the required strength and stiffness and we saw how the decision could vary, whether we bring in cost or not.We found when we did not take into account cost, we looked at titanium, we looked at epoxy coming out very well, but when we looked at cost, we found that more conventional materials such as wood, concrete and structural steel come out well and this is the reason why these materials are so popular and widely used.

Other than that, we also have to keep in mind that all materials have to have a useful life.We have to have a minimum durability that is required in a certain application and this is brought in by a proper understanding of how the material behaves in a mechanical and chemical sense in terms of interaction with its with the loading, other aspects of the application and the environment. And finally, we looked at variability being a very important consideration where we want materials to have as little variability as possible in its properties because having a high variability will bring down the characteristic strength related to its mean value, and this is something that we have to emphasize.When we have different materials or the same material with different variability in its properties, the characteristic values that we will use for each of them is different, because the characteristic value depends not only on the mean value, but also on the standard deviation.Higher the standard deviation, lower will be the characteristic value that we will use in design. So that is where variability comes in.

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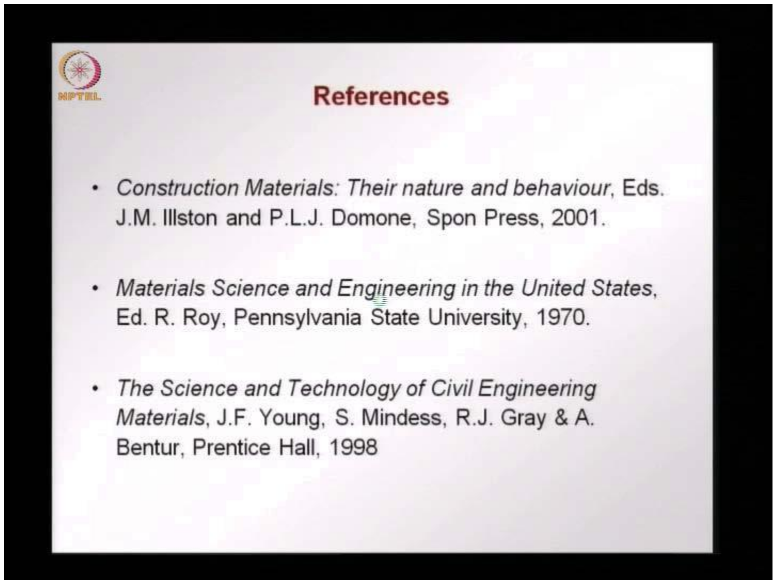

So, these are the references that are used in this lecture and I will give you a list of references in all the lectures at the end and most of these are books that are quiet easily available and give the background needed for that particular lecture. So to summarize, in the two parts of this lecture on introduction to modern construction materials, we'velooked at the different levels of information that we have to study for understanding materials- the micro scale, the mezo or the material scale and the engineering scale, what are the aspects that are important, what we focus on in each of these case. We also looked at a wide range of materials that are available and their properties.We looked at a few typical properties or important properties in terms of engineering such as density, stiffness, strength, fracture toughness or fracture energy and we also looked that cost which cannot be over emphasized in terms of engineering. Then, in the second half we've looked at two aspects which are quiet important in the selection of materials: one is how do we optimize for getting the minimum weight in a structure or structural element or the minimum cost.We looked at the cases of getting the minimum weight and the minimum cost for the desired stiffness, which means that we will have low deformability, low strain values and low deflections.And we also looked at how we would optimize for getting the minimum weight and the minimum cost in case we have to again look at stiffness, required stiffness and strength. And we saw the methodology that we would apply and this methodology can be extended to other mechanical responses and other aspects that are important in terms of the performance. Finally, we looked at variability and why it is important.Materials based on how they are formed, processed and manufactured have different variability in their mechanical properties and we saw the example of steel having very low variability as low as 2% when we talk about the tensile strength and wood on the other hand, which could have variability as highest 35% when we are talking about the strength.This again becomes because steel is a well processed material done in a factory and we have wood which is growing in a natural manner, with defects, with lot of interference from its surroundings, leading on to lot of variability.And there are many other materials which fall within this span, which is sought of bounded by a metal processed properly like a steel and natural material like wood.

We also saw how this variability affects the value that we use in design.The value that we use in design is the characteristic value and we saw how this characteristic value is defined as a safe value, which means that it is associated with an acceptable risk and normally, the risk that we accept in civil engineering is in the order of 5% so we say that, we design such that we allow, we can accept 5% of the results or 5 % of the material to have a properties less than the value that we used in design namely the characteristic value. The variability comes in in the definition of the characteristic value which is the mean strength reduced by a factor of k x s, 'k' coming from the risk that we assume and 's' is the standard deviation. So when we have a lot of variability, the standard deviation is high. So that means we reduce the characteristic value to quite a low value compared to the mean strength.If we had a very small standard deviation, the characteristic value and the mean value will be very close.

So if we have two materials one with a lot of variability but having the same mean strength as other with other low variability, we would be better off choosing the material with low variability, because the characteristic value that we will use in design will be higher, we will take better advantage of the materials.So that is where the variability comes in, and again variability is brought about by how the materials form and processed and we have to understand that through testing and also by an analysis of the micro structure of them. In the next lecture, what we will see is we will start with atomic bounding, we'll look at the chemical nature of bounds that are formed and we will go on to see how this affects the material behavior for a range of materials.

Thank you.

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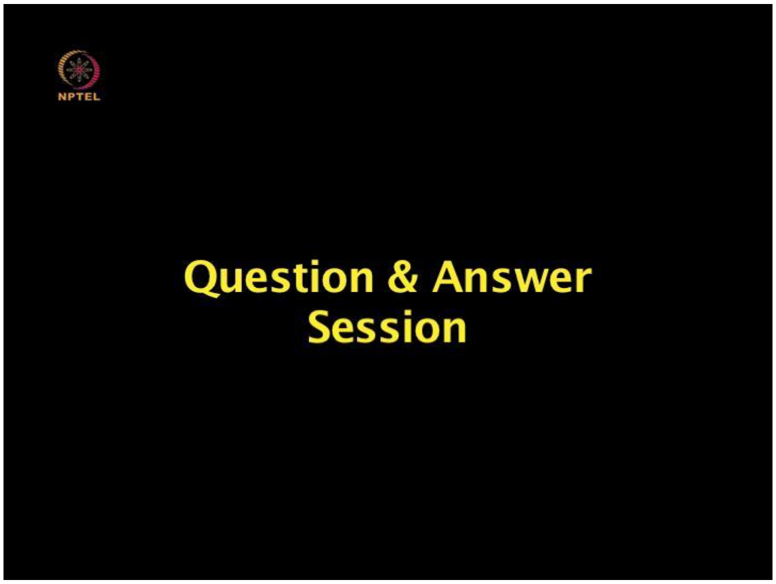

We have a group of students who have joined us and they have some questions from the first lecture on modern construction materials. So we'll take these questions and see what the answers could be and probably some of these questions will coincide with the doubts that you have on the lecture also. We'll start with Karmugil.

Sir, in one of the slide,you have mentioned about composite materials. Can concrete be considered as a composite material?

That's a good question. Concrete,in the engineering sense,we lookat it as a total material.But actually, it is a composite material and we can look at it even with the naked eye, you see that when you a piece of concrete that is broken, you see the coarse aggregates; you see the cement mortar, so it is certainly a composite material.And it is a good example for what we have discussed of the different scales. When we look at the micro scale, we study the hydrated cement paste and we see what the properties are and this has a lot of influence on the durability, on the porosity, and so on. And then in the next scale, we look at the properties of the aggregates like when we do a mix design, when we choose materials for making concrete, we also worry about the properties of the components; we see what the property of sand should be, what is the origin of the coarse aggregates, the strength of the course aggregate, the strength of the cement and so on. And we also look at how the interface behaves. We wantgood bonding between the aggregates and the cement paste. Then in the engineering level, we take concrete as a material.We don't go into, now, the properties of each of the components. But we understand it is a composite material and we find representative parameters like the strength and Young's modulus, which will represent the composite material.So, concrete is certainly a composite material and we have to understand how each of phasesbehaves andthe inter phase behaviour also.

One more question Sir,regarding the cost.Can you giveme some examples where cost is not a parameter that we are considering?

Most civil engineering structures, we are worried about cost.But there could be applications which are very critical, like a nuclear power plant.We can't go for the cheapest material to use there and we can also think of some emergency structures where cost is not that of an issue.We want safety at all cost.

Sir, you discussed properties of different kind of materials.So in future, if I would like to select a material to have a combined performance,so how do we go and select a material? Because we have some compatibility issues among different materials.So how do I go and select a material?

Well, if you have to see an application such as reinforced concrete. You have different materials: you have the concrete and you have steel coming in together.Generally, what we looked at is two aspects. One is for the purpose of each of the components should be the best possible.So we have put in steel and we want steel to have a high tensile strength and it should have a lot of elongation so that the failure is not sudden.We use concrete in the same element because of its compressive strength.So we want concrete to have a good compressive strength.And we also want concrete to protect the steel.So it should not be permeable, it should not let chlorides in, it should not let water in. On the other hand, both of them have to be compatible also, so that is why we choose concrete and steel which have the same thermal expansion coefficients, more or less, so that they can work together and do not crack, there are no cracks in the interface during application. So we choose materials in combination when they can work together and each of them brings in a contribution which is optimum in either case.

I had a question. You were telling that the equation for the selection of a material for beam. In that, can we add composition of the material as one more parameter in that equation?

We can. It becomes more complicated. What we can do is substitute the Young's modulus ***with*** a composite Young's modulus, which also depends on the components. But, it becomes very complicated. As long as you have the equations, you can do it. But, you have to make it simple enough that the results come out in a way that you can understand and use for the material selection.

One more question Sir.You were telling that selection of the materials also depends on the variabilityand timberis having a large variability.In the near future, will timber be found to be competitive in usage as a building material or will become obsolete?

That's a good question.See what we find is the cost of timber is very high and the variability is also high.So when we go for processed timber, when we have plywood or we have MDF, we have chip board and so on, we find that the cost comes down because we are using a range of woods and not just the best wood and also the variability comes down because since we process it, the defects get distributed. We do not have all the defects occuring in a certain piece of material. So both cost and variability comes dowm.That is why you find that nowadays we use more processed wood than thenatural wood- because of both cost and variability.

In the material structure level, you gave an example of mixture of different phases in a composite.So can you explain more about the interaction of the different phases?

So when we say a material is a composite, we consider a material where each of the individual phases retains its characteristics.The opposite or the counter-example would be the alloy, where you have deferent metals which are combined but when you look at the alloy, you don't identify different phases separately; they all act together as one alloy with one property.But if you take the example of concrete that we looked at, the aggregate within concrete retains its properties and you can identify it separately all the time.Similarly when you look at a fiber reinforced plastic or polymer, the fiber retains its properties, acts as such and you can identify as such.And there is obviously an interaction which benefits.Together, the properties are different but each of the phases remains the same and acts the same as it would be separately. OK.

Sir, when we are having a material at hand, how do we decide the level of testing? Like for example you have a brick. Either we do a compressiontest on a brick or do we go for a masonry and then test the masonry?How do we decide all that?

See the final testing that we would do in the engineering level would be for a large element; like when we are talking about concrete, we go for a150 mm cube.For a brick it has to be say a wallet test which would be say at least above 50 cm by 50 cm.You have to include several of the bricks and enough the mortar also to represent the behavior of a masonry.If you go only to the test of the brick, you will not be able to understand how the wall is going to behave.So if you want properties that represent the masonry behavior in a wall, then you have to test a large enough piece which has a lot of bricks and also enough of mortar joints.Only then you will have the behaviour.

Sir, if we are having a material with a very low characteristic strength or very high variability, does it mean that we are adding to the cost? Does it directly mean that it's the cost that we are adding because we are going for a lower strength in design?

Certainly. That is the implication.Because we would need, to simply put it, if thestrength is lower we would need more material to resist the load.More material means more cost.So if your characteristic value is close to the mean value, you are utilizing the material better.So for the same cost, you are getting more strength that you are using in design.So if you have two materials with the same cost and same mean strength, but one has a lot of variability, if you use the material with less variability you are saving a lot in terms of the usage of the material.You will use less material for resisting the same loads.

Sir, adding to Sunitha,if we need higher characteristic value like in case of nuclear structures and in those case can we go beyond this 5 percent risk?

We should. The risk that we take, 5% risk, may be too high in some applications.Then what we will have to do is to go for a lower risk.Then you saw from the equation that the'k' value has to be high. So that means we have to be more careful in terms of processing the material and reduce the variability.Otherwise, we will be penalizing the material. That is certainly true. Generallywe use 5%but in some cases where you have a very critical application that even 5%defects are not acceptable, then you will have to go for lower acceptability, that means your 'k' value will be high.

Sir you said that for the level of testing, we have to go for real representative structure. Soeven if it is a critical structure like a nuclear structure, we will just do normal specimens like 150 x 150 specimen and then we will imply that in the real structure.So can you give any suggestion on that?Is it good to do that?

See the materials that we use, you have tohave certain specimen and size of specimen to get the properties that are representative of that material.How we design with it is another story.The analysis can be more rigorous in terms, has to be more rigorous in terms of a nuclear power plant.You have to be more careful, you have to do more checks.But the properties that you get may be the same for different applications.The same concrete could go into a nuclear power plant and also into a regular building.Right?And the type of testing may also be similar, may be you have to do different test.But the size of the sample would be same because the size of sample comes from the structure of the material. Like again, using the example of concrete: we use a 150 mm cube because your maximum aggregate size is say 25 mm.So as long as that is retained, the size can be the same.We can do more tests, we can try to get more information from different tests but the size of the sample should not depend much on the application, but more on the structure of the material.

OK. Thank you.