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 material, so in the first part what I discussed were the important aspects that going to 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 will continue in the same spirit; I have looking at why we have to understand the physics, why we have to optimize, why do we have to make a carefully 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 which come in to play.

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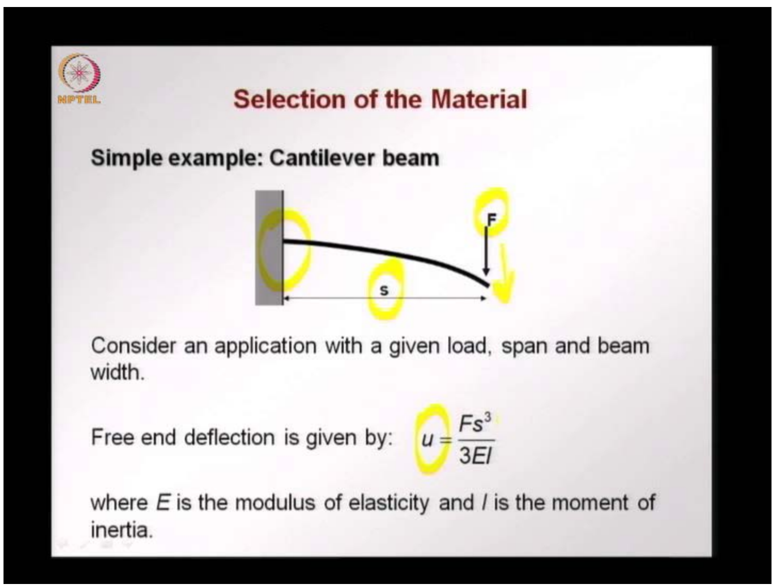

So, we let us take a simple example of a cantilever beam and all of you know what a cantilever beam, it is a beam with a fix tend and it projects out and you have a certain load acting on it. So, let us take a cantilever with a span s and a load applied at the end equal to F and when we use the beam 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 modules multiplied by the moment of inertia.

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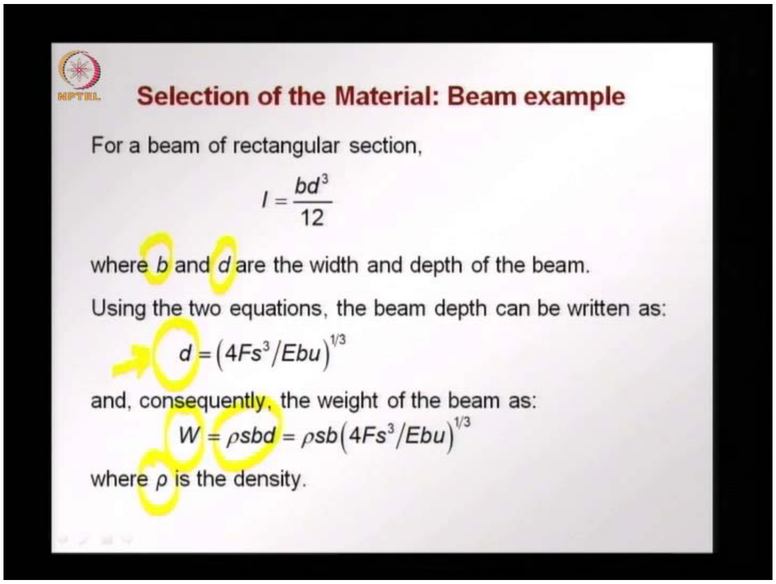

Let us take a simple case of a rectangular beam, where the moment inertia is given by b d cube by 12, where b is the width of the beam, d is the depth of the beam and therefore the moment of inertia is b d cube by 12. Using the two equations that we have looked at we can put these two equations together 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 rho 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 you W given as rho times s b multiplied by the cube root of 4 F s cube divided by E b u.

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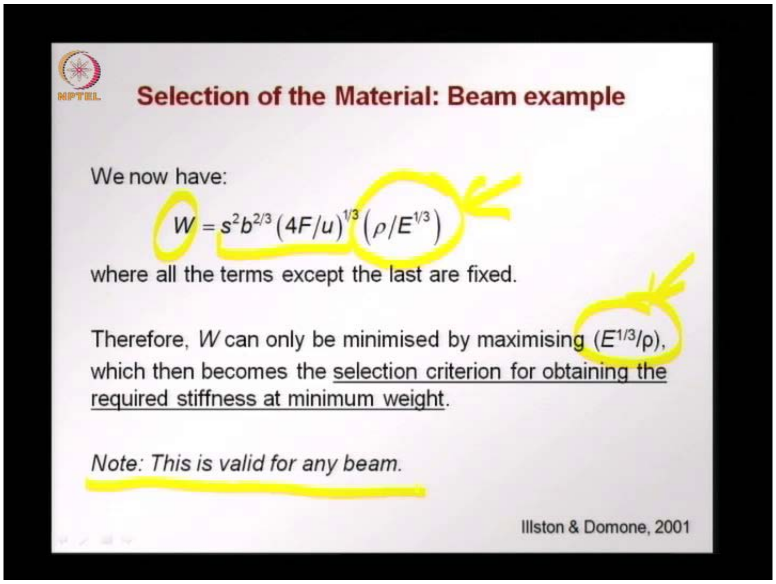

We now rewrite this equation separating them into different terms, where the first part is either fixed or depends on the other parameters and what can vary and influence the weight is this parameter which is rho divided by the cube root of the young's modules. So, what we now find out is that if we want to minimize the weight if we want a beam which waves very little, but still giving us the required stiffness. Then, we have to maximize this parameter. We have to maximize E to the power of one third divided by rho or to decrease the weight we have to minimize rho divided by the cube root of E.

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 rho divided by the cube root of E or the maximum of E to the power of one third divided by rho and what we find out is that this though it has been derived 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 as the minimum weight for the required stiffness we have to maximize the quantity E to the power of one third divided by rho. Now in terms of stiffness which is needed for minimizing the deflection, the deformation and so on.

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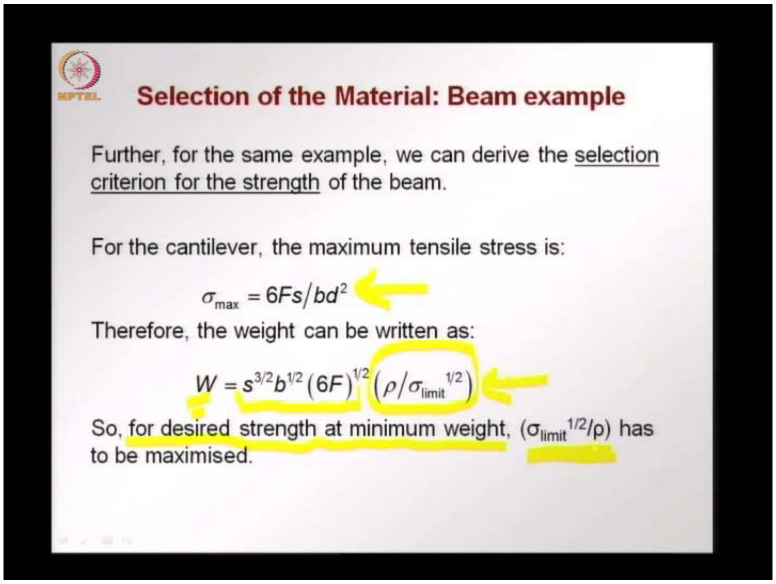

We can also optimize for this strength, we can say that we want a beam with a minimum weight but required strength, so that failure can become the main criteria for the same beam and for the same cantilever we can look at the maximum tensile stress again from elastic beam formula we can get the sigma max for 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 b d square, 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 the material is exceeded by the maximum tensile stress.

So, in this equation we substitute sigma max by the limit strength that could be now a material property and rewrite the equations based on the formula that we have seen before and the sigma max and we get weight return as this, where 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. 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 rho divided by the square root of the limit strength to be minimized. 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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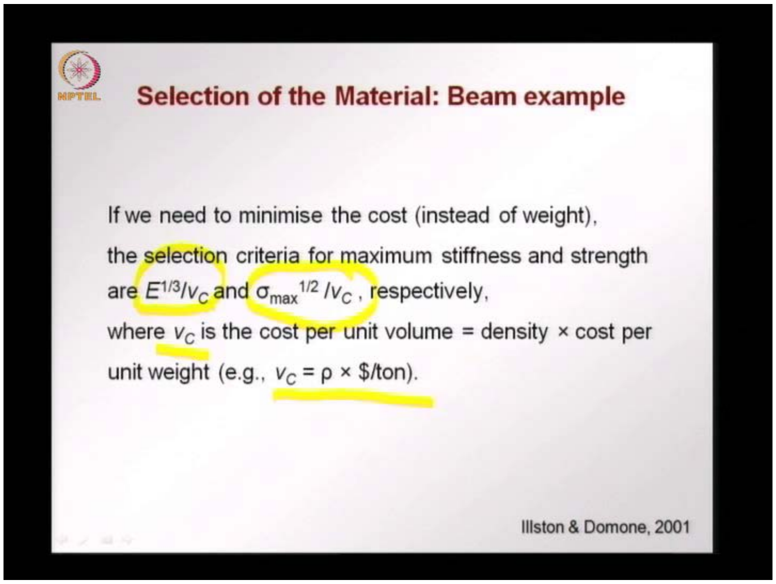

Now, weight may not be always the final objective of design often it is cost effectiveness. In the last lecture, I talked to lot about how cost effectiveness is very important, because cost of the material would we go and to determine the project cost, how much we spend for a structure, budget limitations and so on. Apply, so we have to often minimize the cost instead of just the weight of a material and we introduce now V sub 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 rho which is the density times; a cost per unit weight, I have denoted it as dollars per ton but it could be any monitory unit and for simplicity is denoted as dollar per ton.

What we find is the two criteria that we looked at before for maximum stiffness and strength when we look at cost become this so we have to maximize the cube root of the young's modules 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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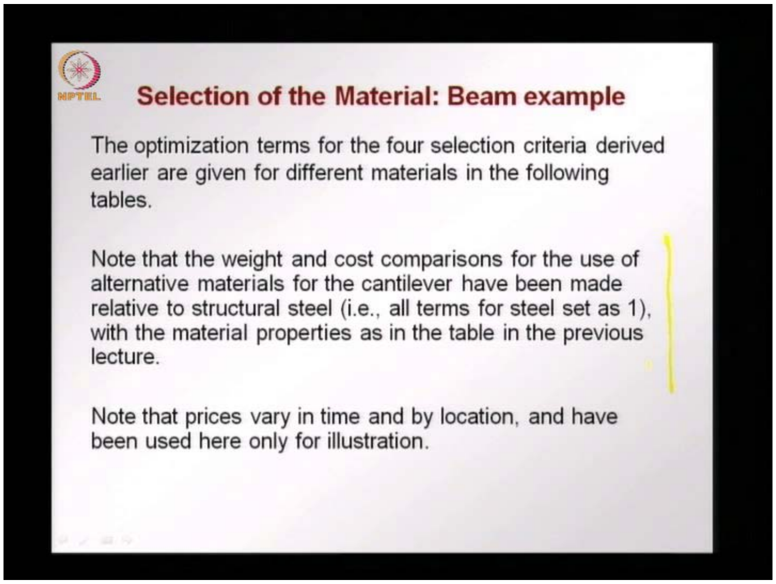

So, these quantities we will try to look at in terms of numbers. We have looked at four selection criteria we have looked at how to minimize weight, while getting the required stiffness we looked at, how to minimize weight getting the required strength we looked at a criterion for minimizing the cost for getting required stiffness and minimizing the 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, cost and so on. Relative to that of structural steel so that we can compare the properties which structural steel and as I told you before in the previous lecture the prices given vary in time and location and here there are just is to illustrate the methodology that is needed for optimizing for the different parameters.

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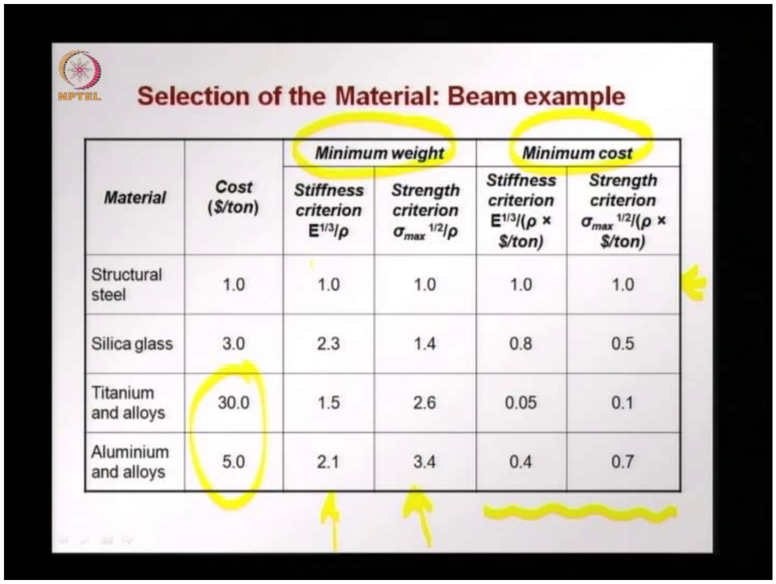

Material	Cost ($/ton)	Minimum weight: Stiffness criterion $E^{1/3}/\rho$	Minimum weight: Strength criterion $\sigma_{max}^{1/2}/\rho$	Minimum cost: Stiffness criterion $E^{1/3}/(\rho \times \$/ton)$	Minimum cost: Strength criterion $\sigma_{max}^{1/2}/(\rho \times \$/ton)$
Structural steel	1.0	1.0	1.0	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 normalized with the value of structural steel. So, in case I have say for silica glass I have the stiffness criterion parameter is 2.3 this means is 2.3 times whatever value came up for structural steel. 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 ton of structural steel.

So, what we see here is that then we are looking at minimum weight we find that glass, titanium and aluminum come out better in terms of stiffness. In terms of strength also aluminum and titanium are much better than steel we find that the numbers here in these two columns are much better for titanium and aluminum then steel. However, when we looked at these two columns 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 looked at the minimum cost materials such as titanium and aluminum do not work out as well as steeled as. So, as to remind you again if we have a parameter, which is higher than 1 that means that the value of those parameters 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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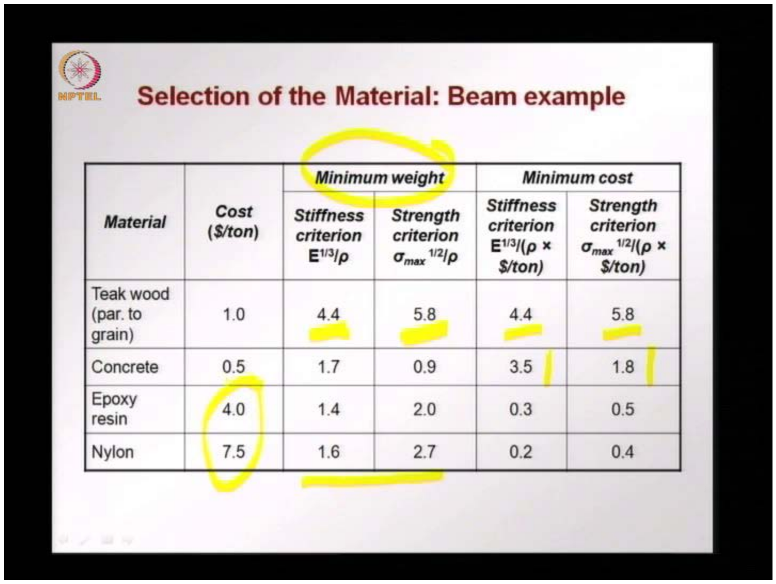

Material	Cost ($/ton)	Minimum weight		Minimum cost	
		Stiffness criterion $E^{1/3}/\rho$	Strength criterion $\sigma_{max}{}^{1/2}/\rho$	Stiffness criterion $E^{1/3}/(\rho \times$ $/ton)	Strength criterion $\sigma_{max}{}^{1/2}/(\rho \times$ $/ton)
Teak wood (par. to grain)	1.0	4.4	5.8	4.4	5.8
Concrete	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 compare 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 in when we want to minimize the cost.

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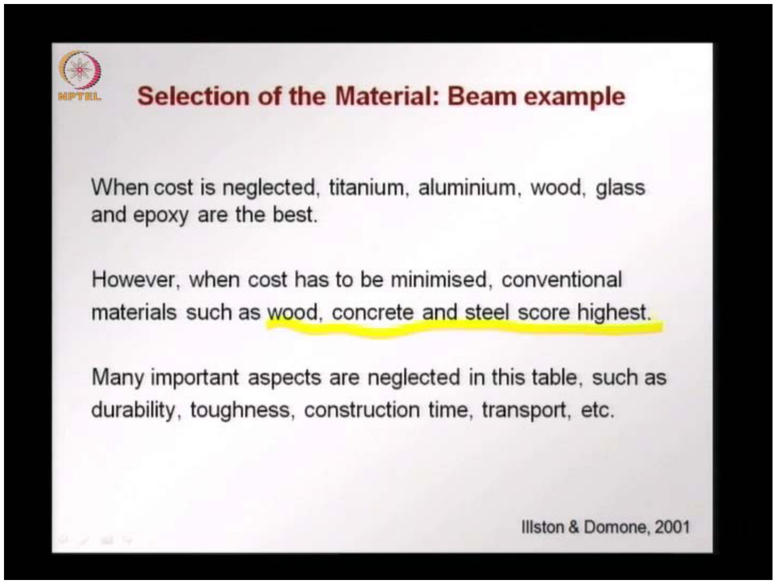

So, what we have seen is when cost is not an issue, when cost is neglected and we are looking at only the mechanical properties be it stiffness or strength materials like titanium and aluminum come out very well; wood, glass and epoxy also, but for most civil engineering applications cost is an issue 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 an eventually select an appropriate material for a certain application in terms of the mechanical response.

Now, they can be the similar exercise done for other properties, which have been neglected in these table and this exercise such as durability, toughness and other aspects such as construction time transportation, the feasibility of the transportation, there 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 extend 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 consider here only stiffness and failure strength as the main criteria for selecting the material to be used as a beam.

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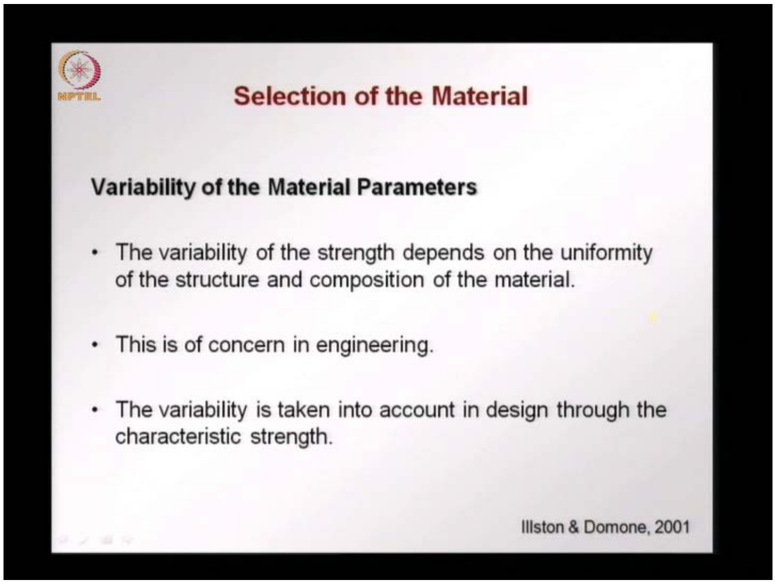

Now, another aspect that is very important when we are talking about the choice of a material other than just the properties and the durability is the variability of the material properties says strength. The variability of strength depends a lot on the uniformity of the structure meaning the micro structure and the composition of the material. When we talked 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 will get between these several specimen taken and 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 characteristics strength. Now, all of you when you have studied design would have taken in to account or 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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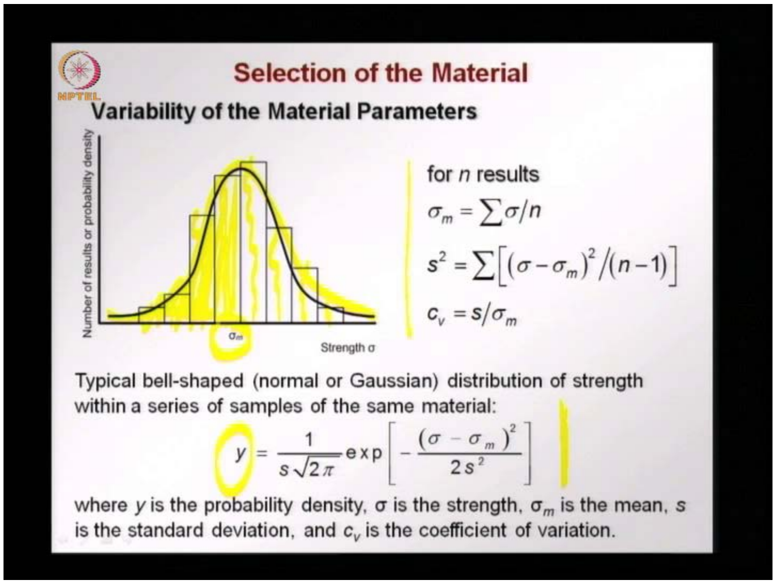

Now, when we talk about the variability of the material parameters, I said that we when we do a lot of test on identical specimens of a certain material we would have different values coming from these tests. So in this plot you see on the x-axis the strength of the different samples tested and on the y-axis we have the number of results obtained for 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 defined the distribution that we see here and given by these equation.

So, again the parameters are the probability density given by this equation sigma is the strength that is given by the test; sigma m is the mean value of all the test that we have conducted, S is the standard division and C sub v is the coefficient of variation. So what we find here and we will continue with this concept later is that we have half this 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 specimen tested to be higher than a certain value. We find that that value if we 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 we will have a strength lower than the mean value, which is un acceptable, 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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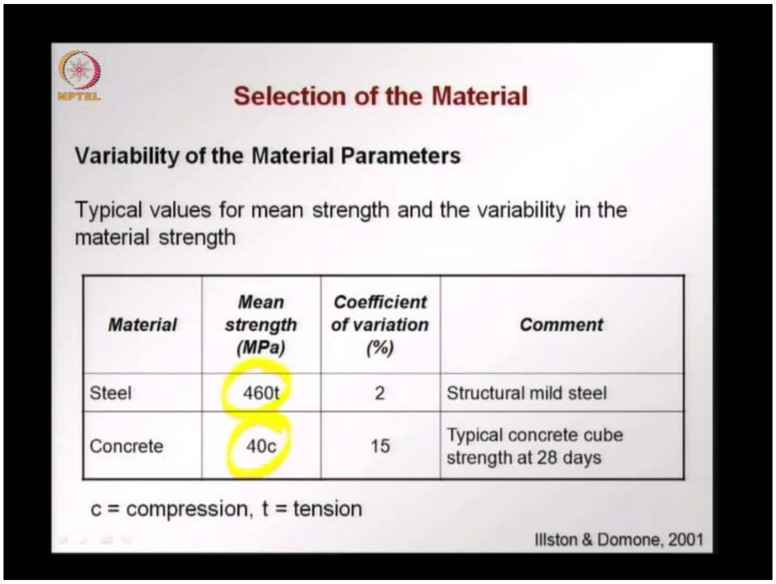

Material	Mean strength (MPa)	Coefficient of variation (%)	Comment
Steel	460t	2	Structural mild steel
Concrete	40c	15	Typical concrete cube strength at 28 days

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 concrete. With steel having say a strength of 460 M Pa tension and concrete having 40 M Pa compression. These are again values taken form ills ton and demon 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 percentage, 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 percentage, 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 suppose to be same we would find that the coefficient of variation between the different tests conducted could be as high as 15 percentage.

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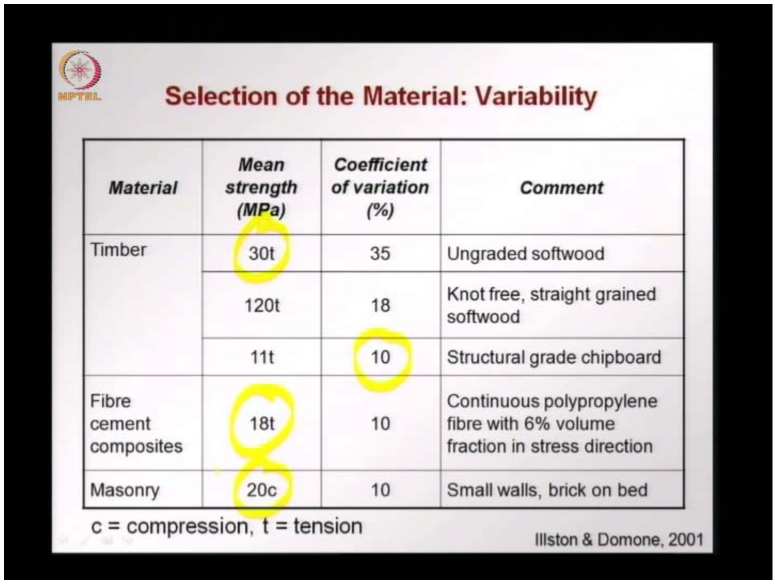

Now, if we go on to other materials we find a range of parameters. Timber we find has generally much higher coefficient of variations. Here, we have the values for un-gradient soft wood with the mean strength of 30 M Pa intention; with the coefficient of variation of 35 percentage. Another material with less defects not free straight grained soft wood with the high tensile strength 120 M Pa could have a lower co efficient of variation 18 percentage.

Now, if we have a product made out of wood, like plywood, chip board and some sought 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, where as timber is as the tree group 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 metrics with 6 percentage volume fraction of poly propylene fibers in a certain direction having strength of 18 M Pa intention could have again coefficient of variation much lower then what we saw for concrete. Masonry small bricks so you have many bricks putting together put along the direction of the larger face brick on bed with 20 M Pa compressive strength again has a coefficient of variation of about 10 percentage.

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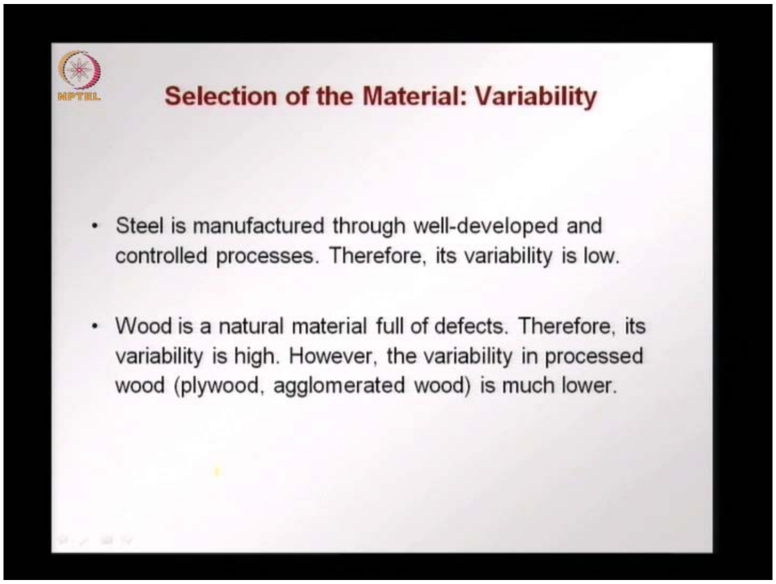

So, we find that material such steel which are manufactured through a well a defined a developed controlled process gives low variability that the material properties do not change a lot between different samples tested. Wood on the other hand is natural materials full of defects as the tree grows there 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 percentage 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 involve the variability comes down quite a bit and it can be as low as 10 percentage.

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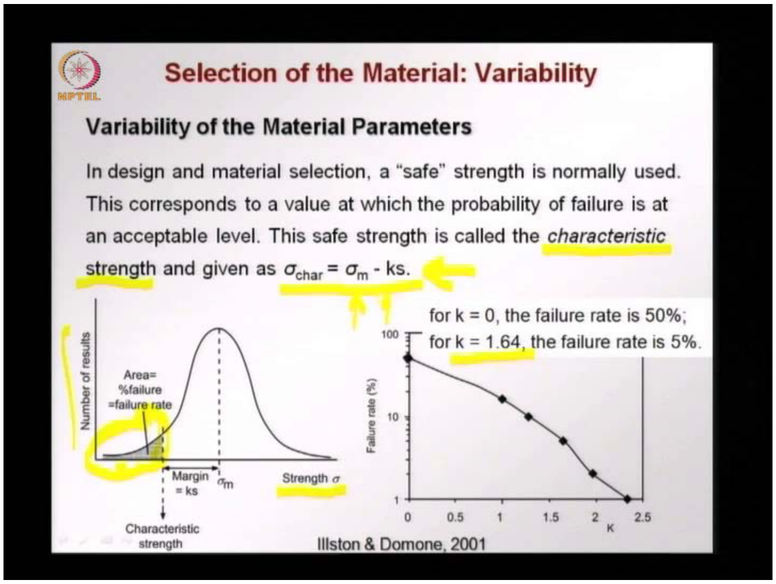

Now, how does this affect our design procedure; I refer to what we call the characteristics strength earlier. The characteristics strength is what is used in design and in material selection and this is a safe strength. It is not the minimum strength or the mean strength or the maximum strength it is 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 safe with when we used 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 zero we are saying that the probability of failure is acceptable and this corresponding value is call the characteristic strength 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 division.

We can understand this better when we look at the figure on the left, which is again giving us the strength of material tested and several specimen tested, number of results obtained and we have the bell shape distribution that we saw before the middle of the bell shape distribution is sigma m which is the strength and the characteristics strength is now, lower than the mean value by a margin given by k times s. So, what we are saying is that the failure that is acceptable is about this much 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 mean value for design or the mean value as the characteristic strength then this failure rate would be 50 percentage ; that is when k is equal to 0 the failure rate is 50 percentage or half the results will fall below the mean strength and this is something that is too high to be acceptable 50 percentage failure rate is too high for any application, so we cannot have such a high failure rate. You will also seen 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 percentage 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 result that could be less than the characteristic value should not be more than 5 percentage . We take 5 percentage 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 us. The 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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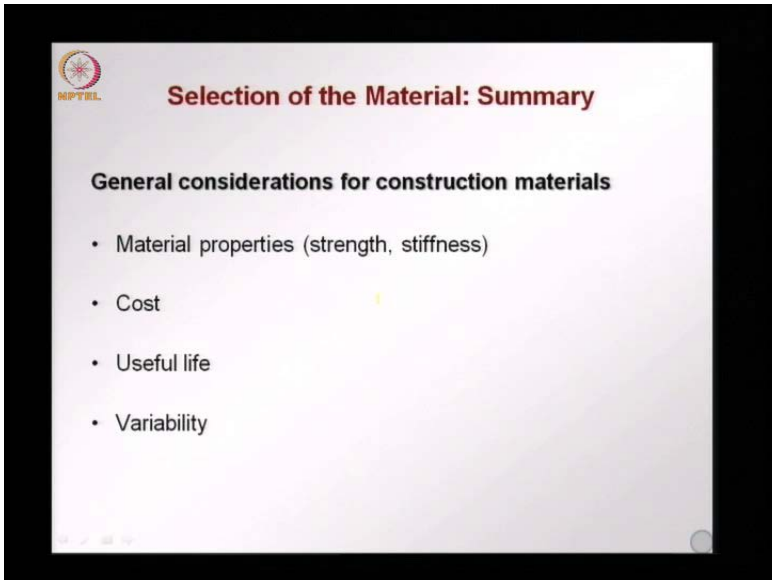

So, when we talk about different construction materials, we have looked at the importance of properties such as strength and stiffness; we carried out an exercise for optimizing for strength and stiffness may be looked at two possible ways of optimization one in terms of minimizing the weight of a structure 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, 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 by 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. Finally, we looked at variability being 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 characteristics 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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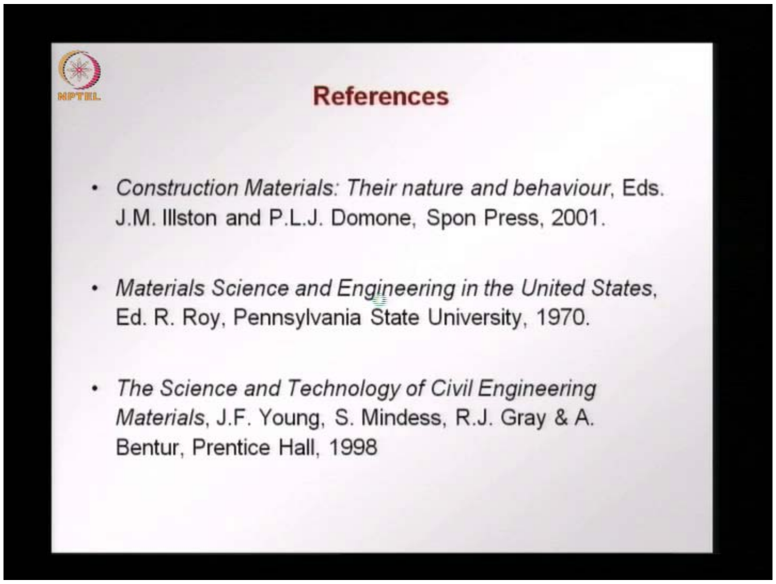

So, these are the references that are used in this lecture and I will do I will give you a list of references in all the lectures at the end and most of these are books that are quiet easily available and give the background needed for that particular lecture. So, to summarize in the two parts of this lecture on introduction to modern construction materials we will looked at the different levels of information that we have to study for understanding materials the micro scale, the mezzo of 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, facture toughness or fracture energy and we also look that cost which cannot be over emphasize in terms of engineering. Then in the second half we looked at two aspects, which are quiet important in the selection of material 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 required stiffness and strength. 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 percentage when we talk about the tensile strength and wood on the other hand, which could have variability as highest 35 percentage 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 process properly like a steel and natural material like wood.

We also saw how this variability effects, the value that we used in design the value that we used 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 percentage so we say that we design such that we allow we can accept 5 percentage of the results or 5 percentage of the material to have a properties less than the value that we are used in design namely the characteristic. The variability comes in the definition of characteristic value which is the mean strength reduced by a factor of k times 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 reduced the characteristic value to quite a low value compare 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 we 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 formed 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 look at the chemical nature of bounds that are formed and we will go on to see how this effects the material behavior for a range of materials.

Thank you.

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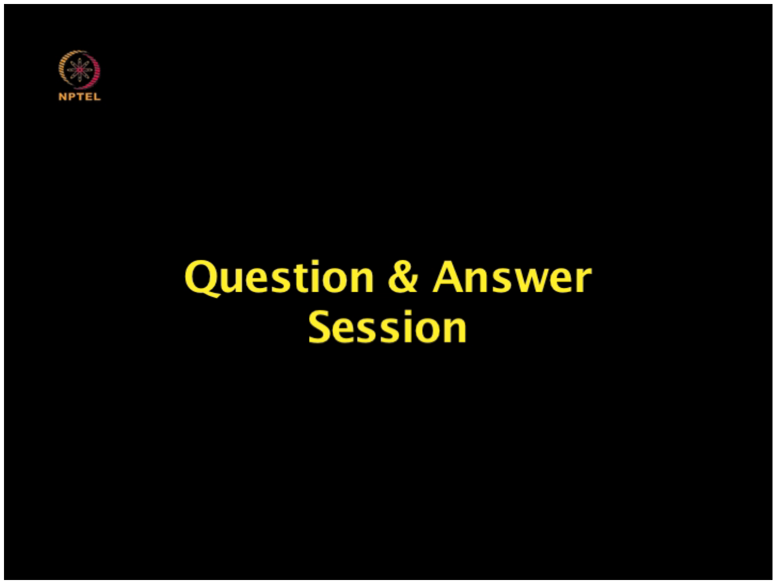

We have a group of students who have joined us and they have some questions from the lecture the first lecture on modern construction material. So, will take these questions and see what the answers could be and probably some of these questions will coincide with the doubts that you have on the lecture also ok we will start with carmogil. Sir, in one of the slide you have mentioned that about the composite materials; can concrete be considered as a composite material? That's a good question concrete we in the engineering sense we look at it as a total material, but actually it is a composite material and if we can looked at it even with the naked eye; you see that when you see a piece of concrete that is broken you see the course aggregates you see the cement mortar so it is certainly a composite material and it's a good example for what we have discussed of the difference scales when we look at the micro scale we study the hydride cement paste and we see what the properties are and this has influence on the durability on the porosity and so on. Then in the next scale we looked 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 is the property of sand should be what is the origin of the course aggregates, the strength of the course aggregate, the strength of the cement and so on. We also look at how the interface behaves; we want the good bounding between the aggregates and the cement placed. 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's a composite material and we find representative parameters like the strength and young's modules, which will represent the composite material so concrete is certainly a composite material and we have to understand how each the phases behaves and the inter phase behavior also. One more question sir regarding the cost can you give me some examples were cost is not a parameter that we are considering

most civil engineering structure we are worried about cost but they 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 we can also think of some emergency structures where cost is not that of an issue we want safety at all cost sir you are discussed a properties of a different kind of material so in future if I would like to select a material to have combine performance so how do we go and select a material because we have some compatibility issues among different material so how do I go and select a material well if you have to see an application such as reinforce concrete you have different materials you have the concrete and you have steel coming in together and 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 we put in steel we want the steel to have 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 it to protect the steel so it's should not be permeable it should let chlorides in it should not let water in and the other hand both have them have to be compactable also so that is why we look 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 they no cracks in the interface during the 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 sir I had a question that you were telling that the equation for selection of a material for beam in that can we add a composition of the material as one more a parameter in that equation we can in because more complicated for example what we could do is substitute the young's modules with a composite young's modules which also depends on the components but 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 cannot understand and used for the materials selection one more question sir and you are telling that selection of the materials also depends on the variability so in the near future as a timber has found to be having a larger variability in the near future is that is timber is found to be competitive in usage as a building material or it will become a obsolete in a near future 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 process timber when we have ply wood or we have m f d or we have chip board and so on we find that the cost comes down because we are using a range of wood 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 deflects accruing in a certain piece of materials so both cost and variability comes down so that so why you find that now a days we used more processed wood then the natural wood because of both cost and variability thank you sir 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 it we consider a material where each of the individual phases retain its characteristics the opposite or the counter example would be an 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 re-force plastic or polymer the fiber retains its properties acts a such you can identify as such and there is obviously interaction with benefits together the properties are different but each of the phases remains the same and acts as 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 examining have a brick either we do a compression brick or do we go for masonry or 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 one fifty mm cube for a brick it has to be say a wallet test which would be say at least above fifty centimeter by fifty centimeters you have to includes 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 the wall then you have to test a large enough piece which has a lot of bricks and also enough of mortar joins only then you will have the behavior. Sir, if we are having a material with very low characteristic and very high variability does it mean that we are have we are adding to the cost does it directly mean that it's a cost that we are adding because we are go for a lowest strength in the design certainly that is the implication because we would need to simply put it if the strength is lower we would need more material to resist the load more material means more cost so if your characteristics 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 all in those case can we go beyond this 5 percentage limiting we should the risk that we take 5 percentage risk may be too high in some application then what we will have to do is to go for a lower risk then you saw from the equation that is 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 to generally we use 5 percentage but in some cases where you have a very critical application that you will 5 percentage defects are not acceptable then you will have to go for lower acceptability that means your k value will be high.

sir you said like few for the level of testing we have to go for real representative structure so even if it is a critical structure like a nuclear structure will just do a normal specimens like 150 specimen and then we imply that in the real structure so you can you give any suggestion on that is it good to do that see the materials that we use you have to have certain specimen and size of specimen to get the properties that are representative of that material how to 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 retain the size can be the same we can do more test 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.