Advanced Marine Structures
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Lecture - 13
Ultimate Limit State - II

We will now discuss the thirteenth lecture on module 1 on the course title advanced marine structures.

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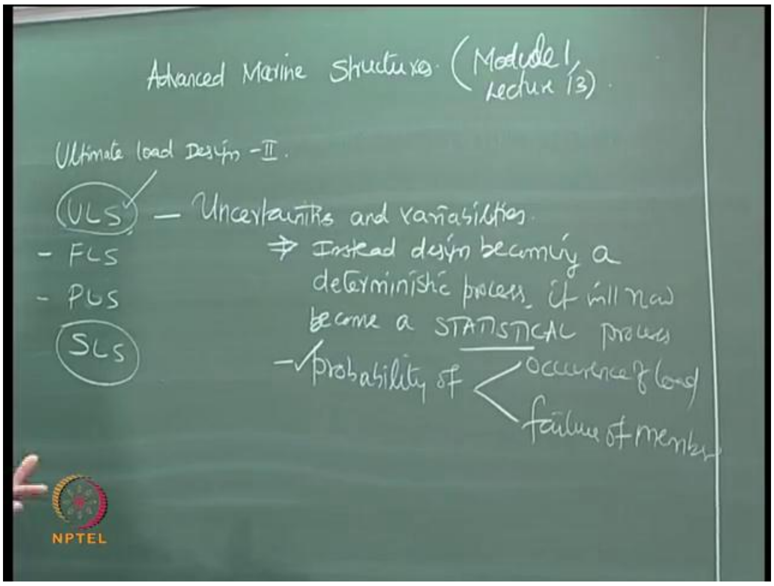

In the last lecture we discussed about the ultimate load design introduction. We discussed four limit states, which are specifically applicable to design of marine structures, namely ultimate limit state, fatigue limit state, limit state of progressive collapse and limit state of serviceability.

We also understood, what is a difference and what are the critical questions, which are binding ultimate limit state and limit state of serviceability. Limit state of serviceability is a mandatory condition which must be met for every design principle, whereas ultimate limit state gives you an advantage of finding out the ultimate load carrying capacity of every member or structure as a whole. Of course, these two are very special cases, which talks about the progressive collapse, because of the damage already created in the system and this talks about damage caused or the stress level induced in a system because of cyclic loading or repetitive loading. These are all very commonly applied to marine structures, but in this course we will talk about mainly the ultimate load limit state or ultimate load design principles.

Now, as we understood yesterday, that ultimate limit state or ultimate load design principle has got lot of uncertainties and variabilities. We will talk about this now, these are the factors, which affect the ultimate load design mechanism as a whole. What are those uncertainties and what are the different variables or how do they vary depending upon the assumptions made in the analysis and design. Now, first let us see what is the immediate consequence of having lot of uncertainties in the design process? The immediate consequences that instead of the design becoming instead the design becoming a deterministic process, you should have a definite answer a closed form solution.

Instead of the design becoming a deterministic process, it will now become a statistical process that is the catch here. The moment I say statistical process, I can always say that there is a probability of occurrence of load failure of member etcetera. So, there is a always a now, a probability being introduced because I am talking about the statistical process. Now, this is an immediate consequences, once we agree that may ultimate load design mechanism has lot of uncertainties and variabilities Now, interestingly as an engineer the question comes to mind is, can you avoid these uncertainties?

So, that I need not have to look into the probable values of failure or safety or occurrence of load. Let me calculate them accurately, let me have a high degree of accuracy in my design. So, obviously to have an high degree of accuracy in the design process, I must avoid or I must eliminate the uncertainties. If I am able to eliminate the uncertainties, I can be sure that my design process will become completely deterministic. Now, first look into what are those uncertainties, then let us try to answer can we eliminate them?

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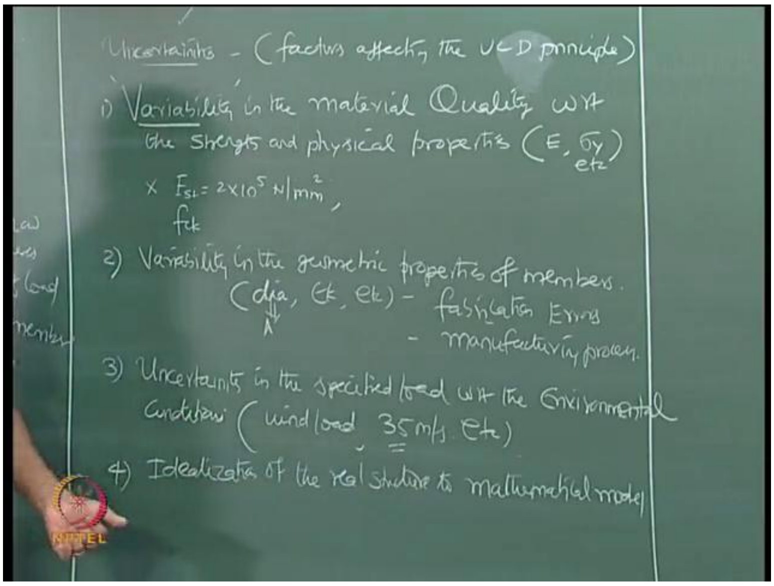

So, the uncertainties that are present in the system, which are also otherwise called as factors affecting the ultimate load design. I will say ULD here onwards, I will not say limit state, I will say ultimate load design principles. These are the factors which are actually affecting the ultimate load design principles, which are otherwise called as uncertainties. There are many there are about 7, we will see one by one. Top in the list is the variability in the material quality, with respect to the strength and physical properties. I can give an example Young's models, yield values etcetera.

So, there is a large amount of variability in the material quality in terms of its strength. So, it means however you employ best quality control of production, you will not get a deterministic value of Young's modulus of the material from the workshop, they will be keep on varying. For example, Young's modulus of t should be 2 10 power 5 Newton per m m square, that is what we must get, but from a different lot of production, from different industries, different grades of steel, different composition of constituency in steel in manufacturing steel, different methods of fabrication processes, different methods of exclusion processes, cold working, hot working, all these complexes put together, you will never get only a single unique value of 2 10 power 5, never.

Is a broad range of values varying from 1.95 to 2.1. So, once I say, then I have got to take a mean, so I am looking into the statistical content back. I cannot have a deterministic set correct accurate one single value, I cannot have. So, that is the variability in the material quality, which is contributing to uncertainties. We talk about strength of concrete, similarly, f c k that is call as characteristic comprehensive strength of concrete. So, concrete strength also varies depending upon the ingredients constituency of concrete, so that is also not a unique value, it keeps on varying. The second is the variability in the geometric properties of members.

For example, the diameter throughout the length of the member may not be uniform, the thickness throughout the length of the section may not be uniform etcetera. These are actually errors, which come from fabrication. You can also call these errors in the manufacturing, whatever may be the reason you put at, I will get lot of variability in the geometric properties of the member. Instead of saying diameter, I can also say the cross sectional area. The third factor, which contributes uncertainty in ULD is uncertainty in the specified loads, with respect to the environmental conditions.

For example, let us talk about wind, you say. That mean wind speed is about, let us say 35 meter per second at a specific sea state, where the platform or the structure is proposed to be design. That does not remain at 35 there is, there can be lot of un force in environmentally effects, which can accelerate this wind speed ,much more that 35 also. So, there is high level of uncertainty, which does not allow you to predict the environmental loads with a high degree of accuracy etcetera. The fourth condition could be, idealization of a real structure, to mathematical model.

When you prepare a mathematical model, we should simulate exactly the real conditions of the structure, you make lot of idealizations, which you call as structural assumptions in the analysis. They all will add to uncertainties in your analysis and design process.

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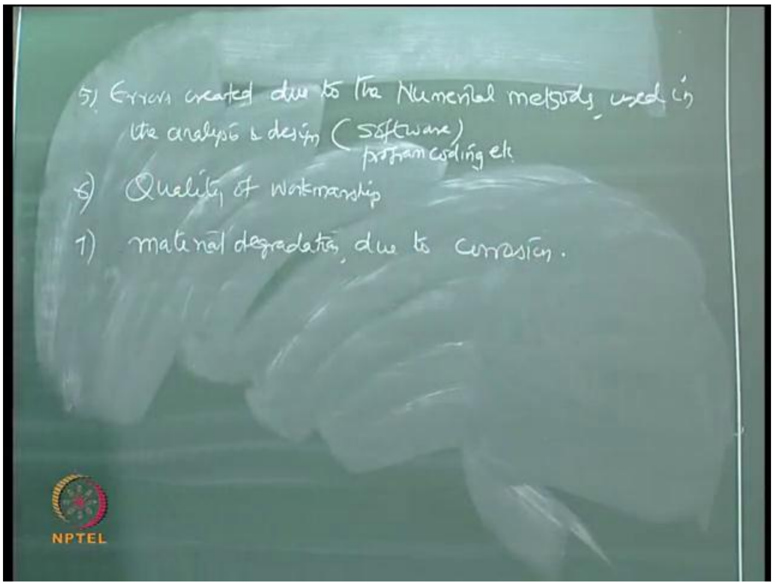

The fifth one could be errors created due to the numerical methods which are used in analysis and design. I am not saying that it is only because of software, but I do have to certainly write here because of the software. I can even a write program also, software, program coding, etcetera. The sixth one could be of course, very importantly the quality of workmanship. The seventh one could be, material degradation due to corrosion because as you understand the corrosion process does not affect material uniformly along it is depth.

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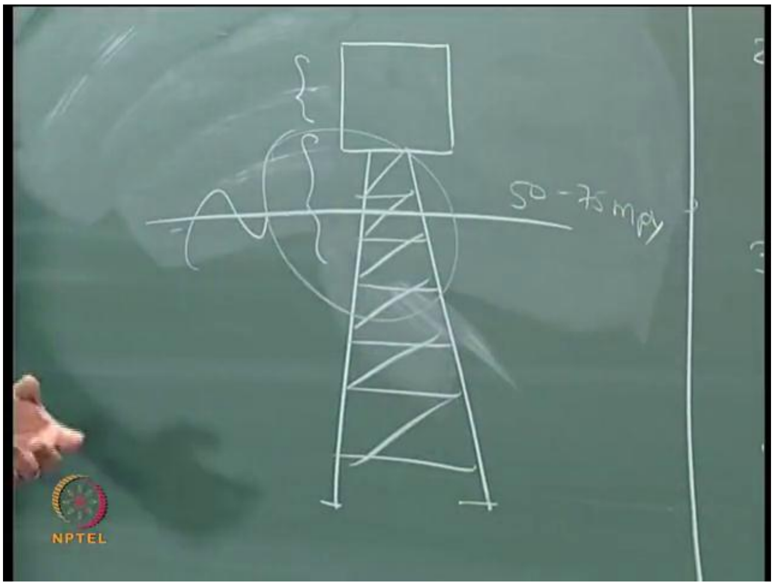

As we understand, if I talk about a jacket structure, you will know that this area is going to be the splash zone. This is an aerated zone, this is middle and deep water zone, the corrosion is going to be maximum in this area, which is about 50 to 75 miles per year. Corrosion rate is very high therefore, the members here or the material here in this zone are subjectable or prone to more corrosion compared that below. So, when we consider this member in uniform member of the same material, I am not talking about the length of the member, the length of the member may be discontinues between the joints, but the material got to be same.

You may agree why it is so? If the material is not uniform, you will again create or induce, the corrosion which is called as… Whenever two different material jointed together you introduce what is called stress corrosion, so you will again create a corrosion by itself. So, let us have a common material of the same strength and properties, in that case the degradation will not be uniform because of one example corrosion which is very, very prominent example in marine structures.

Now, there are lot of uncertainties and there are lot degrees of variabilities, which contribute to not having the design process as a deterministic process. Therefore, we have to account for all these variabilities. Now, we agree the variability's cannot be removed. I cannot exit from a concept of not having variabilities, uncertainties because none of them as you see here could be avoided.

They are implicitly developed in the mechanism, so you cannot avoid. If you cannot avoid them, they should learn how to live these uncertainties, in the design process. You may ask me a question, sir this uncertainties is not new, they were all present. When the day a design process was told to structural engineering in the, let us say early in 1800 s, then also it is continuing for the past 120 years, people have been designing structures. Why suddenly they are talking about or giving more importance to these uncertainties and introducing new concept called ULS? What is the necessity?

The answer is very simple, all these uncertainties will become prominent, when you were talking about exploiting the strength to the maximum value. If you do not want to exploit the strength to the maximum value of it is member, then all these can be ignored. Because if the EST is 2 10 power 5 and you are talking about ultimate load carrying capacity of this material, but you do not want to stress the material beyond the yield value, within which the material remains elastic. We do not bother about them, even we have a poor quality workmanship. We do not have to bother, this is a design stage because my stress level does not exceed a specific value, even much below sigma y. So, remember that, it is very important.

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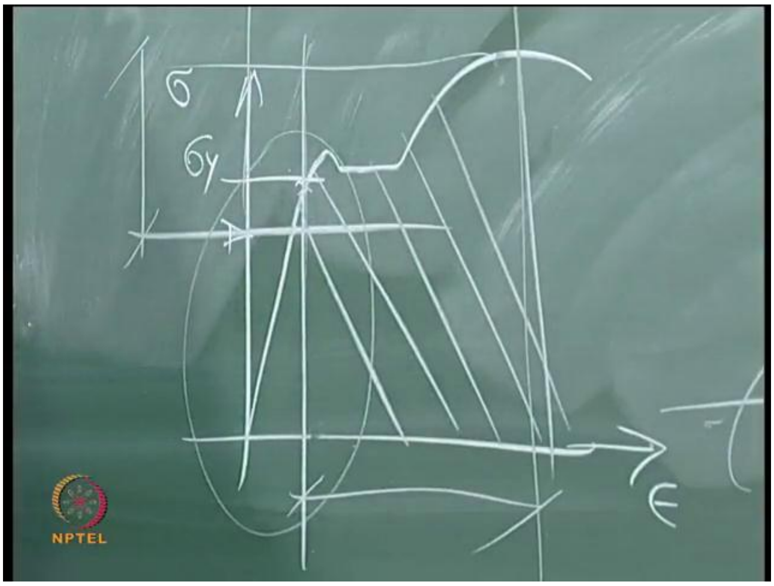

I have this is my classical stressed end curves strain curve or structural steel, if you say this is my yield value, yours strength value for which you will design the section, was much below this. This was the design value which people use to practice for a long time which we call elastic design. So, when you are zone of material characteristics lie within the comfortable zone, where the stress strain remains elastic. All your principles of supper position remains valid, there is no permanent defamation enable in the material, that is called plastic defamation. You are not looking at all these advanced aspects of material characteristic, you do not want to exploit the material to the maximum strength of it is capacity etcetera, you do not bother about them.

Therefore, people said let us ignore all these things for the time being, all became structural idealization, assumptions in the design process, people accepted. Then later people realized in early 70 s, I mean late 80 s that we are wasting a majority area of strength of the material, which is having a high reserve energy beyond a specific point. Why do we waste this? Can we capture this? Then introduce the limit state design, ultimate load design methodology, where these uncertainties will come a prominent load, will play a prominent role because now I am trying to stress the material beyond the limit and take it here.

So, I am looking for what is the ductility the material has, what is the load reserve the material has, I want exploit the material to the maximum possible manner. I have to live with this all these uncertainties. Now, the question comes uncertainty cannot be avoided, cannot be corrected, but how can we live with this in ULD? The ultimate load design accounts for this uncertainties in a very interesting manner.

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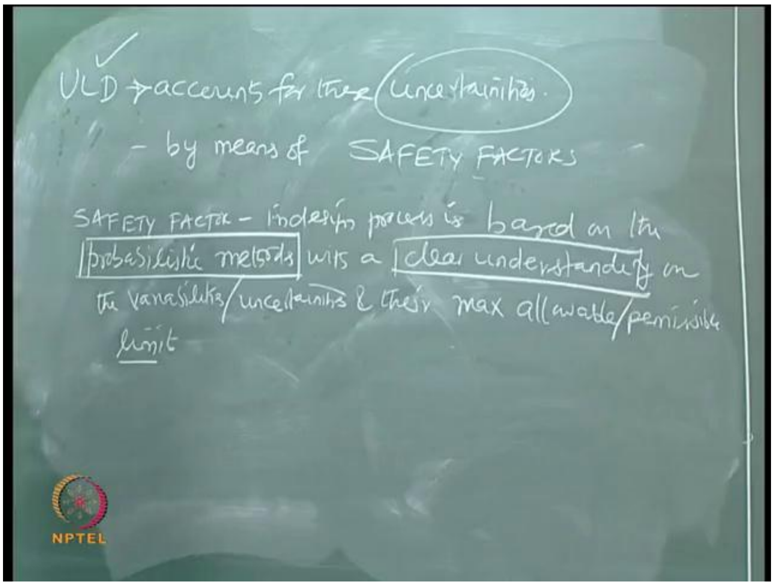

The ultimate load design accounts for these uncertainties, remember very importantly this statement is not reversible. What does it mean is? Since I am accounting for the uncertainties in this design process, can you allow poor workmanship, can you allow a improper fabrication? Answer is No, please understand, this design methodology is not a green flag, given to the manufacturer given to the fabricator given to the engineer, given to the quality inspectors, to wave of. Let us not have a poor, let us have good workmanship, let us use material of any strength, No no that is not so. Then you will agree, how do we impose this? Condition, strictly in the design because it is says bluntly ULD accounts for these uncertainties.

There is a limit beyond which it will not be permitted, is that clear? So, we are not allowing a broad range of variability, but we allow within a certain band what is that band, that is what we are going to discuss today. So, it accounts for uncertainties, but how? By means of safety factors. So, I can redefine, what is a safety factor in design? We can redefine the safety factor in design process is based on the probabilistic methods with a clear understanding of the variabilities oblique uncertainties and their maximum allowable, that is permissible limits. So, safety factor is essentially a derived from the probabilistic method to derive a safety factor on probabilistic method.

You must have a clear understanding of the limits of uncertainties beyond which you should not allow. So, ULD is seen as an advantageous method because it accounts for all these uncertainties, which cannot be otherwise avoided. They are implicitly built inherently present in this system, I cannot get rid of that. So, indirectly they are handled by safety factors. Now, as for as structure is concerned, there are two components here; one is structures is made up of some material, the material has variability in strength and geometric characteristics. So, there should be some safety factor associated with the strength, the structure is subjected to environmental loads which as high variety of uncertainties.

So, there should be some safety factors associated to loads, so there are two safety factors independent of each other. The safety factor associated to strength of the material is not related to the safety factor, which will you account for variability in the environmental loads. There are two distinct explicit unique safety factors, which will account for both of them independently. Interestingly both of them, they are combined together for the actual safety of the system. What does it mean if the strength of the material is more than the load coming on the material or the member or the structure, if the strength of the structure is more than the load coming on the structure? Structure is safe on the contrary, if the load coming on a structure is more than the strength of the structure.

The structure is unsafe, it means the uncertainties which are covered as factor of safety independently on load and strength combine together will give you, the safety of the system. So, they should be combine, though they are independent, though they are not dependent on each other, but still you have to combine them, to define the safety of the system, is that clear? Because safety of the system is an indirect manner of accounting uncertainties in the design process.

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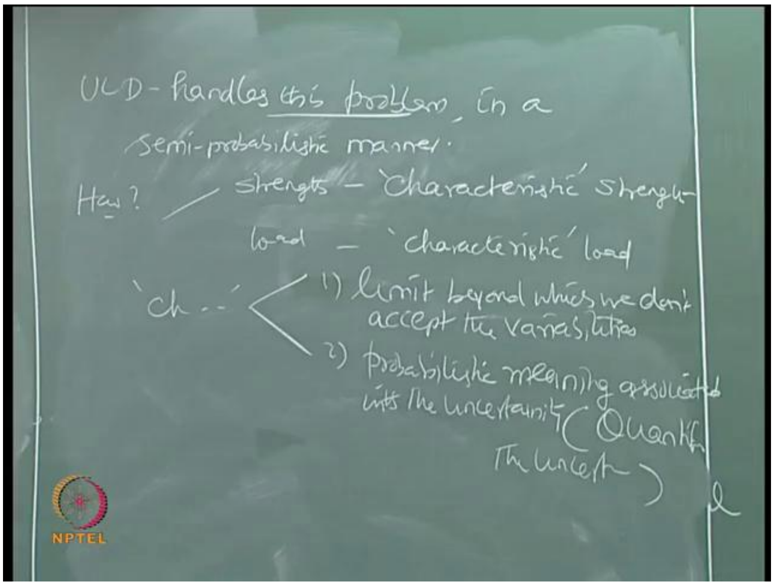

Therefore, the ultimate load design handles this problem. What is this problem? This problem is combining, these two load factors sorry. These two factors, one applicable on load, one applicable on strength together to form a safety factor for the entire system. So, that is a problem, so ULD handle this problem in a semi probabilistic manner. How for the strength, we have to define. What is called characteristic strength for the load? We are going to define, what is called characteristic load?

Now, the term characteristic is a very interesting adjective, which is associated to strength and load independently, which defines two things. The term characteristic defines two things, one the limit beyond, which we do not accept the variabilities, already said there is a limit. So, the characteristic term addresses two things, one is that limit beyond which I will not accept the variabilities to the probabilistic meaning associated with the uncertainties. It will gives a probabilistic meaning to the uncertainty the moment probabilistic, I said gives a number it gives the number uncertainty is a general term. It is a qualitative statement, this quantifies that uncertainties with the number. So, I can say this actually quantifies the uncertainties it quantifies.

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Therefore, structural member should fulfill or should be chosen. If you remember yesterday’s definition of the design already, said you are choosing the member should be chosen to meet the following requirement, what is that requirement characteristic strength by I should say factor of uncertainty. I will tell you very clearly, why I am not saying this is factor of safety? This is called factor of uncertainty. So, far I am not able to establish whether system is safe because for the system to remain safe, I need to maintain a condition. This is factor of uncertainty which is independently apply only to the strength.

Similarly, there will be a characteristic load which will also have a factor of uncertainty, which is independently applied to the load. But in this case I will multiply this, if the characteristic strength by a factor of uncertainty exceeds or equal to the characteristic load, multiplied by factor of uncertainty. I will call this as safe, you understand? There is a classical difference between factor of safety and factor of uncertainty, they are not same statements. Why I am not calling this safety because as long as this equal mathematic equality is not established between these two. I will not know whether this is safe or unsafe? So, I cannot say simply all factors accounting for uncertainty will always lead to a safe design, if this condition is satisfy, then I call these factors indirectly as factor of safety, Is that clear?

There is there is small difference between the statement of factor of safety and factor of uncertainty, that is why I am explicitly writing here is uncertainty. So, 1 is divided 1 is multiplied, let us take two classical examples and try to understand this statement. Now, there is a, there is a case where the load is exceeded load is exceeded. I should write probably, there is a probability of exceedance, a case where the load is exceeded on the marine structure, during its life time. Let us say I have a case here. There is a probability that the load will exceed. Our load is exceeded already in a marine structure during its life time.

Now, the probability of this to happen depends on, can you tell me, what would be the factors on which this probability depend on? It depends on two factors, one the chosen magnitude. For example, you say, you very well know the dead load on a structure, for example, is let us say, 11 kilometer Newton per square meter. That is what, we have already seen in the last class, but in your design, you said that my dead load for which the system design will be 5 kilometer Newton per square meter, by mistake it does a mistake. So, if you chosen a wrong magnitude, then there was a probability there, this will be exceeded. So, chosen magnitude is wrong, two life time you possibly thought the structure will remain 100 years, but structure is design only for 10 years.

So, what is that life time? You are looking for because remember this is a case where the load is likely to be exceeded during it is life time. So, what is that life time we are looking? For it cannot be infinite, it cannot be very large, it cannot be very small, as well, so these are the two factors, which will decide what is the probability of this exceedance, on the service life or life time of the structure? Let us take another example.

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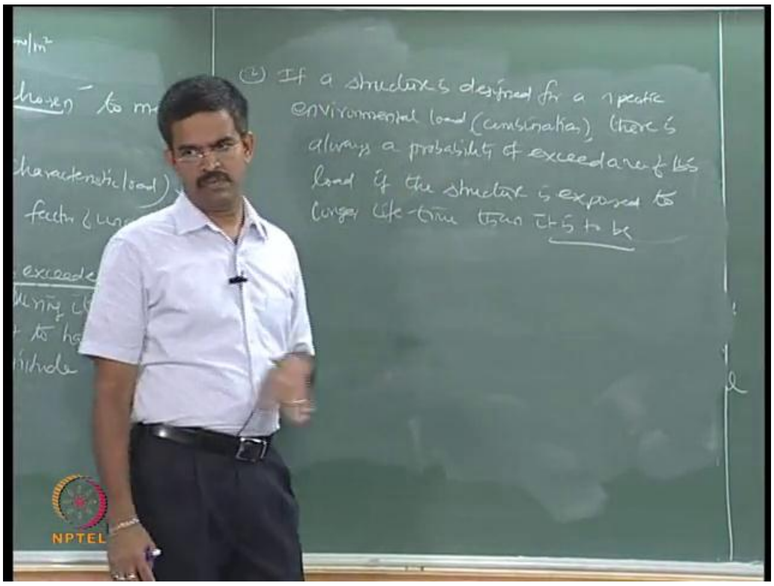

Let us say, if a structure is designed for a specific environmental load, I should say to be in very clear load combination there is always a probability of exceedance of this load. If the structure is expose to to longer life time than it is to be, when you extend the lifetime of structure. For example, you said the structure is should remained only for 15 years, but you are allowing the structure to remain there for 25 years, 50 years. You have extended the life time of the structure, so there is always a certainly probability of exceedance of this kind of load on the structure.

So, it is very important that we must understand the factor of uncertainty, be it strength, be it load both these examples are talking about the load. So, we are talking about this uncertainty factor, will certainly depend on what is that life time of looking at and what is that magnitude we are looking at? If you are not able to fix this properly correctly with the higher level of accuracy, then there is always a probability that your value will get exceeded. So, ultimate load design mechanism as such may look like a wrong process. The process that is not wrong it is that, which value you are saying is exceeded is wrong.

You are chosen a wrong number, you are chosen a wrong life time, you said it is 10 years, but you are allowing the structure to remain for 50 years. So, you are saying it is exceeding therefore, the factor of uncertainty should be revised because it is not giving safe results, is that clear? That is why people have generally feeling that this design process can have difficulties, if not practiced intelligently. So, for beginning engineers, for beginners in structural design to make the design more conservative, people were not recommending ULD for many years, it is a reason.

So, there is nothing wrong in the process, but still the question critically there is, if this process giving me the maximum load carrying capacity beyond which structure cannot sustain, what happens if this is exceeded even by a chance? Easily a catscopic process, if it is dangerous, then this design process should have not been recommended at all, in the first place that question is still critical we have got to answer this, is that clear? We have got answer, this question. Now, we have understood very clearly between the limit state of serviceability and ultimate limit state. They are different things.

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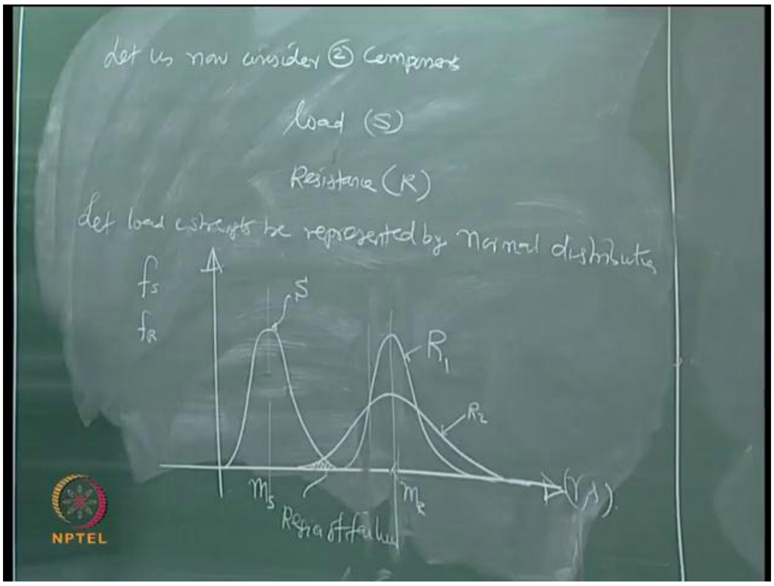

Having said this, let us now consider two components. What are the two components? One is the load, other is the strength. Instead of strength, I will call this as resistance. So, load I put as S resistance, I call as R. Now, as I just now said, the loads have lot of variability, lot of uncertainties, therefore, I must design or define this in statistical terms not in a deterministic value. So, I have to look for a distribution. Let us say, let the load and strength be represented by normal distribution.

So, I draw a figure here, which gives me both the frequency distribution for strength as well as resistance for the values of R and S. So, I am looking for two distributions, one is for the strength sorry the load, other is for the resistance. Let us say this is my normal distribution for the load, this is my normal distribution for the resistance. I call this as R

1, I look for two distributions on resistance. One is not having any overlap with load at all, other is having an overlap with load, I call this as R 2. I have got two distributions for resistance R 1 and R 2, one does not have overlap with the load one has overlap.

With the load, let me hatch that area, which is having overlap with the load. So, look at any point here, in the hatched area any point here in the hatched area you will see that the resistance is lower than the load. So, I can say this is my region of failure because resistance is lower than the load. So, I can call this mean value as mean of load and this is mean value as mean of resistance. I am not changing the mean of both the resistance curves remember that the mean remain same M R.

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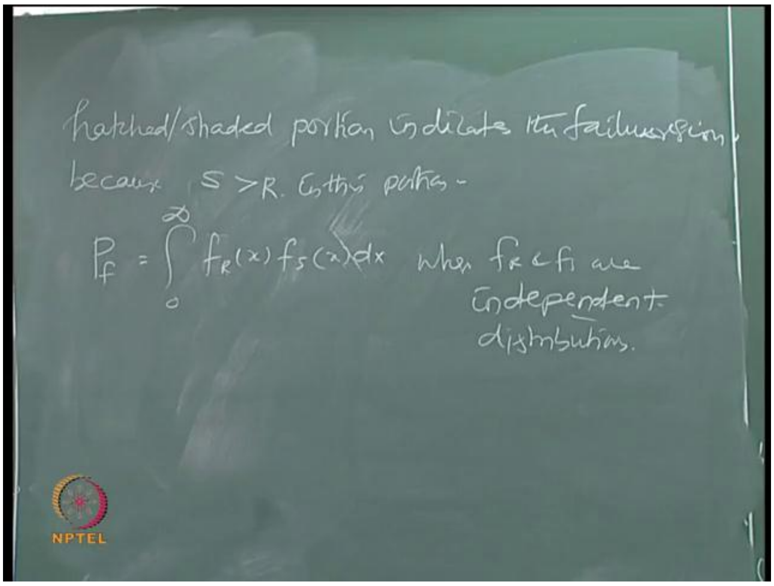

So I should say the hatched or shaded portion indicates the failure region because load exceeds resistance in this portion. Therefore, probability of failure can be given as a integral of this section which is f R x f R x, f s x, d x, if it should be small where F R and f s are independent even in distribution. Having said this now, we are worried about that adjective statement of characteristic. It should quantify the qualitative statement of variability or uncertainty. So, the moment I said is expressed in probabilistic manner should be, should give me a number. So, M R and M S, that is mean value of the load and mean value of the resistance, will not have any significant meaning, unless otherwise the two curves are expressed slightly in a different form. Let us see what is that form we are looking at.

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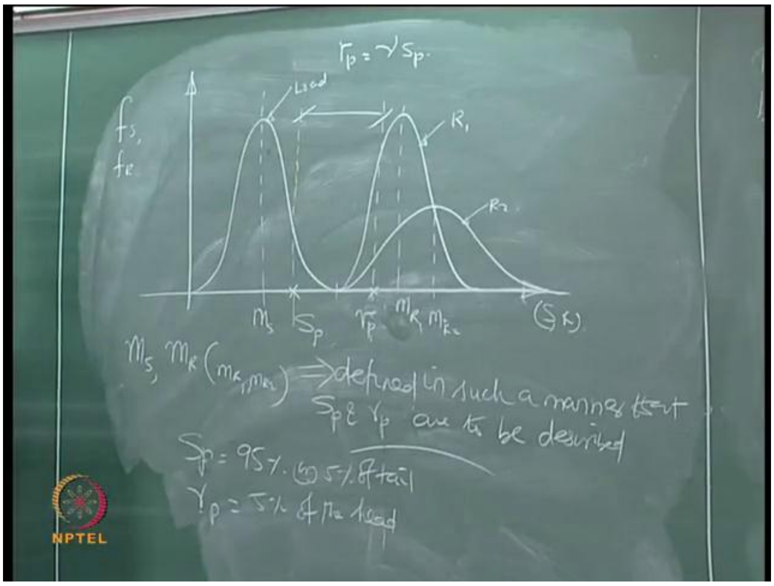

I again redraw the curve is the load, let us say this is my R 1 curve with M R 1 mean of R 1 and I have another curve with the different mean this M R 2. So, what I am trying to define here or the following I want to define a point. In these curves call this point as s P and call this point as R p. I write M R 1 here this is r not gamma, let me rewrite here. This is R p this point and I connect these two as R p is equal to mu times of S p, so how do you get this? It means, the mean value of the load and the mean value of the resistance be it M R 1 or be it M R 2 anything, should be defined in such a manner that S p and R p are to be described.

So, what are the S p s and R p s? S p s and R p s are the characteristic definition of the load and strength respectively, S p’s and R p’s are the characteristic definition of the load and the resistance respectively. What does it mean? I say S p is selected in such a manner at 95 percent or 5 percent of the tail R p is selected in such way that, 5 percent or 95 percent of the 5 percent of the head. That is if this is 100 percent, this 5 percent of this, for this two curves. This is 5 percent of the head, so what does it mean? Characteristic load is that, which is never exceeded with the probability of only 5 percent, 95 percent it will not be exceeded.

Characteristic resistance of strength is that, where the material property 95 percent will be acceptable, there is a chance that it can vary only by 5 percent. So, that is the limit what your talking about, is that clear? For example, you want to really qualify any material, in terms of its Young's modulus picked up the material, find the mean if the mean is beyond 5 percent variation, reject it and so on, is that clear? We will continue this discussion in the next class.